SYMPOSIUM

PROCEEDINGS

The 11th World Construction Symposium - 2023

Accelerating Sustainability in the Built Environment:
Policies, Practices, and Perspectives

Organized by

CEYLON INSTITUTE OF BUILDERS
(CIOB) SRI LANKA

DEPARTMENT OF BUILDING ECONOMICS
UNIVERSITY OF MORATUWA

PROCEEDINGS

of

THE 11TH WORLD CONSTRUCTION SYMPOSIUM 2023

ON

ACCELERATING SUSTAINABILITY IN THE BUILT ENVIRONMENT: POLICIES, PRACTICES, AND PERSPECTIVES

21-22 July 2023

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SYMPOSIUM ORGANISERS

The Ceylon Institute of Builders (CIOB), Sri Lanka

Established in 1961, the Ceylon Institute of Builders (CIOB) is the premier institute for Building Professionals in Sri Lanka with a strong network of Engineers, Architects, Surveyors and similar allied professions who work to inspire, encourage, educate and train students, builders, and professionals in the country. The institute welcomes young entrants and mature professionals with or without a background in construction to achieve professional level careers in the country. They are provided with a well-structured development programme that eventually leading to gaining corporate membership of the institute.

http://www.ciob.lk/

Department of Building Economics University of Moratuwa, Sri Lanka

The Department of Building Economics, University of Moratuwa, Sri Lanka was founded in 1983. It is currently the pioneer Sri Lankan institution to offer programmes in Quantity Surveying, Facilities Management, Project Management, Construction Law and Dispute Resolution and Occupational Safety and Health Management. Building Economics and Management Research Unit (BEMRU) is the research arm of the Department of Building Economics, which specialises in research in Building Economics and Management in the country as well as internationally.

https://uom.lk/becon

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Western Sydney University is a world-class university with a growing international reach and reputation for academic excellence and impact-driven research. It is ranked amongst the top three percent of universities in the world, globally focused, research-led and committed to making a positive impact – at a regional, national and international level. It was established as a modern university in 1989 from its predecessors dating back to 1891. The WSU currently have over 40,000 students in a sprawling series of campuses across the Western Sydney region.

https://www.westernsydney.edu.au/

The University of Newcastle, Australia

The University of Newcastle is a leader in university education, with a reputation for high quality teaching and learning and exciting, contemporary academic programs. It is a research-intensive university and a leading contributor to research in Australia and the world. The University of Newcastle is ranked in the top 10 Australian universities based on research excellence.

https://www.newcastle.edu.au/

Centre for Innovation in Construction and Infrastructure Development (CICID), The University of Hong Kong, Hong Kong

The Centre for Innovation in Construction and Infrastructure Development (CICID) based at the Department of Civil Engineering of the University of Hong Kong, was established in November 2002. The aims include fostering continuous improvements, while targeting excellence in the construction industry in general and infrastructure development in particular, through the development of innovative strategies and techniques.

http://www.civil.hku.hk/cicid

University of Adelaide, Australia

The University of Adelaide is a well-regarded institution of higher learning and innovation located in Adelaide, Australia. It is a member of the prestigious Group of Eight, which consists of Australia's top research-intensive universities. The University of Adelaide has consistently received high ratings from respected international assessments, which is a testament to its commitment to academic excellence. It offers a range of undergraduate and graduate degree programs and has a strong emphasis on research. Students can choose from a variety of areas of study, including accounting and finance, agriculture, food and wine, allied health, animal and veterinary sciences, architecture, arts, biomedical science and biotechnology, and business. he university prides itself on being a future-maker for its state, nation, and the world. It has a strong commitment to creating meaningful change through contemporary educational and research excellence. The institution aims to meet the evolving needs of its local and global communities while applying proven values that celebrate its proud history.

https://www.adelaide.edu.au/

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Deakin University, Australia

Deakin University is a public university in Australia, with multiple campuses across Victoria and New South Wales. It was founded in 1974 and is named after Alfred Deakin, Australia's second Prime Minister. Deakin University offers undergraduate, postgraduate, and research courses across a wide range of disciplines, including Arts, Business and Law, Education, Engineering, Health, Information Technology, Science, and Sport.

https://www.deakin.edu.au/

Massey University, New Zealand

Massey University is a reputable institution of higher learning located in New Zealand that prides itself on academic leadership, research excellence, and innovative teaching grounded in real-world issues. The university offers a range of academic programs and services to support the academic and personal development of its students. The university offers postgraduate degrees that you can complete fully online and is the leading university in New Zealand for online and borderless education.

https://www.massey.ac.nz/

Colombo School of Construction Technology (CSCT), Sri Lanka

The CSCT was established in 2008, with the motto 'Sapientia et Doctrina', which is Latin for Wisdom and Learning. It strives to create a learning environment to nurture the development of critical thinking skills; support innovation; and develop knowledge and expertise of our students. CSCT faculty have expertise in a broad range of specialties and have developed curriculums in each of the programs that meet the needs of the construction industry.

https://csct.edu.lk/

Built Environment Project and Asset Management (BEPAM)

Journal, published by Emerald Group Publishing

BEPAM provides, a unique one-stop forum that publishes peer-reviewed research and innovative developments in both project management and asset / facilities management of building and civil engineering infrastructure. The journal also targets important interface issues between the planning, design and construction activities on the one hand, and the management of the resulting built assets / facilities on the other. Launched in 2011, BEPAM is well established internationally, e.g., being encouraged by CIB, recognised by the Australian Business Deans Council and indexed in SCOPUS, EBSCO, INSPEC and the Emerging Sources Citation Index (ESCI) of Thomas Reuters.

www.emeraldinsight.com/bepam.htm

ACKNOWLEDGEMENT

We would like to express our sincere appreciation to the Ceylon Institute of Builders (CIOB) for inviting Building Economics and Management Research Unit (BEMRU) of the Department of Building Economics, University of Moratuwa to jointly organise this 11th World Construction Symposium (WCS) on the pertinent theme, "Accelerating Sustainability in the Built Environment: Policies, Practices, and Perspectives". This year symposium marks the 11th milestone of the WCS series, which was initiated back in 2012 and was held with the contribution and support extended by many individuals and organisations. Thus, we want to extend our sincere gratitude to the numerous parties who contributed in various ways to make this event a success.

Firstly, we would like to thank our associate partners Western Sydney University, Australia; The University of Newcastle, Australia; Deakin University, Australia; Massey University, New Zealand; The University of Adelaide; Australia; Colombo School of Construction Technology (CSCT), Sri Lanka; and Built Environment Project and Asset Management (BEPAM): Journal, published by Emerald Group Publishing.

We particularly appreciate all the authors for selecting the 11th World Construction Symposium as a platform to disseminate their research work. Our special thanks also go to the eminent international and local scientific committee members for reviewing and offering constructive comments on the papers, which helped to ensure that the accepted papers for the symposium were of a high standard. We would like to extend our gratitude towards the chief guest, keynote speakers, panellists, session chairs, session coordinators, paper presenters and other invitees for their commitment and contributions towards the symposium. The support and enthusiasm of all these parties allowed us to still maintain the momentum of the annual WCS series even while using a digital platform.

Our special thanks also go to Editor-in-Chief of BEPAM Journal and the team at Emerald Group Publishing for their contributions to the symposium. A special thank you goes out to all the sponsors who have provided sponsorships to bring this year's symposium to fruition. We are also thankful to all the government and other institutions and all our supporting partners who have supported the symposium in various ways.

Last but not least, a special thank you goes out to all our colleagues in the organising committee, symposium secretariat and the Department of Building Economics for devoting their time and efforts to make this 11th World Construction Symposium 2023 a success.

Editors

The 11th World Construction Symposium
Colombo, Sri Lanka
July 2023

PREFACE

The 11th World Construction Symposium (WCS 2023), jointly organised by the Ceylon Institute of Builders (CIOB) and Building Economics and Management Research Unit (BEMRU), Department of Building Economics, University of Moratuwa was held on hybrid mode from 21-22 July 2023. The symposium was held in partnership with Western Sydney University, Australia; The University of Newcastle, Australia; Deakin University, Australia; Massey University, New Zealand; The University of Adelaide; Australia; Colombo School of Construction Technology (CSCT), Sri Lanka; and Built Environment Project and Asset Management (BEPAM): Journal, published by Emerald Group Publishing. This year's symposium marks the 11th milestone of the WCS symposium series, which has been held annually since 2012. Throughout the past decade, we are happy to see WCS grow in success and gaining recognition from academics and industry participants from around the world, providing a multi-stakeholder platform for those involved in the built environment and construction industry related research and practice to come together to share their knowledge and experiences. While the Sri Lankan construction industry along with its economy is yet experiencing difficult times and struggling to recover, , this year's symposium was organized around the theme "Accelerating Sustainability in the Built Environment: Policies, Practices, and Perspectives". on hybrid mode.

We received a large number of full papers for the symposium, all of which underwent a rigorous review process as detailed below:

- All submitted full papers were sent to at least two independent referees selected from the symposium scientific committee for double-blind peer review. Reviewers provided constructive comments with respect to the originality, significance, reliability, quality of presentation and relevance to the remit of the symposium of each paper. The Scientific Committee Co-chairs, who are the editors of the symposium proceedings, were responsible for final decisions on accepting or rejecting the papers based on these assessments.
- At least one of the authors of all the accepted papers were required to register and orally present the paper in the symposium.

Altogether, 91 papers were selected for publication following the review process. It is worthwhile to note that the authors of the selected papers are from a range of different countries including Australia, India, New Zealand, Nigeria, Sri Lanka, Turkey, United Kingdom and Australia, Hong Kong, India, Indonesia, New Zealand, Sri Lanka, South Africa, and United Kingdom. The papers covered a wide spectrum of areas under 20 sub-themes such as Green Solutions for Construction, Disaster Resilience, Operation and Maintenance of Built Environment, Blockchain Technology in Construction, Procurement Solutions for Construction, Digitalization in Construction, Construction Management, Sustainability Practices in Construction, Urban-Rural Development, Construction Business Continuity and Management, Economics of Construction, Industrial Symbiosis, Circular Economy in Construction, Construction Human Resource Management, Lean Construction, Legal Practices in Construction, Construction Waste Management, Construction Education and Carbon Footprint.

We as the Scientific Committee Co-chairs are committed to ensuring ethics in publication and quality of articles. Hence, priority was given to the quality and standard of papers rather than the number of papers presented at the symposium. The proceedings emerging from this symposium represent the result of the tireless efforts of all authors and reviewers and has been supported by the support received from symposium organising committee members, associate partners and sponsors. We hope it would pave way for advancement of knowledge as we strive towards a smart, sustainable and resilient built environment.

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SYMPOSIUM INFORMATION

IMPORTANT: To ensure the proper execution of WCS2023 virtual symposium, please pay special attention to the instructions below. If you have any questions or difficulties following the guidelines, please contact the WCS2023 Secretariat (info@ciobwcs.com) who will be happy to help.

How will WCS2023 virtual symposium work?

The conference is delivered over a professional platform, Zoom, and is managed by a competent and experienced technical team.

All paper presentations must be pre-recorded to improve the quality of the delivery, avoid going over time and avoid any technical issue. However, speakers **should be virtually present for their entire session** in order to answer questions and participate in the discussion.

The virtual conference is similar to any in-person conference. Presentations are assembled in parallel sessions according to themes. Participants can access the session of their choice by entering the WCS2023 main meeting using the meeting ID and passcode and then selecting the breakout room for the parallel session of their choice. All registered attendees can attend all parallel sessions and switch from session to session at will.

The symposium inauguration, panel discussion and the sum-up is held in the WCS2023 main meeting room.

As with in-person conferences, there is also be a dedicated period for questions and discussion after the presentations. Participants are able to use the chat or verbally ask questions during the Q&A session. The session chairperson may select a few questions, depending on the time allocated for the discussion, and read them to the presenter, who can answer verbally.

All sessions are fully recorded. Please note that we automatically assume that presenters accept their recorded presentation to be made available to participants for post-conference streaming. In case of refusal, presenters need to notify us at info@ciobwcs.com **before 18 July 2023** and the secretariat will manage the requests.

Preparing for your Virtual Session - Instructions for Presenters:

Use the instructions below when presenting your paper at WCS2023 virtual symposium.

Before the symposium starts

- Make sure that you have uploaded your pre-recorded presentation following the given instructions and have completed the registration process.
- Refer the Symposium Programme and the Session Plan to find your presentation in the symposium programme as scheduled.
- Make sure to install Zoom on your computer and update it to the latest version (version 5.3.0 or higher).
- In preparation for the meeting, you can join a test meeting via https://support.zoom.us/hc/en-us/articles/115002262083-Joining-a-test-meeting. For the best experience, please use your webcam and test your audio.

- Test your internet speed, we recommend an Internet connection download speed of at least 1.5Mbps. You can test your download speed here.
- A microphone is recommended as well as a quiet place cut off from ambient noise for better interactions.

Before your session starts

- Please make sure to join your assigned virtual session **10 minutes prior to the session start time** in case there are any issues that need to be worked out. Each session is conducted in a breakout room within the main Zoom meeting.
- When entering the session, make sure to identify yourself with your **name as it appears on your paper** to help the technical staff and the session chair to find you easily.
- Test your audio and video as you join; Mute your microphone when not speaking; Position your webcam at eye level and make eye contact as much as possible.

During the session

- As with a physical meeting, each session will proceed in the order identified and maintain the schedule.
- Each parallel session comprises of the paper presentations (via playback of pre-recorded presentations) and a subsequent Q&A session.
- **Speakers should be virtually present for their entire session** in order to answer questions and participate in the discussion.
- A session chair is assigned to each session to introduce the presenters, facilitate and oversee time, and the Q&A period. A session coordinator is also assigned to each parallel session to manage the order of the presentations, initiate playback of the pre-recorded presentations and ensure smooth transitions between presentations.
- Pre-recorded presentations are managed by the session coordinator according to the established schedule (see Session Plan).
- A common Q&A session will follow the presentations in each session. The session chair will lead the Q&A period and time allotted.
- Please ensure that your **webcam is on during the Q&A session** so that attendees can view you.
- The participants may submit their questions verbally (You can use the **Raise your hand** tool to inform the session chair if you want to raise a question verbally) or via **Chat**. The session chair will choose the most relevant ones to read for presenters to answer during the Q&A period.
- The **Chat** tool can also be used by session chair and session coordinator to privately contact the presenters if needed. If you need technical assistance, you can inform the session coordinator using this tool.

To Access WCS2023 Virtual Symposium

To access the virtual symposium and the session in which you are presenting:

- Make sure to install Zoom on your computer or update it to the latest version (version 5.3.0 or higher).
- Use the Meeting ID and passcode provided by the Symposium Secretariat to log on to the Main Meeting Room of the symposium. (The symposium inauguration, panel discussion and the sum-up are held in the WCS2023 main meeting room).
- Parallel paper presentation sessions are held in breakout rooms within the main meeting room. Once, the breakout rooms are open, you will be able to select and enter a breakout room of your choice. All registered attendees can attend all parallel sessions and switch from session to session at will. [Note: Participants not joined with the desktop or mobile app (version 5.3.0 or higher) may not be able to self-select a breakout room and will need to be assigned by the Host].
- To join the parallel session of your choice:
    - Click **Breakout Rooms** in your meeting controls.
      This will display the list of open breakout rooms (i.e. parallel sessions) created by the host.
    - Hover your pointer over the number to the right of breakout room you wish to join, click **Join**, then confirm by clicking Join.
    - Repeat as necessary to join other breakout rooms.
    - You can leave the breakout room and return to the main meeting room at any time, or you can leave the meeting entirely from the breakout room.
    - To leave the breakout room click **Leave Breakout Room** and choose if you want to leave the breakout room or the entire meeting (if you want to switch to a different parallel session, make sure to use the 'Leave Room' option to re-enter the main meeting room and join a different parallel session).
    - When the host ends the breakout rooms, you will be notified and given the option to return to the main room immediately, or in 60 seconds.

Virtual Background for Zoom

- You can use an optional virtual background with your university/company logo to hide or standardise your backstage during your parallel session and/or symposium group photo (refer Symposium Agenda).
- We recommend that you do a test beforehand to see which background works better for you, depending on your environment.
- Please click here for instructions on enabling virtual backgrounds on Zoom.

Some other Useful Links

If you need more information on how to use Zoom:

How to join a Zoom meeting

How to configure your audio and video

Participating in breakout rooms

Language

The official language of the symposium is English. There will be no simultaneous translations.

Dress Code

Formal/business/smart casual attire.

Disclaimer

Whilst every attempt be made to ensure that all aspects of the symposium mentioned in this announcement will take place as scheduled, the Organising Committee reserves the prerogative to make last minute changes should the need arise without prior notice.

MESSAGE FROM THE SYMPOSIUM CHAIRPERSON

Prof. Chitra Weddikkara

Chairperson
The 11th World Construction Symposium 2023

It is indeed a great privilege to stand before you today at the 11th World Construction Symposium, organized by The Ceylon Institute of Builders (CIOB) and Building Economics and Management Research Unit (BEMRU), Department of Building Economics, University of Moratuwa. Over the past decade, this symposium has consistently proven its value by making significant contributions to both the construction industry and academia. Today, as we embark on the 11th chapter of this remarkable journey, we gather here under the theme of "Accelerating Sustainability in the Built Environment: Policies, Practices, and Perspectives."

The construction industry holds a pivotal position in the global economy, influencing and being influenced by a multitude of factors, including technological advancements, climate change, resource depletion, and population growth. As direct and indirect stakeholders of this industry, we bear a profound responsibility to address the challenges it presents. This timely and crucial theme of sustainability will provide us with a platform to explore effective solutions for the burning issues we face.

I would like to take a moment to extend my heartfelt congratulations to the organizers of this symposium, as well as the researchers, presenters, and sponsors whose collective efforts have made this event a reality for the 11th time. Their dedication and commitment to advancing the construction industry deserve our utmost appreciation.

MESSAGE FROM THE PRESIDENT, CIOB

Dr. Rohan Karunaratne

President
The Ceylon Institute of Builders (CIOB)

I take great pleasure in welcoming all the delegates to the 11th World Construction Symposium 2023 on the theme "Accelerating Sustainability in the Built Environment: Policies, Practices, and Perspectives" to be held on the 21st and 22nd July 2023 in Colombo. CIOBWCS is an exciting annual venture organized jointly by the Building Economics and Management Research Unit (BEMRU) of the Department of Building Economics, University of Moratuwa, Sri Lanka.

The purpose and vision of this symposium is the promotion of academic and research activities in the field of Sustainable Construction. The Symposium will bring all like-minded individuals on a single platform to discuss new trends and challenges in the field of Sustainable Construction. In the Symposium, Sri Lankan academics, research scholars and practitioners will get the opportunity to interact with eminent experts from overseas on sustainable construction and new trends in global built environment.

I am honored to have a renowned team of academics and researchers to serve on the scientific committee, providing comprehensive reviews to the submissions. The extensive technical programme developed by the scientific committee, includes five concurrent sessions/presentation tracks. The event gives an opportunity for the professionals in the construction industry to achieve targets on their Continued Professional Development.

I wish the symposium to be a great success with your continued participation and the commitment of the University of Moratuwa and the generous support of all from the Sri Lankan Construction Industry.

MESSAGE FROM THE HONY. SECRETARY, CIOB

Eng. Saliya Kaluarachchi

Hony. Secretary
The Ceylon Institute of Builders (CIOB)

I am pleased to welcome you to the 11th World Construction Symposium, 2023 held during the period 21st & 22nd July in Colombo. It gives me immense pleasure to inform you that our institute, Ceylon Institute of Builders has been able to host the World Construction Symposium annually since 2012. The Symposium has become a popular event for both the academics and professionals in the Construction industry in Sri Lanka. I am sure that this Symposium will live up to their expectations and enable the participants to gain knowledge from the presentations and the discussion at the Symposium.

Building Economics and Management Research Unit (BEMRU) of the Department of Building Economics,

University of Moratuwa, Sri Lanka is the joint organizer of this Symposium. I would like to express gratitude to them for their firm commitment and backing. I am also thankful to the Associate Partners of the Symposium.

As in the previous Symposiums, this Symposium has been greatly supported by the Construction industry stakeholders and professional institutions in organizing this Symposium. I wish to record my special thanks to all of our Sponsors and well-wishers for your generous contribution to make this symposium a success.

My best wishes to all of you who have joined the conference for gaining and spreading knowledge.

MESSAGE FROM THE SYMPOSIUM CO-CHAIRPERSONS

Mr. Kalana Alwis

Mr. Sagara Gunawardena

Co-Chairpersons
Organizing Committee
The 11th World Construction Symposium

We are pleased to welcome you to the 11th World Construction Symposium 2023 to be held during 21st and 22nd July 2023 in Colombo. As you already know, this annual symposium has been jointly organized by the Ceylon Institute of Builders and Department of Building Economics, University of Moratuwa since the year 2012. The theme for the symposium will be "Accelerating Sustainability in the Built Environment: Policies, Practices, and Perspectives" by keeping in line with the global situation and the sustainable goals in the construction industry.

During the past decade, CIOB has taken a number of initiatives with the University of Moratuwa through

the highly acknowledged event to play leading roles in the sustainable development process for the construction industry. This has further strengthened integrated multidisciplinary teams to develop a number of appropriate technologies in the field of research and development.

Recognition of such outstanding research achievements among the researchers is a great motivating factor. Achievements by academic and professional bodies together are also a great encouragement for the industry and for further research.

While congratulating and appreciating the work done thus far to the Construction Industry globally and

locally, through this important global event, we wish the WCS 2023 every success in its endeavors.

MESSAGE FROM HEAD, DEPARTMENT OF BUILDING ECONOMICS, UNIVERSITY OF MORATUWA

Prof. Anuradha Waidyasekara

Head of the Department
Department of Building Economics
University of Moratuwa

With great pleasure, I extend my warm wishes to the 11th World Construction Symposium 2023, jointly organised by The Ceylon Institute of Builders (CIOB) and the Building Economics and Management Research Unit (BEMRU) of Department of Building Economics of University of Moratuwa. Several national and international partners are joining hands for the symposium including Western Sydney University, Australia; The University of Newcastle, Australia; Centre for Innovation in Construction and Infrastructure Development (CICID), The University of Hong Kong, Hong Kong; Built Environment Project and Asset Management (BEPAM): Journal, published by Emerald Group Publishing; Colombo School of Construction Technology (CSCT), Sri Lanka; Deakin University; Massey University and University of Adelaide.

Today, more than ever, the world is in need of innovative approaches to ensure that the built environment is sustainable, resilient, and capable of meeting the needs of present and future generations. To provide an overarching and timely setting, the 11th World Construction Symposium themes "Accelerating Sustainability in the Built Environment: Policies, Practices, and Perspectives". The symposium will serve as a catalyst for progress, bringing together industry practitioners, academic communities, and policymakers to share knowledge, concepts, and ideas. By fostering collaboration and interdisciplinary dialogue, we can pave the way for a more sustainable future.

As we embark on this journey together, let us embrace the opportunity to engage in fruitful discussions, explore innovative solutions, and inspire positive change.

I wish the 11th World Construction Symposium serves as a steppingstone towards a more sustainable and prosperous future for the construction industry and global community.

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02.35 pm – 02.45 pm	Address by Head, Department of Building Economics **Prof. Anuradha Waidyasekara**
02.45 pm – 03.00 pm	Address by Deputy Vice Chancellor, University of Moratuwa **Dr. D.P. Chandrasekara**
03.00 pm – 03.30 pm	Keynote Address by Professor of Construction Management in the School for Built Environment, Massey University, New Zealand **Prof. Suzanne Wilkinson**
03.30 pm – 03.45 pm	Sponsors Video
03.45 pm – 04.00 pm	Address by Editor-in-Chief, Journal of Built Environment Project and Asset Management (BEPAM) **Prof. Mohan Kumaraswamy**
04.00 pm – 04.15 pm	Sponsors Video
04.15 pm – 04.20 pm	Symposium Participants Screenshot Photo
04.20 pm – 04.30 pm	Vote of Thanks by Hony. Secretary, CIOB **Eng. Saliya Kaluarachchi**
04.30 pm – 05.00 pm	Break
05.00 pm – 06.30 pm	Parallel Sessions 1
06.30 pm	End of Day 1

SATURDAY, 22 JULY 2023 – DAY TWO (ONLINE)	
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10.30 am – 11.00 am	Break
11.00 am – 12.30 pm	Parallel Sessions 3
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02.15 pm – 02.30 pm	Break
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04.00 pm – 04.30 pm	Break
04.30 pm – 04.40 pm	Rapporteur's Report by Scientific Committee Co-Chairperson **Dr. Thanuja Ramachandra**
04.40 pm – 04.50 pm	Announcing the BEPAM and CIOB Award Winners by **Prof. Mohan Kumaraswamy** **Prof. Yasangika Sandanayake**
04.50 pm – 05.00 pm	Vote of Thanks by Scientific Committee Co-Chairperson **Dr. Tharusha Ranadewa**
05.00 pm	End of Online Sessions
Zoom Link for Online Sessions: https://us06web.zoom.us/j/82838338804?pwd=SkJTMG5KUG51WThZT3UyaUJSellCZz09 Meeting ID: 828 3833 8804 Password: ciob2023	
SATURDAY, 22 JULY 2023 – FELLOWSHIP AND AWARDS NIGHT AT GALADARI HOTEL	
07.00 pm Onwards	Fellowship and Awards Night at Grand Ballroom, Galadari Hotel, Colombo

SYMPOSIUM SESSION PLAN AT-A-GLANCE

SYMPOSIUM SESSION PLAN AT-A-GLANCE					
Friday, 21 July 2023					
02.00 pm - 04.30 pm	Symposium Inauguration				
04.30 pm - 05.00 pm	Break				
05.00 pm - 06.30 pm	Session 1A	Session 1B	Session 1C	Session 1D	Session 1E
	S15119	S15068	S15034	S15015	S15019
	S15089	S15071	S15018	S15056	S15049
	S15046	S15072	S15051	S15060	T15102
	S15117	S15074	S15053	S15100	S15079
	S15032	S15108	S15040	S15116	S15092
	Q&A	Q&A	Q&A	Q&A	Q&A
06.30 pm	End of Day 1				
Saturday, 22 July 2023					
09.00 am - 10.30 am	Session 2A	Session 2B	Session 2C	Session 2D	Session 2E
	S15030	S15011	S15112	S15083	S15004
	S15098	S15099	S15026	S15017	S15090
	S15105	S15077	S15082	S15029	S15061
	S15106	S15044	S15101	S15054	S15020
	S15045		S15093	S15070	S15086
	Q&A	Q&A	Q&A	Q&A	Q&A
10.30 am - 11.00 am	Break				
11.00 am - 12.30 pm	Session 3A	Session 3B	Session 3C	Session 3D	Session 3E
	S15076	S15021	S15013	T15096	S15006
	T15091	S15031	S15081	S15027	S15037
	S15115	S15062	S15085	T15114	S15057
	S15110	S15109	S15121	S15063	S15111
	S15012	S15059	S15010	S15097	S15088
	Q&A	Q&A	Q&A	Q&A	Q&A
12.30 pm - 01.00 pm	Break				
01.00 pm - 02.15 pm	Session 4A	Session 4B	Session 4C	Session 4D	Session 4E
	S15033	S15016	S15107	S15084	S15078
	T15066	S15028	S15087	S15042	S15080
	S15067	S15103	S15094	T15058	S15104
		S15050		S15041	
	Q&A	Q&A	Q&A	Q&A	Q&A
02.15 pm – 02.30 pm	Break				
02.30 pm - 04.00 pm	Panel Discussion				
04.00 pm - 04.30 pm	Break				
04.30 pm – 05.00 pm	End of Online Sessions				
07.00 pm Onwards	Fellowship and Awards Night at Galadari Hotel, Colombo				
11.00 pm	End of Day 2				

DETAILED SESSION PLAN

FRIDAY, 21 JULY 2023

SESSION 1A

Theme	**Green Solutions for Construction**
Session Chair	**Dr. Niluka Domingo**
Session Duration	**05.00 PM - 06.30 PM**

Time	Paper ID, Title and Author(s)
05.00 PM - 05.15 PM	**S15119: Alternative materials for sustainable road construction in Sri Lanka** *H.D.D.P. Kodithuwakku, T. Ramachandra and P. Kajavathani*
05.15 PM - 05.30 PM	**S15089: Adoptability of bioplastic as a sustainable material in Sri Lankan building construction industry** *N.S. Muhammed, S.D. Gallage, B.A.I. Eranga and T.H. Madushanka*
05.30 PM - 05.45 PM	**S15046: Assessment of design and construction related factors influencing maintainability of green roofs: A case of high-rise buildings in Sri Lanka** *G. Kulasekara, B.H. Mallawaarachchi, and A.G.U. Damsari*
05.45 PM - 06.00 PM	**S15117: A study of green roof application in Sri Lanka** *Dasuni Kodituwakku, T. Ramachandra and U.G.D. Madushika*
06.00 PM - 06.15 PM	**S15032: A taxonomy of waterproofing systems for high-rise building projects in the tropics** *H.N.Y. Senarathne and A. S. Asmone*
06.15 PM - 06.30 PM	**Q&A**

Session Coordinator: Ms. Dilmi Atapattu

FRIDAY, 21 JULY 2023

SESSION 1B	
Theme	**Disaster Resilience**
Session Chair	**A/Prof. Thayaparan Gajendran**
Session Duration	**05.00 PM - 06.30 PM**
Time	**Paper ID, Title and Author(s)**
05.00 PM - 05.15 PM	**S15068: Comparative cost assessment of drywall technologies in disaster-induced housing reconstruction** *Nimasha Dilukshi Hulathdoowage and H. Chandanie*
05.15 PM - 05.30 PM	**S15071: Review on the importance of capacity building for enhancing disaster resilience through the effective utilisation of resources** *K.H.K. Dharmadasa, U. Kulatunga, M. Thayaparan and K.P. Keraminiyage*
05.30 PM - 05.45 PM	**S15072: Inclusion of marginalised communities during post-disaster context in Sri Lanka: What methodology?** *A.P.K.D Mendis., M. Thayaparan and Y. Kaluarachchi*
05.45 PM - 06.00 PM	**S15074: Critical assessment of the existing disaster resilience frameworks and their applicability to improve community resilience** *M.L.S.S. Fernando, K.A.T.O. Ranadewa, U. Kulatunga and K.P. Keraminiyage*
06.00 PM - 06.15 PM	**S15108: Cargotecture to minimise problems in post-disaster reconstruction projects in Sri Lanka** *K.D. Gurusinghe, K.A.T.O. Ranadewa, Agana Parameswaran, D. Weerasooriya and M.D.D. Costa*
06.15 PM - 06.30 PM	**Q&A**

Session Coordinator: Ms. Isuri Illeperuma

FRIDAY, 21 JULY 2023

SESSION 1C

Theme	**Operation and Maintenance of Built Environment**
Session Chairs	**Prof. Nayantara De Silva**
Session Duration	**05.00 PM - 06.30 PM**
Time	**Paper ID, Title and Author(s)**
05.00 PM - 05.15 PM	**S15034: Suitability of smart car parking for shopping malls in Sri Lanka** *Sanduni Karunarathna and Uthpala Rathnayake*
05.15 PM - 05.30 PM	**S15018: Applicability of drive-thru banking facility for the new normal setup: A case of COVID-19 pandamic in Sri Lanka** *W.D.N. Fernando, P. Sridarran and Y.J.M. Yatawatta*
05.30 PM - 05.45 PM	**S15051: Conceptual design of port development to support the logistics supply of Indonesia's new Nusantara capital city** *Lusi Aprianti, Mohammed Ali Berawi, Gunawan and Mustika Sari*
05.45 PM - 06.00 PM	**S15053: Maintenance inventory management in the healthcare facilities in Sri Lanka: A study on current issues and possible improvements** *A.S. Edirisingha, F.S. Nazeer and A.M.L. De Alwis*
06.00 PM - 06.15 PM	**S15040: Utilising smart visitor management system to enhance sustainable practices in high-rise buildings in Sri Lanka** *G.G.N. Chandani and A.S. Asmone*
06.15 PM - 06.30 PM	**Q&A**

Session Coordinator: Mr Dilan Weerasooriya

FRIDAY, 21 JULY 2023

SESSION 1D

Theme	**Blockchain Technology in Construction**
Session Chairs	**Dr. Navodana Rodrigo**
Session Duration	**05.00 PM - 06.30 PM**
Time	**Paper ID, Title and Author(s)**
05.00 PM - 05.15 PM	**S15015: Potential impacts of blockchain technology implementation on construction contract management in Sri Lanka** *B.C.T.M. Karunaratne and D.N. Abeynayake*
05.15 PM - 05.30 PM	**S15056: Applicability of blockchain technology to improve the productivity of Sri Lankan construction industry** *G.P.D.A. Weerarathna and K.P.S.P.K. Bandara*
05.30 PM - 05.45 PM	**S15060: Exploring state-of-the-art research on blockchain adoption in the construction industry: A systematic literature review** *S. Hirusheekesan, U. Kulatunga and Adeesha Wijayasiri*
05.45 PM - 06.00 PM	**S15100: Adaptation of blockchain and smart contracts to the construction industry of developing countries** *I.G.N. Anuradha, Krishni Kavindya Ambagala, Samudaya Nanayakkara and Srinath Perera*
06.00 PM - 06.15 PM	**S15116: An introduction to blockchain in building services: A literature review** *Sachindra Hewavitharana, Srinath Perera, Xiaohua Jin, Krisanthi Seneviratne and Keivan Bamdad*
06.15 PM - 06.30 PM	**Q&A**

Session Coordinator: Mr. Dulshan Costa

FRIDAY, 21 JULY 2023

SESSION 1E

Theme	**Procurement Solutions for Construction**
Session Chairs	**Prof. Kanchana Perera**
Session Duration	**05.00 PM - 06.30 PM**
Time	**Paper ID, Title and Author(s)**
05.00 PM - 05.15 PM	**S15019: Is integrated project delivery sufficient to reduce adversarialism in the UK construction industry?** *Abiola Aderibigbe, Nnedinma Umeokafor and Tariq Umar*
05.15 PM - 05.30 PM	**S15049: Strategies to create an enabling environment for public private partnership (PPP) projects in Sri Lanka** *Tharaka Kodippili, G.I. Karunasena, B.H. Mallawarachchi and Shashini Jayakodi*
05.30 PM - 05.45 PM	**T15102: Strategic implementation of PPP for small-scale infrastructure in Sri Lanka: A comparative analysis of alternative PPP models** *Kavini Guruge, Pramuditha Coomasaru and Chathuni Weeraman*
05.45 PM - 06.00 PM	**S15079: Investigating the motivation for implementing unsolicited proposals in the Sri Lankan construction industry** *T.M.P.N. Thennakoon, H.S. Jayasena and U.S. Weerapperuma*
06.00 PM - 06.15 PM	**S15092: Legal and regulatory framework related to unsolicited proposals in various countries: A systematic review for procurement stage** *G. Fernando, U. Kulathunga, M. Thayaparan and H. Chandani*
06.15 PM - 06.30 PM	**Q&A**

Session Coordinator: Ms. Thilini Liyanawatta

SATURDAY, 22 JULY 2023

<u>SESSION 2A</u>

Theme	**Digitalization in Construction**
Session Chairs	**Prof. Srinath Perera**
Session Duration	**09.00 AM - 10.30 AM**

Time	**Paper ID, Title and Author(s)**
09.00 AM - 09.15 AM	**S15030: An IOT-based electrical and electronic appliance management system for Sri Lankan residential buildings** *Samarakoon Arachchige Dinusha Sandaru, D.L.C.P Liyanage, I.G.N Anuradha, Janani Uvasara Kumarathunga and Chanuri Kalugala*
09.15 AM - 09.30 AM	**S15098: Potential use of digital twin for construction progress monitoring** *K. Amirthavarshan, S.D. Gallage, M.D.D. Costa and B.A.I. Eranga*
09.30 AM - 09.45 AM	**S15105: Big data analytics in the Sri Lankan construction industry: An assessment of the challenges and strategies** *A.M.D.S. Atapattu, R.M. Wattuhewa, K.G.A.S. Waidyasekara and R. Dilakshan*
09.45 AM - 10.00 AM	**S15106: Status quo of digitalisation in the Sri Lankan construction industry** *W.S.D. Perera, K.A.T.O. Ranadewa, Agana Parameswaran and D. Weerasooriya*
09.45 AM - 10.15 AM	**S15045: Building information modelling for construction productivity measurement** *Shandraseharan Archchana and Wei Pan*
10.15 AM - 10.30 AM	**Q&A**

Session Coordinator: Mr. Lakshitha Bandaranayake

SATURDAY, 22 JULY 2023

<u>SESSION 2B</u>

Theme	**Construction Management**
Session Chairs	**A/Prof. Sepani Senaratne**
Session Duration	**09.00 AM - 10.30 AM**
Time	**Paper ID, Title and Author(s)**
09.00 AM - 09.15 AM	**S15011: Quantity surveyor's perspective on document management in construction projects: An exploratory study in Sri Lanka** *L.S.D. Rathnayaka, B.K.M. Nadeetharu and U. Kulatunga*
09.15 AM - 09.30 AM	**S15099: Minimising logistic cost of construction materials in the construction industry: Contractor's perspective** *S.M.R. Jayaruwan, H.S. Jayasena and U.S. Weerapperuma*
09.30 AM - 09.45 AM	**S15077: Measures to mitigate termination of construction contracts in Sri Lanka** *S. Laxsana, S. Abiramy and A.F. Fayasa*
09.45 AM - 10.00 AM	**S15044: Use of building information modelling to mitigate cost overruns in design and build projects** *K.L. Chamikara, B.A.K.S. Perera and I.N. Kurukulasooriya*
10.10 AM - 10.30 AM	**Q&A**

Session Coordinator: Mr. Hashan Madushanka

SATURDAY, 22 JULY 2023

<u>SESSION 2C</u>	
Theme	**Sustainability Practices in Construction**
Session Chairs	**Ch. QS Indunil Seneviratne**
Session Duration	**09.00 AM - 10.30 AM**
Time	**Paper ID, Title and Author(s)**
09.00 AM - 09.15 AM	**S15112: Sustainability practices implemented in the Indian construction industry: A focus of construction phase** *Nicola Thounaojam, Ganesh Devkar and Boeing Laishram*
09.15 AM - 09.30 AM	**S15026: Construction innovation towards sustainable construction project success in Sri Lanka** *M.P.T.C. Jayasena, P.A.P.V.D.S. Disaratna and H.C. Victar*
09.30 AM - 09.45 AM	**S15082: Exploring sustainable project management practices in Sri Lankan construction projects: A perspective of MEP contractors** *M.N.M. Amri, M. Francis and T.N. Liyanawatta*
09.45 AM - 10.00 AM	**S15101: Investigation of the challenges of executing sustainable construction practices in the Sri Lankan construction industry** *K.B.K.R.G.G. Wimalarathna, M.L.S.S. Fernando and U. Kulatunga*
10.00 AM - 10.15 AM	**S15093: Digital technology enabled circularity in the construction industry: A bibliometric study** *Shashini Jayakodi, Sepani Senaratne, Srinath Perera and Keivan Bamdad*
10.15 AM - 10.30 AM	**Q&A**

Session Coordinator: Ms Agana Parameswaran

SATURDAY, 22 JULY 2023

SESSION 2D	
Theme	**Urban-Rural Development**
Session Chairs	**Dr. Gamini Weerasinghe**
Session Duration	**09.00 AM - 10.30 AM**
Time	**Paper ID, Title and Author(s)**
09.00 AM - 09.15 AM	**S15083: Management of social sustainability and quality aspects of rural road construction in Sri Lanka** *L.A. Nissanka and K.A. Gunasekara*
09.15 AM - 09.30 AM	**S15017: Need of establishing desalination plants to mitigate water scarcity in dry zones of Sri Lanka** *Y.J.M. Yatawatta and P. Sridarran*
09.30 AM - 09.45 AM	**S15029: Can Colombo port city high-rise tower and podium morphology improve pollutant dispersion and urban ventilation?** *Malithie Vidanapathirana, Narein Perera, Rohinton Emmanuel and Sheleeni Coorey*
09.45 AM - 10.00 AM	**S15054: Smart village concept for rural area development in Sri Lanka: A study on implementation, benefits, and challenges** *I.V.M. Ayodyani, F.S. Nazeer and A.M.L. De Alwis*
10.00 AM - 10.15 AM	**S15070: Barriers to the adoption of emerging technologies for sustainable construction in SMEs** *Samuel Adeniyi Adekunle, Clinton Ohis Aigbavboa, Obuks Ejohwomu and Babatunde Ogunbayo*
10.15 AM - 10.30 AM	**Q&A**

Session Coordinator: Ms. Dasuni Kodithuwakku

SATURDAY, 22 JULY 2023

SESSION 2E	
Theme	**Construction Business Continuity and Management**
Session Chairs	**Dr. Suranga Jayasena**
Session Duration	**09.00 AM - 10.30 AM**
Time	**Paper ID, Title and Author(s)**
09.00 AM - 09.15 AM	**S15004: Key attributes of construction maturity models: A systematic review** *J.K.D.D.T. Jayanetti, B.A.K.S. Perera and K.G.A.S. Waidyasekara*
09.15 AM - 09.30 AM	**S15090: Encumbrances of the competitiveness of South African construction organisations in the business environment of other African countries** *M. Ikuabe, C. Aigbavboa and S. Adekunle*
09.30 AM - 09.45 AM	**S15061: The use of project governance modes to minimise contractors' opportunistic behaviour** *B.P. Arsecularatne*
09.45 AM - 10.00 AM	**S15020: Assessing delay claims in terms of excusability and criticality of delays in FIDIC based contracts** *Eranga Jayasena, U. Kulatunga and P.M.S.U. Sumanarathna*
10.00 AM - 10.15 AM	**S15086: Outsourcing consultant quantity surveying activities during the post-pandemic era** *Dilrangi Samarathunga, Iresha Gamage and Vithusha Lingasabesan*
10.15 AM - 10.30 AM	**Q&A**

Session Coordinator: Ms. Nishadi Nanayakkara

SATURDAY, 22 JULY 2023

<u>SESSION 3A</u>

Theme	**Economics of Construction**
Session Chairs	**Dr. H. Chandanie**
Session Duration	**11.00 AM - 12.30 PM**

Time	Paper ID, Title and Author(s)
11.00 AM - 11.15 AM	**S15076: Economic models of climate change: Systematic review of benefits, limitations, and future directions** *B.K.M. Nadeetharu, U. Kulatunga and M.J.B. Ingirige*
11.15 AM - 11.30 AM	**T15091: Impact of economic crisis on employees of contractors' organisations in the Sri Lankan construction industry** *S.S. De Silva, W.M.C.L.K. Wijekoon and Chanuri Kalugala*
11.30 AM - 11.45 AM	**S15115: The impact of the depletion of foreign currency reserves on the Sri Lankan construction industry** *Naveesha Malmi Jayasinghe and Roshani S. Palliyaguru*
11.45 AM - 12.00 NOON	**S15110: Impact of economic decisions on building construction material prices in Sri Lanka** *K. Thilakshan, B. Arsecularatne and Y.G. Sandanayake*
12.00 NOON - 12.15 PM	**S15012: Transaction costs in Australian construction projects** *Sahani Fernando and Argaw Gurmu*
12.15 PM - 12.30 PM	**Q&A**

Session Coordinator: Ms. Thilini Liyanwatta

SATURDAY, 22 JULY 2023

SESSION 3B

Theme	**Industrial Symbiosis**
Session Chairs	**Dr. Narein Perera**
Session Duration	**11.00 AM - 12.30 PM**
Time	**Paper ID, Title and Author(s)**
11.00 AM - 11.15 AM	**S15021: Internet of things (IoT)-enabled industrial symbiosis model for construction material sharing: Bibliometric analysis** *B.H. Mallawaarachchi and Shashini Jayakodi*
11.15 AM - 11.30 AM	**S15031: The potential of industrial symbiosis: An analysis of barriers to its implementation for better waste management in industrial zones in Sri Lanka** *Pubudu Herath, Piumi Dissanayake and Geethmi Thisakya*
11.30 AM - 11.45 AM	**S15062: Adopting urban symbiosis for sustainable urban water reduction and management: A bibliometric analysis** *Y.J.M. Yatawatta*
11.45 AM - 12.00 NOON	**S15109: Merits and demerits of off-grid solar systems: Key stakeholders' perspective** *D.S.A. Ranasinghe, K.G.A.S. Waidyasekara and D. Weerasooriya*
12.00 NOON - 12.15 PM	**S15059: Barriers to emerging smart solutions adoption for energy efficiency in the construction industry** *Olusegun Aanuoluwapo Oguntona, Fikile Ngobeni, Opeoluwa Akinradewo, Babatunde Ogunbayo and Clinton Aigbavboa*
12.15 PM - 12.30 PM	**Q&A**

Session Coordinator: Ms. Dasuni Kodithuwakku

SATURDAY, 22 JULY 2023

SESSION 3C

Theme	**Circular Economy in Construction**
Session Chairs	**Dr. Jessica Siva**
Session Duration	**11.00 AM - 12.30 PM**
Time	**Paper ID, Title and Author(s)**
11.00 AM - 11.15 AM	**S15013: Minimising construction and demolition waste using circular economy concept to achieve sustainable urban development** *M. Gowsiga and M. Thayaparan*
11.15 AM - 11.30 AM	**S15081: Highly effective circular economic practices for the life cycle of a construction project** *Mohamed Ishan, Iresha Gamage and Vithusha Lingasabesan*
11.30 AM - 11.45 AM	**S15085: Analysis of barriers towards implementing circular economy in Sri Lankan built environment** *Panchali Weerakoon and M. Thayaparan*
11.45 AM - 12.00 NOON	**S15121: Principles of circular economy for building sector: A systematic review** *M. Gowsiga, T. Ramachandra, P. Sridarran and N. Thurairajah*
12.00 NOON - 12.15 PM	**S15010: Synergy between blockchain and circular economy in improving construction waste management: a literature review** *H.S.N.M. Jayarathna, B.A.K.S. Perera, A.M.D.S. Atapattu and M.N.N. Rodrigo*
12.15 NOON - 12.30 PM	**Q&A**

Session Coordinator: Ms. Agana Parameswaran

SATURDAY, 22 JULY 2023

SESSION 3D

Theme	**Construction Human Resource Management**
Session Chairs	**Prof. Lalith De Silva**
Session Duration	**11.00 AM - 12.30 PM**

Time	Paper ID, Title and Author(s)
11.00 AM - 11.15 AM	**T15096: Issues caused by employment of migrant workers in the Sri Lankan construction industry** *W.G.H.K. Nawarathna, M.D.T.E. Abeynayake and I.E. Illeperuma*
11.15 AM - 11.30 AM	**S15027: Comparative study of work-related factors affecting mental well-being of male and female construction workers in Australia** *Maheshi Tennakoon, Aparna Samaraweera, Thomas Colangelo, Shorup Sharma, Jake Tiller, Jayden Zeller and S.D. Gallage*
11.30 AM - 11.45 AM	**T15114: Conflicting situations affecting performance of construction workers at site** *Ayusman Biswal, Syed Husam and Sparsh Johari*
11.45 AM - 12.00 NOON	**S15063: The customer satisfaction on the railway infrastructure in Sri Lanka: A study on railway stations** *M.A.K.N. Perera, F.S. Nazeer and A.M.L. De Alwis*
12.00 NOON - 12.15 PM	**S15097: A study on the physical and mental health issues to the neighbouring residences due to the construction projects in Sri Lanka** *M.P. Arjuna, V. Edirisinghe, K. Manoharan and S.S. Herath*
12.15 PM - 12.30 PM	**Q&A**

Session Coordinator: Ms. Dilmi Atapattu

SATURDAY, 22 JULY 2023

SESSION 3E

Theme	**Lean Construction**
Session Chairs	**Prof. Udayanganie Kulatunga**
Session Duration	**11.00 AM - 12.30 PM**
Time	**Paper ID, Title and Author(s)**
11.00 AM - 11.15 AM	**S15006: Adaptability of lean concept to reduce plumbing waste in high-rise building construction in Sri Lanka** *S.M.A.H. Senanayake, L.D.I.P. Seneviratne and K.A.T.O. Ranadewa*
11.15 AM - 11.30 AM	**S15037: Strategies to implement lean maintenance concept for high-rise commercial buildings in Sri Lanka** *K.K. Arasakulasooriya, P. Sridarran and T. Sivanuja*
11.30 AM - 11.45 AM	**S15057: Lean six sigma tools for improving administrative processes in different sectors: A systematic review** *U.D.R.E. Ruwanpura, B.A.K.S. Perera and K.A.T.O. Ranadewa*
11.45 AM - 12.00 NOON	**S15111: Lean iceberg model to minimise barriers for digital twin implementation: Sri Lankan construction industry perspective** *D.W.J.W. Bandara, K.A.T.O. Ranadewa, Agana Parameswaran, B.A.I. Eranga and Amalka Nawarathna*
12.00 NOON - 12.15 PM	**S15088: Applicability of BIM technology for enhancing the lean construction process in Sri Lanka** *M.D.Y. Madusha, M. Francis and T.N. Liyanawatta*
12.15 PM - 12.30 PM	**Q&A**

Session Coordinator: Ms. Isuri Illeperuma

SATURDAY, 22 JULY 2023

<u>**SESSION 4A**</u>

Theme	**Legal Practices in Construction**
Session Chairs	**Dr. Dilani Abenayake** **Mr. Mahesh Abeynayake**
Session Duration	**01.00 PM - 02.15PM**
Time	**Paper ID, Title and Author(s)**
01.00 PM - 01.15 PM	**S15033: Quantitative analysis of construction-related legal cases in New Zealand** *Pramod Malaka Silva, Niluka Domingo and Noushad Ali Naseem Ameer Ali*
01.15 PM - 01.30 PM	**S15066: Barriers for implementing dispute review board (DRB) method to Sri Lankan construction industry** *M.D.T.E. Abeynayake and T.N. Liyanawatta*
01.30 PM - 01.45 PM	**S15067: Legal and policy provisions for protecting energy and telecommunication infrastructure against hazards: Comparison between Sri Lanka and other countries** *Maheshi Randeniya, Roshani Palliyaguru and Dilanthi Amaratunga*
01.45 PM - 02.15 PM	**Q&A**

Session Coordinator: Mr. Hashan Madusanka

SATURDAY, 22 JULY 2023

SESSION 4B

Theme	**Construction Waste Management**
Session Chairs	**Dr. Gayani Karunasena**
Session Duration	**01.00 PM - 02.15PM**
Time	**Paper ID, Title and Author(s)**
01.00 PM - 01.15 PM	**S15016: Construction and demolition waste management issues in building project life cycle stages: A case of Sri Lanka** *H.C. Victar and K.G.A.S. Waidyasekara*
01.15 PM - 01.30 PM	**S15028: Construction waste estimation methods: A systematic literature review** *Nguyet Tong, Niluka Domingo and An Thi Hoai Le*
01.30 PM - 01.45 PM	**S15103: From grave-to-cradle: Quality assurance system for the demolition waste management** *M.K.C.S. Wijewickrama, N. Chileshe, R. Rameezdeen and J.J. Ochoa*
01.45 PM - 02.00 PM	**S15050: Applicability of recycling and resource recovery for solid waste of Sri Lankan supermarkets** *K.G.M.B. Bandara, M. Gowsiga, A.S. Asmone and R.A.A. Dilogini*
02.00 PM - 02.15 PM	**Q&A**

Session Coordinator: Ms. Nishadi Nanayakkara

SATURDAY, 22 JULY 2023

<u>SESSION 4C</u>

Theme	**Construction Projects**
Session Chairs	**Ch. QS Vijitha Disaratne**
Session Duration	**01.00 PM - 02.15PM**
Time	**Paper ID, Title and Author(s)**
01.00 PM - 01.15 PM	**S15107: Modelling design stage risks in modular integrated construction projects in Sri Lanka** *T.A.S. Sandeepani, E.M.A.C. Ekanayake and Ilnaz Ashayeri*
01.15 PM - 01.30 PM	**S15087: A systematic review of vertical construction project characteristics** *Iresha Jayasinghe, Niluka Domingo, An Le Thi Hoai and Monty Sutrisna*
01.30 PM - 01.45 PM	**S15094: An exploratory study on abandoned construction projects in the Western Province, Sri Lanka** *Dasun Jayamal, Nishanthi Gunarathne and B.L.S.H. Perera*
01.45 PM - 02.15 PM	**Q&A**

Session Coordinator: Mr. Lakshitha Bandaranayake

SATURDAY, 22 JULY 2023

SESSION 4D	
Theme	**Construction Education**
Session Chairs	**Dr. M Thayaparan**
Session Duration	**01.00 PM - 02.15PM**
Time	**Paper ID, Title and Author(s)**
01.00 PM - 01.15 PM	**S15084: Exploring the facilities management education needs in Sri Lanka** *P. Sridarran, Shashini Jayakodi, Sanduni Peiris, Nayanthara De Silva, Joseph H.K. Lai, Uthpala Rathnayake and Piumi Dissanayake*
01.15 PM - 01.30 PM	**S15042: Honour codes and their influence on academic integrity in engineering education** *Sam Wamuziri*
01.30 PM - 01.45 PM	**T15058: Application of experiential knowledge and personal constructs into construction claims management** *R.A.D. Piyumra and P.A.P.V.D.S. Disaratna*
01.45 PM - 02.00 PM	**S15041: A systematic review of the challenges and strategies for addressing plagiarism in engineering education** *Sam Wamuziri*
02.00 PM – 02.15 PM	**Q&A**

Session Coordinator: Mr. Isuru Eranga

SATURDAY, 22 JULY 2023	
SESSION 4E	
Theme	**Carbon Footprint**
Session Chairs	**Dr. Sachie Gunathilake**
Session Duration	**01.00 PM - 02.15PM**
Time	**Paper ID, Title and Author(s)**
01.00 PM - 01.15 PM	**S15078: Data science applications for carbon footprint management in buildings: A systematic literature review** *I.P. Tharindu Sandaruwan, J.A.B. Janardana and K.G.A.S. Waidyasekara*
01.15 PM - 01.30 PM	**S15080: Management of carbon footprint in apparel industry: A systematic literature review** *I.P. Tharindu Sandaruwan, K.G.A.S. Waidyasekara and Nisa Zainudeen*
01.30 PM - 01.45 PM	**S15104: Comparison of embodied carbon estimating methods** *Navodana Rodrigo, Srinath Perera, Sepani Senaratne and Xiaohua Jin*
01.45 PM - 02.15 PM	**Q&A**
Session Coordinator: Mr. Dulshan Costa	

KEYNOTE SPEAKERS

Prof. Suzanne Wilkinson

Professor of Construction Management,
School of Built Environment

Keynote on 'Perspectives on Accelerating Sustainability in the Buit Environment Setting the Agenda for Research and Education with examples from New Zealand'.

Suzanne Wilkinson is a Professor of Construction Management in the School for Built Environment, Massey University and Associate Dean (Research), College of Sciences, Massey University. She has a PhD in Construction Management, and a BEng (Hons) in Civil Engineering, both from Oxford Brookes University, and a Graduate Diploma in Business Studies (Dispute Resolution) from Massey University.

Suzanne's research focuses on resilience, disaster management, construction innovation and smart cities. She is interested in how cities, communities and organisations plan for disasters and manage hazard events and has a particular interest in how cities, communities and organisations rebuild and recover. Suzanne has been advisor to organisations on resilience building and disaster recovery, most recently including Auckland Council, Government Agencies in New Zealand and Hunter Water in Australia. Suzanne has been Principal Investigator and Research Leader on many projects, including a recent 5 year, $10 million NZD project, where she is programme lead, on building capacity and capability for the construction sector and a recently completed 4 million NZD Principal Investigator for the Urban theme in the National Science Challenge: Resilience to Nature's Challenges. She has published over 300 research papers and co-written 3 books, the most recent being Resilient Post Disaster Recovery Through Building Back Better (Routledge in 2019), with her colleagues Sandeeka Mannakkara and Regan Potangaroa. Suzanne is a keen PhD supervisor and has now supervised to completion over 30 PhD students.

PANEL DISCUSSION

Panel Discussion on "Constructing Renaissance in Construction"

Panellists: Eng (Maj) Ranjith Gunatilleke
Dr. Kalana Alwis
Ch. QS. Upul Shantha
Ch. QS. Lalith Rathnayake

Moderator: Ch. QS. Dr. Suranga Jayasena

Panel Discussion Moderator

Ch. QS. Dr. Suranga Jayasena

PhD. University of Moratuwa, M.Sc. (Building), National University of Singapore B.Sc. (Hons) QS University of Moratuwa, F.I.Q.S.SL, MCIOB, UK

Senior Lecturer, Department of Building Economics, University of Moratuwa

Ch. QS. Dr. Suranga Jayasena is a former head of the Department of Building Economics, University of Moratuwa and currently serving as a senior lecturer of the department. He obtained a B.Sc. (Hons) degree in Quantity Surveying from the University of Moratuwa and an M.Sc. in Building from the National University of Singapore. In 2023, Dr. Jayasena completed his PhD at the University of Moratuwa, Sri Lanka.

He is a Fellow member, of the Institute of Quantity Surveyors, Sri Lanka and a member of the Ceylon Institute of Builders.

Dr. Jayasena is an excellent academic professional who is sharing his expert knowledge at several institutions. His exceptional career as a researcher has been awarded on multiple occasions. Dr. Jayasena won the Outstanding Research Performance Awards of the University of Moratuwa in 2008, 2009, 2010, 2012, 2013, 2014, and 2016. Also, he was the winner of CIOB Best Paper Award at The World Construction Symposium 2016 and the Emerald Highly Commended Paper Award at the 4th World Construction Symposium.

Panel Member

Eng (Maj) Ranjith Gunatilleke

CEng, B.Sc (Eng) MIE (SL)MICE(Lond) MSSE(SL)

Eng. Ranjith Gunatilleke is the CEO of the Sanken Group of companies and the Director of CIDA (ICTAD) Management Board. Mr. Gunatilleke is also serving as the chairman of Advisory Committee on Construction of Export Development Board. He is graduated from the Faculty of Engineering, University of Peradeniya, in 1976. He is a Chartered Engineer, and a Member of the Institution of Engineers Sri Lanka, since 1979. Mr. Gunatilleke has served in the Sri Lanka Army Engineers from 1976 to 2007 and was a PastPresident of the Chamber of Construction Industries.

Panel Member

Dr. KALANA ALWIS

D.Eng. (USA)

Director/Chief Executive Officer

NAWALOKA CONSTRUCTION COMPANY (PVT) LTD

Dr. Kalana Alwis commenced his career as a Civil Engineer at the Department of Irrigation of Sri Lanka and later in 1985 joined Nawaloka Construction Company. Later on, Dr. Alwis became a member of Sri Lanka's blue-chip business conglomerate, Nawaloka Group. In 2004, his 32 years of dedication towards the company was richly rewarded by an extraordinary accolade of "Best Employee of the Group". Further, his outstanding performance was crowned as Director /Chief Executive Officer of Nawaloka Construction Company (Private) Limited,

In recognition of his solidified accomplishments and brilliantly laudable contributions toward the Company and the SL Construction Industry, the Advisory Board of American National Business University the USA conferred upon him the title of "Doctor of Engineering Management" in 2022.

His able stewardship led to Nawaloka Construction Company's stakes in the industry and in the country reaching dizzy heights with ISO 9001:2015, ISO 14001:2015 and OHSAS 45001:2018 and making the company a reigning champion amongst the rest on high-rise buildings, highway and heavy construction with "design & build" not only in Sri Lanka but also in the international arena.

Dr. Alwis holds forte as the Chairman, Engineering & Construction, National Chamber of Commerce of Sri Lanka, Vice President of Major Constructors of Sri Lanka, Vice Chairman of Major and Specialist Constructors of Sri Lanka amongst the country's cream of the top construction industrialists. Also, he is a Council Member of the Chamber of Construction Industry of Sri Lanka, Ceylon Institute of Builders Sri Lanka, an Advisory Committee Member of the Sri Lanka Export Development Board and an Executive Committee Member of the Consulate of the Republic of Philippines, Colombo, Sri Lanka.

Panel Member

Ch. QS. Upul Shantha

MBA, BSc (Hons) QS, PG Dip. (Const. Mgt.), FIQSSL, AAIQS

Director, Cost Management Services Pvt. Ltd.

Past President of the Institute of Quantity Surveyors Sri Lanka

Ch. QS. Upul Shantha is a past president of the Institute of Quantity Surveyors (IQSSL), Sri Lanka. He obtained a B.Sc. (Hons) degree in Quantity Surveying from the University of Moratuwa, Sri Lanka in 1992. After that, a Post Graduate Diploma in Construction Management was completed at the Open University, Sri Lanka in 1995. In 2008, Mr. Upul Shantha completed a Master's degree in Business Administration at Macquarie University, Sydney, Australia.

He is an Associate Member of the Australian Institute of Quantity Surveyors, a Fellow Member of the IQSSL and currently Mr. Upul Shantha is positioned as a Board Member of the Construction Industry Development Authority (CIDA), Sri Lanka and a Member of the Credential Committee for CIDA Sri Lanka.

With his vast experience in competitive working environments, he has become a pioneer in introducing Glodon Cubicost 5D BIM and Graphshot 3D BIM software to the Sri Lankan construction industry. Further, Mr. Upul Shantha is a Founder and Principal Partner of Re Energy Development Partners, a Business Promotion Consultancy with a special focus on renewable Energy Assets.

With nearly three decades of experience both locally and internationally and a specialization in analysing, formulation and cost management, Mr. Upul Shantha has been dedicated to quantity surveying professional development as a resource person.

Panel Member

Ch. QS. Lalith Rathnayake

M.Sc. (PM), B.Sc. (Hons) QS, F.I.Q.S.SL

Contract Management Consultant, Director, VFORM Consultants Private Ltd and PROMA Private Ltd.

Ch. QS. Lalith Rathanayake is the immediate Past President of The Institute of Quantity Surveyors Sri Lanka (IQSSL), and a Director of VFORM Consultants (Pvt) Ltd. He is an exceptional character in the construction industry, who has been dedicated to elevating the Quantity Surveying Profession to greater heights. As an excellent teacher, he has been sharing his expert knowledge for nearly 2 decades with various local and international institutions. Mr Rathnayake obtained a B.Sc. (Hons) degree in Quantity Surveying in 1992 and M.Sc. in Project Management in 2012 from the University of Moratuwa, Sri Lanka.

He is a Fellow member, and former chairman of the Professional Affairs Board, Education Board, and Board of Publications of the Institute of Quantity Surveyors, Sri Lanka. Further, Mr. Rathnayake was a past president of the Quantity Surveying Alumni Association of the University of Moratuwa, Sri Lanka and engaged as a resource person and a committee member in the various construction industry; regulatory, academic, and professional institutional events.

Further, Mr. Rathnayake represented IQSSL at the Pacific Association of Quantity Surveyors Congress held in several countries including Australia, Canada, New Zealand, Singapore, Malaysia, Hong Kong, Japan, Brunei, China, Philippines, Indonesia, Fiji, South Korea and South Africa. Significantly, he was the panel moderator of the 4th World Construction Symposium, 2015.

Nearly, three decades of experience in both the local and international construction industry and also two decades of teaching experience in academia, Ch. QS. Lalith Rathnayake has been dedicated to the future of the quantity surveying profession.

CONTENTS OF PAPERS

Kodituwakku, D., Ramachandra, T. and Madushika, U.G.D., 2023. A study of green roof application in Sri Lanka. In: Sandanayake, Y.G., Waidyasekara, K.G.A.S., Ramachandra, T. and Ranadewa, K.A.T.O. (eds). *Proceedings of the 11th World Construction Symposium*, 21-22 July 2023, Sri Lanka. [Online]. pp. 1-13. DOI: https://doi.org/10.31705/WCS.2023.1. Available from: https://ciobwcs.com/papers/

A STUDY OF GREEN ROOF APPLICATION IN SRI LANKA

Dasuni Kodituwakku[1], T. Ramachandra[2] and U.G.D. Madushika[3]

ABSTRACT

Green roofs are one of the green practices, having widespread use in the European and Asian regions due to their numerous benefits. However, country like Sri Lanka is yet to experience its optimum potential application. Thus, this study investigates the application of green roofs in Sri Lanka in terms of current status of its application, role in the green rating systems and implementation barriers to enhance its application in Sri Lanka. Initially, a preliminary survey, followed by semi-structured interviews with green roof construction professionals was conducted where the collected data were analysed using descriptive data analysis techniques. Amongst the identified set of applications, residential and commercial buildings are the most common building types with the extensive and semi-intensive green roof types. Although the most commonly used rating systems of GREEN^SL® and LEED have various provisions, a very few out of number of buildings surveyed have incorporated green roofs. According to the green roof construction professionals, the application is limited in the Sri Lankan buildings due to fourteen (14) key barriers. Amongst those barriers, higher initial and maintenance costs, poor awareness of the public on the concept and lack of clients' willingness on the concept are the mostly identified barriers by the interviewees. Hence, the study recommends taking necessary actions to mitigate the barriers in order to enhance the green roof applications on the Sri Lankan buildings to optimise the multiple benefits if offers.

Keywords: *Application; Barriers; Green Roofs; Sri Lanka.*

1. INTRODUCTION

Modern world is running towards a foul direction with the competition among themselves while aligning with the rapid technological advancements (Dareeju et al., 2011b). The total population of the world is calculated as 7.8 billion in 2020 where it has predicted to increase by more than 25% in 2050 and become 9.9 billion approximately (Population Reference Bureau [PRB], 2021). Energy demand increases day by day and people tend to use low-cost energy sources available with higher greenhouse gas emission rates (Dareeju et al., 2011). However, since the growth and development of the world are considered as unavoidable constrains, immediate actions need to be sought to mitigate the negative impacts it causes on the planet earth (Clark et al., 2008).

Green roofing is considered as one of the worthful construction embedded concept in overcoming such negative impacts of global growths and developments (Mowla, 2010).

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The unused roof spaces can be used to establish sustainable practices while aiding the natural green reduction of the built environments (Rowe & Getter, 2006). The modern enthusiasm on green roof concept was bloomed in Germany while encouraging its citizens to green their roofs (Barreiro, 2012). Researchers identified benefits offered by green roofs over conventional roofs in different aspects globally. Jaffal et al. (2012) identified a significant role of green roofs in reducing energy consumption and controlling indoor air temperature which results for less fuel usage in both summer and winter periods. Further, green roof was identified as a solution to mitigate the Urban Heat Island (UHI) effect in the study of Berardi et al.(2014).

Although green roofs offer more benefits, the applicability of green roofs is limited. One reason could be the financial capability of the people. This is because higher initial and maintenance costs of green roofs compared to the conventional roofs (Wilkinson et al., 2013). Adding to that, a lack of technical knowledge and data, maintenance manuals, accuracy and reliability of available data, and adequate documentation of proven successful green roofing of buildings can be considered as other barriers (Someh et al., 2014). Moreover, Zhang et al. (2012) indicated that lack of government incentives and promotion and social community among the public and private sectors were some other barriers to implementing green roofs. Similarly, Zhang et al., (2012) explained that lack of public awareness of the green roof concept, its benefits, and technology are collective reasons for less adaptation of this concept.

Sri Lanka is also not exceptional to global scenario, the concept is not much popular, and the public awareness is limited (Halwatura, 2013). Despite, few researchers have paid attention to investigate the green roof application in the local context. For example, Wijerathne and Halwatura (2011) experimented to measure the variation of CO_2 in greenery areas against city junctions and acknowledged that green roof implementation is beneficial to the cities of Sri Lanka. Subsequently, Subaskar (2017) has examined the applicability of green roofs to Sri Lankan high-rise buildings through an opinion survey. In addition, some of the studies have assessed the benefits of green roofing such as life cycle costing, mitigation of the urban heat island effect, and thermal performance of green roofing (Dareeju et al., 2011a; Halwatura, 2013).

Hence, prior to assessing the performance of green roofs in the local context, it is important to explore the awareness and application of the green roof concept in the local context as a foundation to enhance the green roof application. To this end, a study is undertaken to investigate the perception of professionals who have involved and gained experience and exposure in green roof application on the awareness based on their benefits and green features, implementation barriers, and strategies to enhance the application of green roofs towards promoting green roof application in Sri Lanka.

2. LITERATURE REVIEW

The green roof is one of the elements included in a green building as an effective strategy to enhance sustainability (Santamouris, 2014). Further, green, living, or eco-friendly roofs are used to provide durability, longevity, and aesthetics to buildings and those can be incorporated into new or existing buildings (Patnaik et al., 2018). Also, green roofs act as a solar protection cover that contributes to mitigating urban warming and cooling the ambient air (Subaskar, 2017). According to Almusaed and Almssad (2018), the origin of the green roof concept come over a long time. There are a variety of green roofs under practice. Green roofs can be categorised based on the substrate thickness, bearing capacity of the rooftop, amount of maintenance required, installation cost, etc. (Capitanio, 2018). Mainly, there are three types of green roofs in practice; intensive, extensive, and semi-intensive (Patnaik et al., 2018). The main characteristics of different green roof types are presented in Table 1.

Table 1: Main characteristics of different green roof types

Details	Extensive	Intensive	Semi-intensive
Load bearing capacity	73-122 kg/m^2	171-391 kg/m^2	25-40 pounds
Substrate thickness	Less than 150 mm	Greater than 150 mm	125 mm - 200 mm
Vegetation usage	Grass	Trees, shrubs, bushes, grass	Shrubs, bushes
Irrigation requirement	Requires little or no irrigation	Requires regular irrigation	Requires considerable regular, little irrigation
Accessibility	Limited or no access	Accessible	Limited access
Structural design	Low or no additional structural design required	High additional structural design required	Moderate additional structural design required
Initial cost	Low	High	Moderate
Maintenance cost	Low	High	Moderate

Sources: (Shahidipour, 2014; Patnaik et al., 2018; Capitanio, 2018)

According to Vijayaraghavan (2016), the detailed layers of a green roof contain vegetation, growth substrate, filter fabric, drainage element, protection layer, root barrier, insulation layer, waterproofing layer and roof deck as shown in above Figure 1. However, the author further stated that the presence and absence of any of these layers will be depended upon the type of the roof, design and client requirements. Therefore, common basic green roof layers can be contrasted as vegetation, growth substrate, filter layer, drainage layer and waterproofing layer (Abass et al., 2020).

Figure 1: Cross-section of a typical green roof
Source: (Minnesota Pollution Control Agency, 2022)

Patnaik et al. (2018) stated that long-term client expectations and environmental benefits both can be achieved through proper selection of each layer. Hence, it is important to select each layer with due consideration as consisting of layers will affect the performance of a green roof (Shafique et al., 2018).

2.1 BENEFITS OF GREEN ROOFS

Green roofs can be identified as one of the green practices that offer more benefits in terms of environmental, economic, and social aspects. Figure 2 indicates a capture of multiple benefits that are offered by the green roofs.

Figure 2: Benefits of green roofs
Source: (Hussain et al., 2023)

Accordingly, improved air quality, ambient noise reduction, improved thermal insulation of the roof, building energy use reduction, new habitat for fauna and flora, reduction of stormwater runoff, ecological use of rainwater, food production, health and wellbeing and increase in roof life are the most significant benefits offered by the green roofs (Hussain et al., 2023). The benefits of improved air quality, ambient noise reduction, new habitat for fauna and flora, reduction of stormwater runoff, ecological use of rainwater can be categorised under the environmental benefits of green roofs (Ozyavuz et al., 2015) while improved thermal insulation of the roof, building energy use reduction and increase in roof life are categorised to the economic benefits of the roofing (Shafique et al., 2018). In addition, food production and health and wellbeing of the beings are the social benefits offered by the green roofs (Shafique et al., 2018).

2.2 BARRIERS TO THE APPLICATION OF GREEN ROOFS

Even though there are numerous benefits offered by the green roofs, still a deficiency can be observed in its application to the built environment (Hossain et al., 2019). Such a deficiency could be raised due to the various barriers that are forbidding the smooth application of the roof. Researchers have dedicated their studies to investigate such barriers that are limiting the application of green roofs in the built environment. Table 3 compiled a list of barriers to green roof application which were identified by various researchers in their studies.

Table 2: Barriers to green roof applications

Barrier	Source					
	(Zhang & He, 2021)	(Mahdiyar et al., 2020)	(Hossain et al., 2019)	(Ezema et al., 2015)	(X. Zhang et al., 2012)	(Williams et al., 2010)
Higher initial cost	√	√	√	√	√	
Higher maintenance cost	√	√	√	√	√	
Poor public awareness on the concept	√	√		√	√	
Lack of technical knowledge		√	√	√		√
Absence of government regulations	√	√		√		√
Challenges in installing on existing roofs	√	√		√	√	
Lack of skilled manpower	√	√	√			
Increase in structural loading	√		√	√		
Lack of established green roof industry						√
Issues in quality of the building	√		√	√		
Lack of suitable plants		√				
Lack of client's interest			√			

According to the table, there are twelve (12) key barriers that are limiting the green roof applications in the built environment. The additional structural requirements in terms of all planning, designing and construction perspectives have increased the initial costs of green roof application in compared to a conventional roof application (Hossain et al., 2019). In addition, there is a maintenance costs for green roofs as its components require regular maintenance activities (Mahdiyar et al., 2020). The concept is yet to have a wider spread in some contexts due to its poor awareness among general public, professionals in the construction industry and the governing authorities such as government (Hossain et al., 2019; Mahdiyar et al., 2020). Still worse, even if there is adequate awareness on the concept, in some contexts green roof application is hindered due to inadequate technical knowledge. The stakeholders do not willing to risks their investments in a concept with a poor technical knowledge and less competencies (Mahdiyar et al., 2020). Especially when the green roof installation is a retrofit for an existing roofing surface, the concerns raised with the structural loadings, design considerations and the quality level of the existing building elements (Hosaain et al., 2019; Mahdiyar et al., 2020). In addition, comparatively a smaller number of studies have identified lack of suitable plants (Mahdiyar et al., 2020) and lack of clients' interest on the concept (Hosaain et al., 2019). However, the limited availability of plants could be varied from context to context. The climatic conditions and the surroundings may determine the plants suitability. Therefore, there can be situations where the locally available plants also rejected in the suitability for the green roof installation. Finally, clients' preferences are also can be considered as a crucial factor in the green roof applications. Even though the roofing concept offer numerous benefits, the lesser willingness of the client on the concept may limit its installations. Accordingly, the identified barriers can limit the green roof applications, which can be subjected to the variations from one context to another.

2.3 WHY FOCUS ON SRI LANKA?

Sri Lanka is a tropical country where rapid urbanisation can be observed in modern society (Halwatura, 2013). There is faster growth in changing urban non-built lands into built lands in the 2000s as 1268 ha per year while it was only 914 ha per year in the 1990s in Sri Lanka (Subasinghe, et al., 2016). Colombo, the commercial capital of the country is going to occupy the highest position in the green space reduction of the Indian sub-continent area (Li & Pussella, 2017). Sri Lankans also have been tensed more on green concepts with the negative impacts they experienced from urbanisation (Charles et al., 2019). Ranagalage, Estoque, and Murayama (2017) stated that the rapid increase in population and housing of the Colombo Metropolitan Area (CMA) has limited the green vegetation of the area, and needs to seek more alternative spaces for greenery. Halwatura (2013) identified green roofs as a positive solution for forthcoming impacts on both environment and society due to rapid urbanisation rates in Sri Lanka.

3. RESEARCH METHODOLOGY

Initially, a comprehensive literature review was conducted to review the existing knowledge on the green roof concept, technology, benefits, and barriers towards the green roof implementation. Thereafter, a preliminary survey was conducted through site visits, interviews with stakeholders and internet surveys to investigate the green roof application in the Sri Lankan buildings and its recognition in green rating systems. Subsequently, semi-structured interviews were conducted to explore the barriers toward less adaptation of the green roof concept in the Sri Lankan context. Accordingly, twelve (12) construction professionals who have directly involved with the identified green roof applications and having industry experience of more than five (5) years were interviewed including Architects, Landscape Architects, Quantity Surveyors, Green Roof Contractors, Maintenance Engineers and Design Engineers. The profile of the participants is presented in Table 3.

Table 3: Profiles of the interviewees

Respondent ID	Designation	Industry Experience
R1	Quantity surveyor	12 years
R2	Landscape Architect	7 years
R3	Chief Architect	25 years
R4	Quantity Surveyor	8 years
R5	Green Roof Contractor	10 years
R6	Green Roof Contractor	7 years
R7	Maintenance Engineer	12 years
R8	Design Engineer	17 years
R9	Landscape Architect	22 years
R10	Design Engineer	10 years
R11	Architect	10 years
R12	Quantity Surveyor	9 years

4. ANALYSIS AND FINDINGS

Green roof application in the Sri Lankan buildings was investigated through a preliminary survey as well as a questionnaire survey. The preliminary survey gathered data on the status of green roofs in the green rating systems, type of the buildings that incorporated green roofs, types of the green roofs available. Accordingly, following sections present the analysis and findings derived, related to green roof applications in the Sri Lankan buildings.

4.1 RECOGNITION OF GREEN ROOFS IN GREEN RATING SYSTEMS USED IN SRI LANKA

GREEN$^{SL®}$ and LEED are the two green rating systems commonly used in Sri Lanka. Green certification for the Sri Lankan buildings is mainly accomplished through two (2) main green rating systems as certification. To date, there are different versions of these rating systems available. For example, GREEN$^{SL®}$ has version 2.1 - the latest version with the total number of points that a building can earn under this rating system is 100 while the minimum point requirement for the certification is 40 points. Similarly, LEED-v4 is consisted of a total of 110 points and required minimum 40 points for its certification.

In both rating systems, there is not any direct points assigned for buildings embedding a green roof. However, there are various criteria whereby a building can indirectly earn credits for its green certification from a green roof. Table 4 illustrates a summary of various green features which support incorporation of green roof and the points assigned for those features.

Table 4: Possible sustainable criteria for embedding green roof

GREEN$^{SL®}$ - version 2.1		**LEED– v4**	
Criteria	**Points**	**Criteria**	**Points**
2.0 Sustainable sites		**Sustainable Sites**	
2.6.3 - Development of Footprint	2	*Open space*	1
2.7 – Storm water design, quality control	3	*Rainwater management*	3
2.8 – Heat Island effect, non – roof	1	*Heat island effect reduction*	2
2.9 – Heat Island effect - roof	1	**Energy and atmosphere**	
4.0 Energy and Atmosphere		*Optimise energy performance*	18*
4.1 – Optimise energy performance	10	**Indoor environmental quality**	
6.0 Indoor environmental quality		*Thermal comfort*	1
6.7 –R Thermal comfort, design and	1	*Acoustic performance*	1
8.0 Social and cultural awareness			
8.1.2 - Social wellbeing	1		

*Except schools and health care buildings. For schools 16 points, for health care buildings 20 points

As per Table, although the green roof is not identified as a separate technology, there is sufficient provisions made for embedding green roofs and absorb its benefits, via rating systems. On other hand, embedding green roofs help to achieve green certification as it contributes to earn required points through various criteria as evidence in Table 4.

4.2 Green Roof Application In Different Types Of Buildings

The survey identified altogether 30 different buildings with green roofs in Sri Lanka. Those buildings include both green certified and non-certified buildings. Figure 3 illustrates the distribution of those green roof applications.

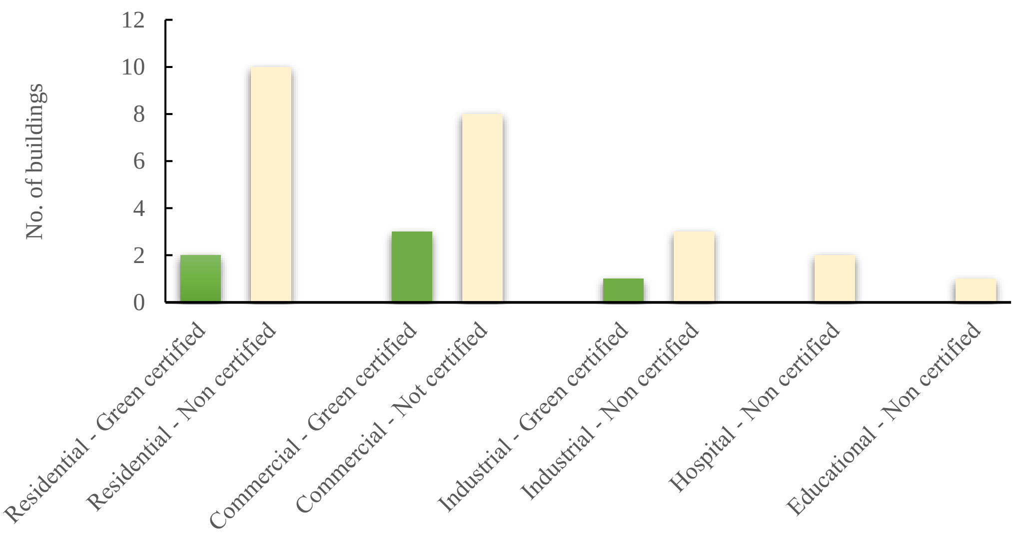

Figure 3: Green roof applications in different types of buildings

As seen from figure, amongst the surveyed buildings, residential (both apartments and single housing units), and commercial buildings (hotels and shopping complex), have mostly incorporated the green roofs, compared to other types. This could be due to owners' motive/willingness to attract the occupants through the green space. Amongst all types of buildings with green roofs, non-certified buildings are higher in numbers than certified. The most common concerns among the building owners were the lack of awareness on the green certification process and their non-willingness to obtain the certificate. Although most of them have installed green for the sake of recreational facility and the green space availability, the implied benefits such as cooling energy conservation, indoor air improvements or the stormwater run-off reductions were seemed to have achieved. It is worthy to note that even if the green ratings failed to provide recognition, building owners are willing to incorporate green roofs.

4.3 Types of Green Roof Used in Sri Lankan Buildings

According to the collected green roof details, all three types of green roofs: intensive, semi-intensive and extensive are in use in the Sri Lankan buildings. Figure 4 represents the distribution of types of green roofs used in the thirty (30) buildings surveyed.

As seen from Figure 4, most of the considered buildings consist of extensive type (13) while the intensive type of roof is least used, only five (5). Semi-intensive type also could be observed in twelve (12) buildings. According to most of the green roof designers and owners of the 30 green roof applications, except a few large-scale green roof stakeholders, the green roofs are being embedded into their buildings for the purpose of aesthetic appearance than other benefits offered.

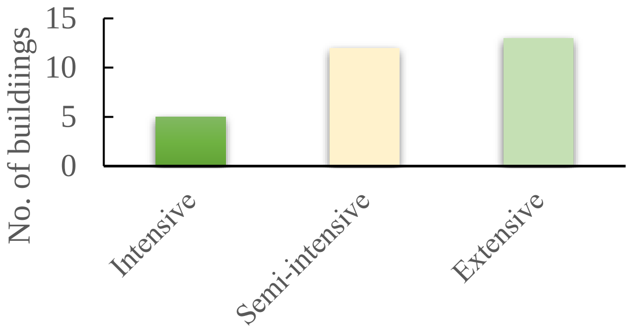

Figure 4: Different types of green roofs used in the buildings

The additional and complex structural design requirements have also influenced the type of green roof. In addition, the maintenance activities of vegetation, mainly the grass or the shrubs are quite simple than larger trees. These have motivated use of higher number of both extensive and semi-intensive.

4.4 BARRIERS TO GREEN ROOF IMPLEMENTATION IN SRI LANKA

The literature findings have mainly identified fourteen (14) barriers for green roof applications in the global context. Interviews with the construction professionals who have directly involved with the green roof applications in the Sri Lankan buildings were focused to investigate the barriers of green roof applications specifically in the Sri Lankan context. According to their responses, all the identified barriers from the literature are considerable in the Sri Lankan context. In addition, the respondents identified that the complexities in the green roof designing and lack of knowledge sharing institutions are also key barriers that limits the green roof application in the Sri Lankan buildings. Table 5 summarises the opinions of the interviewees on all identified barriers to the green roof applications on the Sri Lankan buildings.

Table 5: Summary of responses of the interviewees

Barrier	**Respondent**												**Total**
	R1	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**R11**	**R12**	
Higher initial cost	√	√	√	√	√	√	√	√	√	√	√	√	12
Higher maintenance cost	√	√	√	√	√	√	√	√	√	√	√	√	12
Poor public awareness on the concept	√	√	√	√	√	√	√	√	√	√	√	√	12
Lack of client's interest	√	√	√	√	√	√	√	√	√	√	√	√	12
Absence of government regulations	√	√	√	√	√		√	√	√		√		9
Lack of knowledge sharing authorities		√	√	√	√		√	√		√	√		8
Increase in structural loading	√		√	√		√	√		√	√		√	8

Barrier	Respondent												Total
	R1	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**R11**	**R12**	
Challenges in installing on existing roofs	√	√		√		√		√		√	√		7
Lack of technical knowledge			√	√		√				√	√	√	6
Issues in quality of the building	√	√			√		√	√			√		6
Lack of established green roof industry		√	√			√	√	√	√				6
Design difficulties	√				√		√			√		√	5
Lack of skilled manpower				√			√			√		√	4
Lack of suitable plants		√								√			2

According to the Table, all interviewees have identified high initial cost, high maintenance costs and poor public awareness on the concept as the key barriers to the green roof applications in the Sri Lanka. The barriers were similarly identified as significant in the literature (Hossain et al., 2019; Mahdiyar et al., 2020). However, lack of clients' interest on the roofing was only identified in the study of Hossain et al. (2019) while other referred studies have not identified it. Conversely, all the interviewees have identified the lack of interest of the client as a key barrier to green roof applications in the Sri Lankan buildings. *"Clients are not willing to install green roofs due to their narrow understanding on the concept"* stated by the R2 respondent. *"Therefore, it is required to have knowledge sharing institutions to enhance the awareness on green roof applications in Sri Lanka"* was further added by the respondent. However, there are very few knowledge sharing institutions for green roofs. *"Even there are institutions, those are not specific to the green roofs"* was added by R5 respondent. In addition, R1 respondent emphasised that the design difficulties in green roof installation is still a concern in the Sri Lankan context. *"In the unique designs of green roofs, sometimes our designers are not rich enough to determine some key design considerations"* stated by the R1 respondent. Once again, the issue can be overcome with the availability of a knowledge sharing institution where all the stakeholders can obtain all kinds of advices when required. Similarly, the interviewees have extended their opinions on the other identified barriers also. However, the lack of suitable plants was only identified by 2 interviewees while others stated that the local plants would facilitate any lacking situation. However, the fact emphasised by the R2 respondent was *"we need properly examined a vegetation type before it installs, so how we simply can rely on any locally available plant for the sake of necessity?"*. The argument was same in the study of Mahdiyar et al. (2020), which the only study that the barrier was mentioned. Accordingly, it shows that there are many obstacles that limits the green roof application in the Sri Lankan buildings. Therefore, the stakeholders should take necessary actions to mitigate and overcome these barriers for the smooth application of green roofs in the Sri Lankan buildings.

5. CONCLUSIONS

Amongst the selected sample buildings, residential and commercial buildings have incorporated green roofs mostly. The green spaces attract occupants of those buildings and contribute to increase income and property values. However, the study included a randomly selected limited sample buildings due to accessibility constrains. Another noteworthy conclusion is that most of the buildings (24 out of 30) are not green certified. This gives an indication that even the awareness of green certification lacks, building owners are willing to adopt green roofs. In terms of the type of the green roofs, buildings have mostly embedded extensive and semi-intensive green roofs, different to the experience in global context where intensive type is considered more beneficials while expensive is nature. In terms of the barriers, interviewees have identified all the barriers that stated in the literature while introducing two (2) additional barriers. Among those barriers, high initial and maintenance costs, poor awareness and lack of clients' willingness are the mostly identified barriers by the interviewees. Accordingly, the study recommends the stakeholders to take necessary actions to overcome these barriers while prioritising the most significant barriers.

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A STUDY ON THE PHYSICAL AND MENTAL HEALTH ISSUES TO THE NEIGHBOURING RESIDENCES DUE TO THE CONSTRUCTION PROJECTS IN SRI LANKA

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ABSTRACT

This study investigates the physical and mental health issues experienced by neighbouring residences as a result of construction projects in Sri Lanka. Specifically, it examines the impact of these projects on respiratory distress, hearing impairments, traffic congestion, lack of landscape, and flooding conditions. Additionally, the study explores the psychological effects on residents and emphasises the importance of health and safety measures in project management. Data collection involved conducting interviews with project managers, site safety officers, and a male nurse from three selected construction sites, followed by a questionnaire survey administered to 30 neighbouring residents. The study provides recommendations to mitigate adverse impacts, raise community awareness, and promote environmentally friendly practices in the construction industry. The findings enhance understanding of the health challenges faced by neighbouring residents and offer insights to policymakers and project managers to improve the well-being of affected communities.

Keywords: *Construction Projects; Mental Health; Neighbouring Residences; Physical Health; Sri Lanka.*

1. INTRODUCTION

The construction industry is one of the industries which provide a greater importance in the development of the world today (Fox & Skitmore, 2007). As a results, the construction industry is rapidly developing worldwide using a variety of technologies (Ofori, 2015). However, these construction activities are mainly built-in city centres and places where the masses hang out and these constructions have various effects on the daily life of the people (Wong et al., 2009). Neighbourhood has experienced significant changes in their everyday lives as they immediately experience both the success of the construction projects and the inevitable difficulties that come during the implementation of the construction operations (Budayan & Çelik, 2021).

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A growing body of literature indicates that contact with nature influence people's health and psychological well-being both directly and by moderating processes (Gidlöf-Gunnarsson & Öhrström, 2007). The activities related to construction projects have annoy the nearby inhabitants and companies, which can eventually result in economic loss, especially in urban regions where there is a high population density (Ferguson, 2012). Urban residents and those who live close to a construction site are subject to a wide range of negative impacts that are brought on by construction in terms of ecology, sociology, and economics (Balaban, 2012). Pollution coming from the construction sites, blockages by disposition of construction waste, traffic, dust and noises are several activities which cause diseases and negatively affect the physical and mental health of neighbouring residences (Ali et al., 2022). The World Health Organisation defined the terms physical and mental health as follows:

- **Physical health** – The condition of the body, with normal status being without disease or serious illness.
- **Mental health** – The condition, subject to fluctuations due to biological and social factors, which enables the individual to achieve a satisfactory synthesis of his own potentially conflicting, instinctive drives; to form and maintain harmonious relations with others; and to participate in constructive changes in his social and physical environment.

Nevertheless, it can commonly see that the consultants and contractors do not consider the difficulties faced by the local communities (Teo et al., 2009). Because of that contractors frequently prepare their bids without considering the expenditures necessary to make up for negative effects of construction operations on the community and indirect costs brought on by disputes and controversies (Liu et al., 2013). This leads to the community and non-government organisations frequently join forces and filing lawsuits against project teams (Missonier & Loufrani-Fedida, 2014). Since disputes have identified as one of the major causes for delay and disruption of construction projects (Edirisinghe et al., 2022) and securing the physical and mental health of the society is the social responsibility of the business organisations (Lantos, 2001).

Therefore, this study aims to examine the different situations and their magnitude effect on the physical and mental health of the neighbouring residents due to construction projects.

2. LITERATURE REVIEW

2.1 CONSTRUCTION PROJECTS AND IMPACT ON THE NEIGHBOURING

Majority of the larger constructions carried out near cities and the people around face various negative effect to their environment, social life and economic conditions (Shen et al., 2010). This situation become crucial because of the unprepared project teams and project management (Teo et al., 2009). One of the major reasons is behind that is project managers and the team only focus on completing the project at the lowest cost and with the highest profit margin (Bernheim & Reed, 1996). However, project delay or termination can be seen due to the external influence for the people which indirectly has a greater impact on the country's economy (Celik & Budayan, 2016).

A construction site has a high risk of accidents; thus, it is important to be made aware of the precautions that should be taken to prevent them (Dejus, 2007). There is a lot of potential for these kinds of incidents to occur during the construction of high-rise buildings and thousands of individuals have experienced accidents and distressing circumstances because of this type of development (Wong et al., 2009). Most of the physical injuries are caused by many employees falling from the top of the building as well as various equipment (Murty et al., 2006). In 2011, there were 9057 accidents involving people who became trapped in objects that fell from Highrise structures, such as machinery, wall that were bult badly, scaffoldings, etc. (Gürcanli, 2013). The psychological impact on third parties as well as the professional mental impact on the construction sector are both very significant (Bowen et al., 2014). Effects of physiological strain raise the risk of mental and physical weakness, including insomnia issues, headaches, gastrointestinal problems, increase poor health, and libido less (Blaug et al., 2007). In this way, interpersonal relationship between those working in the construction industry and those living in society at large are seriously affected because of psychological effects (Leung et al., 2008).

2.2 EFFECT ON PHYSICAL HEALTH DUE TO CONSTRUCTION PROJECTS

Due to the construction process, it is a very common situation for the workers in that field as well as the external parties to face various accidents and health issues (Abbe et al., 2011). These effects can range from the loss of human life to a decline in public trust in the services that organisations offer (Hemamalinie et al., 2014). In areas where construction work is ongoing, excessive toxic particles are mixed into the atmosphere almost constantly, due to which these toxic particles can be ingested for a long time and because of respiratory diseases related to allergies as well as immediate death (Apte et al., 2018). Construction dust exposure can cause illnesses such as silicosis, bronchitis, tracheal blockage, and occupational asthma in humans (Xing, 2018.).

Some other effects like gas leaking at a construction and improper use of the landscape during the renovation were discussed by Knegtering et al. (2009). When managing massive equipment like cranes, operators of such machinery must possess very specific training and expertise (Edwards & Holt, 2010). The practice of the project teams, however, is to ignore to consider the negative consequences of the building project on the nearby neighbours. Residents who experience these negative effects may decide to resist the construction project (Teo et al., 2009).

2.3 EFFECT ON MENTAL HEALTH DUE TO CONSTRUCTION PROJECTS

There is a significant direct and indirect cross-effect between people’s physical and mental health (Ohrnberger et al., 2017). In a construction site, there are four different sorts of risks, namely, scaffolding collapse, falls from great heights, being struck by a falling object, and plant and mechanical damage (Wong et al., 2016). When the public get to know about the accidents happening in the construction sites have created emotional stress effecting to the mental health if the community (Leung et al., 2011). This has created conflicts among the neighbouring residences and the project parties. The complexity of the project is another factor that influences how people view it, and it will have a significant impact if the public makes a mistake because of such a project (Abdelhamid & Everett, 2002). 'Heat Stress' was discussed by another researcher related to mental comfort (Jackson & Rosenberg, 2010). Additionally, if significant site accidents occur, they may also put nearby residents under psychological stress (Okorie & Musonda, 2016).

2.4 CAUSES OF ADVERSE EFFECTS ON PHYSICAL AND MENTAL HEALTH

One of the main impediments to sustainable development in the construction industry is noise pollution brought on by the operation of construction activities (Casanovas-Rubio et al., 2020). Noise levels of more than 90 decibels (dB) are hazardous to human health, both physically and mentally (Birkner, 2010). Living close to a construction site and being subjected to loud noises puts you at risk for conditions like loss of voice, incomprehensible speech, hearing impairment, stress, loss of attention, hypertension-enhanced blood pressure, immunity effects, biochemical effects, cardiovascular disease, sleep disturbances, and vascular system diseases (Oliveira & Arenas, 2012).

Excavation, drilling, bulk material transportation, loading and unloading, open-air material storage, the production of concrete and mortar, cutting and filling, and equipment movement are just a few examples of the many sites activities that produce construction dust emission (CDE) (Shen et al., 2010). It will cause dealing with ailments like coughs, wheezing and shortness of breath, cardiovascular and respiratory disorders, lung cancer, strokes, and exacerbation of asthma due to chronic exposure to dust pollution created by building sites in this way. Necessary actions to lessen the harm caused by dust pollution in this way, it will considerably contribute to the development of a future worldwide environmental crisis (Wu et al., 2016).

According to the European Conference of Ministers of Transport (ECMT), there is no standard definition for traffic congestion, and there are various methods for determining it (Agyapong & Ojo, 2018). The major causes of traffic jams created by construction sites are the lack of space needed to stop vehicles surrounding the site and the obstruction between trucks delivering the site's essential supplies and raw materials and vehicles travelling on the highway (Chen & Du, 2009).

It is crucial to prioritise the identification of physical and mental health issues among neighbouring residents in relation to construction projects. Doing so will allow us to effectively address and minimise any adverse impact on the progress of these projects.

3. METHODOLOGY

The objective of this study was to examine the physical and mental health issues experienced by neighbouring residents as a result of construction projects. To gather relevant information, a comprehensive literature survey was conducted, incorporating primary findings from previous research studies (Hedges & Cooper, 1994). The literature survey enabled the identification of health-related concerns faced by neighbouring residents due to construction projects. Primary data for this research was obtained through three case studies involving multi-story construction projects in Sri Lanka.

To collect the data, interviews were conducted with project managers, a male nurse assigned to the construction site for labour healthcare, and safety officers. These interviews provided valuable insights into the standards that stakeholders should adhere to in order to ensure the health of neighbouring residents during construction projects. In order to understand the perspectives of neighbouring residents regarding their health issues, a questionnaire survey was conducted. A total of 30 households participated in this survey.

The collected data was subsequently analysed using Microsoft Excel, allowing for thorough examination and interpretation of the findings.

3.1 DEMOGRAPHICS DATA OF THE INTERVIEW PARTICIPANTS

Table 1 showcases the demographic information of the interview participants. The individuals included in the study consist of project managers, safety officers, and a male nurse, whose professional experiences amount to 14 years, 4-8 years, and 2 years, respectively.

Table 1: Experiences of the professionals working on the selected projects.

Organisations	No	Participants	Experiences
Case 1	2	Project Manager	14 years
		Safety Officer	6 Years
Case 2	2	Safety Officer	4 Years
		Safety Officer	8 Years
Case 3	2	Safety Officer	6 Years
		Male Nurse	2 Years

3.2 CASE STUDY ANALYSIS

The impact of the three selected construction projects on the physical and mental health of the residents living in the surrounding areas is depicted in the following representation: a square symbol (■) indicates the presence of observable physical and mental effects on the residents, while the absence of a square signifies a project-related effect that does not directly affect the residents' physical or mental state.

Table 2: Physical and mental health issues of neighbouring residencies

Issues	Case 1	Case 2	Case 3
Physical Health			
Effected respiratory distress	N	N	N
Effected Hearing impairments	N	N	N
Traffic jams caused	N	N	
Lack of Landscape	N		
Falling objects Cause			
Experienced flooding conditions and clogging of the drains system		N	N
Mental Health			
Effected respiratory distress	N	N	N
Effected Hearing impairments	N	N	N
Traffic jams caused	N	N	
Lack of Landscape	N	N	
Falling objects Cause	N	N	
Experienced flooding conditions and clogging of the drains system		N	N

Based on the data presented in Table 2, the construction projects have resulted in various physical health-related issues. Specifically, respiratory distress and hearing impairments have been commonly observed among the affected residents. Additionally, traffic jams have been reported in Case 1 and Case 2. This is primarily due to the fact that these two projects are located in the Colombo city area, where nearby schools and a larger building footprint contribute to the challenge of parking vehicles. Case 1, in particular, also faces an issue of inadequate landscape due to its larger footprint and limited free land area. However, no incidents related to falling objects have been reported in any of the three projects. On the other hand, Cases 2 and 3 have encountered problems with flooding and drainage system clogging, whereas Case 1 has not experienced such issues.

Based on the analysis of mental health-related issues in Table 2, similar to the physical health-related issues such as respiratory distress and hearing impairments, these issues are commonly observed in all three cases. Although there were no reported physical health-related issues caused by falling objects in any of the cases, Case 1 and Case 2 experienced mental health-related issues. This suggests that false information has been spreading among the neighbouring residents of the construction projects, leading to unnecessary mental health problems, as noted in the study by Leung et al. (2008).

Furthermore, while there was no reported lack of landscape issues under the physical health category, Case 2 exhibited such issues in the context of mental health among the neighbouring residents. Additionally, flooding in Case 2 and Case 3 has caused both physical and mental health issues.

In terms of general practices, it was recommended to obtain certifications such as ISO 14001, ISO 14002, ISO 18001, and ISO 40001 for larger construction sites to ensure adherence to environmental and general safety practices. Case 1 and Case 2 have confirmed the availability of these certificates, which certify the implementation of such practices in their construction sites. Furthermore, it is commonly emphasised that a budget allocation of 1% to 2.5% of the total project budget should be made to prevent accidents and mitigate the impacts caused by construction activities. It is recommended that this percentage be increased to a minimum of 3% to 5% for each project.

Regarding noise control, it is specified that during the afternoon, noise levels exceeding 70dB should not extend beyond the construction site, while the limit is set at 50dB during the night. Special attention is given to managing excessive noise if there are frequent activities that generate high noise levels. In Case 1, special consideration is given to noise control due to the presence of nearby offices.

In situations where piling works may cause vibrations near old buildings, necessary barriers or precautions are implemented. It is advised to maintain the Hertz level between 90-100 within a 36-feet square area, and keeping it below 250 Hertz is considered satisfactory.

3.3 QUESTIONNAIRE SURVEY ANALYSIS

Table 3 presents the responses obtained from neighbouring residencies regarding the physical and mental health issues they have encountered. It provides an overview of the experiences and feedback shared by residents in relation to their well-being.

Table 3: Physical and mental health related issues due to construction projects

Issues	Case 1	Case 2	Case 3
Physical Health			
Effected respiratory distress	**7**	**7**	**6**
Effected Hearing impairments	**6**	**7**	**7**
Traffic jams caused	**6**	**6**	**5**

Issues	Case 1	Case 2	Case 3
Lack of landscape	**7**	**5**	**3**
Falling objects cause	**3**	**5**	**4**
Experienced flooding conditions and clogging of the drains system	**2**	**6**	**7**
Total of Physical Cases (family)	**31**	**36**	**32**
Mental Health			
Effected respiratory distress	**7**	**8**	**6**
Effected hearing impairments	**6**	**6**	**7**
Traffic jams caused	**7**	**7**	**5**
Lack of landscape	**7**	**6**	**3**
Falling objects cause	**6**	**7**	**4**
Experienced flooding conditions and clogging of the drains system	**4**	**6**	**7**
Total of Mental Cases	**37**	**40**	**32**

The responses from neighbouring residencies reveal that they have experienced various physical and mental health-related issues. Falling objects were reported by all three cases, indicating contradictory information regarding physical health concerns. The majority of residents mentioned suffering from respiratory distress, hearing impairments, and the impact of flooding and clogging of the drainage system on their physical health. These issues are similarly reflected in their mental health.

According to the residents, the dust from the construction site has led to diseases such as wheezing, coughing, sore throat, colds, asthma, and pneumonia. Noise-related illnesses include earaches, ear discharge, and frequent headaches. Traffic jams are frequently mentioned and are seen as accidents that occur when crossing roads in the area, causing distress and inconvenience. Prolonged exposure to traffic congestion can even result in fainting due to dehydration. Additionally, the lack of open spaces in the vicinity has psychological effects, particularly for youth and children who have limited areas to play and engage in recreational activities.

3.4 COMPARISON BETWEEN THE CASE STUDY INTERVIEW AND QUESTIONNAIRE SURVEY

The data from both sources indicate that neighbouring residencies experience common physical and mental health issues, including respiratory distress and hearing impairments. Additionally, traffic jams, lack of landscape, and the presence of flooding and clogging significantly impact the well-being of these residents. While the project participants did not explicitly mention incidents related to falling objects in all three cases, it is noteworthy that such incidents have occurred on a few occasions.

Furthermore, when comparing the questionnaire responses, there are no significant differences observed between physical and mental health-related issues. This suggests that both aspects of health are equally affected and should be addressed with equal attention and consideration.

4. CONCLUSIONS AND RECOMMENDATION

In conclusion, the neighbouring residences have reported experiencing respiratory distress and hearing impairments, indicating the impact on both physical and mental health. Additionally, the construction projects have resulted in issues such as traffic jams, lack of landscape, and problems with flooding and clogging in drainage systems. While the project participants did not specifically mention physical and mental health issues related to falling objects, the responses from the residences indicate that they have indeed experienced such incidents, both physically and mentally. These findings highlight the diverse range of challenges faced by the neighbouring residences as a result of the construction projects.

Based on the research findings, several recommendations can be made to address the adverse impacts of construction projects, particularly in partially urbanised areas:

1. Project Management: Allocate a higher percentage of the contract sum to ensure safety and health measures are prioritised. The project management team should be vigilant about health issues affecting the residents and take necessary measures to mitigate their impact.
2. Community Awareness: Inform and educate residents about health and safety measures, helping them understand the steps they can take to minimise the adverse effects caused by the construction project. Open communication and transparency with the community are crucial.
3. Psychological Support: Recognise and address the psychological impacts experienced by people in urban areas due to health issues arising from construction projects. Provide appropriate support and counselling services to help residents cope with the challenges.
4. Environmental Considerations: In areas located far from cities, where natural environmental conditions are more conducive, the impacts on health issues may be naturally resolved. However, it is still important to take necessary measures to ensure the well-being of the local residents. The project manager should actively contribute to maintaining the health of the community.
5. Environmentally Friendly Equipment: Encourage the use of environmentally friendly technical equipment in construction processes to minimise health and safety risks. Review the higher taxes imposed on the importation of such equipment to facilitate their adoption and incentivise sustainable practices.
6. Government Policies: Revise and update government policies related to the construction industry, taking into account the findings and recommendations of this research. Aim to create a regulatory framework that prioritises health, safety, and environmental sustainability in construction projects.

By implementing these recommendations, it is possible to mitigate the adverse impacts of construction projects on the health and well-being of residents in partially urbanised areas, fostering a safer and more sustainable construction industry.

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A SYSTEMATIC REVIEW OF THE CHALLENGES AND STRATEGIES FOR ADDRESSING PLAGIARISM IN ENGINEERING EDUCATION

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ABSTRACT

Plagiarism is a growing issue in higher education institutions world-wide. If left unchallenged, it represents a threat to genuine academic scholarship and integrity. This paper examines the current state of knowledge based on published research with a specific focus on plagiarism in engineering education. The overall aim of the study is to identify major factors that contribute to plagiaristic behaviour and to develop evidence-based tools, resources and interventions to assist students, faculty and higher education institutions to avoid plagiarism. Furthermore, the study seeks to provide policy recommendations that can be implemented at institutional level. It is found that plagiarism occurs at all levels of academic practice in teaching and research. The reasons why students plagiarise include ease of access to materials on the internet, time constraints, pressures to achieve good grades, lack of academic support and failure to integrate students into the university community. Faculty and universities have a role to play in training students to be ethical users of information. Students should be trained to be able to identify their requirements, to source and paraphrase text, cite references properly and attribute all sources of information. Faculty should also develop authentic instruments of assessments. This will motivate students to develop creative solutions. Plagiarism is however a complex aspect of human behaviour and further research is required to understand it better and to find potential solutions.

Keywords: *Academic Integrity; Education; Engineering; Ethics; Plagiarism.*

1. INTRODUCTION

Plagiarism is a problem in all higher education institutions and undermines the education process in several ways. It prevents students from developing critical thinking and analytical skills. It undermines the confidence and trust between students and faculty. If plagiarism goes undetected, it impacts on the academic reputation of the institution concerned and devalues its qualifications and awards (Pecorari, 2008). It is therefore important that all academic staff understand the nature of the plagiarism problem and take steps to address it. This paper provides a systematic review of the research literature on plagiarism in engineering education. The study is based on published scholarly sources such as peer-reviewed journal and conference papers. The

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objectives of the study are four-fold: to examine the current state of knowledge on plagiarism in engineering education; to identify the major themes that emerge from the literature; to develop evidence-based tools, resources and interventions to assist students, faculty and members of the higher education community, and finally to provide policy recommendations for implementation at institutional level. The study is timely and extremely important in that for engineering students, academic integrity at university provides the foundational basis for ethical professional engineering practice. Students who engage in unethical behaviour at college or university are likely to continue doing so in the world of work (Eaton, et al, 2021).

A summary of the key research publications reviewed is firstly outlined. Plagiarism is defined and features that characterise it are evaluated. Causes of plagiarism are given. The reasons why students plagiarise are assessed. The features that define plagiarism help to provide the background for understanding the reasons why students plagiarise. Knowledge of the reasons why students plagiarise assists in designing effective policy and student support interventions. Assessment design to avoid plagiarism is discussed. Detection and punishment of students and staff found guilty of plagiarism is a necessary but not sufficient condition for addressing the problem. Students in particular need to be trained to acquire good academic writing skills and appropriate use and attribution of all sources of information used. Other forms of academic misconduct include cheating in examinations or fabricating of written work, research results, sources of information or supporting another student to commit an act of dishonesty, to name a few (Dobrovska, 2007). These are outside the scope of this paper.

2. RESEARCH METHODOLOGY

The overall aim of the study is to identify the factors that drive student plagiaristic specifically in engineering education. Furthermore, the study aims to develop effective intervention strategies that can be applied to encourage ethical academic practice. This study has been guided by three research questions namely:

1. What factors influence students' plagiaristic behaviour?
2. What steps can university administrators and college deans take to reduce the incidence of plagiarism in engineering programs?
3. How can students be best supported in order to act in an ethical manner and avoid plagiarism?

This paper reports interim findings from the literature review. A systematic review of the literature was undertaken and the work started by identifying rigorous academic literature published in peer-reviewed journal and conference papers, books, theses, dissertations, and academic reports. The literature was identified by searching published sources through electronic search engines including Masader, Google Scholar, Science Direct, and ProQuest. The search terms used to identify the relevant literature were: plagiarism, academic integrity, academic dishonesty, text matching software, Turnitin, and plagiarism detection. These terms were combined with the term engineering or engineering education. The objective of the search was to narrow down and identify those research publications relevant to the engineering education context. Non-academic literature such as university policy documents, social media reports, newspaper articles, unpublished reports were excluded from the study. Other non-scholarly sources of information such as newspapers, blogs, wikis, tweets or social media outlets were also excluded from the study. Publications on other forms of academic misconduct addressing for example cheating in examinations and contract cheating were also excluded.

3. PRINCIPAL THEMES IN THE LITERATURE

This review is comprehensive but not exhaustive and focussed on the research literature specific to the engineering discipline. Engineering is a very broad subject and differences abound between various branches such as civil, electrical, mechanical environmental, electronic or energy engineering, to name a few. In the study, these disciplinary differences have been ignored and the review seeks to encapsulate all areas of engineering. The main themes to emerge from the review are: plagiarism detection and text-matching software, student and faculty perceptions, prevalence of plagiarism, collusion and cheating, international students, academic integrity generally and potential solutions to the plagiarism problem. Table 1 provides a summary of the key papers reviewed and the principal themes identified from each. The content of each of these publications is discussed in the relevant sections of this paper which follow.

Table 1: Summary of key papers reviewed and their principal themes

Paper	Plagiarism detection	Plagiarism Perceptions	Plagiarism prevalence	Academic integrity	Potential solutions
Barrett and Malcolm (2006)	√		√	√	√
Bertram Gallant, et al. (2014)			√		√
Beute, et al. (2008)	√	√			√
Carpenter, et al. (2010)		√	√		
Carpenter, et al. (2006)		√			√
Cooper and Bullard (2014)	√				√
Duff, et al. (2006)			√		√
Eaton, et al. (2020)	√				√
Eckel (2010)					√
Guerrero-Dib, et al. (2020)				√	
Gunnarsson, et al. (2014)				√	√
Henslee, et al. (2015)				√	√
Holi Ali (2013)	√				√
Kaner and Fiedler (2008)	√				
Lyon, et al. (2006)	√				
Mostafa, M (2011)		√		√	√
Parameswaran and Devi (2006)		√			√
Pecorari (2003)			√	√	√
Songsriwittaya, et al. (2009)		√		√	
Šprajc, et al. (2017)		√		√	√
Srikanth and Asmatulu (2014)				√	√
Stappenbelt (2012)		√		√	√
Stappenbelt et al. (2016)			√		√
Starovoytova and Namango (2016)		√		√	

Paper	Plagiarism detection	Plagiarism Perceptions	Plagiarism prevalence	Academic integrity	Potential solutions
Starovoytova (2017)				√	√
Starovoytova and Namango (2017)		√			√
Vesilind (1996)		√		√	
Vieyra, et al. (2013)	√		√		√
Wan, et al. (2011)		√			√
Whittle and Murdoch-Eaton (2008)					
Yeo (2007)		√		√	√
Youmans (2011)	√				√
Zhang, et al. (2014)	√				√
Zigmond and Fischer (2002)		√		√	

4. CHARACTERISTICS OF PLAGIARISM

Plagiarism is the practice of taking text, work or ideas of someone and presenting them as your own without acknowledging the source. Text in this context includes sets of equations, words, program codes, photographs, to name a few. Plagiarism is a form of deception or cheating. Sutherland-Smith (2008) presents a six-element definitional model of plagiarism. The key elements are that an object which may include language, words or text is taken from a particular source by a student, academic or other person without adequate acknowledgement and with or without intent to deceive. In computer programming for example, source-code plagiarism is defined as the reproduction and copying of code without making any major changes or adaptations (Pawelczak, 2018). Plagiarism constitutes academic dishonesty. It is for this reason plagiarism is treated very seriously in colleges and universities.

Plagiarism occurs at all academic levels. It includes both undergraduate and postgraduate levels. Bretag (2013) reports results of a survey at Australian Universities, which found that one in five postgraduate research students had never heard of academic integrity and two in five postgraduate students did not know whether their university had an academic integrity policy or not. Some established researchers are involved in questionable academic practices too. Bretag (2013) reports results of a survey in the United States of America that found that one-third of respondents had engaged in questionable research practices. The Committee on Publications Ethics (COPE) discusses thirty to forty alleged cases of research plagiarism over a ten-year period. Established researchers have also been found to engage in self-plagiarism where they duplicate substantial parts of their already published work without sufficient acknowledgement (Cross, 2007).

The four attributes that are necessary to identify plagiarism include the following. Firstly, there must be similarity between the texts. Secondly, production of the second text must have been based on the earlier text. Thirdly, there must be an inter-textural relationship. That is, the text must be similar enough to suggest a causal relationship although similarity on its own alone is not sufficient proof that there is plagiarism. All materials that were referred to in the production of a piece of academic writing must be correctly acknowledged. If not, that may constitute plagiarism. Finally, there must be intent to deceive on the part of the plagiarist. Many policies in colleges and universities do not take intent to be relevant. In any case, proving intent can be difficult because it is only the culprit who knows whether they intended to plagiarise or not. Isoc (2014) argues that there is no such thing as unintentional plagiarism and that unintentional plagiarism is a hypothetical concept.

Dobrovska (2007) compares and contrasts cheating, plagiarism and collusion. She asserts that cheating is an intentional act of dishonesty. However, plagiarism can be committed intentionally or unintentionally. Furthermore, collusion is an act of dishonesty that is undertaken in co-operation and collaboration with others. However, what constitutes plagiarism is not so clear-cut for students particularly in their early years of higher education (Stappenbelt & Rowles, 2010; Stappenbelt, 2012). Skill deficiencies and language barriers are the two main factors that may explain the incidence of plagiarism where it occurs particularly for international students. Fortunately, both international and domestic students possess the abilities to recognise plagiarism and to take steps to correct it (Duff et al., 2006). Yeo (2007) concludes that although students can provide sound theoretical definitions of plagiarism, they do not always appreciate the scope of activities that constitute plagiarism.

5. INCIDENCE OF PLAGIARISM IN HIGHER EDUCATION

Almost all universities have policies in place to address the issue and they take their responsibilities very seriously. The Quality Assurance Agency (QAA) in the United Kingdom report that 50,000 students over a three-year period were caught cheating. This equates to about 17,000 students per year or 0.7% of students every year (QAA, 2020). The vast majority of universities have sound policies in place and use of text-matching software for plagiarism detection. These numbers show that plagiarism is not an isolated event. If it were, then it could be addressed through detection and punishment. Plagiarism is actually much more widespread although the exact extent remains uncertain.

Eaton et al. (2021) find that plagiarism is widespread amongst students and academic staff in engineering, as in other fields but policies and their implementation are often inconsistent. Universities therefore need to provide clearer guidelines and greater support for students and academic staff. Mostafa (2011) argues that creative disciplines such architecture require discipline specific approaches to address plagiarism in education and this should assist in promoting ethical behaviour in their later years when in professional practice. Carpenter et al. (2010) found that engineering students self-reported higher rates of academically dishonest behaviours compared to their peers in other programs of study. This is not because of their innate characters but probably due to the contributory factors of the nature of the curriculum and course design. Plagiarism rates may be higher in technical disciplines precisely because reports and essays may not be the predominant form of assessment (Barrett & Malcolm, 2006).

There is concern that many students may submit assignments written by essay mills where the work is obtained through contract cheating. Text-matching software and tools such as Turnitin, Unicheck or Crosscheck cannot detect this. Detecting this kind of paid impersonation is nearly impossible. Techniques such as stylometry used by historians investigating authorship of historical documents can assist (Cross, 2007). However, systems to identify academic misconduct of this nature are yet to be developed. There is need for research to ascertain the extent to which plagiarism and contract cheating may be prevalent in higher education institutions internationally. There is also need to evaluate the extent to which there may be concerns regarding contract cheating and plagiarism among students, academics, employers and members of the general public regarding the risks posed by plagiarism and contract cheating. Best practice in detecting and addressing contract cheating and plagiarism should be identified and disseminated.

6. REASONS WHY STUDENTS PLAGIARISE

In order to prevent the reoccurrence of plagiarism in an institution and to develop an ethical academic culture, it is essential to understand student attitudes to plagiarism in the first instance (Stappenbelt, 2016). If students are warned that they should not plagiarise and if they know that the consequences of cheating when caught will be severe, it would be expected that this would make students less likely to plagiarise. However, if the students perceive that the chances of not being caught are high, then they are likely to plagiarise. Students plagiarise because they have ease of access to materials on the internet and new technologies which make it easy to copy materials. As to whether male students are much more likely to plagiarise than female students, results of research into this question are mixed.

Time constraints are also likely to be a contributory factor. The lack of time, inability to cope with the workload, lack of knowledge regarding how to cite sources, how to find materials and how to research or ability to express ideas are all possible reasons for why students plagiarise (Šprajc et al., 2107). Time constraints may arise because students have part-time jobs or have been given unrealistic deadlines. Extremely challenging assessments may also drive students to work together which inadvertently leads to collusion.

The pressure to achieve excellent grades is also a factor. An excellent student keen on getting a good grade but faced with a particularly difficult assignment may be tempted to plagiarise. However, it should be noted that there is an inverse correlation between student plagiarism patterns and examination grades. Cheating leads to higher failure rates, lower scores in examinations and raises the possibility of dropping out of a program (Pawelczak, 2018).

Students who are loners and do not feel particularly integrated as part of the University community are more likely to plagiarise. Finally, strong peer disapproval of plagiarism means that students are less likely to plagiarise. However, students who are in a group where others are plagiarising are much more likely to follow suite (Pecorari, 2003).

Prior warning of students about plagiarism checks does not necessarily reduce incidence of plagiarism (Youman, 2011). The amount of plagiarism that instructors can expect may depend on the type of assignment that students are required to complete. Dense scientific work may be difficult for students or even experienced researchers to summarise. Plagiarism detection software is not a silver bullet for elimination of plagiarism but it is a helpful tool for identifying sources of plagiarism. Plagiarism is a complex human behaviour that requires further studies to understand and address. Plagiarism if left unchallenged represents a threat to genuine and authentic scholarship.

Plagiarism is caused by a novice approach to information (Keilson & Cooperstein, 2007). Thus, academic staff have a responsibility to teach students competencies of information literacy. Students should be taught the skills to define their information needs, locate relevant information, access it, evaluate it, analyse it and use it ethically.

Librarians can also support students to develop these skills including academic writing (Eckel, 2010). In addition, other departments in universities can be useful in supporting students to develop academic writing skills. These include academic advisors, academic writing and student support centres.

7. ROLE OF ACADEMIC STAFF IN ADDRESSING PLAGIARSIM

At the heart of addressing plagiarism are individual academic staff. A questionnaire survey of fifteen academic staff in an engineering school conducted by Starovoytova and Namango (2017) concluded that there was a lack of understanding among faculty about the basic elements of scientific writing which leads to plagiarism. The study also revealed lack of relevant policies to detect and punish plagiarism at that particular institution. Clearly, the sample size for this study was very small and the results cannot be generalised (Starovoytova & Namango, 2017). However, this calls for further studies on plagiarism on a larger scale and in-depth analysis. Behaviour, attitudes and values acquired by students during their formative years at university provide the foundational basis for their careers and professional practice. Of relevance to this are behaviours related to academic integrity and plagiarism.

A small-scale study based on a survey of twenty-five engineering students revealed that overall, there is widespread deficiency in students' understanding of plagiarism and what constitutes good academic writing. Engineering students should therefore be trained in areas such as information gathering, research techniques, analytical and referencing techniques as part of their undergraduate curriculum (Starovoytova & Namango, 2016). Whilst the results from this study cannot be generalised because it is based on a relatively small sample of students in one engineering school, it reveals that further research is required. The results are also based on self-reports from students. Detailed research is required to uncover the root causes of plagiarism behaviour by students and to develop effective intervention strategies (Starovoytova, 2017).

Detection of plagiarism where it occurs is the responsibility of academic staff. It is advisable for recently appointed academic staff to consult with their peers or Heads of Departments before pursuing a case of plagiarism against a student. Norms in a program, college or university influence student actions and behaviour (Bertram-Gallant, et al, (2014). If students notice that an institution has lapsed systems and academic misconduct is not detected, they are more likely to continue engaging in such unacceptable behaviour. Zigmond and Fischer (2002) argue that even small transgressions of academic misconduct should not be condoned. Tacit acceptance of these little unacceptable behaviours may in due course lead to serious unethical behaviours.

Academic staff have a role to play in promoting academic integrity by designing academic assessments that require original solutions. One approach to tackling plagiarism in higher education is to rethink academic assessments. Students can generally be assessed using a range of assessment methods (Race, 2014). Whatever the chosen method of assessment, all academics and their institutions would like to be confident that the work submitted is that of the student. Therefore, at one extreme end of the assessment spectrum would be to increase the proportion of marks allocated to supervised final examinations. The main limitations of examinations are that they are not a good indicator of the breadth of skills and intellectual abilities that employers require.

Academic staff, colleges and universities should consider developing authentic assessments. Authentic assessments seek to replicate the sorts of problems that graduates encounter in the world of work (Barrett & Malcolm, 2006). Authentic assessments provide opportunities for students to demonstrate a whole range of transferable skills including critical thinking, problem solving, team working and communication. For example, project-based activities make it harder for students to plagiarise work from outside sources. Students can still copy solutions developed by others within the same class but this is easier to detect, for small class sizes but not large cohorts. Plagiarism detection tools are available to detect levels of similarity and therefore likely collusion between students (Adeva et al., 2006).

Training of students to avoid plagiarism can take many forms. Online tutorials are as effective as pre-recorded lectures in addressing students' skills deficiencies to tackle plagiarism (Henslee et al, 2015). Further work is however required on this to compare and contrast the effectiveness of two teaching strategies namely: online tutorials and pre-recorded lectures as opposed to taking no intervention at all. Whatever form it takes, instructional support and engagement with students is a very promising approach to reducing plagiarism (Duff et al., 2006).

8. ROLE OF THE HIGHER EDUCATIONS INSTITUTIONS

Most, if not all, colleges and universities take plagiarism very seriously. The first role of the Higher Education Institution in this area is to define and disseminate to students and staff an appropriate policy and regulations which govern plagiarism and all other forms of academic misconduct. Most policies will define and explain what plagiarism is and the procedures that should be invoked by academic staff where plagiarism is suspected. Policies should be clear and specific enough so that all stakeholders know how to apply them in practice. A policy that is ambiguous is likely to lead to staff difficulties in implementation. Detection of plagiarism is important. Students in particular should be aware and know that any plagiarism or attempts to plagiarise are likely to be detected and punished. Staff will require professional training and development in this regard.

Text-matching software provides detailed and rich feedback to students and staff alike, thus helping them to improve quality of their academic writing to avoid plagiarism. They save time and also provide a quantitative measure of the percentage of text matching other publicly available online sources. However, these reports have limitations. One of them is that many engineering publications particularly old ones are not part of text-matching databases and therefore cannot be detected. Secondly, students can play with software settings in an attempt to falsify output reports from the text-matching software.

An increase in plagiarism cases in an institution may signal that its students are cheats. A decrease may indicate that faculty at the higher education institution do not take plagiarism seriously. It is essential that the institution collects annual statistics on incidences of plagiarism and benchmarks this data with other similar educational institutions of its size. This will enable the institution to be able to evaluate the effectiveness of its anti-plagiarism measures.

Concerns have been expressed regarding the interpretation of text-matching software reports. Student concerns include use of unavoidable technical terminology and phrases which are highlighted by the software as plagiarised text (Whittle & Murdoch-Eaton, 2008). A percentage figure copied in a report that is deemed acceptable or the declared cut-off point by the institution also requires interpretation. Text-matching software should be perceived by students as learning aids and not as tools for detecting poor academic practice. Text-matching software is not a substitute for supporting students and teaching them to develop good academic writing skills. This is the responsibility of all academic staff.

It should also be noted that text-matching software detects textural similarities, but may not detect non-textural elements such as graphs and figures which tend to be common in engineering publications (Zhang et al, (2014). Furthermore, text matching software cannot detect some forms of plagiarism such as undocumented ideas and collusion. This occurs for example in situations where students are given an individual assignment but students then choose to share solutions to the assignments. This is relevant in engineering where students are usually given tasks to design systems, solve technical problems, write reports or develop computer codes, etc. Techniques for detection and prevention of this type of plagiarism include for example giving each student a unique assignment and requiring individual presentations of the assignment findings, (Halak & El-Hajjar, 2016).

Other plagiarism detection software includes FreeStyler which detects uncharacteristic changes in writing style in a document. This can be used to show if paragraphs or sections of a document have been lifted from a different source. Stylometric programs can assess a range of factors such as spelling conventions, punctuations and where these changes simultaneously give a reasonable indicator that such material has been copied from somewhere (Cross, 2007). Plagiarism detection also has some limitations in the context of a learning environment. For example, students may also be forced in some instances to obfuscate solutions so as to bypass plagiarism detection (Pawelczak, 2018). Plagiarism detection has however advanced to a point that it can be applied in other languages such as Chinese and programming codes too (Lyon, Barrett, & Malcolm, 2006).

Plagiarism should be approached as an educational matter and not as a punitive one (Gunnarsson et al., 2014). All students at both undergraduate and postgraduate levels need the education on how to paraphrase text, cite and reference properly. International students have not been found to plagiarise more than domestic students particular when they have been trained to understand what constitutes plagiarism (Smith et al., 2016). Students need to be trained to become better and ethical consumers of information. Students need to be trained to be able to locate what they need. To enable engineering colleges to do so effectively requires a deeper understanding of how practicing engineers research for information and to develop strategies and approaches to ensure that these methods are addressed effectively in the engineering curriculum. Surveys of practicing engineers, faculty and students would shed more light on these training needs.

9. THE WAY FORWARD

This study was limited to a literature review, where it suggests broader and in-depth investigation in to the study area. Hence, using both qualitative and quantitative research techniques, the next stage of the study will involve collection and analysis of primary data. Data will be collected using telephone interviews, focus groups and self-completion questionnaires. Online and digital technologies will be used to collect survey data and focus groups will be conducted via online team meetings. Survey respondents and membership of focus groups will include university administrators, engineering faculty and students. The survey will be extended to cover universities from different countries to enable comparative analysis. Factor analysis will be undertaken with tests such as the Kaiser-Meyer-Olkin measures and the Bartlett's test of sphericity being applied to ascertain the robustness and suitability of the data. Other techniques that will be employed include logistic regression and structural equation modelling. Descriptive and inferential statistics will be used including the chi-squared and F-tests. Computer packages such as MINITAB and SPSS will be used to aid analysis of quantitative data.

10. CONCLUSIONS

Plagiarism continues to be of increasing concern in higher education institutions world-wide. In many institutions, text-matching software such as Turnitin or Uni-check are integrated with Learning Management Systems such as Moodle or Blackboard. This enables work submitted by students to be checked automatically for plagiarism. Such software should be seen as a tool only to help students to improve their academic writing practice. Turnitin or Uni-check per se cannot detect poor academic writing practice. Use of Turnitin should be seen as part of a major cultural change required in institutions. It is essential that every institution develops a culture of ethical behaviour where students receive appropriate support to develop time management, critical thinking, communication and academic writing skills. Time management will enable students to submit assignments on time and reduce stress, which has been found to be one of the key causes of plagiarism.

Plagiarism should be taught in engineering schools in the context of work ethics and educational culture. All students irrespective of their background have the potential to address plagiarism issues. Addressing plagiarism effectively will require academic staff to be more innovative and to review their assessment strategies in order to test the students' learning outcomes. Academic staff will need to develop creative approaches in assessing students' knowledge. By modifying and individualising their assignments and tests and developing authentic assessments, students will be forced to develop creative solutions to assignments and this will make it harder for them plagiarise. Ethics is central in engineering education. Academic staff must do everything possible to detect and deter cheating of all forms and to prevent it from happening in the first instance. Instructor inaction constitutes complicity with cheating practices and this is entirely unacceptable. Fortunately, student support, engagement and training in academic writing skills represents the most effective approach to addressing the plagiarism problem in engineering education. Finally, although the exact extent of plagiarism in Higher Education Institutions is unknown, there is need for research to collect empirical evidence on its prevalence and to develop best practice guidance for addressing all forms of plagiarism including contract cheating in engineering education.

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A SYSTEMATIC REVIEW OF VERTICAL CONSTRUCTION PROJECT CHARACTERISTICS

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ABSTRACT

The construction industry is one of the key contributors to the development of any country. Depending on the orientation of the construction, it divides into two types; vertical and horizontal constructions. However, different project characteristics play a vital role in the industry as it has the power to influence the decision-making on projects. While vertical construction project characteristics are more specific, to identify the project characteristics of vertical construction and their influence on vertical construction projects, mixed method data analysis comprising science mapping and thematic analysis has been followed. The literature was searched in Scopus and made 43 articles to review, followed by a bibliometric search strategy. The keywords used for searching are "project characteristic", "project attribute*", "construction" and "building*". After an extensive literature review, different types of vertical construction projects were identified, and 21 characteristics affect the decision-making on any vertical construction. The results implied that the project characteristics are the key players in any decision-making process, delivery methods selection, risk management, disputes, cost estimation, reworks and delays. This study contributed to the research community to update their knowledge of vertical construction projects' characteristics and for the professionals to identify their significance of them before deciding.*

Keywords: *Building; Construction; Project Attributes; Project Characteristics; Vertical Construction.*

1. INTRODUCTION

One way of dividing the construction industry is vertical and horizontal construction based on their nature (Horizontal Construction vs. Vertical Construction Part 1, 2023). While vertical construction has segments constructed vertically, horizontal construction projects have segments that run horizontally (Shrestha & Prajapati, 2022). For example, single-storey or multi-storey buildings are considered vertical and ground-level constructions; roads, bridges and tunnels are considered horizontal construction (Chang-Richards et al., 2019; Shrestha & Prajapati, 2022). Over the last two decades, there has

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been a significant increase in the number of high-rise buildings worldwide, and the vertical construction sector plays a prominent role in urban development (Glauser, 2022).

Vertical construction projects are more complex than horizontal infrastructure projects due to the various activities incorporated from the execution to completion and, thus, the involvement of multiple stakeholders to fulfil those activities (Chang-Richards et al., 2019; Shrestha & Prajapati, 2022). The success of any construction project depends on the project's characteristics (Cho et al., 2009). Consequently, the vertical construction sector's characteristics directly affect a project's success. Therefore, identifying the critical project characteristics and understanding the effect of these factors is essential to mitigate any failure in the future (Shehu et al., 2015). Hence, an up-to-date evaluation of the significant areas and emerging trends is required. This study aims to deliver comprehensive literature on vertical construction project characteristics and how they affect vertical construction projects.

Therefore, the study is structured as follows: an introduction, including the scientific context, the application of the topic, the contributions of earlier research for the field and the objectives of this paper. The methodology for performing this research is summarised in Section 2, which represents the literature selection procedure. Section 3 outlines the results from the science mapping approach and literature survey. Section 4 further considers the discussion on subject areas, followed by the conclusion in Section 5.

2. METHODOLOGY

A bibliometric analysis enables determining the depth of knowledge of any research topic by looking at the research front and creating network arrangements of the interested research community (El Baz & Iddik, 2022). For the construction industry, Oraee et al. (2018) recommended bibliometric analysis to identify specific concepts of the construction sector. Through document analysis, bibliometric analysis is applied to determine the topics related to a field based on the research's profiles, relationships, and clusters (Zou et al., 2018). Therefore, science mapping was employed to analyze and visualise bibliometric networks (Chen, 2017). Qualitative analysis was applied to describe the data in rich detail and summarise and interpret various aspects of the research topic (Braun & Clarke, 2022).

This paper follows three stages. The first stage is the bibliometric search strategy. Generally, many databases offer a thorough analysis of the literature; however, one database is used as the focus is on the simple reproduction of the findings (Bryman & Buchanan, 2011). In this regard, Scopus, one of the well-established and competing citation databases (Zhu & Liu, 2020), has been selected and the data search was carried out on 28 March 2023. The survey started with the inclusion criteria that combined the keywords: "project characteristics" OR "project attributes" AND "construction" AND "building" in separate search strings connected by Boolean connectors. Considered publications on this subject ranged between 2000 to 2023. The terms were searched by article title, abstract and keywords of each article to collect the maximum amount of information in the database on this topic. One hundred-seven publications were retrieved for this search. Exclusion criteria were identified and adopted to enhance the results narrow the scope and improve the review process. Accordingly, (1) English language articles; (2) Relevant subjects in the construction field filters were adopted and 78 articles were generated. Next, the abstract was screened and selected the relevant articles. Finally, the backward and forward snowballing method was applied to increase the value of this study. Therefore, the final collection includes 43 up-to-date studies.

In the second stage, VOS viewer, where VOS stands for "Visualization of Similarities", a free text mining software that offers the essential operation, is used to construct and visualise the bibliometric networks (van Eck & Waltman, 2014). VOS viewer enables mapping a moderately large number of items and displays such maps satisfactorily (van Eck & Waltman, 2010). Consequently, VOS viewer was utilised to visualise keyword co-occurrence analysis. Finally, the content analysis was followed to identify vertical construction projects' characteristics and their influence on vertical construction.

3. FINDINGS

3.1 KEYWORDS CO-OCCURRENCE ANALYSIS

A network of keywords was generated to demonstrate the rationale and organisation of the research subjects. The co-occurrence analysis of keywords using VOSviewer with the 43 selected papers. The keywords with a frequency greater than two were chosen for the co-occurrence analysis, resulting in a visual word co-occurrence network, as shown in Figure 1. The circular nodes in the visual word co-occurrence network are colour-coded to represent different clusters. The node sizes indicate the frequencies of occurrence of the respective keywords; the arcs indicate co-occurrence relationships between keywords, and the line thickness indicates the strength of each relationship. After excluding the standard terms such as "construction industry", "construction projects", and "building", 50 keywords were selected and the whole network was divided into 5 clusters automatically, each cluster domains for the same studies.

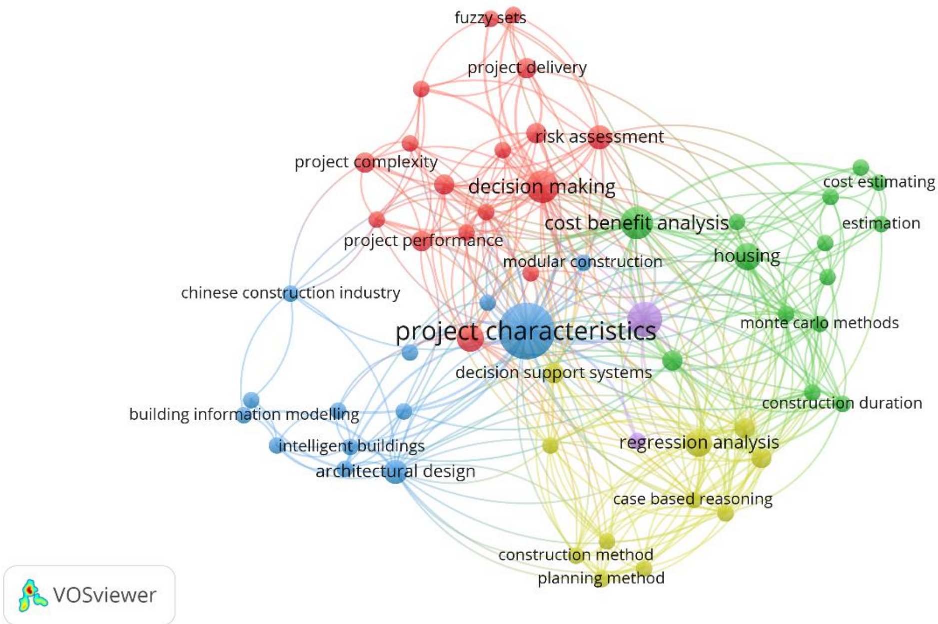

Figure 1: Keywords co-occurrence

Most studies have been focused on project characteristics, cost-benefit analysis, risk assessment, budget control and decision-making. Cluster 1 contains 17 items on cost, housing, risk and cost estimation. Cluster 2 includes design, complexity, risk management, and delivery systems items. The 3rd cluster (13 items) domains for building information modelling (BIM), modular construction, intelligent building, project characteristics, and sustainable development. Cluster 4 (11 items) emphasises decision making tools on delivery methods in construction industry. Cluster 5 indicates cost and productivity only. Housing, model buildings and office buildings have all received thoughtful consideration.

3.2 PROJECT CHARACTERISTICS

Project characteristics are described in quantitative and qualitative ways (Koo et al., 2010). Attributes that are numeric in nature are considered quantitative characteristics, and categorical features such as client type or project types are considered qualitative characteristics (Cheng & Ma, 2015). The findings are summarised in Table 1.

Table 1: Project characteristics

Sr No	Project Characteristic	References
1	Site location	(Bayram, 2017; Forcada et al., 2017; Francis et al., 2022; Hu & Skibniewski, 2022; Koo et al., 2010; Le-Hoai & Lee, 2009; Wang et al., 2022; Wuni & Shen, 2022)
2	Floor area	(Bayram, 2017; Cheng & Ma, 2015; Koo et al., 2010; Wang et al., 2022)
3	Size of the project	(Cao et al., 2015; Hu & Skibniewski, 2022; Koo et al., 2010; Schultz et al., 2015; Sing et al., 2021; Wuni & Shen, 2022)
4	Number of stories	(Koo et al., 2010)
5	Duration	(Alenazi et al., 2022; Bayram, 2017; Forcada et al., 2017; Koo et al., 2010; Wang et al., 2022)
6	Land ratio	(Cheng & Ma, 2015; Koo et al., 2010)
7	Complexity	(Bayram, 2017; Francis et al., 2022; Hu & Skibniewski, 2022; Ma et al., 2022; Moon et al., 2011; Olbina & Elliott, 2019; Sing et al., 2021; Wang et al., 2022; Wuni & Shen, 2022)
8	Type of Client	(Chen et al., 2016; Cheng & Ma, 2015; Francis et al., 2022; Le-Hoai & Lee, 2009)
9	Well defined scope	(Cho et al., 2009; Songer & Molenaar, 1997)
10	Project Type	(AlMuharraqi et al., 2022; Bayram, 2017; Cao et al., 2015; Chen et al., 2016; Cheng & Ma, 2015; Forcada et al., 2017; Francis et al., 2022; Hu & Skibniewski, 2022; Olbina & Elliott, 2019; Wang et al., 2022; Wuni & Shen, 2022)
11	Cost	(Alenazi et al., 2022; Bayram, 2017; Forcada et al., 2017; Francis et al., 2022; Wang et al., 2022)
12	Contract type	(Chen et al., 2016; Forcada et al., 2017; Francis et al., 2022; Schultz et al., 2015)
13	Height	(Bayram, 2017; Wuni & Shen, 2022)
14	Risk	(Moon et al., 2011; Wuni & Shen, 2022)
15	Project confidentiality	(Liu et al., 2016; Mostafavi & Karamouz, 2010; Oyetunji & Anderson, 2006)
16	Innovation	(Moon et al., 2011)
17	Flexibility	(Moon et al., 2011)
18	Material availability	(Hu & Skibniewski, 2022)
19	Construction type	(Hu & Skibniewski, 2022)
20	Bidding procedure	(Le-Hoai & Lee, 2009)
21	Uncertainty	(Luu et al., 2005; Rahmani et al., 2013; Rahmani et al., 2022)

According to the features of each character, they are categorised under three main groups: project-related, technical-related and client related characteristics.

3.2.1 Project Related Characteristics

Firstly, the project location is discussed relating to the venue of a contractor/consultant/ client's head office; thus, it could be categorised as local, regional, national or international (Forcada et al., 2017). Then, a large construction project includes many sub-projects and various activities related to time and space, which requires more technology and discipline types and thus the management becomes complicated (Jiang et al., 2008). The contract amount (Liu et al., 2016; Menches et al., 2008) and the original estimated total work hours (Menches et al., 2008) are the two aspects which describe the size of a building project.

Moreover, construction sum, total construction area and building height are considered for predicting the duration of a vertical construction project (Bayram, 2017). Many authors have discussed the duration as a project characteristic (Menches et al., 2008). Mostly, a building project has a time limit to finish the project; therefore, the completion date should be fixed from a fixed schedule or a finish date (Songer & Molenaar, 1997). Therefore, accelerating the project development and avoiding project delivery delays are the two main constraints that are the main parameters of the on-time completion of a construction project (Li et al., 2005). Further, non-working days must be analysed before calculating the construction duration (Koo et al., 2010). Liu et al. (2016) have described three attributes: design speed, construction and delivery, which affect the duration of a construction project.

Rahmani (2021) has highlighted that a construction project will face significant uncertainty in different areas, such as time, cost, and scope. When the price, duration and the client's awareness of how much they must pay at each stage of the building phase are unclear, the project's completion on the scheduled date is not guaranteed (Luu et al., 2005). When a project's scope is difficult to define because of potential developing circumstances that are unknown initially, scope uncertainty arises and the amount of work to accomplish the project's goals is not quantifiable or measurable (Rahmani et al., 2022). A real tender risk allocated price helps eliminate or diminish the uncertainty through the contractor's knowledge and experience in the early phase of the project life cycle (Rahmani et al., 2013).

3.2.2 Technical Related Characteristics

The authors have identified several types of vertical projects based on their functions. They are offices (Cheng & Ma, 2015; Hu & Skibniewski, 2022), retail (Cheng & Ma, 2015), educational (Bayram, 2017; Cheng & Ma, 2015; Forcada et al., 2017), social works (Bayram, 2017; Cheng & Ma, 2015; Hu & Skibniewski, 2022), lodging (Cheng & Ma, 2015), health care (Bayram, 2017; Cheng & Ma, 2015), service (Bayram, 2017; Cheng & Ma, 2015), warehouse and distribution centre (Cheng & Ma, 2015), industrial manufacturing (Cheng & Ma, 2015; Forcada et al., 2017; Liu et al., 2016; Menches et al., 2008), public order and safety (Cheng & Ma, 2015), residential (Cheng & Ma, 2015; Forcada et al., 2017; Koo et al., 2010; Le-Hoai & Lee, 2009), Laboratory (Cheng & Ma, 2015), Data centre (Cheng & Ma, 2015), Commercial (Chen et al., 2016; Forcada et al., 2017; Le-Hoai & Lee, 2009; Menches et al., 2008; Olbina & Elliott, 2019), Parking garages (Olbina & Elliott, 2019 and Modular building (Sing et al., 2021). Australian and New Zealand Standard Industrial Classification (ANZSIC) 2006 clearly illustrates the types of projects under Division E: Construction (Le et al., 2022). It divides the building sector into residential (house, apartment, flat, duplex house and semi-attached house) and non-residential activities (Commercial, industrial and offices).

When a particular project requires innovation and a unique construction process indicates it is complex (Liu et al., 2016). The prevalence of interdependent variables interacting in a hard way is referred to as complexity (Williams et al., 2010). Only the experience and knowledge gained from earlier initiatives may be used to determine cause and effect in a complicated environment, and future results are unknown (Snowden & Boone, 2007). Jiang et al. (2008) have identified two types of complexities: space complexity and time complexity, according to the characteristics of large construction projects. They described those large-scale projects as requiring massive construction areas and many stakeholders to complete them, leading to space complexity. Further, the lengthy construction period is the reason for the time complexity (Jiang et al., 2008).

Many other factors influence the projects from a technical perspective; they are construction type, innovation, material availability and well-defined scope. For instance, Hu and Skibniewski (2022) defined the types of construction as new construction, total renovation, minor renovation, restoration and other types. Here, the owner initially should hold a comprehensive knowledge of the scope of the project before inviting the bidders (Cho et al., 2009) or before the execution (Songer & Molenaar, 1997). The potential to implement innovative ideas has been defined as project characteristics that affect the selection of the delivery methods in vertical projects (Moon et al., 2011). The availability of materials is a proxy for supply chain maturity and impacts the project's cost (Hu & Skibniewski, 2022).

3.2.3 Client Related Characteristics

There are two main clients in the industry. They are public and private clients (Le-Hoai & Lee, 2009; Shehu et al., 2015). Further, the clients are classified as corporate, government, educational, investors, religious and community development corporations (Cheng & Ma, 2015). Moreover, the administrative burden from the owner is considered a project characteristic (Cho et al., 2009). Next, the client decides on the type of contract, which becomes a project characteristic of how the project is awarded (Liu et al., 2016). Chen et al. (2016) have identified lump sum, guaranteed maximum price and cost plus fee for contract types as per their study. Before the procurement and execution start, the client must define the cost in both cases. Accordingly, Wang et al. (2022) mentioned that the budget should be fixed before procurement starts. Further, Liu et al. (2016) explained that cost estimation should be defined precisely before the contract signing stage.

Moreover, project confidentiality has been identified as the confidentiality of the project documents that include business or engineering information of a particular project is critical for the project's success (Liu et al., 2016; Mostafavi & Karamouz, 2010; Oyetunji & Anderson, 2006). Next, minimising the risk factors through the risk management process has become vital in vertical construction projects before the decision on the delivery method (Moon et al., 2011). Many authors have identified the bidding process characteristics as under the project characteristics. They are the bidding environment, the bidder's knowledge of the budget, time for a contractor to bid (Cho et al., 2009; Liu et al., 2016), owners/consultants to evaluate bids, time to fix the budget (Cho et al., 2009), number of bidders, bid evaluation & selection criteria, pre-qualification or shortlisting and open or negotiated tender (Le-Hoai & Lee, 2009).

4. DISCUSSION

Project characteristics should be considered as they are one of the most significant factors in any project's success (Moon et al., 2011). Further, Liu et al. (2016) proved that project characteristics are essential in deciding project delivery methods. A study reveals that a construction project's performance mainly depends on the pre-construction planning and the project characteristics (Menches et al., 2008). Other than the procurement selection criteria, project characteristics play a vital role in the performance of a project (Mohammed, 2023). A similar study by Chen et al. (2016) provided empirical evidence for the relationship between project characteristics and performance. Therefore, understanding project characteristics is vital for any project team to ensure the success of the project delivery.

Understanding project characteristics can also help forecast project costs and durations, effectively contributing to the bid/no bid decision-making process. There are various tools to predict the construction cost and the duration at the initial stages of a vertical construction project. They are: (1) Case-based reasoning (analogical method), (2) Multiple regression analysis (statistical method), (3) Artificial neural networks (repetitive learning method), and (4) Monte-Carlo simulation (stochastic method) (Cheng & Ma, 2015; Koo et al., 2010; Wang et al., 2022). Therefore, these models estimate the construction cost based on the project characteristics (Wang et al., 2022). Moreover, Bayram (2017) suggested that a vertical construction project's height, area and cost are significant determinants of the project duration. When contractors calculate the overhead and markup of a bid, project size, location, time and type of work are considered (Chao & Liaw, 2019). The ratio of the winning bid to budget to project attributes is related by a regression equation that can be constructed from public sector bids found online and it is used to calculate the likelihood of winning for various rates (Chao & Liaw, 2019).

Vertical construction project characteristics that have links to the project defects, disputes and delays have been examined. A study on project defects has identified that the size and contract type of projects is influenced considerably for the project defects after handing over (Schultz et al., 2015). Thus, the design-build contracts achieve better results; however, large construction projects are faced severe defects (Schultz et al., 2015). A similar study by Forcada et al. (2017) has determined that project type, location, type of contract, contract sum and duration contributed to reworks at the site. Another subject area in that project characteristic has been identified as project delays. A study by Alenazi et al. (2022) has determined that project cost, additional time and additional cost are positively related to the client-related cause of delay. Risk management is another field where project characteristics are studied, which relates to the selection of project delivery methods (Msomba et al., 2018). Francis et al. (2022) described disputes are influenced by the project characteristics relating to client, site, time and duration.

Researchers also agreed that identifying project characteristics is the first step in adopting modern construction methods. Recently, research related to building information management (BIM) and offsite construction has been done and has a future trend to do more. According to Olbina and Elliott (2019), BIM is adopted from simple residential projects to complex construction projects to visualise the phases of projects. Thus, BIM improves the procedure and the accuracy of cost estimations and bidding prices and helps improve the project delivery of complex projects (Olbina & Elliott, 2019). Cao et al.,

(2015) argued that project characteristics influence the success of BIM in a construction project.

5. CONCLUSIONS

The findings contribute to theoretical and practical knowledge using a comprehensive approach to conducting a systematic literature review of vertical project characteristics. Project characteristics are one factor affecting the decision-making process of construction projects from the beginning. Since the vertical construction sector includes construction from modular components to tall buildings, the construction process is more complex. Therefore, the client has to consider the characteristics of the building before making any decision. According to the literature, project type, location, duration, cost and contract type have been discussed more and influenced the decision-making process of vertical construction projects. The science mapping reveals the major research clusters centred on risk, cost, duration and decision-making.

Further, currently, the researchers have focused the studies on intelligent building, sustainability and BIM. Moreover, housing, modular construction and office buildings have been focused on identifying the project characteristics. The critical suggestion for future works is: (1) empirical research on commercial buildings, apartments, hospitals, and educational buildings, and (2) investigation of project characteristics influenced by current project delivery methods. Hence the study’s selection criteria make this study a limitation, offering new light into future trends.

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A TAXONOMY OF WATERPROOFING SYSTEMS FOR HIGH-RISE BUILDING PROJECTS IN THE TROPICS

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ABSTRACT

The building construction is the most significant sector that has acquired significant attention in recent years among the various construction industries and the necessity of erection of high-rise buildings was emphasised because of the restricted space in urban areas. Since the unique and complex characteristics are involved in a building project, the structure must be strong enough in terms of its durability, stability as well as the appearance. Accordingly, water is the most persistent opponent of a high-rise building, and gradually, building components might erode, compromising their structure and requiring costly repairs. Thus, the purpose of this study is to examine the factors that influence the choice of the best waterproofing system in high-rise building projects in the tropics. Semi structured interviews were used to determine how the factors affected the choice of waterproofing. All respondents were project managers or engineers with extensive backgrounds in the building sector and expertise in waterproofing. Collected data were analysed using manual content analysis. The taxonomy was created using the opinions of experts and contractors on the choice of waterproofing. The most important category in the Taxonomy was related to detailing technology, while the least important category was related to legal requirements and compliance.

Keywords: *Construction Industry; Highrise; Taxonomy; Waterproofing.*

1. INTRODUCTION

Water is the most persistent opponent of a high-rise building, and gradually, building components might erode, compromising their structure and requiring costly repairs (Jonathan, 2013). Leakage, rising dampness, and water seepage may occur not just in old buildings but also in modern buildings (Mydin et al., 2017). Repairing the failure of the waterproofing membrane is the most expensive investment when it comes to leaking (Basheer et al., 2001). As argued by Sriravindrarajah and Tran (2018), waterproofing is necessary for every surface area that comes into touch with water, has the potential to let water in, or could result in water getting inside a building. Further to the author, waterproofing may be considered high-risk or important when it is over a dwelling space. Defects and deficiencies due to the poor waterproofing in the building might have a negative view and affect all stakeholders, whether explicitly or implicitly (Mydin et al., 2017). Customers are dissatisfied due to the aspects of less stability and durability of the

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structure (Karunasena & Ranatunga, 2009). Since proper waterproofing helps to maintain the integrity of the building while lowering maintenance costs of the building, it is a key aspect in building construction (Sriravindrarajah & Tran, 2018). Prior to selecting a waterproofing system, an architect or waterproofing designer must consider numerous factors such as material, water table, soil characteristics, substrate stability, construction sequence, risk vs. cost, ease of application, codes and standards, contractor competencies etc. (Grachev, 2021). Since there are number of factors affecting to the decision on waterproofing selection, evaluation of those might be beneficial when selecting suitable waterproofing system to a building (Kimick et al., 2021). Apart from that, despite the fact that many studies have been conducted on waterproofing as a defect (Chew, 2005; Sokova & Smirnova, 2019), researchers have not focused on how to select proper waterproofing considering their significant factors. That facet might be viewed as a major contribution to current knowledge gap. As a result, overcoming the knowledge gap can be termed a prevalent necessity and therefore, the study investigates, how to select most suitable waterproofing system in high-rise buildings in the tropics by considering significant factors.

2. LITERATURE REVIEW

2.1 WATERPROOFING IN HIGH RISE BUILDINGS IN THE TROPICS

The region of land and ocean between the Tropic of Cancer (latitude 2 3.5/N) and the Tropic of Capricorn (latitude 2 3.5/S) is known as the tropical zone (Wahab et al., 2013). Further to the author, although the tropics itself have a variety of climates, 90% of the tropical zones reflect hot, humid climate regions, whether year-round or seasonal. Many construction issues have unavoidably arisen as a result of the rapid expansion of new development in tropical areas (Briffett, 1991). This indicates that structures in tropical regions have a tendency to age quickly, especially when it comes to exterior construction materials that are exposed to elements like rain, wind, sunlight, ultraviolet light, and air pollution (Ahzahar et al., 2011). All high-rise buildings are vulnerable to extreme humidity and a lot of rain (Bahadur, 2017). Interior, external, and sub-grade works are the three main areas to be considered when waterproofing high rise buildings and thorough waterproofing system is made up of a number of interrelated elements, including substrate preparation, membrane detail, drainage design, design, installation, quality assurance, and maintenance (Sriravindrarajah & Tran, 2018). More than 50% of the structures had issues with interior water leaks, which contributed to their high life cycle costs and high maintenance, repair, and replacement requirements over their useful lives (Chew & De Silva, 2002). In order to preserve a building's aesthetic qualities, avoid structural damage, and ensure the occupants' safety, waterproofing has become a crucial part of the construction (Fonseka et al., 2014). Leaks at structural components including the roof, wall, and ceiling are the primary source of moisture issues in buildings (Othman et al., 2015). For instance, among the 14 key defects at walls and floors highlighted by Chew (2005), are water leaks through cracks, pipe penetration, and joints. As per Grachev (2021), wetting of enclosed structures can happen from moisture intrusion into a building's walls, moisture condensation in the wall material as a result of temperature changes, moisture in the form of precipitation above ground, and moisture in the underground due to groundwater which results reduction in the thermal insulating capabilities of structures, their early demise, and a breach of the indoor microenvironment.

2.2 ISSUES AND IMPACTS OF POOR WATERPROOFING

By reviewing the scholars (Panchal et al., 2015) which have defined the waterproofing in different ways, simply the waterproofing is a formation of barrier on the surface that comes into contact with water, has the potential to ingress water, or poses a risk of allowing water to enter the structure. Staining, cracks, peeling paint, discoloration, corrosion, stalactite and stalagmite, mould growth. Condensation, water patches and dampness, concrete spalling, temperature difference in indoor and outdoor, stagnant water, dirt collection on the surface, nasty odour, water penetration, wood decay and insect infestation are the identified common causes of poor waterproofing through peer reviews (Garcia, 2018; Heseltine & Rosen, 2009; Kumar, 2020; Othman et al., 2015; Sriravindrarajah & Tran, 2018; Stock & Meadow, 2012).

According to Nguyen et al. (2020), due to the decay of the concrete, seepage in building structures is a problematic issue that has many adverse impacts on the calibre, effectiveness, and long-term durability of buildings. Leakage has a number of impacts that can harm other building finishes and result in health issues because of the formation of mould, fungus, dust mites, as well as other biological air contaminants (Panchal et al., 2015). Damage to the building itself is costly, with building owners and tenants bearing a significant share of the cost, including absenteeism due to illnesses such as asthma, reduced productivity as a result of moisture-related health and comfort issues, increased insurance risk, repair and replacement costs for corroded structural fasteners, wiring, and moisture-sensitive materials, costs of repairing and replacing damaged furniture, products, and supplies, uselessness of building spaces following damage and during repairs insurance and litigation costs associated with moisture damage claims have risen (Heseltine & Rosen, 2009).

2.3 IMPORTANCE OF WATERPROOFING

Building structural defects should be taken seriously because they are a source of tremendous concern since both the home buyers and the inhabitants will have various concerns when a structure does not perform up to expectations or at all (Mydin et al., 2017). Building envelops will remain untouched and avoid needless repairs by regulating groundwater, rainwater, and surface water because water may seriously damage concrete, masonry, and natural stone buildings (Kubal, 2008).

If the requirement to keep the building as dry as feasible is not met, it is likely that the building will become inhabitable and unsafe structurally (Panchal et al., 2015). As per Sokova and Smirnova (2019), waterproofing is essential for guaranteeing standards-compliant durability and secure conditions. Sriravindrarajah and Tran (2018) has demonstrated that the appropriate waterproofing system is robust enough to drain water away from the source. The best solution will increase the maintainability and longevity of the operation of buildings and structures, reduce the complexity of the work on the implementation of repair work with hydraulic protection of structures, and determine long-term and reliable waterproofing by selecting the most optimal materials and technologies (Sokova & Smirnova, 2019). If neglected, inadequate waterproofing not only compromises building safety but also poses a risk to hygiene (Wong & Hui, 2005).

2.4 CHALLENGES OF WATERPROOFING

The inability to determine the root and source of the seepage, accessibility issues, underutilisation of the expertise and experience of the building professionals in seepage preliminary investigation, inadequacy of current testing methods and equipment, and some defendant owners and occupiers' reluctance to collaborate with the relevant parties and public officials are the main issues with handling seepage complaints (Wong & Hui, 2005). Water proofing and drainage are two areas where most contractors lack knowledge, and they are frequently completed in an ineffective manner, resulting in water seepage through the roof ceiling or block wall (Assaf et al., 1995). Most of the manufacturers do not have trained, inspected, licensed, or approved contractors to install their waterproofing materials, and most manufacturers also do not provide performance guarantees for waterproofing membranes (Pratt, 1990).

Whereas most builders concentrate on aesthetic and design components to waterproof the structure, it has been observed that key areas such gaps between walls, wall coatings, and tiles of the building terrace that would also adversely affect the waterproofing are given comparatively less attention (Bahadur, 2017). Once the concrete is poured, the blind side waterproofing cannot be assessed and even if the membranes are put after the concrete has been cast, it is too late to repair improper installation once the waterproofing has been buried (Kadlubowski & Yates, 2010). Further to the author, if the system fails, rehabilitation may necessitate extensive excavation and rebuilding of surface, landscaping, and wall systems. As argued by Panchal et al. (2015), even the most difficult waterproofing applications can be solved with some careful investigation and innovative water management solutions.

2.5 FACTORS TO CONSIDER WHEN SELECTING WATERPROOFING: WHAT DOES LITERATURE TELL US?

The ideal solution will decrease the complexity of the work required to implement repair work with hydraulic protection of structures, increase the maintainability and durability of the operation of buildings and structures (Sokova & Smirnova, 2019). Table 1 provides a summary of the research's findings with reference to the deciding criteria in the selection of waterproofing. Further the 31 sub factors were categorised into 7 main factors.

Table 1: Factors to be considered when selecting waterproofing.

No	Sub Factors	Main Factors	Source
01	Application site		
02	Purpose of application		
03	Recommendation of suppliers		
04	Standards		
05	Useful life (durability)		
06	Easy application	Material	[1][2][3][4][5][6][7][8]
07	Resistant to UV		
08	Comfort of the interior		
09	Porosity and the strength of materials		
10	Sustainability of materials		
11	Design rules		[2][3][4][5][6][7][8][10][11]

No	Sub Factors	Main Factors	Source
12	Mechanical effect	Detailing and technology	
13	Special skills and equipment		
14	Testing requirements		
15	Composition of the structural elements of the building	Building profile	[2][6][7][8][12]
16	Operating condition of the building		
17	Water table and soil characteristics of the building location		
18	Occupancy		
19	Cost of materials	Cost	[2][5][6][7]
20	Required investment		
21	Labour cost		
22	Changes in the temperature and humidity	Climate and environment	[2][3][13]
23	Chemical composition of groundwater		
24	Codes and Standards	Legal requirements and compliance	[2][5][9]
25	Reputation	Suitability of contractor	[5][12][13]
26	Capability to undertake the works		
27	Water proofer's history on similar projects		
28	Financial position		
29	Available human resources		
30	Ability to meet all the environmental, safety, quality, statutory and government requirements, and regulations		
31	Ability and confidence to warrant the product		

Sources: [1] Kimick et al., (2021); [2] Grachev, (2021); [3] Kubal, (2008); [4] Othman et al., (2015); [5] Sriravindrarajah & Tran (2018); [6] Mydin et al., (2017); [7] D'Annunzio, (2014); [8] Kumar, (2020); [9] Windapo & Cattell, (2010); [10] Panchal et al., (2015); [11] Larisch, (2016); [12] Chew & De Silva, (2002); [13] Kadlubowski & Yates, (2010)

The selection of material, detailing and technology, and associated cost are the primary criteria that are frequently mentioned and have a significant impact on the choice of waterproofing, according to the findings of the aforementioned literature review.

2.5.1 Material

By selecting the best materials and methods, waterproofing must now be determined to be long-lasting and dependable (Sokova & Smirnova, 2019). The protective materials must not only waterproof the building but also shield the concrete and/or masonry from assault by corrosive substances that are dissolved in water or found in the soil or other nearby materials (Pratt, 1990). Long-term waterproofing failures were caused, among other things, by a lack of knowledge about the methods and the choice of incorrect materials (Kimick et al., 2021; Song et al., 2017).

2.5.2 Detailing and Technology

The construction industry has seen technological breakthroughs in waterproofing materials over the last two decades, including integral waterproofing systems and more modern membrane materials (Panchal et al., 2015). The risk of water seeping into the structure could be decreased by using technology more effectively during the project's design, construction, and post-completion phases, such as scheduling waterproof membrane installations and selecting qualified and experienced water proofers to supply and install membranes, designing landscaped areas around movement joints, avoiding low-priced tenders, and performing adequate inspection and maintenance to detect flaws (Sriravindrarajah & Tran, 2018).

2.5.3 Cost

Waterproofing structures is a fairly time-consuming and responsible process that accounts for up to 3% of the total labour costs for building a structure (Grachev, 2021). Further to the author, it is estimated to cost between 0.1% and 0.5% of the estimated cost of construction and installation work. Failures in the waterproofing process have an impact on both project participants and building occupants (Sriravindrarajah & Tran, 2018). However, Sriravindrarajah and Tran (2018) further stated that, when awarding waterproofing contracts to subcontractors, financial considerations shouldn't be the single determining factor.

2.5.4 Building Profile

Selection of waterproofing is varied based on the building profile due to its uniqueness (Chew & De Silva, 2002). Unlike any other outside building component, waterproofing materials are distinctive in that they are subjected to substantially tougher environmental conditions (D'Annunzio, 2014; Kumar, 2020). Further to the authors, at the waterproofing surface, the majority of the exposure elements are always present and do not wane as they do at the other outside components.

2.5.5 Climate and Environment

Being constantly exposed to a range of climatic and environmental components, such as wind, sunlight, temperature, rain, and other factors, causes buildings all over the world to interact with their local climate in unique ways (Kubal, 2008). Further to the author, this is why different building designs and construction techniques are used in different places to address various issues. For instance, the average air temperature affects the thickness and quantity of insulation in a building, with colder places needing more insulation to retain heat (Othman et al., 2015). As a result of the amount of rain that falls there each year, buildings needs to address the issue of waterproofing (Kadlubowski & Yates, 2010).

2.5.6 Legal Requirements and Compliance

Since buildings play such a significant role in environmental health, living standards, and economic stability, it is critical to encounter standard guidelines, regulatory controls, and criteria to regulate their design, construction focusing on the structural stability (Windapo & Cattell, 2010). Further to the author, as one of the most significant factors to consider is statutory requirements, and when selecting the best waterproofing system, it is critical to choose manufacturers who are code compliance and industry certified.

2.5.7 Suitability of Contractor

The skill of the waterproofing applicator and the calibre of the membrane should be taken into account as the primary deciding elements (Chew & De Silva, 2002). When contractors don't take care with materials and installation, even the most meticulous and demanding drawings and specifications are of little help and for instance, damage from heavy machinery and irresponsible backfilling are two major causes of waterproofing failure (Kadlubowski & Yates, 2010).

3. RESEARCH METHODOLOGY

The methodology is the approach used to carry out the intended study objectives. Initially, a comprehensive literature review on the waterproofing in high-rise buildings and factors to be considered in selection of proper waterproofing was carried out. Secondly, Secondly, industry experts in waterproofing were approached for semi-structured interviews in order to gather data from many angles. Purposive sampling was used to select experts since it allows the researcher to gather information from others who hold similar opinions (Etikan & Bala, 2017). Additionally, using purposive sampling allows for the effective use of time and other resources while collecting information from the most knowledgeable experts (Palinkas et al., 2015). The sample size was limited to ten participants, since after the sixth interview, the data was appeared to be more stable. Table 2 shows the details of the respondents who were participated to the expert interviews.

Table 2: Details of the respondents

Respondent	Profession	Designation	Experience in the industry
R01	Engineering	Chief engineer	30 years
R02	Engineering	Director	35 years
R03	MEP Engineering	MEP Manager	15 years
R04	Engineering	Project Manager	27 years
R05	Engineering	Project Manager	25 years
R06	Engineering	Site Engineer	11 years
R07	Engineering	Site Engineer	10 years
R08	Safety Engineer	Maintenance Engineer	10 years
R09	Engineering	Project Manager	25 years
R10	Engineering	Project Manager	20 years

Regarding expertise, all respondents possessed sufficient industrial experience in the waterproofing industry, along with at least 10 years of construction industry experience, to contribute to the study with their technical and professional understand. The fact that only ten experts were selected to participate in the semi-structured interviews highlights how important and acceptable qualifying experience is. As a result, the information profile of research participants shows that the data acquired is credible. The primary objective of the expert interviews was to assess how effectively the conclusions of the literature review applied to waterproofing system. Accordingly, most influencing sub-factors (31 Nos) were identified under different categories (7 Nos) with the help of previous literature. 10 experts in construction industry were asked questions focusing on main factors to be considered in selection of waterproofing. Manual content analysis was chosen as the best data analysis technique for the research in order to have a thorough understanding of the textual and qualitative data gathered through the interviews, to conduct a flexible data analysis, and to have the researcher reasonably interpret the results of the analysis. Finally, Taxonomy was developed analysing gathered data from expert interviews.

4. RESULTS AND DISCUSSION

Information gathered through the expert interviews were analysed using manual content analysis. Based on the expert opinions for main factors, Taxonomy was developed (Refer Figure 1).

As agreed by all respondents, cost and suitability of contractor are the most considerable factors when selecting waterproofing system in terms of client or owner of the project. There is no doubt that the scarcity of funds is always a constraint, in the context of a construction, renovation or replacement. However, if a building owner or general contractor wants to cut costs, the waterproofing system is not the place to do so. As noted, the cost incurred for even minor repairs could easily exceed the initial cost of the system (D'Annunzio, 2014). Further, suitability of contractors should not be the first consideration still they need to be considered because some reasons such as competitiveness in the market.

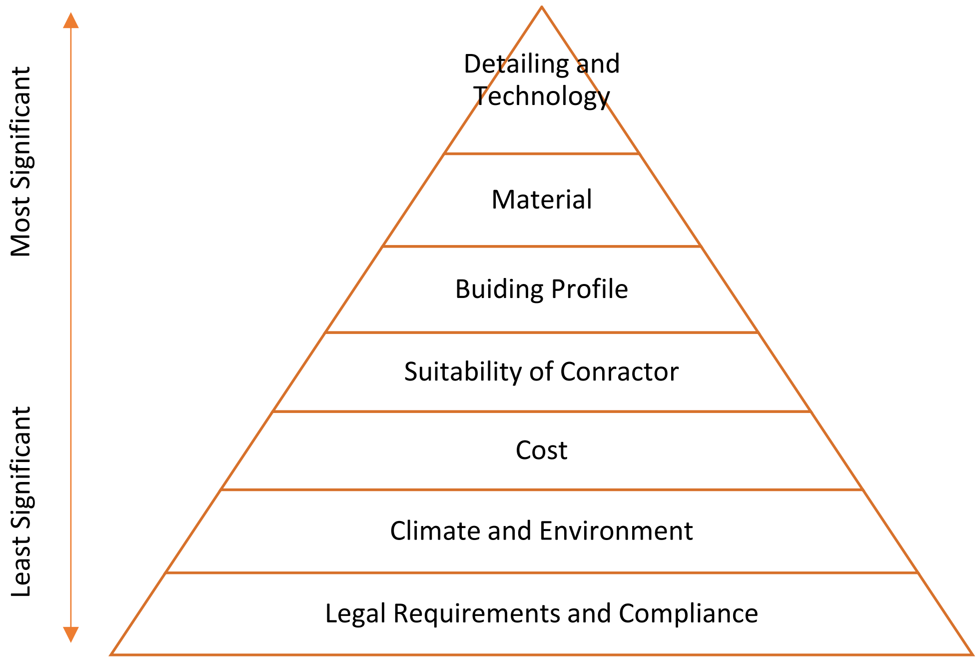

Figure 1: Formulated Taxonomy

Consequently, Taxonomy (Refer Figure 1) represents the view of an expert regarding the criteria that should be considered sequentially while choosing waterproofing. Simply expressed, the Taxonomy illustrates the hierarchy of considerations that must be considered while choosing the appropriate waterproofing. The most important category for affecting the choice of waterproofing, according to Figure 1, was one associated towards detailing and technology, whereas the category with the least influence was one related to legal requirements and compliance. While selecting the optimal waterproofing solution, the final results provided a clear understanding of the most important decision factors.

As agreed by all respondents, long-term waterproofing problems were caused by, among other things, a lack of knowledge about the detailing and the choice of incorrect materials. R05 stated that, "*The waterproofing will fail for sure if you don't match the thermal insulation qualities with your choice. Even if you use the greatest material or waterproofing, poor technical details will lead to poor waterproofing*".

No one pays attention to enhancing the essential and frequently crucial detailing that is required to transition from one building facade component to the next, despite the fact that individual waterproofing materials and systems continue to advance. Although the structural design of waterproofed building components is outside the scope of the manual, a waterproofing designer is nevertheless required to have a basic grasp of waterproofing design concepts and techniques (Henshell, 2000). Further, applying a product with higher performance saves costs on the application and maintenance of the building. The outcomes of the finding from the expert interviews were also supported by these literary findings. The third important consideration, according to experts, is the building profile since using the right waterproofing system for the location in concern is essential to choosing the finest solution. R07 stated that, "*The appropriate waterproofing system should be utilised in accordance with their region of specification*".

As there are still instances of infiltrations, which may be attributed to a lack of trained specialists in the region or a failure to carry out the proper execution, the eligibility of the contractor needs to be considered before the cost is evaluated. The waterproofing system is not the place to minimise expenses, according to experts, whether a building owner or general contractor wishes to do so. R01 stated that, "*Severe corrective treatment might sometimes cost more than 300 times the price of the membrane. First cost is therefore not a good initial consideration to consider when making decisions*". Since, after installation of the waterproofing layer, it is not severely exposed to the environmental conditions it is not thought to be the most important aspect. Moreover, waterproofing practices are not legally required, and they are regarded as the least important factor.

4.1 USAGE OF TAXONOMY

The suggested taxonomy may be used to provide recommendations to avoid choosing a waterproofing that is useless and misleading. By using this Taxonomy, Mitigate the frequency of replacement and refurbishment of waterproofing can be mitigated since the optimum solution will be selected through this Taxonomy. Further reducing the requirement of maintenance, maintaining the structural stability and appearance of the building through a best waterproofing solution and ensuring the safety and comfort of the occupant by avoiding poor waterproofing defects are some of the key benefits that can be gained by adapting this Taxonomy while making the decision on selection of waterproofing. Moreover, by reducing resource wastages through reducing the waterproofing defect rectification value for money can be ensured. The Taxonomy developed, including research findings was recommended for the reference of industry practitioners who are involved in waterproofing buildings in the tropics, for the identification of the strategies for the enhancement of the quality of the building and structural stability. Further the developed taxonomy can be incorporated during the initial design and construction stages of the buildings and post occupancy buildings which require remedial waterproofing.

5. CONCLUSIONS

Waterproofing is an essential topic to be researched as it has direct influence on the building in the tropics. In this research, 31 sub factors were evaluated under 7 main factors. As the final objective, all the seven factors were ordered according to the significance of them. Hence, taxonomy was developed considering waterproofing selection criteria. Most influencing factor was selected as detailing, and technology related factors and least influencing factor was considered as legal requirement and compliance. As the result shows, a waterproofing system can be characterised as a set of materials, preparation of specifications, and application methods created while taking the client's or owner's needs into account to provide concrete structures with effective, dependable, and long-lasting protection while requiring the least amount of maintenance. Hence, it can be inferred that the ideal solution will lessen the complexity of the implementation of repair work with hydraulic protection of structures, raise the maintainability and lifespan of the operation of buildings and structures. Consequently, this research contributes to the future construction industry as a framework to decision makers who are engaged in waterproofing projects. Further, in order to further enhance the quality and accuracy of the decision of selection, it is recommended to monitor these factors through the reinforcement learning to imitate the way of humans learn.

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ADAPTABILITY OF LEAN CONCEPT TO REDUCE PLUMBING WASTE IN HIGH-RISE BUILDING CONSTRUCTION IN SRI LANKA

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ABSTRACT

The waste generation due to the plumbing work substantially influences the total waste. Waste management is one of the most critical processes to achieve effective and productive construction projects successfully. Lean is a philosophy that is adopted in several sectors to mitigate waste. Thus, this paper intends to identify the adaptability of lean concepts to reduce plumbing waste in high-rise building construction in Sri Lanka. Data collection was done through two Delphi round interviews. The collected data were analysed using manual content analysis. As a result, comprising a total of twenty-seven barriers were identified under five sets of barrier groups for implementing lean concept to reduce plumbing waste in high-rise building construction in Sri Lanka. The strategies to successfully overcome each challenge and barrier were identified. Conducting CPD programmes, training programmes, showing the benefits of lean implementation and providing knowledge about lean through universities and other higher education institutes are the most common strategies to overcome the barriers to lean application. This study paves the path to lean professionals to align their strategy with lean practices by understanding and identifying the major obstacles.

Keywords: *Barriers; Lean implementation; Plumbing waste; Strategies.*

1. INTRODUCTION

Construction is one of the most predominant sectors which contributes to the economic growth of Sri Lanka (Perera & Gunatilake, 2020). High population growth and urbanisation have increased the demand for high-rise residential buildings due to the scarcity of land (Mostafavi et al., 2021). Mechanical, Electrical, and Plumbing (MEP) work is a critical aspect of high-rise building construction as it accounts for a significant portion of the total project cost, typically around 20-25% (Baradaran-Noveiri et al., 2022). The plumbing system is an essential part of MEP works in building construction as it is responsible for the distribution of potable water and removal of wastewater throughout the building, ensuring a safe and functional water supply for the occupants while adhering to relevant regulations and promoting water conservation (Atencio et al., 2022). Further,

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Husin (2019) highlighted that 5.3% of the total project cost is allocated for plumbing workers, which is part of the 14.1% allocated for the whole MEP workers.

In the Sri Lankan construction industry, processing the MEP works generates a considerable amount of construction waste. Waste generated from the plumbing work enormously impacted the construction projects' environment, cost, and time overrun (Nagapan et al., 2012). Hence, it is crucial to implement effective strategies within the construction industry to reduce waste (Bayhan et al., 2019). Lean construction is a project delivery method that emphasises efficiency, waste reduction, and continuous improvement (Shurrab & Hussain, 2018). Lean construction is based on lean manufacturing principles and applies them to the construction industry (Zahraee et al., 2021). The goal of lean construction is to optimise the use of resources and eliminate waste, resulting in cost savings, improved productivity, and higher-quality outcomes (Huda & Berawi, 2021). The lean approach has been gaining popularity in the construction industry to manage waste and improve efficiency (Memon et al., 2018). However, lean implementation in the construction industry is still challenging due to a lack of knowledge, unfamiliar with the long-term benefits and the misconception that lean practices are costly (Bayhan et al., 2019). Even though several studies have been done to identify the general barriers in lean implementation in construction, there is a lack of research relating to identifying barriers and strategies in implementing lean to reduce plumbing waste in construction. Hence, this study aims to fill the literature gap and industry need by identifying the adaptability of lean concept to reduce plumbing waste in high-rise building construction in Sri Lanka with the objectives of identifying barriers to implementing lean concept to reduce plumbing waste in high-rise building construction in Sri Lanka and to propose suitable strategies to overcome the identified barriers..

2. LITERATURE REVIEW

2.1 LEAN IMPLEMENTATION IN PLUMBING WASTE REDUCTION

The construction industry significantly impacts the environment due to the heavy use of natural resources and energy, the generation of large amount of waste and the emissions of toxic pollutants into the air (Sharma et al., 2021). Construction waste refers to materials and debris generated during the building process and cannot be used for their intended purpose, such as those that do not meet specifications or damaged or in excess (Papastamoulis et al., 2021). MEP works generate a considerable amount of waste in constructing high-rise buildings (Husin, 2019). Plumbing waste can generate as materials, labour, time or cost (Seppänen & Görsch, 2022; Turner & Filella, 2021). Material waste can occur as damaged materials, excessive materials, rework, defective items rejected, and low-quality materials (Hung & Kamaludin, 2017; Kalsaas, 2010). Further, during the process of plumbing work, time and cost are wasted due to resource idling, double handling and additional transportation. Plumbing work in high-rise buildings is a critical factor in the Sri Lankan construction industry since it can significantly impact the overall cost of a project and lead to cost overruns (Ariyawansha & Francis, 2022). Further, plumbing works have significantly impacted the project time overruns (Seppänen & Görsch, 2022). Hence, it is essential to identify and track plumbing waste to minimise and manage them effectively at construction site.

Waste is unavoidable (Ali et al., 2019), and zero waste may not be entirely achievable in the construction industry (Moreno, 2021). However, waste can be minimised by using different design concepts, altering the materials (Da-Cunha & De-Aguiar, 2020), and altering construction processes (Porwal et al., 2020). Moreover, researchers such as Ranadewa et al. (2021) and Shaqour (2022) highlighted the possibility of implementing lean to eliminate non-value-adding activities in construction. Initially, lean concepts were practised in the automobile manufacturing industry, and gradually expanded to other sectors, such as construction, healthcare, banking, food industry, etc., to enhance efficiency and quality (Bajjou & Chafi, 2018; Wahab et al., 2013). The International Group for Lean Construction (IGLC) has made a significant contribution to the understanding of theoretical foundations of lean construction by extracting the core concept of lean production and applying the lean concept to the management of the construction process (Salem et al., 2005) in different countries such as United State America (Evans et al., 2022), the United Kingdom (Bashir et al., 2010), Denmark (Hansen, 2005), New Zealand (Likita & Jelodar, 2019), Saudi Arab (Sarhan et al., 2017), Jordan (Al Balkhy et al., 2021) and China (Xing et al., 2021). Even though various countries benefit from lean implementation, it is still at a developing stage in Sri Lanka (Madanayake, 2015). The main issue with the application of lean in developing countries is that the construction industry faces numerous challenges and barriers while implementing the lean concept (Kanafani, 2015).

2.2 CHALLENGES AND BARRIERS TO LEAN IMPLEMENTATION

Main barriers to adapting lean in construction organisations are the organisation's cultural, managerial and financial characteristics (Demirkesen et al., 2019; Gupta et al., 2020). Moreover, the stakeholders' knowledge on lean tools and practices shall also affect lean implementation in the construction industry (Lodgaard et al., 2016). Resistance to changes and lack of top management involvement, commitment, and attitude is regularly highlighted as the most significant barrier in the lean implementing process (Abu et al., 2019; Secchi & Camuffo, 2019). In addition, leadership and support from all the managers including top management will influence the lean adaptation (Panwar et al., 2015). Further, knowledge, skills and expertise are important factors for successful lean implementation (Bajjou & Chafi, 2018). Within the lean community, there is lack of understanding of the potential benefits of lean (Chaple et al., 2021). Factors such as poor communication, lack of clear definition of individual responsibilities and lack of resources will also negatively affect lean implementation (Sarhan et al., 2018). If the challenges and barriers are not properly managed, it may affect the application of lean and especially the project performance (Sarhan & Fox, 2013).

2.3 STRATEGIES TO OVERCOME BARRIERS

Paying attention to minimise the negative impact caused by barriers is important (Shang & Pheng, 2014). The authors further stated that most human-related barriers can be overcome through proper training and education. Moreover, conveying the benefits of lean adoption can overcome the challenges and that would lead to the bottom-line result (Nahm et al., 2012). Benefits such as customer satisfaction, quality improvement, supplier relation improvement and better inventory control can be achieved through lean implementation (Sarhan et al., 2017). Changing the culture is important for effective lean implementation (Erthal & Marques, 2020). Moreover, proper planning and effective communication within an organisation can change and manage the barriers caused by lean implementation (Asnan et al., 2015; Kundu & Manohar, 2012).

Although past researchers have discussed the barriers for adapting lean in different fields of construction, there is lack of research relating to implementing lean to reduce plumbing waste within the construction stage of high-rise buildings in Sri Lanka. An industrial gap exists for a way to overcome those barriers to lean implementation and to gain competitive advantage. Therefore, this research is aimed identifying barriers and proposing strategies to overcome such barriers towards minimising plumbing waste during the construction stage of high-rise buildings in Sri Lanka.

3. RESEARCH METHODOLOGY

The research approach should be based on the nature of the research problem, the study's audience, and the researcher's personal experience (Creswell, 2014). A qualitative approach is the most suitable when a subject lacks an existing theoretical concept (Madter et al., 2012). Lean implementation is not widespread in the Sri Lankan construction industry. Further, since this study connected with the themes of lean in plumbing waste reduction and barriers to lean implementation, the study followed a qualitative approach to answer the research question, "what are the barriers when implementing lean to reduce plumbing waste during the construction stage?". Answering this question required consensus from several subject area experts. Delphi survey is employed when consensual opinions from a panel of experts regarding a specific area are required (Avella, 2016). Moreover, the Delphi method facilitates an open-ended, inexpensive and more structured data collection process either through traditional or electronic mode (Brady, 2015). Hence, the Delphi method was used to identify the barriers to implementing lean to reduce plumbing waste and provided a consensus through the questions being asked from experts. For the data collection purpose, semi-structured interviews were used as it facilitates verbal argument and making qualitative judgements (Kuusi, 1999). The data collection was stopped at two Delphi rounds, and reaching a consensus is the basis for the end of Delphi rounds (Habibi et al., 2014). Selecting participants is one of the most challenging parts of data collection (Gray, 2016). The study used a purposive sampling technique using the expert selection criteria given in Table 1 and round 1 stopped at 12 interviews when new ideas were not created and data reached saturation.

Table 1: Profile of the experts

Code	**Designation**	**Experience in**		**Accessibility**	**Delphi Round 1**	**Delphi Round 2**
		High-rise building construction >10 years	Use of lean concept > 3 years			
E01	MEP Quantity Surveyor	yes	yes	✓	P	P
E02	Mechanical Engineer	yes	yes	✓	P	P
E03	Quantity Surveyor	yes	yes	✓	P	P
E04	Quantity Surveyor	yes	yes	✓	P	P
E05	Quantity Surveyor	yes	yes	✓	P	NP
E06	Civil Engineer	yes	yes	✓	P	P
E07	Mechanical Engineer	yes	yes	✓	P	P
E08	Quantity Surveyor	yes	yes	✓	P	NP
E09	Civil Engineer	yes	yes	✓	P	P
E10	Quantity Surveyor	yes	yes	✓	P	P
E11	Mechanical Engineer	yes	yes	✓	P	P
E12	Mechanical Engineer	yes	yes	✓	P	P

Only ten experts from round 1 participated in round 2 due to consensus reached on the findings. The collected data were analysed by using manual content analysis. The results were considered robust (Sankaran et al., 2018) since data saturation was reached after conducting two Delphi rounds, and the agreement percentage of barriers among the respondents was over 75%, which was considered the cut-off point. Further, strategies having an agreement of 75% were considered for round 2 as the cut-off point. Table 2 discloses the summary of questions in the Delphi rounds.

Table 2: Summary of questions used in the delphi rounds

Delphi Round 1		Delphi Round 2	
R1Q1	What barriers impede lean implementation in construction to reduce plumbing waste in high-rise building construction in Sri Lanka?	R2Q1	Could you please match the identified strategies against each barrier under the relevant category?
R1Q2	What should be the potential strategies to overcome the barriers to implementing lean to reduce plumbing waste in high-rise building construction in Sri Lanka?		

4. DATA ANALYSIS AND FINDINGS

4.1 BARRIERS TO LEAN IMPLEMENTATION TO REDUCE PLUMBING WASTE

Table 3 shows the identified barriers to lean implementation to reduce plumbing waste during the construction stage of high-rise building construction. Twenty-seven barriers have been identified and categorised under five main categories: cultural, knowledge, managerial, financial, and lean tools and practices. The new barriers raised during the Delphi survey are shown in italic letters.

Table 3: Barriers to lean implementation to reduce plumbing waste

Code	Barriers
CULTURAL barrier group	
CB1	Resistance to changes
CB2	Unwillingness to learn and see about lean
CB3	Fragmentation and subcontracting
CB4	Non-lean behaviour
CB5	Attitude of workmen
KNOWLEDGE barrier group	
KB1	Inadequate knowledge, skill, and expertise
KB2	Insufficient understanding of the potential benefits
KB3	*All kinds of waste are considered unavoidable*
MANAGERIAL barrier group	
MB1	Lack of top management involvement, commitment, and attitude
MB2	Delay in material delivery
MB3	Lack of clear definition of individual responsibilities
MB4	Adhere to traditional management concepts due to time and cost pressure
MB5	Poor communication
MB6	Existing policies and regulations (Government and organisation)
MB7	Insufficient time allocated for the improvement program

Code	Barriers	
MB8	Lack of customer satisfaction measurement system	
MB9	Lack of resources	Human
		Financial
		Technical
MB10	Incomplete and complicated design	
MB11	Lack of individual performance measurement and motivation	
MB12	Lack of standardisation	
MB13	Lack of leadership skills and support	
FINANCIAL barrier group		
FB1	Consulting cost in lean	
FB2	Market conditions	
LEAN TOOLS AND PRACTICES barrier group		
LB1	Failure to prioritise lean tools and practices	
LB2	Isolated use of lean tools and practices	
LB3	*Wrong selection of lean tools*	
LB4	*Risk associated with lean implementing*	

The cultural barriers were significant because lean is still a young concept, especially in the Sri Lankan construction industry. The majority of experts agreed that 'resistance to changes' in plumbing works arises due to plumbing contractors having deeply ingrained, long-standing practices and habits, posing barriers to the adaption of the lean concept. In addition, E02 explained that "*lack of understanding, comfort with existing practices and fear of job loss are major causes to resistance to the changes*". Further, when considering Sri Lankan construction industry, fragmentation of work items, especially MEP works, including plumbing work, is another barrier to implementing lean to reduce the waste generated from plumbing works. According to E12, " *Different trades are involved due to the fragmentation and cause several barriers such as coordination, handing over, duplication of works and inefficient workflows*". Moreover, E03 mentioned that peoples hesitate to learn new things and update their knowledge. Lack of knowledge, skill and expertise is another barrier to lean adaptation. Lean philosophy is still not entirely understood and has not conceived the understanding of lean and its benefits. During the Delphi round 01, E02 disclosed that people in the construction industry considered 'all kinds of waste are unavoidable' and do not take any prevention or mitigation measures.

Management involvement in lean implementation is very important. Proving that, E11 expressed that "*top management involvement is mostly lacking when it comes to applying new strategies in construction*". Most of the time top management tends to adhere to traditional management concepts due to time and cost pressure. As a result, sometimes employees may select the wrong or missing lean tools and practices. Existing governmental and organisational rules and regulations may cause deficiencies in information flow, which would slow down the lean adaptation process. Moreover, the lack of resources and inefficiency of resource planning may cause plumbing waste generation and impact lean adaptation. Most of the time plumbing works in high-rise buildings are carried out by specialised subcontractors. They avoid implementing lean due to time, cost and new technology constraints. Installation of plumbing in high-rise buildings is a complex process because it involves intricate pipe systems, fixtures, valves and other accessories with incomplete and complicated drawings. Hence, implementing lean with these difficulties in plumbing installation create many barriers. The current market conditions of Sri Lanka have adversely affected the lean adaptation to plumbing waste reduction in construction. Market fluctuations can have an effect on the dependability and accessibility of plumbing supplies, leading to supply chain disruptions like delayed deliveries or component shortages, which impede effective lean procedures, causing project timeline delays and lower customer satisfaction. Moreover, sometimes specialised subcontractors such as plumbing subcontractors face difficulties while balancing the workload may cause lean implementation. Since lack of lean practitioners in the Sri Lankan construction industry, consulting cost of lean might be high. Lean adaptation requires effective communication mechanisms among different stakeholders, as it is difficult to have in plumbing installation works since many stakeholders such as architects, engineers, plumbers, contractors, etc are involved in plumbing installation works.

Under lean tools and practices, experts suggested wrong selection of lean tools is one of the common barriers faced by the construction industry while reducing plumbing waste. Most organisations are struggling and unable to find the right lean tools which are suitable to start the lean execution and for the organisation's growth. E05 mentioned that lack of knowledge and training caused the wrong selection of lean tools and practices.

4.2 STRATEGIES TO OVERCOME BARRIERS TO LEAN IMPLEMENTATION TO REDUCE PLUMBING WASTE IN HIGH-RISE BUILDING CONSTRUCTION IN SRI LANKA

Table 4 shows the proposed strategies to overcome the identified barriers to lean implementation to reduce plumbing waste in high-rise building construction in Sri Lanka.

Table 4: Barriers and strategies to overcome the barriers

Barriers	Strategies
CULTURAL	
CB1	Open the door for innovations
	Let the employees know how lean is beneficial to them
	Switch a few people who are conversant with the lean construction
	Provide incentives for adaptation
	Punishment and penalties for not adapting
CB2	Show the benefits
	Conduct practical sessions on lean implementation
CB3	Application of smart technologies • BIM implementation
	Evaluate the previous experience of sub-contractors
	Provide guidelines
CB4	Show the effect of existing behaviour and the benefits of lean behaviour
	Create new organisational policies • Publish guidelines
	Provide rewards and incentives
CB5	Provide incentives
	Changes to the organisation culture
	Change the minds toward the lean
KNOWLEDGE	
KB1	Participate in Continuing Professional Development (CPD) events
	Conduct training programs
	Improve within education systems

Barriers	Strategies
KB2	Show the benefits of lean implementation
KB3	Provide knowledge about lean tools
	Initiate recycling and reusing materials
MANAGERIAL	
MB1	Change to the organisational culture
	Conduct CPD sessions
MB2	Proper planning • Proper material delivery schedules
	Proper communication platform
	Provide barcode and QR code systems
MB3	Draft contract documents properly
	Be aware of the scope of competencies
	Define the interfaces between parties properly
	Provide guides through suitable supervisors
MB4	Adopt the modern procurement system
	Show the benefits
MB5	Have a proper communication mechanism
	Online platforms
	Introduce proper meeting, conference and workshops procedure
MB6	Provide Government concession • Tax reductions
	Create new policies for the organisation
MB7	Buffer time allocation
	Accurately calculate and allocate time • get professional involvement • Having a proper scheduling technique
	Do first and run the study
	Use the previous lesson learned
MB8	Have a proper mechanism to evaluate customer satisfaction in the post-construction stage • An apartment building should evaluate the end-user (real consumer). Not the client
	Establish KPIs
MB9	Get help from foreign countries who are experts in lean
	Get some concession • Tax reduction for material and overall construction value
	Take government support • Interest-free loans
MB10	Lean implementation
	Proper designing and use of skilful designers
MB11	Provide incentives and welfare facilities
	Establish benchmarking system
	Establish KPIs
	Conduct awareness programmes
MB12	Maintain proper quality control system
	In BOQ, mention the standards and brand name or equivalent
	Establish benchmarking system • Modular coordination
MB13	Train the leaders

Barriers	Strategies
	• Improve communication skills • Conduct CPD session
	Appoint the most suitable persons for the positions • leaders with good behaviour, support, knowledge, experience
FINANCIAL	
FB1	Assessing value provide by the lean implementation
FB2	Modify the lean concept to better suit the market conditions
	Diversifying the product and service lines (to get a robust revenue stream)
LEAN TOOLS AND PRACTICES	
LB1	Show the benefits of lean tools and practices
	Familiarise with valid live examples to converse the setup
	Carrying out awareness programs
LB2	Provide knowledge about lean tools
	Familiarise with valid live examples to converse the setup
LB3	Provide training to workers
	Issue licenses
	Provide trained professional
	Establish benchmarks
	Trail running
	Involvement of lean expert for the selections
	Publish guidelines and books based on lean
LB4	Move forward step by step • first step is to implement the lean tools and assess risk. Then provide solutions and move forward
	Follow the risk management procedure
	Have proper skill and expertise when implementing lean

Conducting CPD events, training programs, and improving within education systems are the most commonly used strategies to overcome the barriers to lean implementation. Moreover, E07 said that "*incorporation of lean principles and practices can be done through curriculum development, training programme, practical application and collaboration with industry partners".* In addition, E09 has proposed that "*learning lean concepts through higher education is important for employees to familiarise themselves with the lean"*. Moreover, since lean concepts are not familiar to the Sri Lankan construction industry, it is important to let the employees know how lean is beneficial. Fragmented and subcontracting nature of the plumbing works, it is essential to implement new smart technologies such as BIM to overcome the barriers. Further, organisational culture could be changed towards lean and should increase the involvement of top management.

4.3 DISCUSSION

According to the findings of the study, resistance to change is one of the most critical barriers in adapting to the lean concept in the construction industry. Proving this, many authors consider this as an important barrier (Huaman-Orosco & Erazo-Rondinel, 2021; Prasad et al., 2022). The respondents highlighted that unwillingness to learn lean is a significant barrier as it requires effective communication, education and focus on the benefits of the lean methodologies. Researchers disclosed that lack of awareness, fear of job security and complacency and comfort zone are the major reasons for the unwillingness to learn about lean (Abu et al., 2021; Gomez et al., 2020). The majority of plumbing works are carried out by specialised subcontractors. Hence, the fragmentation and subcontracting nature of the construction industry is another significant barrier to lean adaptation. Maraqa et al (2021) discussed that the fragmentation and subcontracting of plumbing work may lead to lack coordination and control and a barrier to information and communication. In order to adapt the organisation culture towards lean, a systematic and comprehensive approach is required. Hence, leadership commitment, education and training, and fostering a continuous improvement mindset are required (O'Connor & Cormican, 2022). The plumbers should be encouraged to experiment new concepts such as lean and technologies and should provide room for trying out innovation. Promoting a culture of innovation helps plumbers actively seek out and implement lean concepts (Garcia & Murguia, 2021).

5. CONCLUSIONS

Previous studies have discussed the barriers to implementing lean in the construction industry in different contexts. This study assessed the barriers to implementing lean to reduce plumbing waste and strategies to overcome the barriers, which have not been discussed so far especially for high-rise building construction in Sri Lanka. Twenty-nine barriers were identified which affect the adaptability of lean concept to reduce plumbing waste in high-rise building construction in Sri Lanka. Then, strategies to overcome each barrier were identified. The experts highlighted the importance of initial experiments on the suggested strategies to check the practicality of implementing such novel concepts regarding cost, quality and time concerns and make necessary adjustments before implementation. The study contributed to the body of knowledge in two ways: the barriers to lean implementation to reduce plumbing waste in high-rise building construction in Sri Lanka and the strategies to overcome the barriers were subsequently explored. The study helped the construction industry pave the path to reducing plumbing waste and enhancing collaboration with subcontractors to reduce plumbing waste. Further, study findings will help to enhance the efficiency and quality of construction work. The lean concept is novel to the Sri Lankan construction industry. This study focuses on using the lean concept in the Sri Lankan construction industry, specifically for high-rise building projects. This is one of the first studies focusing on using lean for plumbing waste reduction in high-rise building projects in Sri Lanka. The findings can be further validated through case studies, which will be the next research phase. The study is expected to be useful as a benchmark for future research studies.

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ADAPTATION OF BLOCKCHAIN AND SMART CONTRACTS TO THE CONSTRUCTION INDUSTRY OF DEVELOPING COUNTRIES

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ABSTRACT

The construction industry is often criticised due to its inherited challenges. Lack of trust and transparency, inadequate collaboration and complex structure have plagued the construction sector. Blockchain is a technology that has the potential to address these issues by automating procedures and enhancing traceability and transparency with its salient features. Whereas adaptation of blockchain within the construction industry is still at its inception. The situation is bleak in developing countries and there are numerous barriers and limitations that impact the implementation process. Therefore, this paper aimed to distinguish the barriers that affect the adaptation of blockchain and smart contracts for the construction industry of developing countries. The study used a mixed research approach. The barriers were ranked based on the data collected through a questionnaire survey and strategies to overcome them were identified through expert interviews. Findings derived from the analysis indicate that having a limited number of construction related software applications (powered by blockchain), the reluctance of the companies to bear additional costs to adapt blockchain and sluggish adaptation to new technologies as the significant barriers. As per the identified strategies, conducting an industry-wide digitalisation analysis, developing an industry-wide digitalisation strategy and recruiting skillful staff can be pointed out as the weighty strategies. The outcomes of this research were gained through the data collected from Sri Lanka, which is a limitation of this study. Eventually, a framework was developed as a guideline to implement blockchain and smart contracts for the construction industry of developing countries.

Keywords: *Barriers; Blockchain; Construction Industry; Smart Contracts; Strategies.*

1. INTRODUCTION

The construction industry is an indispensable part of the economy and it is contributing approximately 13% to the global gross domestic product (Blanco et al., 2020). Whereas, the construction industry is considered as the second-lowest sector in terms of Information and Communication Technology (ICT) usage (Agarwal et al., 2016). The construction industry faces productivity related issues due to various challenges such as

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poor payment practices, inadequate collaboration, weak information accessibility and sharing, etc. (Li et al., 2019). Inadequate technology adaptation is one of the main reasons for the low productivity of the construction industry (Nanayakkara et al., 2021). Blockchain technology is recognised as one of the evolving technologies which can improve the productivity of many sectors, including the construction industry (Kim et al., 2020).

Blockchain technology is a distributed ledger technology which stores digital data within a peer to peer network and it is the underpinning technology of the cryptocurrencies such as Bitcoin (Penzes et al., 2018). The key concepts of blockchain technology are consensus mechanism, peer-to-peer network, decentralisation and cryptography (Zheng et al., 2018). It is a secured data storing mechanism that shares and synchronizes data across different geographical locations without a centralised administration (Hewavitharana et al., 2019). The main advantages of blockchain technology are trust without third parties, greater transparency, higher security, traceability, immutability, autonomous and faster processing (Hamma-adama et al., 2020). Although blockchain technology was initially adapted to create cryptocurrencies, new applications for different sectors were found later (Dujak & Sajter, 2019).

The construction firms in developing countries are in the early stage of adapting ICT and still rely on hand-operated communication methods such as phones, emails, and faxes (Moshood et al., 2020). Even though the implementation of blockchain and smart contracts brings numerous advantages, some barriers need to be eliminated in adapting blockchain and smart contracts for the construction industry of developing countries (Graham, 2019). Therefore, the successful implementation of new technology like blockchain within the construction industry of a developing country is a challenging process (Paudyal & Prakriti, 2016).

Although there are some researches have been conducted on blockchain related to the construction industry, a limited number of research have focused on the barriers which affect the implementation of blockchain and smart contracts for the construction industry of developing countries and to come up with strategies to overcome them. Therefore, this research aimed to address this research gap by identifying the barriers which affect the implementation of blockchain and smart contracts for the construction industry of developing countries and to develop a suitable framework to overcome them.

2. LITERATURE REVIEW

2.1 BLOCKCHAIN TECHNOLOGY

Blockchain can be defined as a decentralised distributed ledger technology that records, stores and shares a real-time updated copy of all transactions with the members of the network (Nawari & Ravindran, 2019). Blockchain technology is a combination of the concepts, including peer-to-peer protocols, hashing algorithms, cryptographic primitives such as public-key cryptography and distributed consensus algorithms (Deng et al., 2021).

A blockchain network is made up of hundreds to thousands of peers known as nodes (Javaid et al., 2021). These nodes share data throughout the networking peer-to-peer protocols (Perera et al., 2020). All these nodes are connected with each other, and each node maintains a complete set of records named a blockchain ledger (Hewavitharana et al., 2019). The blocks of data that make up the blockchain ledger are connected to one another by their hash values. A block consists of one or more transactions. When a new block is created, it includes the previous one's hash value and is appended to the blockchain ledger. If a single bit of data was changed in any block, the next block identifies a mismatch between the previous and new values (Alharby & Van Moorsel, 2017).

2.2 SMART CONTRACTS

Smart contracts are the computer protocols that digitally facilitate, execute, and enforce the contracts made between two or more parties on the blockchain (Wang et al., 2019). Blockchain enables smart contracts were first introduced in 1990 by Nick Szabo (Zheng et al., 2018). It is an automatically executing contract or agreement which is directly recorded in the system and exists across the entire blockchain network (Nanayakkara et al., 2021). One of the key features of smart contracts is the peer-to-peer connection between the participants of the network without the intervention of a third party (Alharby & Van Moorsel, 2017). Therefore, smart contracts can replace the traditional forms of contracts by enhancing efficiency, and transactional safety and reducing the risk of breaching contracts (Allam, 2018). Furthermore, this concept guarantees a trustful payment chain between the parties, and also it minimises cost overruns due to the reduction of disputes (Ahmadisheykhsarmast & Sonmez, 2018).

2.3 SIGNIFICANCE OF BLOCKCHAIN AND SMART CONTRACTS FOR THE CONSTRUCTION INDUSTRY

Enormous benefits can be gained by adapting blockchain technology to the different segments of construction industry such as asset management, construction supply chain, contract management, payment handling, etc. (Nanayakkara et al., 2019). Therefore, the potential of blockchain applications for the construction industry is quite high (San et al., 2019). Furthermore, blockchain technology has the capability to transform the construction industry by creating a new platform for employees to transact and collaborate with each other (Nguyen et al., 2019). Immutability, transparency, auditability, decentralisation and security are some of the main benefits of blockchain which can be used to enhance the performance of the construction industry (Singh, 2020). In addition, blockchain and smart contracts together provide a number of advantages to the construction projects, such as minimising the transaction cost, improving the trust among the parties, enhancing the efficiency, etc. (Ahmadisheykhsarmast & Sonmez, 2018).

2.4 BARRIERS IN ADOPTING BLOCKCHAIN AND SMART CONTRACTS FOR THE CONSTRUCTION INDUSTRY

Being a novel concept, there are some barriers in adapting blockchain technology for the construction industry (Graham, 2019). The main barriers are pointed out Table 1.

Table 1: Barriers in adapting blockchain technology for the construction industry

Category	Barriers	References
Organisational	The reluctance of the companies to bear expenses relate to new technologies	(Wang et al., 2019)
	Relevant leadership is not received from the management for the new technology adaptation such as blockchain	(Zamani & Giaglis, 2018)
Industrial	Slow adaptation to new technologies	(Hamma-adama et al., 2020)
	Prevailing practices in the industry (e.g., conventional requirements and norms)	(Graham, 2019)
	The status of the information technology within the construction industry	(Koutsogiannis & Berntsen, 2017)
	Lack of awareness regarding blockchain technology	(Weerakoon & Chandanie, 2021)
Human	Having few blockchain consultants/experts that suit the industry requirements	(Angelis & Da Silva, 2019)
	Low technological competency level of industry and IT related employees	(Weerakoon & Chandanie, 2021)
	The natural reluctance of the industry practitioners to change	(Weerakoon & Chandanie, 2021)
	Having low trust towards new technologies like blockchain	(Graham, 2019)
Technical	Having less number of construction related software applications (powered by blockchain)	(Kshetri, 2017)
	Privacy and security concerns regarding novel ICT	(Li et al., 2019)
	Lack of connectivity and bandwidth	(Kamble et al., 2020)
Legal and political	Lack of legal protocols to prevent misconduct	(Li et al., 2019)
	Lack of government policies	(San et al., 2019)

3. METHODOLOGY

A mixed research approach which includes both qualitative and quantitative methods, was adopted to fulfil the research aim of this study. The research process of this study mainly consists of four key steps;

A. Comprehensive literature review

A comprehensive literature review was conducted to identify the barriers which affect the implementation of blockchain and smart contracts for the construction industry.

B. Questionnaire survey

A questionnaire survey was carried out to determine the level of impact of both barriers and the blockchain applicable areas identified through literature and to know the current ICT status in Sri Lankan construction industry. Sri Lankan construction industry professionals with good ICT knowledge, including blockchain, were selected as a purposive sample to collect the data through a questionnaire survey. Since blockchain technology is still new to Sri Lanka, there are only a few blockchain experts in the Sri Lankan construction industry. Therefore, the construction digitalisation experts who have knowledge on blockchain technology were selected. The selected sample for the study included project managers, engineers, quantity surveyors, architects and facility managers. The questionnaire was distributed among 60 professionals within the Sri Lankan construction industry, and 44 had responded. Three main sections, applicable areas of blockchain technology for the construction industry, current construction-related ICT level in Sri Lanka, level of impact of the barriers for the adaptation of blockchain and smart contracts for the construction industry of developing countries, were targeted by this questionnaire.

The respondents of the questionnaire were asked to rank the statements and barriers using a five-point Likert scale. Next, the data (which were gained from respondents) were analysed using the Relative Important Index (RII) method. The following formula was used to analyse the collected data.

$$RII = (\sum W)/(A \times N)$$

W = Weight given to each variable by the respondent, A = The highest weight (5)

N = Total number of people who participated as the respondents for the survey

In order to rank the barrier categories, the Weighted Mean Average (WMA) method was used. The following formula was adopted to rank the barrier categories.

$$W = \frac{\sum_i^n wiXi}{\sum_i^n wi}$$

W = Weighted average, n = Number of terms to be averaged, wi = Weights apply to x values, X = Data values to be averaged.

C. Expert interviews

Expert interviews were used to come up with strategies to overcome the identified barriers through the questionnaire survey. Since there were only a few blockchain experts in the Sri Lankan construction industry, expert interviews were limited to five (5). There the collected data through expert interviews were analysed with the use of content analysis (manually).

D. Framework development

Based on the questionnaire survey and findings of content analysis, a framework was developed to implement blockchain and smart contracts for the construction industry of developing countries.

4. FINDINGS AND DISCUSSION

4.1 THE CURRENT CONSTRUCTION RELATED ICT LEVEL

In order to adapt blockchain technology to the construction industry, identifying the current construction-related ICT level is crucial. Therefore, it was targeted within the questionnaire. The analysis revealed that infrastructure and facilities (e.g., computers, networks, etc.), awareness regarding new ICT and government policies related to new ICT (e.g., digital signature) are at a satisfactory level. Therefore, those factors have a positive impact on blockchain implementation. Nevertheless, as per the analysis results, adapting to new technologies, the interest of the construction industry, including governing bodies and policymakers, to adopt new ICT like blockchain and industry standards regarding information technologies (e.g., BIM requirement standards) need to be improved for the better adaptation of blockchain technology for the construction industry of Sri Lanka. RII analysis results relate to the "current construction-related ICT level" is portrayed in Table 2.

Table 2: RII results of the current construction-related ICT level

Statements	RII	Rank
Infrastructure and facilities (e.g., computer, network, etc.) to implement novel technologies like blockchain	0.886	1
Awareness regarding new ICT	0.874	2
Government policies related to new ICT (e.g., digital signature)	0.820	3
Adapting to new technologies	0.660	4
The interest of the construction industry (governing bodies and policymakers) to adopt new ICT like blockchain	0.614	5
Industry standards regarding Information Technologies (e.g., BIM requirement standards)	0.585	6

4.2 BARRIERS WHICH AFFECT THE IMPLEMENTATION OF BLOCKCHAIN AND SMART CONTRACTS FOR THE CONSTRUCTION INDUSTRY

In referring to barriers, having less number of construction related software applications (powered by blockchain) was identified as the highest impactful barrier, with a RII value of 0.909. Being a novel technology, market ready software applications (powered by blockchain) are limited. The reluctance of the companies to bear expenses relate to new technologies has received the second place in the overall ranking with a 0.877 RII value. This is followed by slow adaptation to new technologies, having few blockchain consultants/experts that suit the industry requirements and low technological competency level of industry and IT related employees with RII values of 0.845, 0.832 and 0.827, accordingly.

As per the results, it was identified that the organisational barriers are the most significant barrier category with a grand mean value of 4.182. Moreover, the industrial barriers were posed as the second most significant category (grand mean value-3.813), and human, technical and legal & political barriers received the third, fourth and fifth places with grand mean values of 3.744, 3.523 and 3.159 accordingly. It is graphically shown in Table 4.

Table 3: RII and mean values of the barriers which affect the implementation of blockchain and smart contracts for the construction industry

Category	Barriers	RII	Mean	Rank
Organisational	The reluctance of the companies to bear expenses relate to new technologies	0.877	4.386	2
	Relevant leadership is not received from the management for the new technology adaptation such as blockchain	0.795	3.977	6
	Grand mean of organisational barriers		4.182	
Industrial	Slow adaptation to new technologies	0.845	4.227	3
	Prevailing practices in the industry (e.g., conventional requirements and norms)	0.773	3.864	7

	The status of the information technology within the construction industry	0.736	3.682	9
	Lack of awareness regarding blockchain technology	0.695	3.477	10
	Grand mean of industrial barriers		3.813	
Human	Having few blockchain consultants/experts that suit the industry requirements	0.832	4.159	4
	Low technological competency level of industry and IT related employees	0.827	4.136	5
	The natural reluctance of the industry practitioners to change	0.750	3.750	8
	Having low trust towards new technologies like blockchain	0.586	2.932	14
	Grand mean of human-related barriers		3.744	
Technical	Having less number of construction related software applications (powered by blockchain)	0.909	4.545	1
	Privacy and security concerns regarding novel ICT	0.664	3.318	11
	Lack of connectivity and bandwidth	0.541	2.705	15
	Grand mean of technical barriers			
Legal and political	Lack of legal protocols to prevent misconduct	0.645	3.227	12
	Lack of government policies	0.618	3.091	13
	Grand mean of legal & political barriers		3.159	

Organisational barriers

These barriers emphasise that the companies within the construction industry are reluctant to change their existing practice. In supporting this Li (2019) stated that the organisations within the construction industry are historically resistant to change. Since there is no proper leadership and funds from the side of the company, it is really though to adopt new technology like blockchain, and employees like to adopt it. Therefore, this reflects that the organisational barriers have a notable impact on the blockchain implementation process.

Industrial barriers

The category of industrial barriers has been crowned as the second most impactful barrier category. Among the four barriers within the industrial category, slow adaptation to new technologies plays a major role. In proving it, Hamma-adama (2020) states that the construction industry is still lagging in terms of digitalisation. Lack of awareness regarding blockchain technology is another impactful barrier that belongs to the category of industrial barriers. In supporting it, Weerakoon & Chandanie (2021) reveals that the awareness regarding blockchain technology is low in Sri Lanka. Furthermore, Wang (2017) mention that the blockchain is still a new technology for most construction professionals. Therefore, the lack of awareness and the slow adaptation to new technologies like blockchain affects the implementation of blockchain and smart contracts to the construction industry of developing countries.

Human-related barriers

The most impactful human-related barriers identified from the analysis are the having few blockchain consultants/experts that suit the industry requirements and the low technological competency level of industry and IT related employees. In confirming this, Weerakoon and Chandanie, (2021) has identified that the technical incapacity of the professionals within the construction industry is one of the predominant barriers to adapt a new technology like blockchain. This reflects that the knowledge and technical skills of industry professionals related to blockchain need to be improved for the proper implementation of blockchain and smart contracts in the construction industry in developing countries. Further, the RII analysis revealed that the natural reluctance of the industry practitioners to change is another key human-related barrier. Therefore, less collaboration can be seen among the industry professionals especially related to ICT-related new implementations, and this barrier should be overcome. In emphasising it, (Li et al., 2019), suggests that the blockchain implementation process requires the collaboration of all the construction professionals in the industry. Therefore, all the construction professionals should be ready to change accordingly to adopt a new technology like blockchain for construction projects.

Technical barriers

Technical barriers have received fourth place out of all five categories. Nevertheless, the most impactful barrier out of all fifteen barriers belongs to this category which is having less number of construction related software applications (powered by blockchain). Wang (2019) even utters in their study that there are few blockchain-based construction-related applications are currently available. This is crucial as the implementation of blockchain and smart contracts for the construction industry is not successful without the relevant software. However, the other two barriers belong to this category, privacy and security concerns regarding novel ICT and lack of connectivity and bandwidth, are ranked 11th and 15th accordingly. The reason for receiving low ranks from respondents is privacy and security concerns regarding novel ICT, and connectivity and bandwidth are at a satisfactory level in Sri Lanka. Therefore, the impact of these two barriers is very less for the adaptation of blockchain and smart contracts for construction projects.

Legal and political barriers

The legal and political barrier category has received last (fifth) place in the ranking. Barriers which belong to this category are a lack of legal protocols to prevent misconduct and a lack of government policies. Both the barriers have received the ranks of 12th and 13th among the fifteen barriers. However, according to Li (2019), there is a lack of legal protocols and regulations related to blockchain. Nevertheless, the existing legal protocols and regulations in Sri Lanka are fair enough to start the implementation process of blockchain and smart contracts for construction projects. Therefore, the category of legal and political barriers has posed as the lowest impactful barrier category.

4.3 STRATEGIES TO OVERCOME THE BARRIERS

The experts were asked to propose suitable strategies to overcome the identified barriers in implementing blockchain in the construction industry. Altogether, seven strategies were proposed by them. All five experts emphasised that conducting an industry-wide digitalisation analysis to figure out the IT status of the construction industry is the most significant strategy that needs to be followed prior to the implementation of blockchain technology. In accordance with the experts, knowing the current IT status is really crucial to deciding the other strategies for better adaptation of blockchain and smart contracts. The development of an industry-wide digitalisation strategy was suggested as the second most prominent strategy by all interviewees, A, B, C, D, and E. As per the interviewees, proper implementation of the first strategy is quite crucial to materialise this strategy. As the next strategy, all five experts proposed to have skilful IT staff for construction companies to implement blockchain and smart contracts for construction projects. Further, they pointed out that currently, there are very few skilful IT staff is within the construction companies of developing countries, and this has become a major reason for less adaptation to new ICT technologies like blockchain for construction projects.

Next, A, B, D and E suggested that it is necessary to influence the policy-making bodies regarding the benefits of adopting blockchain technology in construction projects. In Sri Lanka, some policy-making bodies relate to construction industry such as CIDA, UDA, etc. and influencing these policy-making institutes regarding the benefits of adopting blockchain and smart contracts will trigger them to implement new policies related to blockchain implementation to the construction projects. This may reason to attract construction professionals and companies to adopt blockchain and smart contracts for construction projects. Furthermore, A, B, C and E emphasised that the awareness of the construction firms and the construction industry professionals regarding blockchain technology is necessary to be improved. There they suggested conducting CPD programs by different professional institutes to make aware and educate the construction industry professionals on blockchain and smart contracts.

Moreover, conducting awareness sessions for the construction and consultancy firms is also a fruitful way to enhance the awareness of blockchain and smart contracts within the construction industry. Three interviewees, A, C and E proposed that it is necessary to create certain action plans and materialise them to promote blockchain and its benefits among the people within the society. Next, B, C and E suggested that including blockchain and smart contracts in the curriculums of construction-related degree programs and other higher education programs as a very good initiative. This may urge to take the attraction of the various young stakeholders who enter the construction industry and subsequently leads to the adaptation of blockchain and smart contracts to the construction industry.

4.4 FRAMEWORK TO ADAPT BLOCKCHAIN AND SMART CONTRACTS FOR THE CONSTRUCTION INDUSTRY

A comprehensive framework was developed to adopt blockchain and smart contracts for the construction industry with the use of the findings of literature and the collected and analysed data from questionnaire survey and expert interviews. Figure 2 represents the developed framework to adopt blockchain and smart contracts for the construction industry of developing countries.

The first step of the framework is to identify the barriers that affect the implementation of blockchain and smart contracts. The barriers have been classified into five categories organisational, industrial, human, technical and legal and political. The barrier categories have been listed within the framework according to their impact on the adaptation of blockchain and smart contracts for the construction industry of developing countries. Afterwards, suitable strategies to overcome the identified barriers (which were gained through expert interviews) have been listed within the next cage. There the strategies have been listed from the highest rated to the lowest based on the answers of the interviewees. The third step of this framework is to distinguish the suitable blockchain-appliable areas within the construction industry. There it has highlighted payment management, construction supply chain, sustainability management, tendering and contract management as the key areas where blockchain and smart contracts can be mainly applicable within the construction industry of developing countries. After distinguishing the applicable areas, the last step has illustrated the outcomes which can be gained through the adaptation of blockchain and smart contracts for the construction industry. As a whole, this framework can be adopted by policy-making institutes and governments as a guideline to adapt blockchain and smart contracts. Sri Lanka is a developing country (Department of Foreign Affairs and Trade [DFAT], 2022). In considering the status of other developing countries they have similar technological background in terms of construction (Mahbub, 2012). Therefore, this framework can be adapted to those countries as well. Further, this framework was not validated, and it is a limitation of this study.

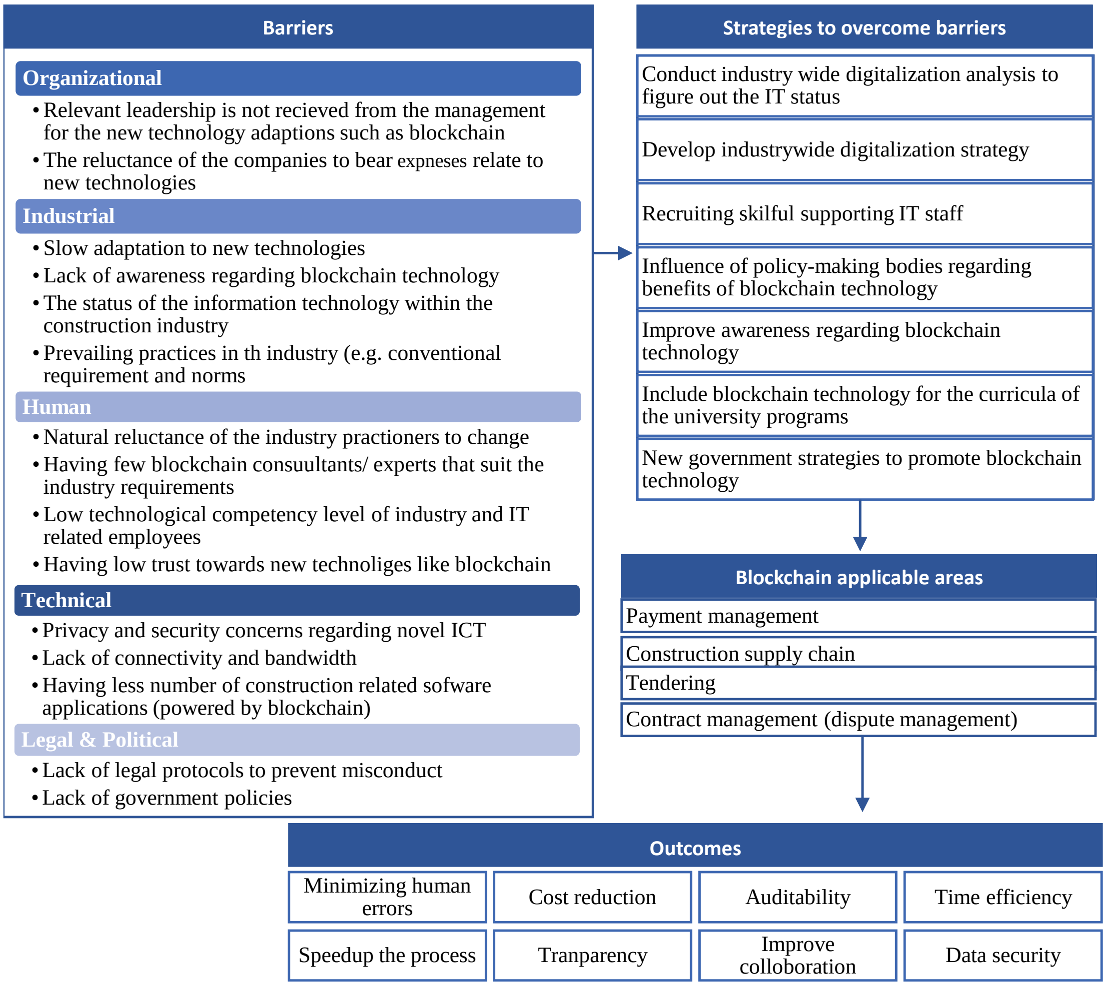

Figure 1: Framework to adapt blockchain and smart contracts for the construction industry of developing countries

5. CONCLUSIONS

Comparing to developed countries, developing countries face numerous barriers in implementing a new technology such as blockchain for the construction industry. Therefore, this research aimed to address this research gap by identifying the barriers which affect the implementation of blockchain and smart contracts for the construction industry of developing countries and to come up with a suitable framework to overcome the identified barriers. Fifteen barriers were identified through a comprehensive literature review and in referring to the findings of the analysis, having a smaller number of construction related software applications (powered by blockchain) was highlighted as the most impactful barrier to blockchain adaptation. Moreover, the reluctance of the companies to bear additional costs to adapt new ICT such as blockchain, slow adaptation to new technologies, having few blockchain consultants/experts that suit the industry requirements, technical incompetency of industry professionals and IT professionals in construction companies were posed as the 2nd, 3rd, 4th and 5th most significant barriers accordingly. Therefore, more focus has to be given to these barriers in adapting blockchain and smart contracts for the construction industry of developing countries. Moreover, seven strategies were identified in order to overcome the distinguished barriers in blockchain adaptation to the construction industry. Conducting industry-wide digitalisation analysis (to figure out the IT status) was suggested as the most important strategy by the experts, and developing an industry-wide digitalisation strategy, recruiting skilful supporting IT staff, and influencing policy-making bodies regarding the benefits of blockchain technology were also highlighted as the next main strategies to overcome the barriers in adapting blockchain and smart contracts. Based on the findings of the analysis, a framework was developed, and it can be followed by the policy-making bodies and the governments of developing countries as a guideline to adapt blockchain and smart contracts for the construction industry. Further, implementing these strategies appropriately will lead to more productive construction industry for the future generation of developing countries. Eventually, future research should focus more towards developing blockchain related software applications for the construction industry and to come up with certain mechanisms to feed data to the nodes of the blockchain.

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ADOPTABILITY OF BIOPLASTIC AS A SUSTAINABLE MATERIAL IN SRI LANKAN BUILDING CONSTRUCTION INDUSTRY

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ABSTRACT

The Sri Lankan construction industry is facing significant challenges in building construction projects due to the negative impacts of using traditional building materials. Consequently, there has been a surge of interest in sustainable materials, and among them, bioplastics have emerged as a promising alternative. The aim of this study is to investigate the potential of bioplastics as a sustainable building material specifically for the Sri Lankan construction industry. To achieve this, the study applied a qualitative research approach to collect data through semi-structured interviews. The research objectives are to identify alternative sustainable materials used in construction and identify how bioplastics could contribute to the construction industry as ta sustainable material. In addition to that, the study also identifies the motivators and challenges to the use of polymer building materials in Sri Lanka and subsequently develop a framework including potential strategies to use bioplastic as a sustainable construction material. The study's findings have identified significant factors that establish bioplastics as a sustainable material suitable for the Sri Lankan construction sector. Moreover, the research offers valuable recommendations to address challenges related to the adoption of polymer building materials. Furthermore, the study would contribute to the formulation of policies and regulations that promote the use of bioplastics as a sustainable building material.

Keywords: *Alternative Materials; Bioplastics; Biopolymer Building Materials; Sri Lankan Construction Industry; Sustainable Building Material.*

1. INTRODUCTION

Building is a major global user of both biological and physical natural resources, which significantly contributes to the current, unsustainable development of the global economy (Spence & Mulligant, 1995; Kulatunga et al., 2006). In addition, the construction industry is highly criticised for inefficient use of these natural resources (Kulatunga et al., 2006), According to the evidence, around 40% of the garbage generated globally comes from building development and demolition, and thus makes up a significant amount of the solid waste thrown in landfills around the world. On the other hand, waste materials are a significant environmental issue that poses a risk to the environment. It is critical to recycle and dispose of these materials (Dachowski & Kostrzewa, 2016). Since the dawn of the

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industrial revolution, the effects of the construction industry on the environment have been a major source of concern. Buildings consumed 30% of global energy in 2013 and produced 25% of total CO_2 emissions. Furthermore, the construction industry accounts for nearly 75% of global trash (Lasvaux et al., 2015). Even while bio-based polymers provide the potential for a brand-new, environmentally friendly building material that can be composted or returned to the land after construction. Bioplastics may potentially pave the way for new low-embodied-energy construction materials, enhancing energy efficiency (Ivanov & Christopher, 2016).

The construction industry faces challenges like environmental issues, material waste, and shortages, affecting productivity. To tackle these, a sustainable approach and biomaterials like bioplastics are being explored. Biopolymers offer benefits such as reduced fossil fuel use, smaller carbon footprint, and renewable resource utilisation, making them eco-friendly and waste-solving. However, there is limited research on bioplastic construction in Sri Lanka, and industry readiness is unclear. Further empirical exploration is needed. Embracing sustainability is crucial for long-term industry viability (Lamberti et al., 2020).

Developing countries like Sri Lanka face drawbacks with unsuitable building materials and long, intertwined supply chains, increasing environmental impact (Bon & Hutchinson, 2000). Without adopting alternative materials, reliance on imports and environmental impact will continue to rise (Bon & Crosthwaite, 2001). Increasing use of plastics in buildings, driven by the need for improved services, brings economic implications but also environmental and social concerns (Haque, 2019). To overcome these issues, the aim of this research project is to investigate the suitability and adoptability of bioplastic material as an alternative sustainable material for building construction in Sri Lanka. To achieve this aim, several objectives have been identified. Firstly, major and alternative sustainable materials used in the construction industry will be identified. Secondly, the potential factors for using bioplastic as a sustainable material will be identified and analysed. Thirdly, motivators and challenges to using polymer building materials in building construction in Sri Lanka will be analysed.

2. LITERATURE REVIEW

2.1 POLLUTION IN CONSTRUCTION INDUSTRY

The construction industry, a major global sector, heavily consumes natural resources. It faces challenges affecting project goals and economic growth (Wang & Adeli, 2014). Developing countries often experience material shortages due to reliance on imported conventional materials (Ofori, 1993). Construction has negative environmental impacts, depleting resources, generating greenhouse gases from fossil fuel burning (Li et al., 2010). Disposing construction waste in underground landfills harms the environment (Zhang et al., 2022). Thermoplastics are widely consumed in packaging, automotive, electrical, electronic, and building sectors (Haran et al., 2020).

Sustainable building design, also known as high-performance or green design, requires changing attitudes, paradigms, procedures, and systems to address specific challenges (Wang & Adeli, 2014). The concept of sustainable development focuses on economic, societal, and environmental advancement for future generations.

2.2 SUSTAINABLE BUILDING DEVELOPMENT

Sustainable development includes, among other things, increasing social, economic, and environmental conditions for both the present and future generations while also enhancing quality of life. In order to achieve sustainable development from the numerous environmental, social, economic, and cultural sides, the building industry has developed a new concept called sustainable construction. Traditional construction methods solely prioritise cost-cutting, performance, and quality goals, but sustainable methods additionally prioritise reducing resource depletion, environmental degradation, and improving the built environment (Jayalath & Gunawardhana, 2017).

In order to create a structure that is accessible, inexpensive, and ecologically friendly, a genuinely sustainable construction project should take economic, social, and environmental concerns into account during the design, construction, and demolition stages (Vanegas et al., 1995). Choosing materials that leave a smaller environmental imprint is one of the best ways to accomplish sustainable building. In this regard, it is advised that designers and architects pay attention to these factors from the very beginning of the design process (Mahmoudkelaye et al., 2018).

2.3 BIOPLASTIC

Bioplastics are polymers created from raw materials that are both natural and renewable, such as sugarcane, maize starch, wood, waste paper, vegetable oils, lipids, bacteria, algae, and other microorganisms. Since non-renewable petroleum is used to make the vast bulk of commercial plastics, they can have a negative impact on the environment (Sidek et al., 2019). Initial research on bioplastics dates as far back as 1962, and since then different varieties of bioplastics have been produced as depicted in Figure 1.

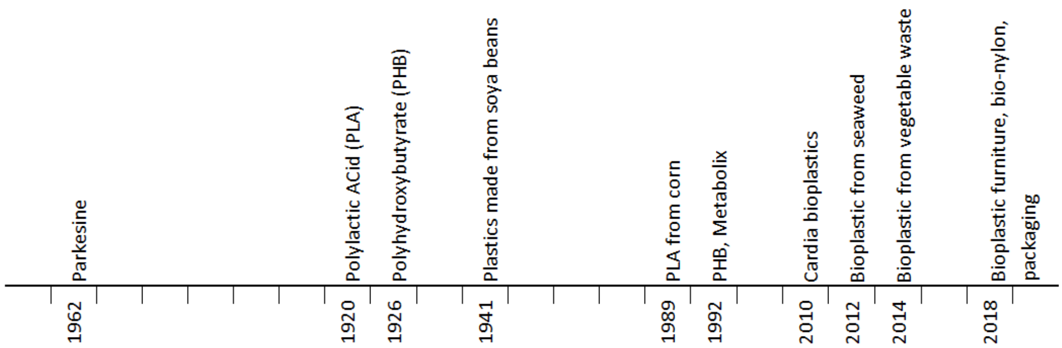

Figure 1: Bioplastic development

The chemical composition of Bioplastics is similar to traditional plastics, hence having similar characteristics (Rahman & Bhoi, 2021). The chemical composition of the bioplastic can be altered to produce non-biodegradable plastics as well as biodegradable, compostable plastics (Batori et al., 2018). While Polyethylene terephthalate (bio-PET), Polyamide (bio-PA), Polyethylene (bio-PE) display non-biodegradable properties that require special processing to initiate degradation, while polyhydroxyalkanoate (PHA), Polyvinyl alcohol (PVA), can be anaerobically degraded (Rahman & Bhoi, 2021). With the current concerns over sustainability and circular economy bioplastics presents as a viable alternative since bioplastics can be degraded avoiding any harmful residue after being used in different production cycles (Oberti & Paciello, 2022).

However, developing nations face challenges due to limited access to bioplastic production technology and material supply. Lack of knowledge and underdeveloped resources further hinder optimal utilisation (Liliani et al., 2020). Regulations regarding bio-plastics vary, often being weak in developing nations (Filiciotto & Rothenberg, 2021). Health and safety laws may also apply (Thompson et al., 2009). Affordability is a hurdle in poorer nations, but investment in infrastructure, research, and sustainable farming methods can improve accessibility while utilising waste products as raw materials (Wellenreuther et al., 2022).

Bioplastics are sustainable and renewable materials gaining attention in the construction industry, reducing greenhouse gas emissions (Reddy et al., 2008). They find applications in packaging, automotive, biomedical, and engineering fields. Biopolymers are used as concrete admixtures to enhance water retention (Oberti & Paciello, 2022). Alternative concrete formulations using enhanced cornstarch and expanded polylactic acid (EPLA) have shown promise (Sayadi, 2018). Glucan biopolymer can substitute cement in earthen construction, reducing carbon footprint (Chang & Cho, 2012). Biopolymers are also explored as filament materials in 3D printing and insulation materials (Hebel & Heisel, 2017).

Temporary structures are the most common application of bioplastics, including bio composite packing sheets, solid foam silt, and dust barriers, sealants, insulators, and non-structural components like dividing walls and partitions (Pilla, 2011). With the use of PLA, biodegradable fibres for building material reinforcement, bio composite sheets, biodegradable resins, and environmentally friendly flooring can all be produced (John & Thomas, 2008).

2.4 MOTIVATION AND CHALLENGES

Table 1 presents the enablers and challenges to the adoption of bioplastics in the construction industry. These factors have been identified from the literature.

Table 1: Enablers and challenges for adopting bioplastics identified from literature

Enablers	Challenges
The majority of landfills contains construction waste (Ariadurai, 2012)	Revolutionary technology that needs further research and development (Renee, 2017)
Reduced carbon footprint (Reddy et al., 2008)	Certain bioplastics degradation at high temperature (Misra et al., 2011)
Bioplastics do not even produce harmful waste or leak chemicals (Ivana et al., 2017)	Certain bioplastics need special treatment processes (Thakur et al., 2018)
Bioplastics have zero waste end of life (GreeenHome, 2008)	Economic factors will not be enough to propel this technology (high cost) (Iles & Martin, 2013)
Negligible impact on climate changes (Weiss et al., 2012)	Large amount of production create demand for agricultural crops (Shah et al., 2008)

3. RESEARCH METHODOLOGY

This study investigates the challenges associated with the adoption of bioplastic in the Sri Lankan construction industry using qualitative research methodology. Due to the exploratory nature of this research, qualitative research approach was employed, which investigates a phenomenon in its natural setting using non-quantifiable data (Ryan et al., 2009). Being a technology that is most practiced in manufacturing sector in Sri Lankan context, locating experts with construction related experience was difficult. Hence, purposive sampling method was employed to select relevant respondents together with snowballing technique to locate more experts. Expert interviews were used to gather rich and detailed information from individuals with specialised knowledge and experience in the field (Kothari, 2004). The manual code-based content analysis was used to identify patterns and themes within the data (Hsieh & Shannon, 2005), providing insights into the challenges associated with the adoption of bioplastic packaging in the Sri Lankan construction industry.

4. DATA ANALYSIS AND FINDINGS

The research utilised expert interviews to collect data on the adoptability of bioplastic as a sustainable material in Sri Lankan building construction industry. Six semi-structured interviews were conducted in two phases with experts in bioplastic concepts and those working in the construction industry. The collected data was transcribed and analysed manually using code-based content analysis. The utilisation of expert interviews proved to be an effective method for gathering data, particularly in the Sri Lankan context where access to experts can be limited. The profile of the interviewees is provided in Table 2.

Table 2: Expert profiles

Name	Designation	Company Type	Years of Experience	Years of Experience in Bioplastic	Experience in Bioplastic
R01	Chairman	Production company	35	8	PhD studies relating to the bioplastic; more than 5 years in Sri Lankan Bioplastic Association
R02	Material Engineer	Production company	3	2	Participated several programs on bioplastic
R03	Assistant manager	Production company	12	3	Participated several programs on bioplastic
R04	Chartered Architect	Consultant	35	25	Participated in material selection involving bioplastic in foreign projects
R05	Material Engineer	Consultant	18	8	Conducted continuing professional development (CPD) on bioplastic in other industries
R06	University Lecturer	University	15	10	PhD studies relating to the bioplastic; conducted workshop on bioplastics in manufacturing industry

4.1 BIOPLASTICS AS CONSTRUCTION MATERIALS

The use of bioplastics in the building construction business may be a sustainable choice. R06 mentioned that "*The use of biomass sources rather of fossil fuels makes bioplastics more environmentally friendly than conventional plastics*" highlighting the positive effects on sustainability.

Regarding the use of bioplastics in construction R04 and R06 stated that *"Bioplastics could replace traditional plastic-based building materials used in packaging, insulating and non-structural finishes. They can reduce greenhouse gas emissions, decrease dependence on fossil fuels, and promote eco-friendly building techniques"*. However, respondents also highlighted the importance of considering procurement of the raw materials on the environment and to confirm that the bioplastics are produced using sustainable and biodegradable resources.

Construction companies may become more sustainable by using bioplastics to package their products, which can minimise the amount of plastic trash they produce. it would be crucial to encourage the use of bioplastics in the building sector and create a sustainable supply chain for the raw ingredients.

According to R01, R04 and R06 "*Bioplastics made from plant-based resources can replace traditional wood-based construction materials, such as insulation, roofing, plumbing, and composites".* The respondents further elaborated that they have a smaller carbon footprint and can also be used for packaging and building components.

4.2 FACTORS CONTRIBUTING TO USE OF BIOPLASTIC AS A SUSTAINABLE MATERIAL

After recognising the potential use of bioplastic in Sri Lankan construction industry, the respondents were then inquired about the facilitators that should exist for seamless adoption of bioplastic in place of conventional material.

4.2.1 Technology

Research suggests that bioplastics in construction are still emerging but have made significant progress recently and are expected to grow further. R04, R05 and R06 held that, Sri Lanka possesses advanced technology in packaging and rubber industries but lacks in the building sector. However, the country can utilise its existing rubber industry technology to implement bioplastics in construction. Moreover, Sri Lanka has access to raw resources for bio-based polymers. Bioplastics technology is globally well-developed and accessible.

4.2.2 Availability of Raw Material

Sri Lanka, an agricultural country with abundant natural resources, possesses a large supply of raw ingredients for bioplastics. R05 and R06 mentioned that *"Agricultural waste such as rice bran, coconut shell, and coir dust are utilised for bioplastics production. Numerous R&D projects are focused on utilising these materials."* Bioplastics manufacturing makes use of underutilised agricultural areas, contributing to waste management. Additionally, bioplastic production indirectly aids in addressing Sri Lanka's waste management challenges. Furthermore, R06 mentioned that with nearly 50% of agricultural lands still unused, there is an opportunity to utilise these lands for obtaining sufficient raw materials.

4.2.3 Manufactures

Respondents acknowledged the existence of a few prominent natural rubber and plastic manufacturers in Sri Lanka who has the potential to venture into bioplastics production. R06 mention that, *"Sri Lanka is already a major producer of packaging materials and bio-based tires, which are exported globally. Sri Lanka's reputation for manufacturing high-quality products makes it an ideal location for bioplastics production in the construction sector".* The government could also actively promote the growth of the industrial sector, including the development of bioplastics, to stimulate economic expansion and job creation. Importing bioplastics and collaborating with foreign manufacturers was also identified as a viable option.

4.2.4 Suppliers

Given the limited number of local producers capable of manufacturing bioplastic, the responded thought that importing bioplastics into Sri Lanka could be a viable option to facilitate the adoptability. R04, R05 and R06 also highlighted the additional costs like shipping and import duties should be considered. Furthermore, all respondents highlighted the importance of issuing licence to ensure that the imported bioplastics comply with Sri Lankan laws and standards. Adherence to regulations and permits is required for vendors importing bioplastics. Verification of availability, quality, and certifications is necessary to meet specific requirements.

Additionally, R04 and R06 mentioned that Private companies in Sri Lanka are actively involved in bioplastics production and development in beverage manufacturing industry could offer expertise and guidance on utilising bioplastics in the construction industry. These companies can provide valuable information to businesses interested in implementing bioplastics.

4.2.5 Research and Development

Universities in Sri Lanka with faculties of engineering, chemistry, and material science carry out bioplastics research. Government organisations that perform bioplastics research and development include the National Science Foundation (NSF) and Industrial Technology Institute (ITI). R05 emphasises that although though Sri Lanka's bioplastics business is still in its infancy, it is crucial that professionals in the area are able to create high-quality bioplastics that satisfy local building codes

4.2.6 Legal Background

Legal and regulatory barriers should be considered when utilising bioplastics in Sri Lanka's construction industry. The Sri Lanka National Building Code (NBC), Sri Lanka Standard Institution (SLSI), and organisations like NBRO and the Central Environmental Authority (CEA) oversee the usage of sustainable building materials, as highlighted by R05. The government has implemented measures to promote bioplastics, including building regulations, support for research and development, tax incentives for green buildings, public-private partnerships, and a green building rating system that encourages energy efficiency and renewable energy utilisation, as mentioned by R04, R05, and R06

4.2.7 Health and Safety

Certain base components of bioplastics pose health and safety concerns, as highlighted by R04, R05, and R06. However, these risks can be minimised by using bioplastics made from non-toxic chemicals, handling them with care, and ensuring proper disposal. R05 also points out that certain bioplastics that are not biodegradable may contribute to plastic pollution. Moreover, R06 warns that certain bioplastics contain harmful elements that can pose risks to humans and animals if ingested. Additionally, some bioplastics have a higher flammability than traditional plastics, emphasising the importance of proper handling to avoid fire hazards.

4.2.8 Production Cost

Despite higher costs in the short term, bioplastics offer sustainability benefits and could be a viable option for Sri Lanka's construction industry. R04 suggests that the use of additives can reduce the production cost of bioplastics, enhancing their affordability. Another approach is improving manufacturing efficiency through new technologies and process optimisation, leading to cost reductions. As new technologies and production techniques emerge and economies of scale are achieved, the cost of bioplastics is gradually decreasing, as mentioned by experts.

4.3 POTENTIAL OF FULL FILLING THE REQUIREMENTS

Experts agree that bioplastics can address issues associated with conventional building materials such as material scarcity, environmental concerns, and waste management as identified in the literature. Bioplastics utilise renewable resources like maize starch, sugarcane, and cassava, ensuring a sustainable supply for construction. Unlike traditional plastics made from oil, bioplastics have a lower carbon footprint and can be compostable and biodegradable, as noted by R04, R05, and R06. In certain applications, bioplastics have the potential to serve as a viable alternative to traditional building materials.

4.4 ENABLERS AND CHALLENGES TO ADOPTION OF BIOPLASTIC IN CONSTRUCTION INDUSTRY

4.4.1 Enablers

According to all experts bioplastics offer promising solutions to reduce the environmental impact of conventional materials, particularly in the context of building and demolition waste. By providing biodegradable and recyclable alternatives, they contribute to a decrease in landfill accumulation. Biodegradable bioplastics further aid in waste reduction by decomposing in the presence of microorganisms, heat, and humidity.

However, not all bioplastics are equal, and some bioplastics may not achieve a zero-waste end-of-life. R04 held that biodegradable bioplastics can significantly reduce the carbon footprint. Biodegradable bioplastics, eliminate the release of toxins during disposal and reducing the generation of toxic waste. Bio-based products, while reducing carbon emissions, may still contain hazardous substances. The potential for a zero-waste end-of-life depends on the bioplastic's recyclability. If they can be completely recycled, they can be considered zero-waste.

By minimising greenhouse gas emissions and reducing fossil fuel consumption, bioplastics help lower their manufacturing impact. This dual benefit of being biodegradable and having reduced emissions ensures that bioplastics have a positive environmental impact, leaving no detrimental traces. Additionally, their use contributes to the reduction of landfill waste, thus supporting efforts to mitigate the effects of climate change.

4.4.2 Challenges

Bioplastics are an evolving technology that requires further research to fully understand their properties and environmental impact, as stated by R04, R05, and R06. Pyrolysis, a method involving high-temperature treatment without oxygen, can be used to dispose of certain bioplastics. However, some non-biodegradable bioplastics necessitate specialised disposal methods due to their resistance to decomposition by microorganisms, heat, and humidity.

In the Sri Lankan construction industry, the cost of bioplastics can be a limiting factor. Nevertheless, the long-term cost savings should be considered. Utilising the country's abundant unusable farmland for cultivating crops for bioplastics could provide additional income for farmers and employment opportunities in the bioplastics sector. With over half of Sri Lanka's land unsuitable for agriculture, it presents a valuable resource for sustainable bioplastics production. This utilisation of land can address material scarcity and ensure a sustainable supply of construction materials.

5. CONCLUSIONS

In Sri Lanka's building construction sector, bioplastics have the potential to replace conventional materials in a sustainable way. The study found that bioplastics' capacity to minimise waste and pollution, their renewable and biodegradable nature, and their low carbon footprint are the main potential benefits of adopting them. Environmental considerations, economic effectiveness, and the accessibility of substitute materials are some of the driving forces behind the use of polymer building materials in construction.

The study initially identified key factors contributing the adoption of bioplastic through literature and later verified the applicability of said factors to Sri Lankan context through expert interviews. The findings revealed the enablers as well as the challenges stemming from the aforementioned factors. While the availability of natural material and similar technologies in other industries were highlighted as enablers, research also drew attention to several issues that need to be resolved, such as the lack of knowledge and understanding of bioplastics, the absence of laws and standards, and the restricted availability of bioplastic goods. These findings and relationship between the key factors are further elaborated in Figure 2.

This research emphasises the potential of bioplastics to enhance sustainability in the Sri Lankan construction sector. It identifies key factors, enabling a better understanding of the challenges and opportunities of adopting bioplastics. This knowledge can guide further research and exploration of sustainable building materials in Sri Lanka and similar contexts. The study underscores the importance of education and awareness initiatives to overcome adoption barriers. Policymakers, industry professionals, and stakeholders in the construction sector can benefit from the practical insights provided by this research. Collaboration among stakeholders is crucial to address knowledge gaps and establish relevant laws and standards that promote the use of bioplastics.

Overall, the research highlights the theoretical and practical implications of integrating bioplastics into the Sri Lankan building construction sector. By identifying enablers and challenges, emphasising collaboration, knowledge dissemination, and regulatory support, this study contributes to the ongoing efforts to promote sustainable practices and environmentally friendly materials in construction. The findings serve as a stepping stone for future endeavours aimed at enhancing the sustainability and resilience of the building industry, not only in Sri Lanka but also globally.

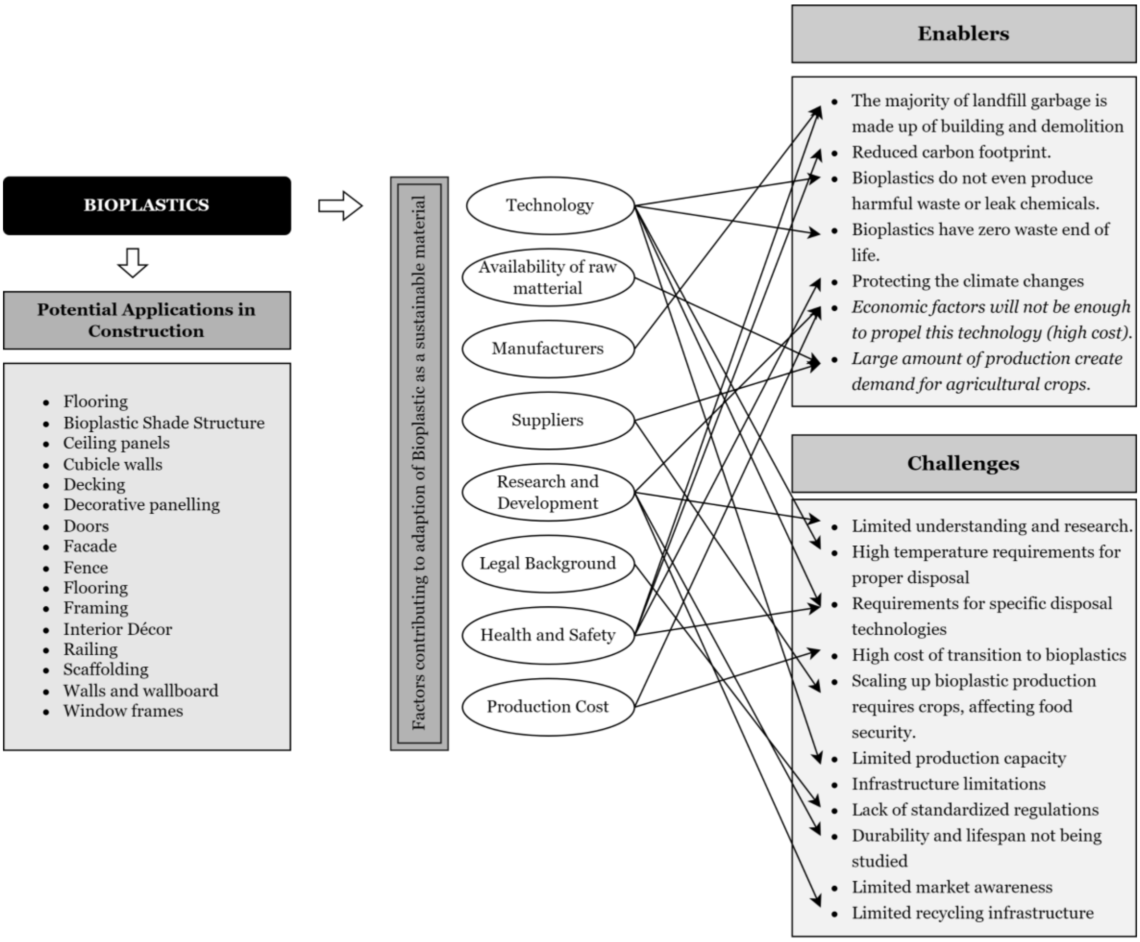

Figure 2: Relationship between the key factors

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ADOPTING URBAN SYMBIOSIS FOR SUSTAINABLE URBAN WATER REDUCTION AND MANAGEMENT: A BIBLIOMETRIC ANALYSIS

Y.J.M. Yatawatta[1]

ABSTRACT

This research aims to explore the feasibility of adopting urban symbiosis for sustainable urban water reduction and management through a bibliometric analysis of key literature. A Scopus-based systematic review was conducted to analyse journal articles related to urban symbiosis, water management, and water reduction, with a focus on their intersection towards achieving sustainability. The outcomes of the systematic review were analysed using bibliometric techniques to examine the evolution of publications, identify leading journals, and determine the authors and countries which have published the most papers on the topic. The research also conceptualised the benefits, barriers, and enablers associated with adopting urban symbiosis for water reduction and management. The findings of this study contribute to a deeper understanding of the potential implications and practical implications of urban symbiosis in the context of sustainable water management. The study contributes to the knowledge of the potential of urban symbiosis in addressing the challenges of water management in urban areas and gives insights to policymakers, urban planners, and practitioners interested in implementing sustainable water management practices in urban areas.

Keywords: *Barriers, Benefits, Urban Symbiosis, Water Management, Water Reduction.*

1. INTRODUCTION

Water scarcity is one of the most critical issues of the twenty-first century (Food and Agriculture Organization [FAO], 2018). Water is scarcity when the demand for fresh water in a particular area exceeds to water supply (Food and Agriculture Organization (FAO), 2012). Water scarcity refers to the condition of a lack of water supply for both human and environmental uses, and it is a severe and expanding issue on a global scale (White, 2014).

Four billion people out of the whole world's population face water scarcity once annually and half a billion people face water scarcity throughout the year (Gao et al., 2018). Moreover, water scarcity affected more than three billion people in 2021 (Carbon Disclosure Project [CDP], 2018). Half of the world's population would be living in water-stressed areas by 2025 (World Health Organization [WHO], 2019). By 2050, the world's

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population is expected to reach around nine billion people (Srinivasan et al., 2012). However, water consumption has risen twice the global population growth rate (Project World Impact [PWI], 2021). By 2050, most of the three billion additional people will live in developing countries, mainly in areas where water supplies are already depleted and increasingly in cities with inadequate water and additional water requirements (CDP, 2018). According to the authors, water scarcity will be in the future.

Climatic changes, water pollution, population growth and deforestation are some of the major reasons for water scarcity (Ellison et al., 2017; Porkka et al., 2016; Srinivasan et al., 2012). Climatic changes can affect water supply by changing precipitation and demand patterns (United Nation Environment Programme [UNEP], 2011). Different demography, political-economic, social, and technological developments, global energy consumption, developments in construction, GHG emissions and pollutants are the reasons for climatic changes (Alley et al., 2003). Water pollution is the consequence that makes water unfit for human consumption (Solar Impulse Foundation [SIF], 2021). However, many factors contribute to water pollution, including domestic sewage, industrial wastewater, stormwater runoff, septic tank water and agricultural practices (Chowdhary et al., 2019). As a result of population growth, food production has risen; as a result, water scarcity has increased significantly (Porkka et al., 2016). Ellison et al. (2017) stated that increased deforestation is expected to have the most significant impact on land-atmosphere interactions, resulting in less rain and increasing water scarcity.

Water management and water reduction are two strategies to reduce water scarcity (World Wide Fund [WWF], 2023). Many advantages for reducing water scarcity and enhancing water management in urban areas can be achieved through urban symbiosis (Estévez et al., 2022). Urban symbiosis can contribute to the creation of more sustainable and resilient cities by encouraging the reuse of wastewater and the optimal use of water resources(Estévez et al., 2022).

2. LITERATURE REVIEW

2.1 URBAN SYMBIOSIS

Urban symbiosis is a cooperative relationship between various urban actors (such as households, commercials, and institutions) that entails the exchange of resources and services for the benefit of both parties to increase resource efficiency and water efficiency and promote sustainability (Mulder, 2021). As an extended concept of urban symbiosis, which is an expanded idea of industrial symbiosis, investigates synergies in urban and industrial areas by converting municipal solid waste into industrial space and using industries to supply living resources, such as waste heat and hot water (Sun et al., 2017). Urban symbiosis is seen from a geographical perspective, optimises the regional metabolic network by allocating resources and infrastructures, hence minimising resource consumption, emissions and coordinating the interaction of industry with urban development (Sun et al., 2017).

2.2 THE CONCEPT OF URBAN SYMBIOSIS FOR WATER REDUCTION AND MANAGEMENT

A promising strategy for reducing water use and enhancing water management in cities has been identified as urban symbiosis (Wadström et al., 2023). Under this strategy, several urban organisations, including municipal governments, businesses, and households, work together to share and utilise water resources (Wadström et al., 2023).

Urban symbiosis success in managing water can be attributed to its ability to encourage the reuse and recycling of water, minimise distribution network losses, and maximise water consumption through effective technology and procedures (Santos et al., 2023; Tom et al., 2021). Also, urban symbiosis collaborative character can encourage innovation and create novel opportunities for sustainable water management (Valentine, 2016).

Urban symbiosis encourages the effective use and recycling of water resources in cities, which might help to reduce water scarcity (Estévez et al., 2022). In order to reduce the demand for freshwater and available water supplies, various urban actors might cooperate to cooperatively identify options for sharing and recycling water resources. The development of water reuse networks, in which wastewater from one user is treated and reused by another, is an illustration of this strategy (Santos et al., 2023).

Urban symbiosis involves attaining economic, environmental, and social benefits in urban areas by collaborating and sharing resources, knowledge, and experience (Raymond et al., 2017). The effective management of water resources is one of the main advantages of urban symbiosis. Urban symbiosis can help urban areas use water sustainably by encouraging efficient water usage, minimising wastewater generation, and encouraging water reuse (Estévez et al., 2022). A key component of urban symbiosis that can reduce water usage in cities is efficient water use. Urban symbiosis encourages water-saving techniques like rainwater collection, greywater reusing, and the use of low-flow plumbing equipment to reduce water consumption (López Zavala et al., 2016). In conclusion, urban symbiosis can have a big impact on water management and water use reduction in urban areas. Urban symbiosis' key components, efficient water utilisation, reduced wastewater production, and encouragement of water reusing can support the sustainable use of water resources in urban environments.

3. RESEARCH METHODOLOGY

To complete the present study, a systematic review of the literature was used as the methodological basis. Hence, by a systematic review of the Scopus database, it was first recognised that key literature was published indicating the intersection of the fields of water use reduction, urban symbiosis, and water management. This Scopus-based review article presents the first insights into the growth of urban symbiosis for water reduction and management from 2016 to 2023.

Using the keywords "water reduction," "urban symbiosis," and "water management," the Scopus database was searched for relevant titles, abstracts, and documents published from 2016 to 2023 [TITLE-ABS-KEY ("water reduction" AND "water management" OR "urban symbiosis"]. The Scopus search tool's filters, I DOCUMENT TYPES=(Articles) AND (ii) SOURCE TYPE=(Journals), were used to further narrow down the initial 133 articles to find the best literature. In light of this, 67 journal articles were chosen as the foundation for the bibliometric study.

Two (02) chosen indicators of the co-occurrence of words and the number of articles illustrating the intersection of the fields of water management, water reduction, and urban symbiosis were used to conduct the analysis of the literature. Leading journals that have published on the intersection of water management, water use reduction, and urban symbiosis, as well as the top authors who have published a significant number of articles combining these fields, as well as the top publishing countries, were identified through this evolution in the number of journal articles published over time. The literature was chosen in accordance with the selected bibliometric indicators in order to comprehend how water management, water reduction, and urban symbiosis connect.

4. RESULTS AND DISCUSSION

This section of the paper presents the key research findings related to two major areas: (i) outcomes of bibliometric analysis, and (ii) urban symbiosis for water reduction and management. The bibliometric analysis identified the most influential publications, authors and countries in the field of urban symbiosis, highlighting the growing interest in this area of research.

4.1 OUTCOMES OF BIBLIOMETRIC ANALYSIS

As the initial step, a Scopus-based systematic review was conducted to collect data related to the evolution of the urban symbiosis concept for water reduction and management. The collected data for the period from 2016 to 2023 was analysed using bibliometric analysis. The results were organised under four key headings: (i) evolution of the number of journal articles published, (ii) leading journals that published articles related to urban symbiosis for water reduction and management, (iii) analysis of the leading authors in this field, and (iv) analysis of leading countries of journals that published articles on the topic. This analysis provides valuable insights into the trends and patterns of research in this area, highlighting the growing interest in urban symbiosis as a promising approach to water management in urban areas.

4.1.1 Evolution of the Number of Journal Articles Published on Urban Symbiosis for Water Reduction and Management

The systematic review analysed a total of 67 journal articles published between 2016 and 2023, focusing on the intersection of urban symbiosis for water reduction and management. The evolution of the number of journal articles published on this topic in the Scopus database is presented in Figure 1.

The analysis revealed that 13 articles was published in 2016, but the number of articles is reduced as 9 and 8 respectively in 2017 and 2018. In 2019, increased to 11 articles, followed by 8 and 7 in 2020 and 2021, respectively. As shown in Figure 1, the number of publications peaked in 2016 with a total of 13 articles, while three articles were published in the first three months of 2023. The overall trend indicates a decreasing number of publications on urban symbiosis for water reduction and management from 2016 to 2018, followed by an increasing trend in 2019 and beyond. After 2019, it again decreased until 2021. But in 2022, it little bit increased publishing 8 articles. Many of the published articles focused on water management and sustainability, highlighting the growing interest in this topic.

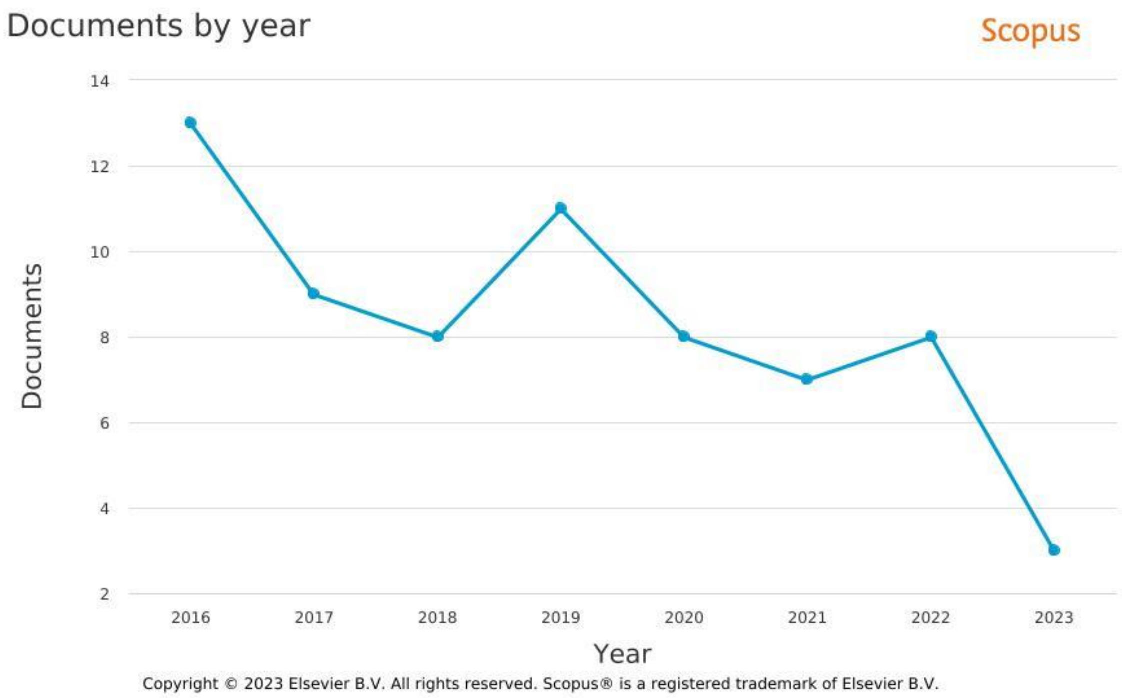

Figure 1: Evolution of the number of articles
Source: Scopus-based systematic review

4.1.2 Leading Journals Published Urban Symbiosis for Water Reduction and Management

Urban water symbiosis has emerged as a revolutionary concept in today's world, with a limited number of journals currently dedicated to its publication. Figure 2 presents the leading journals that published articles on the intersection of urban symbiosis for water reduction and management between 2016 and 2023. According to the analysis, the Journal of Cleaner Production published the highest number of articles (three) on this topic during the period. Other leading journals that published a high number of articles include Agriculture Water Management, Desalination and Water Treatment, Science of the Total Environment, and Water Science and Technology: Water Supply.

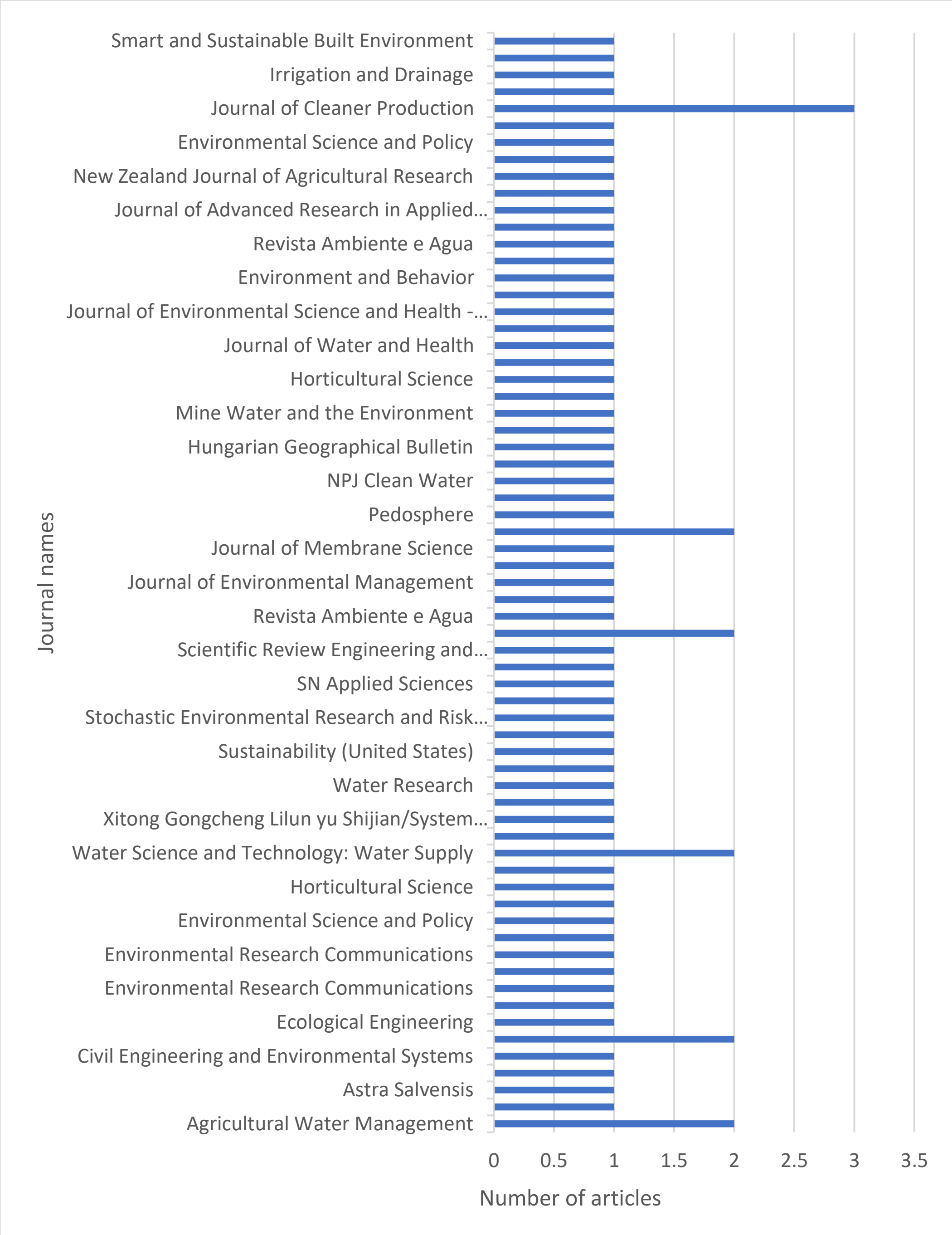

Figure 2: Leading journals that published most articles
Source: Scopus-based systematic review

4.1.3 Leading Authors in the Concept

Figure 3 displays the leading authors who have contributed to the adoption of urban symbiosis for water reduction and management. The analysis of the data from Scopus for the period between 2016 and 2023 reveals that Moghini and Sepaskhah published the most articles (three) on this topic. Other authors who have made significant contributions include Kanakpudis V, Klingel P, and Mastaller M, each of whom has published two articles in Scopus.

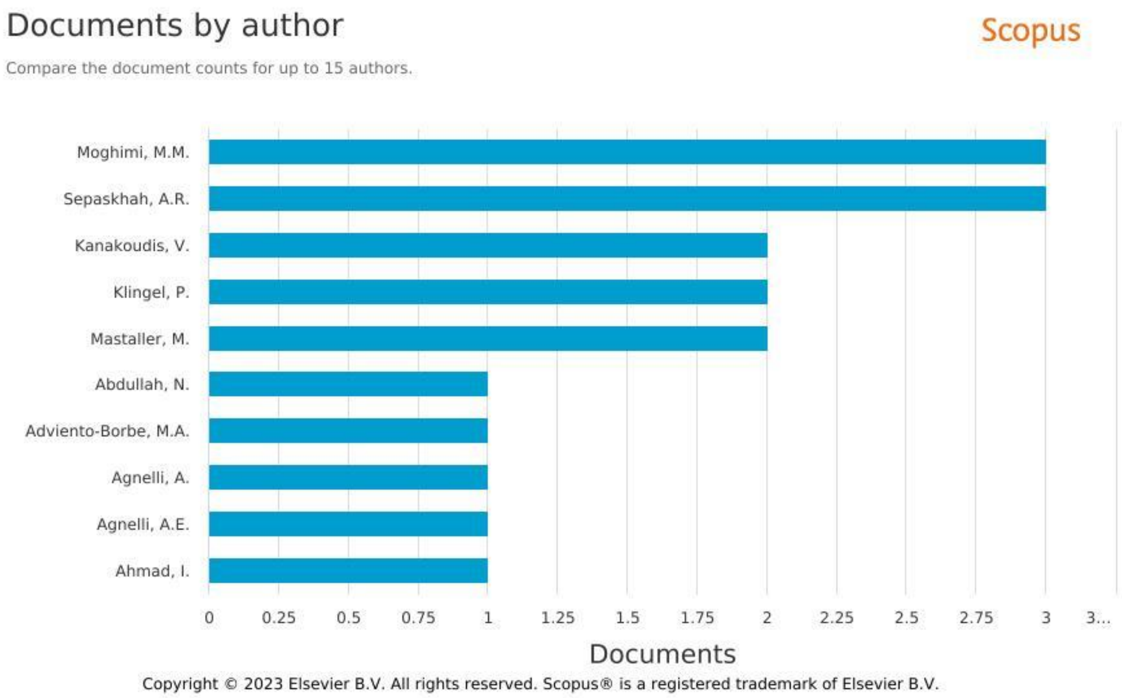

Figure 3: Leading authors in the field
Source: Scopus-based systematic review

4.1.4 Leading Countries in the Concept

The leading journal countries that have published most articles considering urban symbiosis for water reduction and management intersection over the period from 2016 to 2023 are presented in Figure 4. As shown in Figure 4, China is the leading country that published the highest number of articles on the intersection of water management, water reduction and urban symbiosis during the period from 2016 to 2023. China is one of the countries which is used the urban symbiosis concept for water reduction and management (Li et al., 2021). The United State is the second leading country that published a journal for urban symbiosis, water management and water reduction. United Kingdom, Iran, Italy, Australia, Greece, Malaysia, Brazil and Canada are the other leading countries which published journals regarding urban symbiosis for water reduction and management.

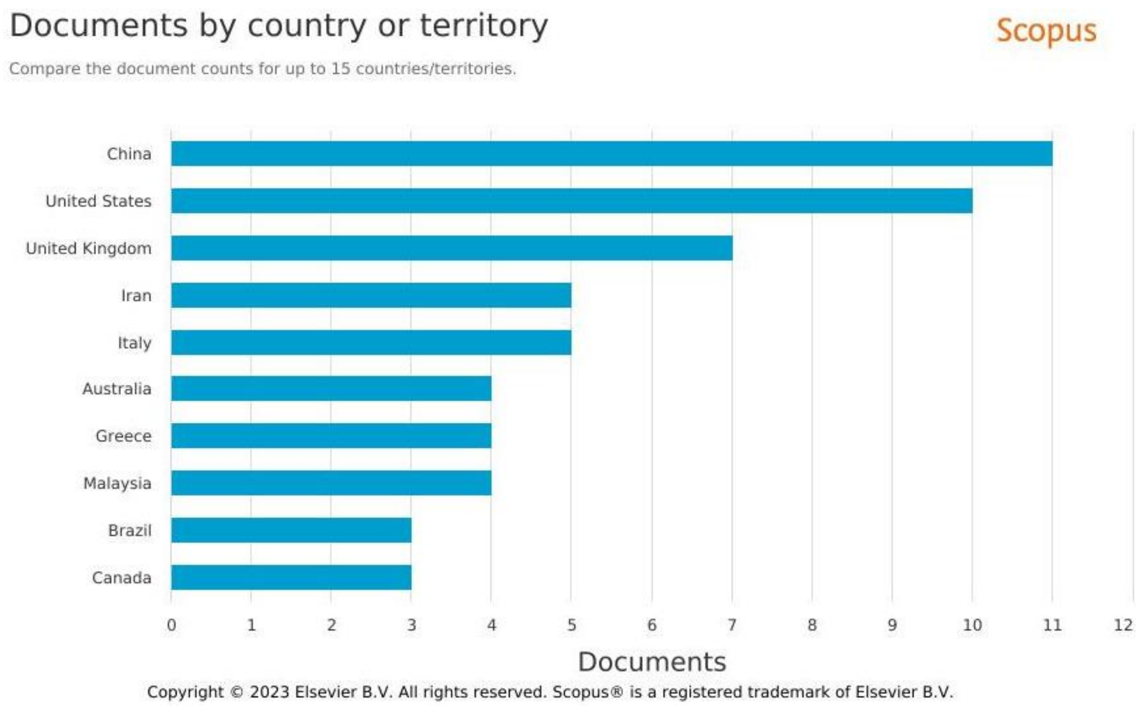

Figure 4: Documents by countries
Source: Scopus-based systematic review

According to the analysis, the concept of urban symbiosis is evolving as a developing study worldwide. The current application of urban symbiosis is focused on water reduction and management.

4.2 ADOPTING THE URBAN SYMBIOSIS CONCEPT FOR WATER REDUCTION AND WATER MANAGEMENT

Urban water symbiosis has gained significant attention and adoption by numerous countries worldwide due to its potential to address multiple challenges associated with water management in urban areas. This innovative concept promotes the integration and collaboration of various urban water systems to achieve greater resource efficiency, sustainability, and resilience.

Recent journal articles suggest that adopting the concept of urban symbiosis can be an effective approach to reducing water consumption and managing water resources in urban areas. For example, discovered that urban symbiosis-based strategies, such as water collection and reuse, can significantly reduce water use in residential building(Tian et al., 2017). Another study by Bao et al., (2019) looked at how urban symbiosis might help public places to reduce the consumption of water. The study discovered methods based on urban symbiosis, such as using recycled wastewater in daily works of the residential area. Furthermore, a recent review by Tian et al., (2017) highlighted the potential of urban symbiosis for water management in China.

An urban symbiosis is a promising approach for reducing water consumption and improving water management in urban areas(Byrne et al., 2020). One of the key benefits of urban symbiosis is its potential to create more efficient and sustainable water systems. For example, green infrastructure-based approaches, such as rain gardens and bioswales, can be used to capture and collect stormwater runoff, which can then be used for irrigation or other non-potable uses (Byrne et al., 2020). Another benefit of urban symbiosis is its potential to promote circular economies and reduce waste. For instance, industrial symbiosis-based approaches, such as the reuse of treated wastewater for industrial processes, can help reduce the demand for freshwater resources (Tian et al., 2017). In addition, urban symbiosis can also help reduce water pollution by promoting the use of more sustainable practices and technologies (Sun et al., 2017). Overall, these benefits highlight the potential of urban symbiosis to improve water management and reduce water-related challenges in urban areas.

Urban symbiosis has been used in a variety of countries to enhance water management and reduction. For example, the government of China has established a national urban symbiosis program to promote the exchange of resources, energy, and water among facilities (Tian et al., 2017). Participating organisations' water consumption and wastewater output have decreased as a result of the program (Li et al., 2021). Another example is Colombia, where a project to promote urban symbiosis has been implemented in public places to lessen wastewater generation and encourage the reuse of water resources (Park et al., 2018). Other countries that have implemented urban symbiosis projects for water reduction and management include South Korea, Japan, the United States, Brazil, South Africa and India (Neves et al., 2020)

Despite the potential benefits of urban symbiosis in water reduction and management, several barriers can hinder its implementation. One of the key issues is the lack of institutional and regulatory frameworks that support collaborative resource management and exchange (Andersson et al., 2019). Andersson et al., (2019) stated that because of this, it could be challenging for various urban actors to collaborate and gain access to the infrastructure and resources needed to create symbiotic partnerships. Uncertainty about urban symbiosis and its potential advantages is another barrier, which can make it challenging to involve stakeholders and build support for cooperation (Neves et al., 2020). The implementation of urban symbiosis might also be limited by financial and economic barriers because symbiotic relationships may be more expensive to establish and maintain than traditional water management strategies (Park et al., 2018). Finally, cultural and societal barriers can also play a role, since attitudes and ideas about ownership, competition, and privacy may limit collaboration and the sharing of resources (Andersson et al., 2019).

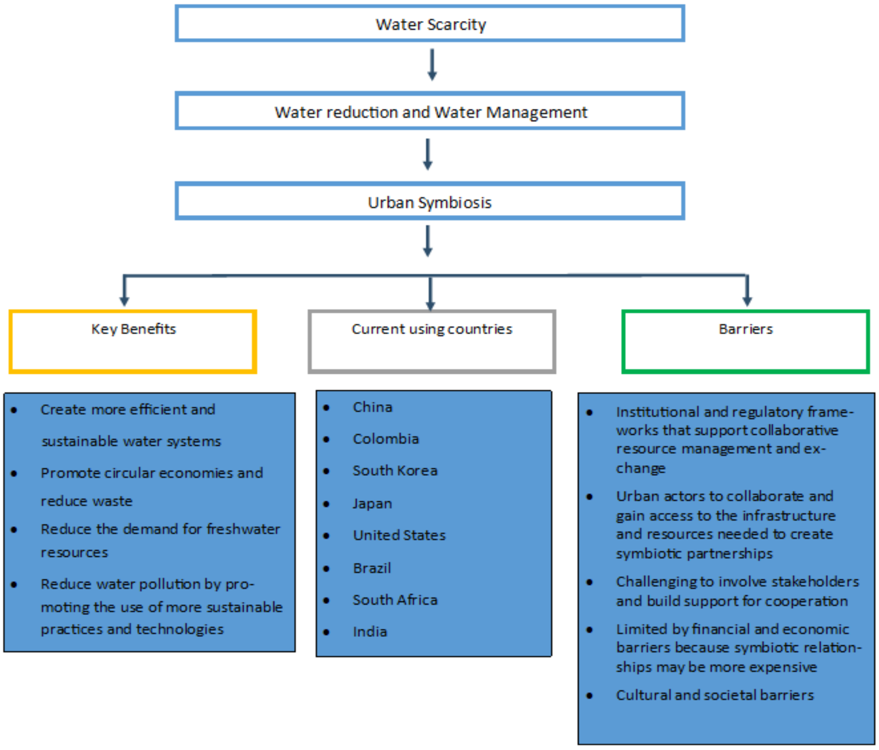

Figure 5: Summary of details for adopting urban symbiosis for water reduction and management

5. CONCLUSIONS

This study has conducted a systematic review of key literature published in the Scopus database between 2016 and 2023 to explore the feasibility of adopting urban symbiosis for sustainable urban water reduction and management. The bibliometric analysis outcomes contribute significantly to identifying the number of published journals, leading journal authors, and countries in the field of urban symbiosis. It is evident from the analysis that urban symbiosis is an evolving and growing area of study worldwide, with a particular focus on water reduction and management. Through the analysis of existing literature, several key findings have emerged regarding the implementation of urban symbiosis for water reduction and management. The identified benefits of adopting urban symbiosis include the creation of more efficient and sustainable water systems, the promotion of circular economies, waste reduction, and the reduction of freshwater resource demand and water pollution through sustainable practices and technologies. Countries such as China, Colombia, South Korea, Japan, the United States, Brazil, South Africa, and India have already implemented urban symbiosis projects for water reduction and management. However, certain barriers need to be addressed when implementing urban symbiosis. These include the lack of institutional and regulatory frameworks that support collaborative resource management and exchange, gaining access to the infrastructure and resources needed to create symbiotic partnerships, challenges to involve stakeholders and build support for cooperation, and financial and economic barriers because symbiotic relationships may be more expensive to establish and maintain than traditional water management strategies and attitudes and ideas about ownership, competition, and privacy may limit collaboration and the sharing of resources. In conclusion, this research provides valuable insights into the feasibility and potential of adopting urban symbiosis for sustainable urban water reduction and management. The study serves as a guide to identifying the benefits, barriers, and countries implementing urban symbiosis in the water sector. It is hoped that this work will contribute to the development of more effective strategies and approaches for sustainable water management in urban areas.

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ALTERNATIVE MATERIALS FOR SUSTAINABLE ROAD CONSTRUCTION IN SRI LANKA

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ABSTRACT

The current socioeconomic demand requires adequate engineering performance and environmentally friendly materials from the perspective of sustainable development. The scarcity of conventional natural resources and the severe environmental consequences of extraction have prompted research into alternative materials and resources for use in the road industry. Based on the findings of the existing studies, this research aims to explore the suitability of alternative materials for road construction projects towards sustainability in Sri Lanka. A quantitative research strategy was employed in the current study, and the questionnaire was distributed among 44 professionals involved in different types of road projects. The collected data were analysed by using Relative Important Index (RII). 84% of respondents considered alternative sustainable construction materials are highly suitable for the construction of road elements. Bituminous materials, natural soil, crushed rock and cement concrete are mostly commonly traditional materials. Construction and demolition waste (C&D), fly ash, plastic waste, and waste rubber tires were selected as the best materials for base construction, cement kiln dust waste, fly ash, glass waste, and waste rubber for sub-base and C&D waste and glass waste for sub-grade construction. Alternative sustainable materials can solve the waste disposal issue, scarcity of natural materials, and cost savings. Thus, this study presents a collective listing of the most viable alternative materials already in use by the global industry, with the goal of establishing a noble notion for better incorporation of alternative sustainable materials into road construction in Sri Lanka.

Keywords: *Alternative Sustainable Materials; Environmental Sustainability; Recycling; Road Construction; Waste Material.*

1. INTRODUCTION

The road is the legally permissible way for vehicles and other traffic to traverse. Roads include passageways, side drains, culverts, bridges and land needed for upcoming widening. Bamigboye et al. (2021) stated that the construction and maintenance of roads and other transportation amenities continue to be important factors in socio economic progress. Transport contributes 10% to 20% of the Gross Domestic Product (GDP) where road transportation represents between 3% to 5% of the GDP excluding the inputs of

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transport equipment of fuel, and infrastructure. Road infrastructure has benefited societies and economies in a variety of ways (Lee et al., 2019). Further, it improves accessibility in terms of transportation, education, goods, and services, and it can save travel time and costs.

Road construction is always evolving, notably in terms of road paving technology. It is highly reliant on government policies and scientific progress. Possible road pavement technology growth paths must be studied to provide robust information to decision-makers (Radziszewski et al., 2016). The continued growth of the global economy and level of life will almost certainly lead to an increase in raw material consumption worldwide. Over the past two decades, academics have researched how to use environmentally friendly alternative materials in road construction to combat this issue and promote conservation.

In the Sri Lankan context, several researches have been conducted to study different areas of road construction, such as causes for claims in road construction projects, risk management strategies, procurement methods frequently used in road construction projects, integration of sustainability concepts in road construction, and other areas. Modern technologies and new materials have great attention in construction projects to reduce cost and time and to improve the construction quality. Using currently available materials and technology, it is possible to significantly improve the substitution of virgin materials with recycled materials (Gómez-Meijide et al., 2015). Long durability periods are required in terms of social costs; such a solution is attainable (Lee et al., 2019). After a critical review of the existing literature, it is noticed that there is a knowledge gap on the suitability of alternative materials for sustainability in road construction projects in Sri Lanka. Therefore, this study aimed to analyse the alternative materials for sustainable in road construction in Sri Lanka.

2. LITERATURE REVIEW

2.1 OVERVIEW OF ROAD CONSTRUCTION

Sri Lanka has a well-connected 116,000-kilometer road network. Sri Lanka currently has 1.7 kilometres of roads per square kilometre, which is higher than its regional counterparts (Siyambalapitiya, 2018). In Sri Lanka, 753 numbers of class "A," "B," and "E" roads totalling 12,496.337 kilometres in length. The current roadway structure comprises a soil base, base, additional base layer, and coating layers (Halushko et al., 2020). The components of the road pavement structure include the base (broken stone aggregates), subsoil (natural soil compacting), the subgrade (disintegrated rocks like gravel, sand, and clay), and surfacing (bituminous material).

2.2 ALTERNATIVE MATERIALS FOR ROAD CONSTRUCTION

Pavements are broadly classified into two types: flexible pavements and rigid pavements. The classification is based on the structural performance of the materials used (Halushko et al., 2020). Flexible pavements are bituminous roads that have low flexural strength, whereas rigid pavements are concrete roads with great flexural strength. Other novel breakthroughs in changing the qualities of various sorts of pavements have resulted in categories such as pervious pavements, reflecting pavements, interlocking pavements, and composite pavements, among others (Nwakaire et al., 2020). Depending on the binding material, any of them can be classed as either flexible or stiff pavements. The quality of the pavement is directly and mostly determined by the quality of the materials used to construct it. The primary purpose of pavement structural design is to ensure that the pavement stays functional throughout its service life, and material selection is crucial both during the design and construction stages (Nwakaire et al., 2020).

Construction industry generates a larger proportion of solid waste, more attention is being devoted to Construction and demolition (C&D) waste management (Banihashemi et al., 2018). Recycled C&D as an alternative is an environmentally beneficial and sustainable solution to the C&D waste problem (Zhang et al., 2019). C&D waste includes ceramics, concrete, electrical wiring, bricks, tiles, timber, tar and bituminous products, glass, hazardous components plastic, asphalt, metals, soil and dredged soil, combined C&D, insulation materials, and gypsum-based materials (Ghosh et al., 2016). While it is anticipated that road construction activity will remain stable in the near future, the quantity of C&D is constantly rising (Zhang et al., 2019).

Kurpińska et al. (2019) estimated that glass waste account for 10% to 15% of global garbage production. Several strategies have been developed to reduce the environmental impact of glass waste, including using recycled crushed glass as an aggregate for asphalt concrete in the road and civil engineering projects. Plastic is a non-biodegradable polymer-based substance and is one of the most discarded materials on the planet (Rahman et al., 2020). 5 trillion plastic bags are used worldwide yearly, and 1 million plastic bottles are bought every minute. These plastic wastes are being disposed of at an increasing rate, which has negative effects such as visual pollution, flooding, and the extinction of sea life, and it has been found that plastic waste has the potential to be used as a secondary aggregate (Maharaj et al., 2019).

Discarded rubber tires, also known as end-of-life tires or styrene-butadiene-styrene, are non-biodegradable materials and are designed to withstand harsh climatic conditions (Sugiyanto, 2017). Rubber tires have exceptional resistance to acid and water resistance, have a high impact resistance, plastic energy absorption, and provide thermal insulation (Saberian & Li, 2019). End-of-life tyres have been a major issue in a number of countries over the years (Sugiyanto, 2017). The use of waste rubber as a construction material is seen as a viable alternative to waste rubber disposal (Fernandes et al., 2019). Further, the waste rubber is used in embankment construction, aggregate substitution, asphalt modifier, retaining walls, drainage, backfills, and thermal insulation.

Coconut shells and fibres have recently been used in the asphalt paving industry. Ting et al. (2017) investigated the impact of an asphalt mix with coconut shells instead of aggregates. A stone mastic asphalt mix was developed in Brazil using coconut, sisal, cellulose, and polyester fibres (Agunsoye et al., 2014). Cement kiln dust is collected as a waste product of cement manufacturing activities (Seo et al., 2019). Cement kiln dust comprises high-alkaline fine-particulate solids that look like Portland cement and used as an alternative material for cement concrete for road surfaces and building constructions. The cement kiln dust and flyash mix as a binder in stabilising C&D waste aggregates for road construction (Arulrajah et al., 2017). The majority of ceramic waste is generated during building interior construction. These wastes are disposed of in landfills as part of waste management. Recycling this widely generated heavy waste can relieve burden on landfills (Muniandy et al., 2018).

Massive amounts of waste are generated by quarries all over the world. Quarry aggregates have properties and appearances similar to ordinary aggregates (Rahman et al., 2020).

They can be used to construct asphalt pavement for low to medium-traffic situations. Because traditional granite and basalt aggregates are expensive, many countries rely on quarry waste imports for road construction. Mining waste aggregates replaced up to 50% of traditional basalt aggregates in asphalt mix samples (Akbulut & Gurer, 2007). Bio oils, which are derived from biomass adaptation, are a sustainable source of energy that can be used as a modifier in the production of bio asphalt (Raman et al., 2015). Zhang et al. (2019) also investigated the effectiveness of sawdust bio-oil as a rejuvenator for aged asphalt binders. Raman et al. (2015) discovered that bio-asphalts outperform traditional asphalt. Modifiers and substitute aggregates can give leftover materials a second chance at life while assisting in reducing the consumption of natural aggregates (Rahman et al., 2020). The long-term sustainability of the material's environmental impact over of its life cycle is ensured by using alternative binder materials.

2.3 ECONOMIC AND ENVIRONMENTAL ASPECTS

Materials typically account for more than 40% of the total cost of a construction project. Better material management can result in a small reduction in material costs, which can significantly impact the overall project cost (Rahman et al., 2020). According to professionals, using novel materials during the construction of road surfaces and subsequent operations becomes economically viable. Several road pavement life cycle assessment studies have been conducted in recent years (Bamigboye et al., 2021). Modern pavements should be built with materials that reduce traffic noise and improve water drainage (Freitas et al., 2012). Using currently available materials and technology, it is possible to achieve significant improvements in substituting virgin materials with alternative materials (Gomez-Meijide et al., 2015). Both economic and environmental factors influence the growing demand for alternative environmentally friendly materials in asphalt concrete pavements. Therefore, this study focuses on comparative analysis between traditional and alternative materials towards sustainability in road construction project

3. RESEARCH METHODOLOGY

The quantitative questionnaire analysis is a common research method that can provide valuable insights into the attitudes, perceptions, and preferences of individuals. It can be useful to quantify the frequency of specific phenomena or behaviours and to identify patterns or trends (Borrego et al., 2009). It enables researchers to collect quantitative data, which is useful for quantifying the incidence of specific phenomena or behaviours and identifying trends or patterns. Moreover, Zheng et al. (2019) highlight the significance of questionnaire analysis in determining the suitability of alternative sustainable materials for construction. The authors note that questionnaires allow researchers to collect data on the reasons why certain materials are preferred or not preferred as sustainable alternatives, thereby gaining valuable insights for decision-making in road construction projects. In addition, it is emphasised the importance of using questionnaires to collect information on construction materials and sustainability. By quantifying preferences and evaluating various factors such as durability, cost-effectiveness, and environmental impact, questionnaire analysis can help identify the most optimal alternative material for road elements, according to the researchers. Through this method, researchers are able to compare conventional construction materials with sustainable alternatives, allowing for a thorough analysis of their respective benefits and drawbacks.

The sample size for this research study was determined to be 44 due to time constraints. A 4-point Likert scale is used to grade the suitability of alternative sustainable construction materials for various road elements, and a 5-point Likert scale is used to grade the most suitable alternative sustainable material for road elements and to compare it to traditional construction materials. Table 1 and Table 2 present the 4-point and 5-point Likert scales respectively.

Table 2: Four-point Likert scale

Excellent	Good	Average	Poor
1	2	3	4

Table 1: Five-point Likert scale

Very much suitable	Suitable	Neural	Bad	Very Bad
5	4	3	2	1

The Relative Important Index (RII) is a statistical method used to calculate the relative importance of each material and to accurately rank accordingly. On the other hand, MWR technique provides a decision on significance of parameter with related to the received mean values. The following equation (Eq.: 1) is used to determine RII:

$$\boldsymbol{RII = \frac{\sum w}{A \times N}} \qquad \text{..... } Eq. (1)$$

Where: w = Weighting given to each factor; A = Highest weight; N = Total respondents

Importance level is categorised considering RII levels, as shown in Table 3.

Table 3: Recommended ranges for Relative Importance Index (RII)

RII values	**Importance level**
0.8 ≤ RII ≤ 1	High
0.6 ≤ RII ≤ 0.8	High - medium
0.4 ≤ RII ≤ 0.6	Medium
0.2 ≤ RII ≤ 0.4	Medium - low

Source: (Akadiri, 2011)

The collected data were analysed using RII. The obtained results were presented graphically in the form of pie charts, percentage-subdivided bar diagrams, and tables.

4. RESEARCH FINDINGS AND ANALYSIS

The questionnaires were distributed to 50 professionals in the road construction industry. Most professionals had hands-on experience and a comprehensive understanding of sustainable alternative materials. Following the exclusion of incomplete questionnaires, 44 responses were deemed suitable for analysis, resulting in an 88% response rate. The questionnaire mainly analysed the suitable alternative materials for different road elements compared to traditional materials.

4.1 RESPONDENT PROFILES

The questionnaire was distributed among 44 selected civil engineers, quantity surveyors, project managers, design engineers, quality assurance managers, engineering assistants, and technical officer in order to cover different aspects of alternative materials perspectives of different construction professionals. Among selected respondents, 14% have more than 20 years of experience, while 25% have 10 to 20 years. Further, the selected professionals also had experience in different types of road projects, including asphalt roads, and concrete roads. gravel road, highways and Double bituminous surface treatment (DBST) pavement. Table 4 provides the respondent's profiles.

Table 4: Respondent's Profile

Designation	Number of Respondents	Level of Experience	Number of Respondents	Road Type	Number of Respondents
Civil Engineers	15	1-5	17	Asphalt road	19
Quantity Surveyor	14	5-10	10	Concrete road	13
Project Managers	10	10-20	11	Gravel road	6
Other	5	More than 20 years	6	Highway	5
				DBST pavement	1

According to Table 4, the majority of the workers have worked in asphalt and concrete road construction. 19 worked asphalt road construction, while 13 worked in concrete road construction. 6 and 5 of the respondents worked in gravel road and highway construction, respectively. Only 1 respondent had worked on DBST road construction projects.

4.2 TRADITIONAL MATERIALS USED IN ROAD CONSTRUCTION

Initially, the questionnaire focused on capturing the traditional materials used in Sri Lankan road construction apart from the literature findings based on their experience. Figure 1 presents traditional materials used in the road construction industry.

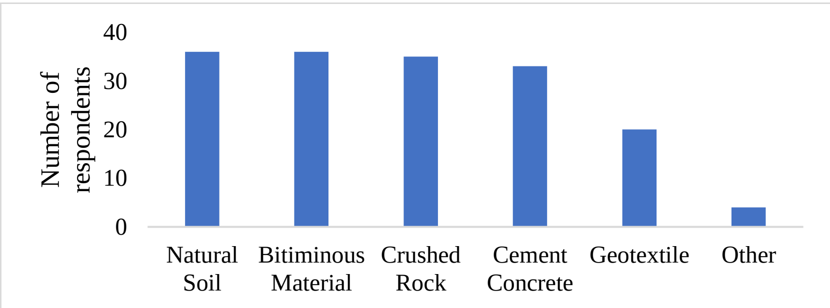

Figure 1: Traditional materials used in the road construction industry.

Figure 1 shows that the industry made extensive use of natural soil, bituminous materials, crushed rock, and cement concrete. Twenty respondents stated that geotextile is a traditional material. Further, respondents added precast concrete, porfido and limestone as other traditional materials for road construction. Out of 44 respondents, 84% of professionals are aware of alternative sustainable materials. Respondents were further inquired about, using sustainable alternative materials for road construction under in Sri

Lankan context to rate as excellent, good, average and poor. 50% of respondents graded the suitability of alternative sustainable construction material as excellent, while 34% graded it as good, yielding 84% of positive responses.

4.3 ALTERNATIVE MATERIALS USED IN ROAD CONSTRUCTION

The applicability of alternative materials identified from the literature to different road elements, including subgrade, subbase, base, surfacing and shoulders, were inquired. This suggests suitable materials for road elements. Figure 2 provides C&D wastes, glass wastes, plastic wastes, waste rubber tires and coconut, sisal, cellulose, and polyestor fiber as alternative sustainable materials in different road construction elements.

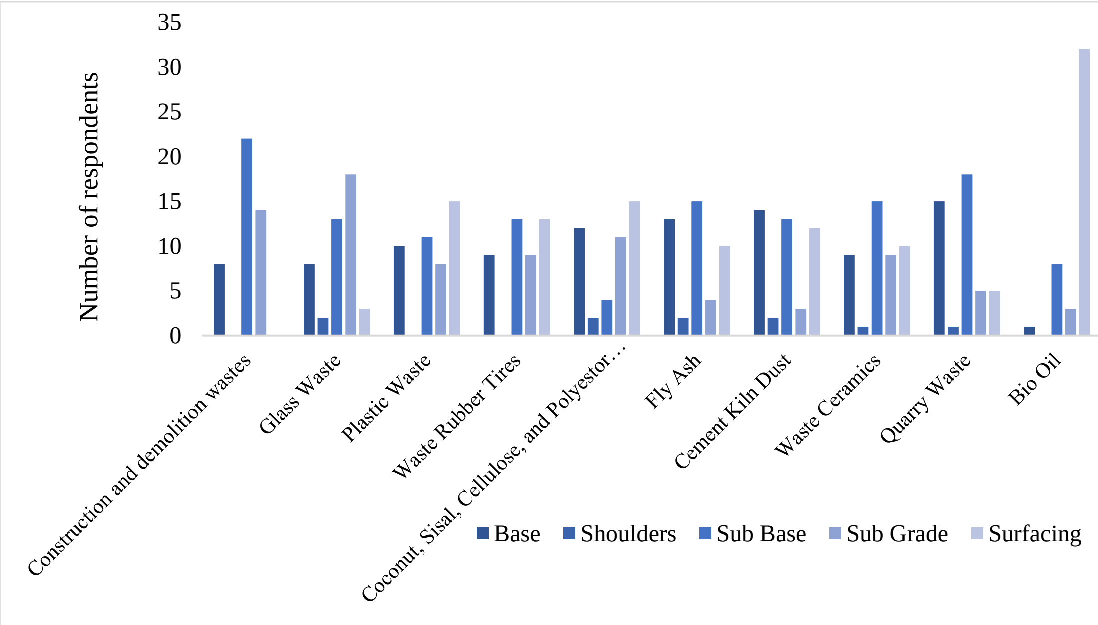

Figure 2: Utilisation of alternative sustainable material

According to Figure 2, 22 respondents stated that C&D wastes could be primarily used as an alternative sustainable material in the sub-base and a significant percentage for subgrade. Most glass waste is used in the subgrade and sub-base. Glass waste can be used moderately as an alternative material in the base. Still, only a few respondents agreed on using glass waste for shoulders and surfacing. Except for shoulder construction, plastic waste and waste rubber tires are commonly used in different road parts. Coconut, sisal, cellulose, and polyestor fiber are utilised mainly in surfacing, base and sub-grade and least in sub-base and shoulders. Fly ash and cement kiln dust can be used moderately for sub-base, base, surfacing, and least in sub-grade and shoulders. Like fly ash and cement kiln dust, waste ceramics and quarry waste are moderately used in sub-base, base and surfacing and least in shoulders. However, compared to fly ash and cement kilns, waste ceramics and quarry waste are preferred for sub-base. Bio oils were primarily used for surfacing, and a few number of professionals marked for sub-grade, Sub-base and base. Compared to all the materials, bio-oil is the least used as an alternative material for different parts of road construction.

4.4 SUITABILITY OF ALTERNATIVE SUSTAINABLE MATERIALS

There are numerous reasons why alternative sustainable materials are preferred, including as a solution to the waste disposal issue and scarcity of natural materials, as a means of cost saving, due to the material properties and performance, durability, and time reduction. On the other hand, it is not preferred due to lack of knowledge on alternative sustainable materials, lack of support for innovators and researchers, apprehensive about taking the risk and lack of government intervention. Respondents were asked to Table 5 summarises the results based on data collected from the respondents.

Table 5: Reasons for suitability of sustainable alternative materials

Reasons	**Responses**		**% of response**		**RII**	**Importance Level**	**Overall Rank**
	Agreed	**Not Agreed**	**Agreed**	**Not Agreed**			
Suitability of alternative sustainable materials							
Solution for the waste disposal issue	43	1	98%	2%	0.9818	High	1
Solution for the scarcity of natural materials	42	2	95%	5%	0.9636	High	2
Cost saving	39	5	89%	11%	0.9090	High	3
Material properties and performance	30	14	68%	32%	0.7454	High- medium	4
Durability	26	18	59%	41%	0.6727	High- medium	5
Time reduction	25	19	57%	43%	0.6545	High- medium	6
Non-suitability of alternative sustainable materials							
Lack of knowledge	38	6	86%	14%	0.8909	High	1
Lack of support for innovators and researchers	36	8	82%	18%	0.8545	High	2
Apprehensive about taking the risk	35	9	80%	20%	0.8363	High	3
Lack of government intervention	34	10	77%	23%	0.8181	High	4

The primary justification for using alternative construction materials was that it was a solution to the waste disposal issue and a solution to the scarcity of natural materials, as demonstrated by the RII value of 0.9818 and 0.9636 respectively, indicating a high importance level. Alternative sustainable materials were considered suitable with a high-medium important level of suitability due to cost savings, material properties and performance, durability, and time reduction. Lack of knowledge, lack of support for researchers and innovators, apprehensive about taking the risk and lack of government intervention were demonstrated by RII values greater than 0.8 and were prioritised as highly important reasons for the non - suitability of alternative sustainable materials.

4.5 MOST SUITABLE ALTERNATIVE MATERIAL FOR ROAD ELEMENTS

The respondents were inquired regarding the suitability of available sustainable alternative materials for road components such as base, sub-base, asphalt surfacing, sub-grade and interlocking. Table 6 lists the most suitable alternative material for road elements.

Table 6: Most suitable alternative material for road elements

Element	Alternative Material	RII	Rank
Base	C&D wastes	0.7590	1
	Fly ash	0.7590	1
	Plastic waste	0.7454	2
	Waste rubber tires	0.7318	3
Sub-base	C&D wastes	0.7818	1
	Fly ash	0.7590	2
	Cement kiln dust	0.7590	2
	Waste rubber tires	0.7409	3
Sub-grade	Plastic waste	0.7136	1
Surfacing	Plastic waste	0.7727	1
	Coconut, sisal, cellulose, and polyester fibers	0.7045	2
	Bio-oil	0.7000	3
	Waste Ceramic	0.6863	4
	Quarry waste	0.6681	5
Interlocking	Cement kiln dust	0.7909	1

According to the WMR and RII values, the most suitable alternative sustainable material for the base are C&D waste and fly ash. Following that, plastic waste and waste rubber tyres are ranked. C&D waste is the best sustainable alternative material for the sub-base. After that, fly ash, cement kiln dust, and waste rubber tyres were ranked. Only plastic waste is used as an alternative material for subgrade. Numerous substitute products, including plastic waste, quarry waste, bio-oil, waste ceramic, coconut, sisal, cellulose, and polyester fibres, were listed under the asphalt surfacing materials. Considering RII values, comparatively, all the alternative sustainable materials were assigned a high-medium importance level for different road construction elements.

4.6 COMPARATIVE ANALYSIS BETWEEN TRADITIONAL AND ALTERNATIVE SUSTAINABLE CONSTRUCTION MATERIAL

Compared to traditional construction materials, many alternative sustainable materials are available for different road elements. Table 7 discusses the applicability of traditional construction materials and alternative sustainable materials for the construction of different road elements using MWR and RII.

Table 7: Comparison of traditional construction materials and alternative sustainable materials

Element	Traditional Materials	RII	Rank	Alternative Materials	RII	Rank
Base	Crushed rock	0.7670	1	C&D *waste*	0.7790	1
	Gravel	0.6988	2	*Fly ash*	0.7386	2
				Plastic waste	0.7159	3
Sub Base	Aggregate	0.7954	1	*Cement kiln dust waste*	0.7329	1
	Granular soil	0.7784	2	*Fly ash*	0.7272	2
	Boulders	0.7556	3	*Glass waste*	0.6931	3

Element	Traditional Materials	RII	Rank	Alternative Materials	RII	Rank
	Stabilised soil	0.7386	4	*Waste rubbertires*	0.6802	4
Sub Grade	Gravel	0.8238	1	C& D waste	0.7215	1
	Crushed rock	0.7613	2	Glass waste	0.6988	2
	Crushed concrete	0.7386	3			
	Sand	0.6306	4			
Surfacing	Asphalt concrete	0.8352	1	*Plastic waste*	0.7272	1
	Concrete	0.8068	2	*Bio-oil*	0.7159	2
	Plastic waste	0.7272	1	*Waste rubber tires*	0.7151	3
	Bio-oil	0.7159	2	*Coconut shell*	0.6534	4
	Waste rubber tires	0.7151	3	*Glass waste*	0.6306	5

According to Table 9, crushed rock and gravel were significant traditional building materials for base construction, while C&D waste, fly ash, and plastic waste were significant sustainable alternatives. Compared to crushed rock, C&D waste are considered more important. Similarly, fly ash and plastic waste are considered more important in base construction than gravel. Aggregate, granular soil, boulders, and stabilised soil were more crucial traditional building materials for sub-base construction than alternate sustainable materials. Gravel, crushed rock, and crushed concrete were more crucial traditional building materials for sub-grade construction, whereas C&D waste is a more crucial sustainable alternative material. Comparatively least importance is given to sand and glass waste for sub-grade construction. Regarding surfacing construction, asphalt concrete and concrete were prioritised over alternative sustainable materials such as plastic waste, bio-oil, baste rubber tyres, coconut shell, and glass waste.

5. DISCUSSIONS

The continued growth of the global economy and level of life will almost certainly lead to an increase in raw material consumption worldwide. Modern technologies and new materials have great attention in construction projects to reduce cost and time and to improve construction quality. Using currently available materials and technology, it is possible to significantly improve the substitution of virgin materials with recycled materials. The research has utilised a questionnaire analysis survey mainly based on Engineers, Quantity surveyors and Project Managers providing information on technical and cost-related aspects of the alternative materials further, professionals were considered based on different types of pavements.

The industry highly utilises traditional materials including natural soil, bituminous materials, crushed rock, and cement concrete. 84% of respondents graded the suitability of alternative sustainable construction materials as good. C&D wastes, especially glass, can be used in sub-base and sub-grade. Rubber and plastic tyres are used in road parts. Coconut, sisal, cellulose, and polyestor fibres are used in surfacing, base, and subgrade, with fly ash and cement kiln dust moderately used in shoulders and sub-base. Waste ceramics and quarry waste are moderately used in sub-base, base, and surfacing, but they are preferred for sub-base. Bio oils are mostly used for surfacing, with bio-oil being the least used. C&D waste, fly ash, plastic waste and waste rubber tires are best for the base of the road and plastic waste, bio-oil, waste rubber tires, coconut shells and glass waste, are best for road surfacing. Crushed rock and gravel for the base construction, building and demolition waste, fly ash, and plastic waste are some other sustainable resources for road elements. In the base construction, trash from buildings and demolition is more significant than gravel. For sub-base construction, aggregate, granular soil, boulders, and stabilised soil are particularly important. Concrete and asphalt are preferable for surface construction over substitutes, including plastic, bio-oil, rubber tyres, coconut shells, and glass scrap.

6. CONCLUSIONS AND RECOMMENDATIONS

This study investigates the sustainability of alternative materials for road construction initiatives in Sri Lanka. According to a quantitative survey of 44 professionals, 84% of respondents evaluated alternative sustainable construction materials for road elements. The preferable construction materials were bituminous materials, natural soil, pulverised gravel, and cement concrete. Alternative sustainable materials offer solutions for waste disposal, natural resource scarcity, and cost reductions. This study aims to develop a principle for the improved incorporation of sustainable materials in road construction in Sri Lanka. According to WMR and RII values, fly ash, scrap rubber tyres, and building and demolition debris are the most appropriate sustainable resources for the basis. The greatest environmentally friendly option for the sub-base is C&D debris, which is followed by fly ash, cement kiln dust, and used rubber tyres. For road building components, alternative sustainable materials are given a high-medium relevance rating. Alternative sustainable materials are preferable for many reasons. These include a solution to the waste disposal problem and the depletion of natural resources, a method to reduce costs due to the material's qualities and performance, durability, and labour savings, and a solution to the problem of waste disposal and the depletion of natural resources. On the other side, it is not favoured because people do not comprehend alternative sustainable materials, there is little support for researchers and inventors, people are afraid to take chances, and there is no government action. With a high level of significance, alternative construction materials were predominantly utilised for waste disposal and natural material scarcity. Due to cost savings, material properties, efficacy, durability, and time savings, they were deemed suitable. However, a lack of knowledge, support, risk aversion, and government intervention were cited as major reasons for their unsuitability.

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AN EXPLORATORY STUDY ON ABANDONED CONSTRUCTION PROJECTS IN THE WESTERN PROVINCE, SRI LANKA

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ABSTRACT

The construction industry creates a considerable impact on the country's economy. The current economic crisis has severely affected the Sri Lankan construction industry whereby also affecting the entire construction supply chain. Researchers have mentioned that a project abandonment has an overall negative impact on both economy of the country and the construction industry. Thus, this research paper aims to explore the reasons for the abandonment of construction projects during the current economic crisis in Sri Lanka and identify the remedies to avoid in the future. A comprehensive literature review, a questionnaire survey, and semi-structured interviews were conducted to gather data in both qualitative and quantitative procedures. Semi-structured preliminary interviews were conducted to gather preliminary data before developing the final questionnaire. The empirical findings revealed that the material import restrictions imposed by the government, price increments in materials due to restrictions, disruptions in machinery operations due to scarcity of fuel, rising labour costs, and shutdowns in government-funded projects are the main reasons for the projects to be abandoned during the economic crisis. Encouraging foreign investments, controlling inflation and keeping on track of the country's economy, easing tight import restrictions, and proper pricing mechanisms for construction materials are some of the remedies proposed to avoid projects being abandoned during the crisis. The research findings deliver valuable evidence to the practitioners with an in-depth understanding of the remedies to take over during a period of a crisis and thereby minimize the projects being abandoned.

Keywords: *Abandoned Construction Projects; Economic Crises; Sri Lanka; Western Province.*

1. INTRODUCTION

Through the first quarter of 2018, the economic growth of many countries in the world was improving. However, with the spread of the COVID-19 pandemic, global economic growth was decelerated. Mainly the supply and demand imbalances can be categorized as economic impacts of COVID-19. By the middle of 2021, the world economy was recovering with the relaxation of restrictions imposed for COVID-19. Also, many countries controlled rising inflation and accelerated efforts to stimulate growth at the beginning of 2022. But the Russia-Ukraine crisis escalated while the countries were

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accelerating efforts to achieve economic growth after the COVID pandemic, and in February 2022, Russia invaded Ukraine. The war also led to a political crisis between Russia and the Western nations. In addition to the rising cost of living and other economic factors, this war had a significant impact on the world economy in the number of sectors, including the international supply chain, international stock markets, oil and gas prices, the international banking system, and international inflation (Balbaa et al., 2022). The COVID-19 pandemic and the current global financial crisis have had a major impact on the Sri Lankan economy as well. The Sri Lankan economy suffered a rapid collapse during the last five years due to various reasons. Sri Lanka decided not to strive to increase its overseas commerce after the end of its civil war in 2009, instead concentrating on supplying its domestic market. Perera (2022) has stated that the country has run out of foreign currency reserves owing to numerous reasons and it currently imports USD 3 billion, which is more than its exports. In 2019, the government implemented significant tax cuts, which caused a loss of more than USD 1.4 billion in yearly revenue. In early 2021, due to foreign currency shortages, the government of Sri Lanka (GOSL) attempted to limit them by outlawing the import of chemical fertilizers. As a result, many domestic crops were destroyed and as a result severe food shortage is evident now. The need to import essential food items and medical stocks was another reason for aggravating the foreign currency shortage. Due to daily power cuts and lack of necessities like fuel, food, and medicine, citizens are in a dire state during mid-2022. Also, essential services such as transport were disrupted, and many supply chain bottlenecks were evident due to the fuel crisis. The fuel shortage has led to price hikes of fuel and daily essentials which ended up with island-wide protests against the ruling party. For the first time in history, the GOSL failed to service its external debt in May 2022 and declared bankruptcy (Perera, 2022).

The construction industry creates a huge impact on the country's economy. In both developed and developing countries, the construction industry contributes a vital share to the process of development (Agung, 2011). Due to the current economic crisis in Sri Lanka, the construction industry has been severely affected. Despite the economic crisis in Sri Lanka commenced three years ago; living conditions of the island nation have significantly worsened today than before. Inflation, which is the barometer of the general price level increase in the overall economy has escalated unprecedently throughout the crisis period. The Colombo Consumer Price Index (CCPI), which measures headline inflation, increased from 29.8 % in April 2022, 60.8% in July 2022, and 66.0 % in October 2022 to reach 50.6% in February 2023 (Department of Census and Statistics, 2022). Further, the prices of construction materials were also increased drastically. According to the National Construction Association (NCA) of Sri Lanka around 75% of construction projects have been put on hold as a result of rising building material prices and fuel costs (Nilar, 2022). Shortage of energy has a negative impact on the construction industry while the construction supply chain was entirely disturbed due to untimely changes in policy directions such as import restrictions on construction materials. According to Razeek (2022), the construction industry employs, nearly 1 million of the workforce, including 600,000 of direct positions in the industry. Due to the economic crisis, the local construction industry dealt with thousands of job losses and a severely falling number of new construction projects (Razeek, 2022).

The stakeholder is one who involves directly or indirectly in the project. Out of the stakeholders, The Client and the Contractor facing many issues in their projects due to the economic crisis. Due to COVID-19 pandemic and the present economic crisis, many contractors found it difficult when proceeding the construction because of import restrictions, high inflation, foreign exchange crisis, foreign debt, construction labour cost, and transportation issues. The investors are not willing to invest in the projects given this situation which becomes a huge issue for the contractors and clients (Namarathna, & Gunarathna, 2022). Moreover, the authors have mentioned that almost all the industry stakeholders were impacted due to the crisis at varying capacities in Sri Lanka. Therefore, many contractors failed to proceed with the ongoing construction projects and were compelled to abandon their projects.

Project abandonment could occur at any stage of its life cycle. Projects could be abandoned at the tender stage, at the design stage, at the construction stage, and midway through the project. Not only the building construction projects but also the infrastructure related (including roads, bridges, factories, dams, power, and communication) projects can be abandoned (Doraisamy et al., 2015). According to Yap et al. (2010), common causes such as financial challenges faced by the owner and contractor, unexpectedly poor economic conditions, improper project financing, delays in interim payments, insufficient project feasibility studies, unreliable contractors or subcontractors, project control issues, improper project planning and scheduling, and administration issues will bring a project to the abandoned stage. Time and cost are very important parameters in the construction industry. Duma (2017) mentioned that projects being abandoned would present significant difficulties for the clients, the contractors, and the country's economy since the project has been initiated, involved a number of stakeholders and they consumed a considerable amount of time to elevate the project to the construction stage.

The construction industry is now experiencing a wide range of issues as a result of the present economic climate, many of which can only be resolved by state-level action. Increasing material costs, payment delays, terminating government projects, difficulties importing commodities, and increased interest rates are the main problems the sector is now experiencing (Soyza, 2022). Current projects cannot be completed because of the high rise in the cost of construction materials due to the rising dollar rate and inflation rates. Some suppliers are also taking advantage of this circumstance by raising their margins. The majority of State-Owned Enterprises (SOEs) are not adhering to the 20% price increase that the cabinet also permitted. Table 1 illustrates the building materials price increases during last three years (Wijeratne, 2022).

Table 1: Price changes of five basic building materials (in Rs.)

Material	Dec 2020	Dec 2021	April 2022	% Increase
Cement (50kg bag)	850.00	1275.00	2,175.00	155.9
Tor Steel (M Ton)	165,000.00	25,000.00	595,000.00	260.6
Structural Steel (M Ton)	170,000.00	330,000.00	750,000.00	341.2
0.47mm Zn Al roof sheet (m)	1,522.00	2,802.05	4,500.00	195.7
Asbestos roof sheet (m)	846.55	1,127.50	1,711.65	102.2

By reviewing the above literature findings, it assists to identify the gap within the research, where there are no any research articles which address to propose remedies to avoid projects being abandoned during the period of the economic crisis. Therefore, the aim of this study is to explore the reasons for the abandonment of construction projects in Sri Lanka during the current economic crisis and identify the remedies to avoid this in the future. Therefore, the objectives of the study are split to identify the impact of the current economic crisis on the construction industry in Sri Lanka, to identify the problems faced by the contractors and clients due to the current economic crisis in Sri Lanka, to explore the reasons for the abandonment of those construction projects and to propose remedies to minimize abandonment of construction projects in future.

2. METHODOLOGY

The study has adopted the mixed method research approach, the essence of which, Harvard Catalyst (2023) combines both deductive and inductive thinking and facilitates a more comprehensive understanding of the interviews' opinions and to rate the remedies for the future to avoid projects being abandoned. Semi-structured preliminary interviews were conducted as a basis to develop the questionnaire survey with the industry practitioners who are in and familiar with the abandoned projects. The study follows the purposive sampling technique. The developed questionnaire included both the Likert scale and open-ended questions to collect both qualitative and quantitative data. The questionnaire survey was conducted through physical meetings among the construction industry practitioners who are currently working on abandoned construction projects or who are familiar with construction projects that have been abandoned in the recent past due to current economic crisis. Hence the study covered both the small scale and large-scale construction projects which are in abandoned state at present. A total of 30 construction industry experts including Engineers, Quantity Surveyors, Project Managers, Architects, and Construction Company Owners participated in the survey. Qualitative data gathered were analysed through the thematic analysis method while the quantitative data were analysed through the descriptive statistical analysis and use graphs/ charts to demonstrate quantitative summary statistics and used the weighted mean. Thematic analysis is a popular method for evaluating qualitative data on unexplained phenomena (Creswell & Poth, 2018; Maguire & Delahunt, 2017). It is a technique for defining and analysing data based on themes and relative frequency. It is also a platform for organizing and analysing data in order to come up with clear conclusions and outcomes (Vaismoradi et al., 2013). Accordingly, thematic content analysis was performed under six main themes.

Table 2 presents the profile of the respondents of the questionnaire survey on the abandoned construction projects that were considered with the intention of collecting more accurate data for the research study.

Table 2: Profile of the respondents

Designations	Response rate (%)
Quantity Surveyors	54%
Engineers	27%
Project Managers	13%
Architects	1%
Company Owners	1%

3. DATA ANALYSIS AND DISCUSSION

3.1 EFFECTS OF THE CURRENT ECONOMIC CRISIS ON CONSTRUCTION PROJECTS/ORGANIZATIONS

The study findings show that the survey respondents strongly agreed that the current economic crisis has highly affected the Sri Lankan construction industry. As shown in Figure 1 76.7% of survey respondents strongly agreed with the statement. Further, 20% of the survey respondents moderately agreed with the statement.

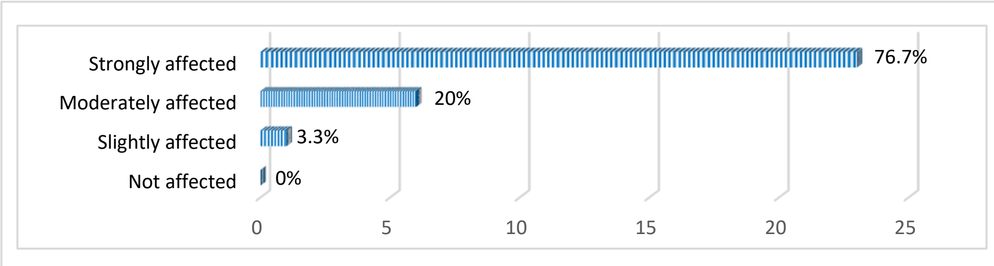

Figure 1:Effect of the current economic crisis on the construction projects

3.2 COMPARISON BETWEEN THE NUMBER OF PROJECTS HANDLED BY THE ORGANIZATIONS BEFORE THE CRISIS AND DURING THE CRISIS

As illustrated in Figure 2, before the economic crisis in Sri Lanka, there were 2 number of contracting organizations handled more than 30 projects annually. Similarly, 7 number of contracting organizations handled 20–30 projects annually while, 11 contracting organizations handled 10–20 projects, and 10 organizations handled 0–10 projects annually. Because of the current economic crisis, all these organizations currently handle 0–10 projects annually. None of the contracting organizations handle more than 10 projects during the economic crisis. This proves the magnitude of the impact of the current economic crisis towards the construction industry in Sri Lanka, where there are very limited number of construction projects progress today.

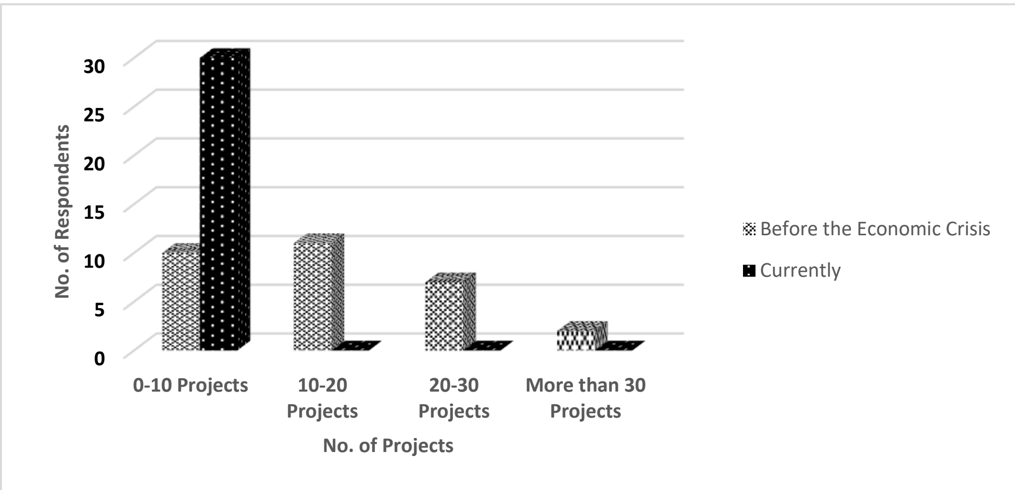

Figure 2: Status of the no. of projects carried out by the organizations annually before and after the the crisis

3.3 ISSUES FACED BY THE CONSTRUCTION ORGANIZATIONS DURING THE ECONOMIC CRISIS

Each survey respondent has mentioned that their organizations are handling projects with issues during the economic crisis. Figure 3 illustrates the number of such projects with issues handled by the construction organizations at present.

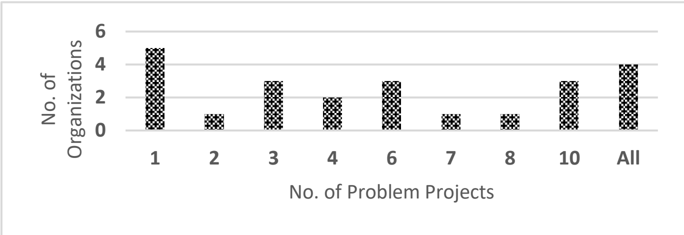

Figure 3: Number of projects with issues handled by organizations

During elaborative discussions, one of the QS has stated that "organizations are facing difficulties in paying staff salaries, labour wages since the organizations are not making profits from the projects". Many professionals have stated that "the rising cost of raw materials and shortage in fuel were the main issues they are facing during the period of economic crisis". Table 3 shows the exact issues that the respondents have faced due to the current economic crisis.

Table 3: Issues faced by the organizations - in terms of handling construction projects

Issues	Response rate (%)
Slowdown of construction projects	93.3%
Lack of work / projects not progressing (projects in different stages)	53.3%
Disruptions to the functioning of construction sites	46.7%
Complete shutdown in government funded projects	40.0%
Only execute foreign funded projects	10%
Other	10%

The highest response rate of 93.3% has indicated that the slowdown of construction projects was the exact issue faced by many contractor and client organizations. Most of the contractors and clients were not able to speed up the execution of the project activities.

Further, Table 4 presents the common issues faced by the contracting organizations and the construction projects during the economic crisis.

Table 4: Common issues faced by the contractor organizations/projects during the economic crisis

Issues	Response rate (%)
Increasing material prices due to the import restrictions	90.0%
Disruptions in machinery operations due to scarcity of fuel	83.3%
Slow down the project progress	80.0%
Barring the machinery idling cost due to the shortage of fuel	73.3%
Material import restrictions imposed by the government	53.3%

Issues	Response rate (%)
Disruptions to project activity workflow due to transport difficulties faced by the site staff	46.7%
Maintenance cost for unused machineries, plant and equipment	43.3%
Complete shutdown in government funded projects	30.0%
Other	10.0%

As per table 4, increasing material prices due to import restrictions has shown the highest response rate of 90%. Many construction projects that import materials face this issue as contractors couldn't open letters of credit for the respective projects. At the same time, 10% of the response rate shows various other issues faced by the respondents. One of the quantity surveyors has stated that "*increasing the financial cost of the project created difficulties for the employer in funding the project and also the contractor face difficulty in managing the project cash flow*". Also, an engineer in one of the abandoned projects has stated that "*both the employer and the contractor organizations could not get any bank loans due to the economic crisis*".

3.4 REASONS FOR CONSTRUCTION PROJECTS BEING ABANDONED DURING THE ECONOMIC CRISIS

Figure 4 shows the reasons for the overall construction industry perspectives on the construction projects being abandonment during the economic crisis.

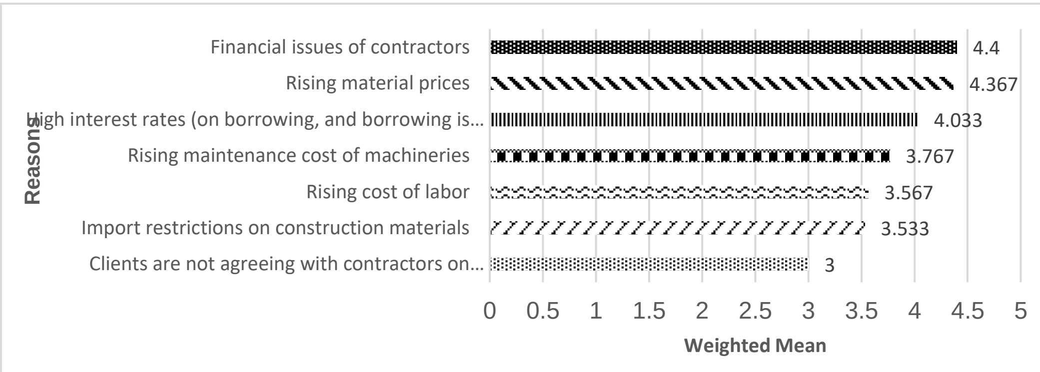

Figure 4: Reasons for construction projects being abandonment during the economic crisis

$$\textit{Weighted mean} = \frac{\sum_{i=0}^{n} \omega i.Xi}{\sum_{i=0}^{n} \omega i} \qquad (01)$$

where, ω = frequency of responses and X = rating of each reason.

The reasons were ranked and shown graphically based on the weighted mean. and all the reasons have weighted mean value between 3.00 and 5.00. Table 5 illustrates the ranked reasons as per the weighted mean.

Table 5: Ranking of reasons

Reasons	Weighted Mean	Rank
Contractors' financial issues	4.400	1
Rising material prices	4.367	2
High interest rates	4.033	3

Reasons	Weighted Mean	Rank
Rising maintenance cost of machineries	3.767	4
Rising cost of labour	3.567	5
Import restrictions on construction materials	3.533	6
Clients not agreeing on alternative proposals with the contractors	3.000	7

According to the study findings illustrated in Table 5, financial issues faced by the contracting organizations were ranked the top place as a reason for construction project abandonment. Rising material prices, high-interest rates, rising maintenance costs for machinery due to idling, increasing the labour cost, import restrictions imposed by the government on construction materials, and clients not moving to alternative proposals during the economic crisis were identified as the reasons for the construction project's abandonment.

3.5 REMEDIES OR MEASURES TO AVOID PROJECTS BEING ABANDONED

In terms of remedies or measures to avoid projects being abandoned, seven major measures were identified after conducting the semi-structured preliminary interviews. All the professionals were asked to rate measures that they have practiced towards avoiding projects being abandoned, on a Likert scale from 1 to 5 (1 being not practicing and 5 being mostly practicing), based on the magnitude of practicing measures. Collected data from the Likert scale was analysed and ranked by the weighted mean method.

According to Table 6, most of the contractor organizations minimized their overhead costs in the projects during the economic crisis as a remedy to avoid their projects being abandoned. Introducing alternative budgets and value engineering proposals, limiting the operating hours, not providing extra overtime and allowances, reducing the workforce up to 50% and reducing salary scales were ranked among other remedies respectively.

Table 6: Ranking of remedies/measures

Remedies / Measures	Weighted Mean	Rank
Minimizing the overhead cost of the organization	4.367	1
Introducing alternative budget and value engineering proposals	3.267	2
Limiting the operating hours	3.133	3
Reducing the extra allowances for workers	3.100	4
Reducing the workforce at least up to 50%	2.800	5
Stock up some of raw materials before the crisis	2.700	6
Reducing the salary scales	2.433	7

Additionally, the survey respondents proposed below remedies to avoid construction projects being abandoned in future.

- Encourage foreign investments,
- Country's economy should be in the proper track,
- Inflation should be controlled,
- Encourage exports and ease tight import restrictions, and

- Introduce proper price regulation mechanisms for all types of construction materials.

Apart from the above-proposed remedies, if the economic crisis continues for another 2-3 years, the respondents have suggested below plans that they will be taking over to avoid their construction projects being abandoned.

According to figure 5, 23 out of 30 (76.7%) respondents have mentioned controlling the overhead strictly in the organization as a key mechanism to face the crisis. While 22 out of 30 (73.3%) has mentioned going ahead with providing value-added services to clients such as providing value engineering proposals to the on-going projects. 20 out of 30 (66.7%) has stated that engaging on small-scale projects can keep low-profit margins for their survival if the economic crisis continues for another 2-3 years. Further, there were 5 out of 30 (16%) respondents has mentioned that they might reduce the salary scale of the employees. According to the given percentages, the reduction of workforce and the reduced salaries of employees seem to be the least preferred options. Because, projects cannot be implemented successfully if the workforce and their salaries were reduced. There were three other suggestions mentioned by them as to diversify the field, monitor the cash flow and negotiate with employers to maintain a positive cash flow, and propose to sell apartments for foreign currency to survive if the economic crisis continues for another 2-3 years.

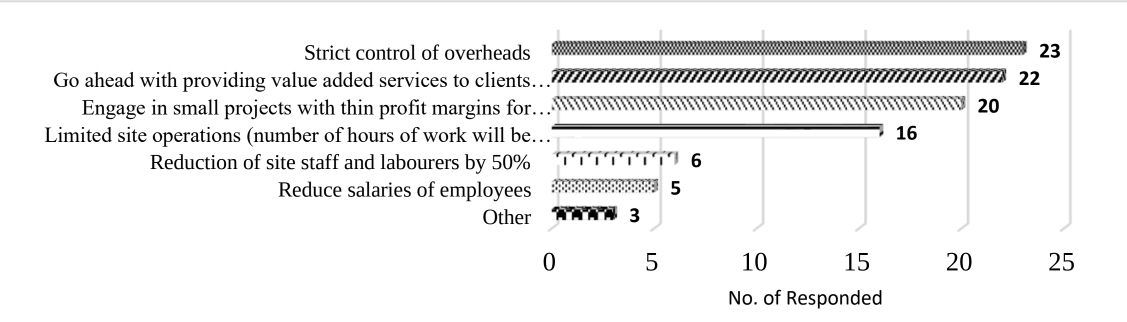

Figure 5: Future remedies if the economic crisis continues for another 2-3 years

3.6 ROLES OF THE INDUSTRY REGULATORS AND PROFESSIONAL BODIES TO LESSEN THE IMPACT TO THE CONSTRUCTION INDUSTRY DUE TO THE ECONOMIC CRISIS

Majority of professionals who participated in the questionnaire survey has mentioned that the industry regulators should make necessary adjustments to avoid the downfall of the construction industry. They must make new regulations with the government to safeguard the industry. One of the quantity surveyors has stated that "*review human resource requirement and assist with knowledge sharing programs, undertake researches regards to the economic crisis matters and suggest some reliable solutions, remedies, and encourage to send skilled labour workforce to abroad projects*". Another quantity surveyor has stated that "*need to assist contractors financially, corporate them with the government lending organizations and the treasury, and also execute mechanisms for attracting foreign investments*". One of the engineers has stated "*try to provide practical construction strategies to continuation of construction projects without abandoning*".

Industry regulators should formulate workable strategies to save the industry during this economic crisis. One of the project managers has stated "*encourage foreign investments by giving them offers and encourage exports of professional services in Sri Lanka*". The government should negotiate with the relevant authorities and attract foreign investors by giving them various benefits. By encouraging them to bring foreign exchange, the country's economy can be stabilized to some extent. Another project manager has stated that "*making a common formula for the price fluctuation*". Due to the economic crisis, each of the material prices were changed on daily basis. Therefore, there should be a common formula for the price fluctuation need to provide by the main role like Construction Industry Development Authorities (CIDA) to lessen the adverse impact on the construction industry.

Professional bodies in the industry such as Sri Lanka Institute of Architects (SLIA), Institute of Engineers Sri Lanka (IESL), Institute of Quantity Surveyors Sri Lanka (IQSSL) could also take actions to lessen the adverse impact on the construction industry due to the economic crisis. Most of the participants have mentioned that the professional bodies should make awareness programs about the economic crisis for the professionals in the construction industry. Those awareness programs can be conducted through online platforms. Also, they could mediate with the government and take better decisions to protect the industry.

4. CONCLUSIONS

The defined aim and the objectives have been accomplished towards the exploratory study on abandoned construction projects in the western province Sri Lanka. The study revealed that there is a high degree of impact on the construction industry due to the economic crisis. The impact has directly affected to the country's economy. Most of the construction projects in Sri Lanka were slowdown and temporally shutdown due to the economic crisis. Both the client and the contractor faced many different issues due to the economic crisis which by lowering the number of projects handling within the organization by reducing the work force and their salary, wages, increasing the material prices, less progress in the projects, transportation difficulties, shortage of fuel, import restrictions, increasing the maintenance cost of machineries, and high interest rates. As a result of these analysed issues, it clearly brought out that many construction projects have been abandoned in Sri Lanka during the economic crisis. Therefore, to avoid construction projects being abandoned, the government needs to make proper plan to control the unnecessary increments in material prices and at the same time encourage foreign investments. There should be price regulation mechanism for all the construction materials to avoid rising prices rapidly. The government should ease tight import restrictions. The CIDA as the regulatory body and the professional bodies such as SLIA, IESL and IQSSL need to bring up rules and regulations with the involvement of the government to avoid the construction projects being abandoned while securing the construction industry.

The exploratory study was only limited to abandoned construction projects in the Western province of Sri Lanka due to time constraints and further limited to gathering data from the practitioners in abandoned construction projects during the period of economic crisis in Sri Lanka.

In addition, it was recommended that this exploratory study on abandoned construction projects could be extended to other provinces to bring out in-depth understanding of remedies to cater all range of contracting organisations in the future during a period of economic crisis.

5. ACKNOWLEDGMENTS

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AN INTRODUCTION TO BLOCKCHAIN IN BUILDING SERVICES: A LITERATURE REVIEW

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ABSTRACT

Mechanical, Electrical and Plumbing (MEP) systems often comprise a significant part of the construction project. These are complex systems with high stakeholder involvement, a lengthy lifecycle, and high financial cost. Due to this nature, MEP systems have complex procurement and management requirements which create uphill of challenges such as lack of transparency, instantaneous changes in designs, lack of trust, incompatibility of designs and specifications, lack of coordination, miscommunication, lack of security, traceability and confidentiality etc. This paper presents an analysis of how Blockchain technology can be used to address the issues arising from the procurement and management (P&M) of MEP systems. A literature review approach was used to identify issues in P&M of MEP systems that could benefit from the implementation of Blockchain technology. P&M phases of MEP systems is based on RIBA (2020). The literature review was carried out using articles in ScienceDirect that appeared in the context of MEP and Blockchain-related terms such as "Blockchain and MEP", and "Blockchain and building services practices". Forty papers were studied to gain insight into the issues, features of Blockchain technology and to explore how these features can provide possible solutions to the identified issues. In conclusion, this paper established that Blockchain technology can be used as a solution for the issues associated with each stage of the P&M of MEP systems.

Keywords: *Blockchain; Literature Review; Management; MEP Systems; Procurement.*

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1. INTRODUCTION

Mechanical, Electrical, and Plumbing (MEP) systems are essential for the functioning of a structure. These systems are responsible for the features that make a building habitable and comfortable, no matter the size or complexity of the structure. Not only the comfortableness but also life safety is provided by the MEP systems for the building occupants (Chauhan et al., 2022; Kumari et al., 2022).

MEP systems are taking up a larger share of construction projects (Zhao et al., 2016). These systems provide the necessary functions for a building to operate properly, however, they can come at a much higher cost than other building systems such as architectural and structural. They usually make up a large portion of the total construction costs (typically ranging from 15% to 60%) which is a major factor in the final overall project price (Chauhan et al., 2022). The expense of an MEP system can vary substantially, depending on the magnitude and intricacy of the project. The installation of the MEP systems can take up to a maximum of 50% of the entire duration of the project (De Almeida et al., 2009). Thus, it is paramount to the success of a construction project (Wang et al., 2017).

However, not like other resources, MEP systems typically have a complex procurement requirements and work with large number of specified material components which are sourced from a variety of suppliers and manufacturers. The traditional manual procurement and management processes which adopted for MEP systems are time-consuming, expensive, and tend to contain mistakes due to the human factor. Further, currently there is no unified systems even support all construction procurement processes and data exchanges (Fernando et al., 2019; Hewavitharana et al., 2021; Perera et al., 2021). For example, Building Information Modelling (BIM) enhances the transferring and managing of information by detecting clashes, 3D modelling, constructability analysis and cost estimation (Hewavitharana & Perera, 2020; Teo et al., 2022), but not supported to solve issues related to procurement in supply chains (Perera et al., 2021).

MEP engineers and other professionals face uphill challenges due to the lack of transparency, instantaneous changes in designs, lack of trust, incompatibility of designs and specifications, lack of coordination, miscommunication, lack of security, traceability and confidentiality (Hewavitharana et al., 2019; Rabb & Vesali, 2022; Xu et al., 2021). Because of these issues, construction organisations consider different ways to incorporate novel concepts and adopt novel strategies to enhance their operations (Turner et al., 2021; Zou et al., 2007). Perera et al. (2021) signify that construction procurement and management is an area wherein new technology adoption should be given particular attention. As mentioned above, MEP is one of the most paramount sectors in construction projects and technology adoption in procurement and management of MEP systems is further essential. With the Industry 4.0, there are number of technologies (e.g., BIM, IoT, AI, Cloud Computing, AR, Blockchain) which revolutionised the construction industry (Alaloul et al., 2020). However, when consider the issues in procurement and management of MEP systems and unique feature of Blockchain, it is established that Blockchain is the one best solution to address the identified issues.

2. METHODOLOGY

A literature review can be labelled as a well-established method for accumulating existing knowledge within a domain of interest (Mingxiao et al., 2017). As the methodology for this article, it is expected to apply literature review approach. To find the relevant articles for reviewing, various keywords were searched within ScienceDirect database. ScienceDirect is selected because it is one of the leading sources of scientific, technical and medical research. The publishing period was decided to lie between 2015-2023 to reduce the search scope. Different keywords such as "Blockchain in procurement of MEP", "Blockchain in management of MEP", "Blockchain in MEP projects", "Blockchain and MEP", "Blockchain and building services practices", "application of Blockchain" were used to find relevant articles. However, articles were identified relating to the targeted topic in specific. The topics were broadened, and the articles' abstracts were carefully read to check their relevance. After having a critical literature review of forty selected articles as shown in Figure 1, issues in the procurement and management of MEP systems were identified. Procurement and management of MEP systems is divided in to eight phases according to the RIBA Plan of Work (2020). Issues in each phases were identified separately. Then, the features of Blockchain were investigated. Subsequently, the features of the Blockchain mapped to solve the identified issues.

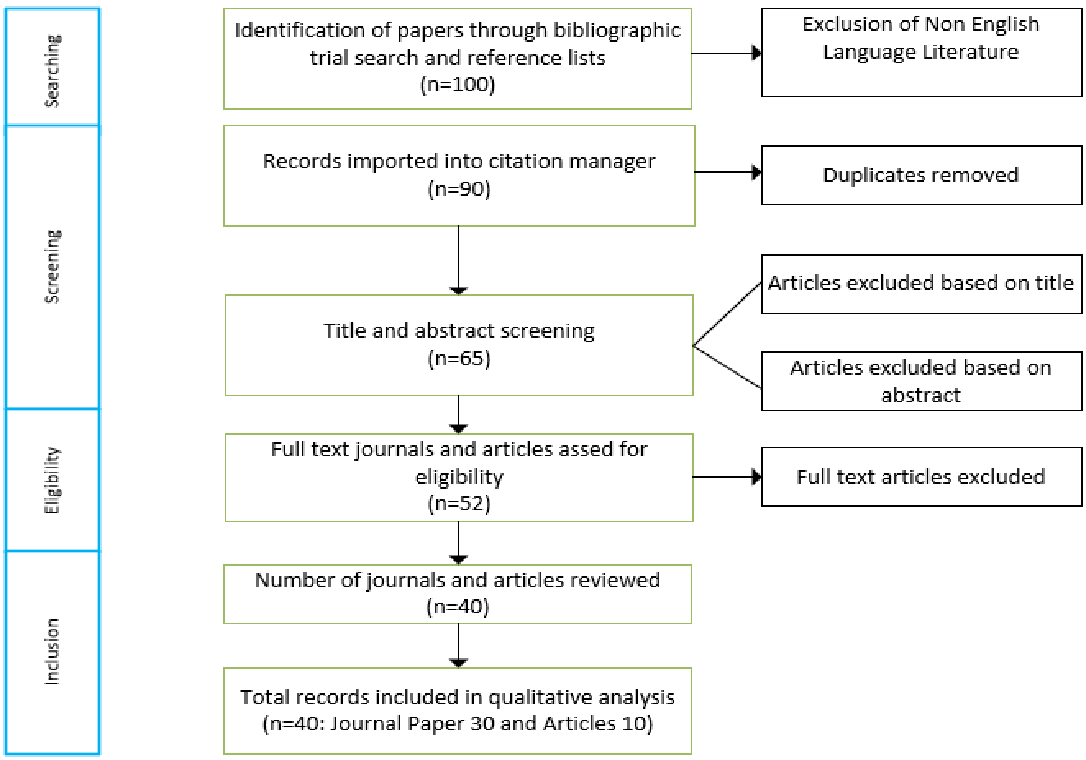

Figure 1: Derivation of referred Journal papers and Articles

3. DISCUSSION

3.1 PROCUREMENT AND MANAGEMENT OF MEP SYSTEMS

MEP systems have a complex procurement requirements and work with large number of specified material components which are sourced from a variety of suppliers and manufacturers (Xu et al., 2021). Planning of MEP procurement is much critical than normal construction materials. As outlined above, the cost and timeline associated with MEP systems are significant, creating a high risk to the construction project. To avoid the risks, MEP procurement is heavily based on MEP design and specifications. Additionally, special subcontractor (expert in MEP) is selected for MEP system installation through single or two-stage tender process (Mosley Jr & Bubshait, 2017). After the selection, MEP subcontractor can make special provisions for unknown levels of risk if the design is simple. Before finalising the designs, all stakeholders must collaborate each other to avoid clashes in each discipline. This is a back-to-back and time-consuming process (Teo et al., 2022). Therefore, it is established that MEP procurement is complicated and much riskier than usual procurement of construction materials. Further, it empathises the necessity of systematic procurement method which will lead to greater level of certainty, avoiding requirement changes and re-work.

In this study, it is expected to consider all the operation of MEP systems from planning to maintenance and disposal (procurement and management). Therefore, in here, “procurement” denotes procedures from planning to installation of MEP systems as per the above-mentioned definition (Perera et al., 2021). In other terms, “procurement” states the processes related to pre-installation of the MEP systems. “management” implies the maintenance and disposal of MEP systems. Simply, it illustrates the processes associated with the post-installation of MEP systems.

Understanding the processes of whole procurement and management of MEP systems is difficult. Thus, it is divided into eight stages based on RIBA Plan of Work (2020). They are Strategic Definition, Preparation and Briefing, Concept Design, Spatial Coordination, Technical Design, Manufacturing and Construction, Handover and Use. RIBA Plan of work (2020) is considered as the most prominent framework which is used to organise any construction project (Celik et al., 2023). It evolved through its history to reflect the increasing complexity of projects, to incorporate increasing and changing regulatory requirements and to reflect the demands of industry and government reports criticising the industry. Although RIBA Plan of Work (2020) refers to the stages of construction project it can also utilised to MEP works, as MEP works are embedded in the scope of work of a construction project. Further, the terminologies used in the RIBA plan of works (2020) can be easily incorporated to the MEP Plan of Woks. After establishing RIBA Plan of Work (2020) as the basis of deriving stages, the stages of RIBA are mapped with MEP services. Core activities which are implemented in each stage are summarised in Table 1. The stages are denoted from P0-P7.

Table 1: Phases for the study

Phase No	RIBA Plan of Work	Core activity related to P&M of MEP
P0	Strategic Definition	Identify client’s requirement (MEP)
P1	Preparation and Briefing	Feasibility study of installing MEP (E.g Energy Consumption)
P2	Concept Design	Concept designs regarding MEP systems
P3	Spatial Coordination	Checking MEP spatial requirement and clash detection
P4	Technical Design	Technical design, Tendering and documentation for MEP installer selection
P5	Manufacturing and Construction	Manufacturing/Customising/Assembling MEP systems and Installation
P6	Handover	Handover the MEP system to the Client
P7	Use	Maintenance and Disposal of MEP systems

Having discussed the phases of procurement and management of MEP systems, following section describes the issues raised in each stage.

3.2 ISSUES IN PROCUREMENT AND MANAGEMENT OF MEP SYSTEMS

Having done a critical literature review on issues of P&M of MEP system, Table 2 is developed as a summary.

Table 2: Issues in MEP Procurement and Management

Stage	Issues	References
General Issues	Multiple stakeholders are involved in the MEP coordination process and can lead to numerous clashes (I1)	(Chauhan et al., 2022; UKAID, 2013)
	Difficulty in establishing trust, exchanging data, and managing the workflow (I2)	(Akhil & Das, 2019; Ibem & Laryea, 2014; Yik et al., 2006)
	Lack of transparency (I3)	(Singh et al., 2018; Yik et al., 2006)
	Delays in approvals (I4)	(Arslan et al., 2006; Zou et al., 2007)
Strategic Definition (P0)	Unclear requirements of the client (I5)	(Aggarwal & Kumar, 2021a, 2021b; Chauhan et al., 2022)
	Sudden changes in the client's requirements (I6)	(Arslan et al., 2006)
	Miscommunication between parties and lack of trust (I7)	(Scott et al., 2021)
Preparation and Briefing (P1)	Poor decision making based on inaccurate information (I8)	(Agrawal et al., 2022)
	Lack of trust regarding project information (I9)	(Chauhan et al., 2022; Ibem & Laryea, 2014; Scott et al., 2021; Zhao et al., 2016).
Concept Design (P2)	Unclear conceptual designs (I10)	(Chauhan et al., 2022)
	Instantaneous feedback about the design decisions (I11)	(Arslan et al., 2006)
Spatial Coordination (P3)	Clashes related to missing information, poorly communicated information, inconsistencies between documentation (I12)	(Chauhan et al., 2022; Scott et al., 2021; UKAID, 2013)
	Incompatibility among design software (I13)	(Arslan et al.; Chauhan et al., 2022)
	Lack of trust between parties (I14)	(Chauhan et al., 2022)
	Miscommunication between parties and lack of transparency (I15)	(Scott et al., 2021)
Technical Design (P4)	Noncompliance with building practitioner regulations (I16)	(Work Safe, 2022)
	Detection of potential clashes between design and specifications (I17)	(Aggarwal & Kumar, 2021a, 2021b; Latiffi et al., 2013)
	Low quotation to order ratio (I18)	(Hvam et al., 2006)
	Long and complicated tendering processes (I119)	(Hvam et al., 2006)
	Risks associated with insurances (I20)	(Zou et al., 2007)

Stage	Issues	References
	Large scale of dark purchasing (I21)	(Tatum & Korman, 2000)
	Conflicts in Contracts (I22)	(Zou et al., 2007)
	Inaccurate and non-reliable information (I23)	(Hvam et al., 2006)
	Supply risks associated with procurement process (I24)	(Nanayakkara et al., 2019)
Manufacturing and Construction (P5)	Lack of transparency in manufacturing procedure (I25)	(Singh et al., 2018)
	Not comply with quality standards (I26)	(Singh et al., 2018; Wu et al., 2022)
	Conflicts in compliance (I27)	(Wan & Kumaraswamy, 2012)
	Issues related to equipment delivery (I28)	(Zou et al., 2007)
Handover (P6)	Issues in service provisions (I29)	(Howkins, 2017; Korman et al., 2003; Work Safe, 2022)
Use (P7)	Lack of proper inspections (I30)	(Howkins, 2017)
	Issues in Warranty Provisions (I31)	(Howkins, 2017)
	Lack of adhering to the government regulations (I32)	(Work Safe, 2022)
	Difficult in decision making due to lack of information (I33)	(KONE Cooperation, 2019)

Having identified the issues following sections describe how Blockchain technology can positively impact to the procurement and management of MEP systems.

3.3 BLOCKCHAIN TECHNOLOGY

The term "Blockchain" refers to a decentralised database which creates, validates and records encrypted transactions of digital assets in an incorruptible way. As a data structure, a Blockchain is an ordered list of blocks, where each block contains a list of transactions. Each block is "chained" back to the previous block, by containing a hash of the representation of the previous block. The *hash value* is generated by a cryptographic hash function. The hash function is a one-way function, meaning that it is practically impossible to derive the input from the hash value as an output (Sadeghi et al., 2022). Therefore, data stored in the Blockchain transactions may not be deleted or altered without invalidating the chain of hashes. In addition, every transaction is signed by the transaction sender using a *private key*. Such a digital signature is a valid proof of the authenticity of the data sent by the transaction sender (Wu et al., 2019). Trust in the Blockchain is achieved from the interactions between nodes within the network. The participants of *Blockchain network* rely on the Blockchain software and the consensus protocol used by the peer-to-peer network rather than relying on trusted third-party to facilitate transactions (Kim et al., 2020; Perera, 2021). Further, the concept of Blockchain has been expanded to encompass *distributed ledger systems* that are used to validate and store any type of transaction (Lu et al., 2021). *Smart contracts* can be thought of as computer programs that use if/then statements to divide a project's work into smaller, measurable packages, and automate the process of compliance and payment (Xu et al., 2022). Each work package or milestone is defined by specific conditions, and when these conditions are met, the predetermined compensation is triggered automatically. This approach provides a new type of work breakdown structure, which enables all stakeholders to better comprehend their obligations and requirements.

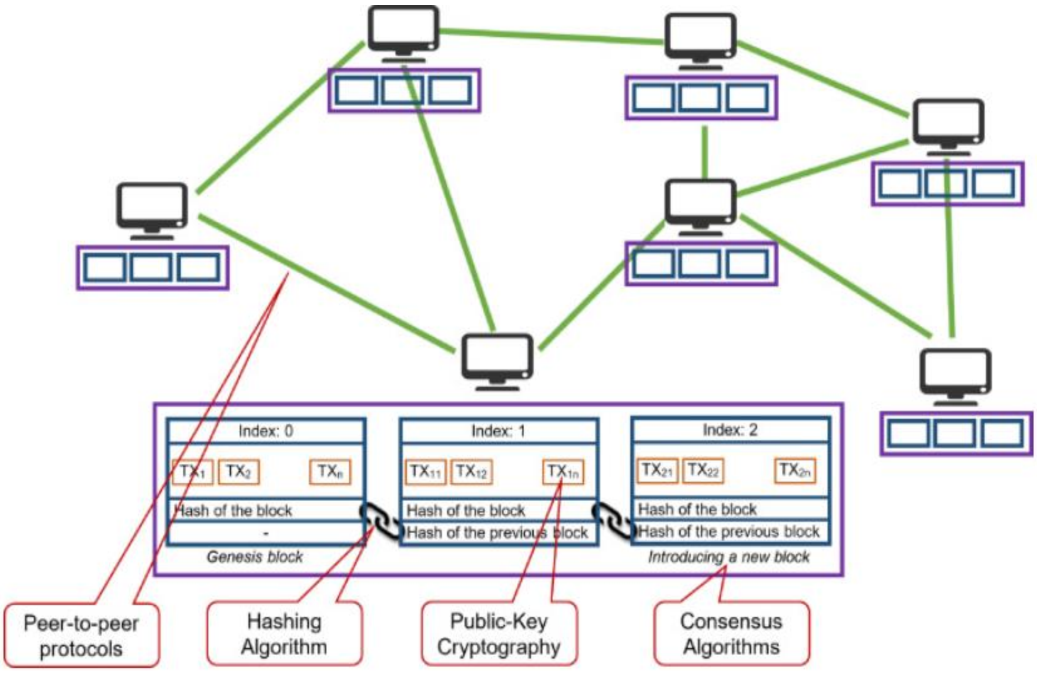

Figure 2: Peer-to-Peer Blockchain Architecture
Source: (Perera et al., 2021)

3.4 Potential of Blockchain to Solve the Issues Identified in Procurement and Management of MEP Systems

Following section describes how Blockchain technology can positively impact to the procurement and management of MEP systems.

- In the design phases, Blockchain enables to cooperate with other digital tools like BIM. As an example, Blockchain technology can store a hash of the BIM model, which can be used by a lookup service to compare the hash of a downloaded model with the hash stored on the chain. The application then provides the user with a verification receipt that confirms the model's validity (Scott et al., 2021). On another note, a case study by Mason (2019) has proven that how logging geometry and volume in BIM models can be translated into computable code for smart contracts.
- Smart contracts in Blockchain can be applied to contract agreements between clients and construction parties, as well as between clients and their project consultants such as designers, cost engineers, and project managers (Das et al., 2019). This will help addressing issues related to non-payment or late-payment, which are often faced in current construction contracts, by utilising a trust-in-machine concept in Smart Contract. As a result, the nature of legal contracts in construction will likely undergo a significant change, with prevention taking precedence over litigation (San et al., 2019).
- Sometimes MEP manufacturer and customising companies try to keep sovereignty in the market. In Australia, most of the MEP systems are imported

from other countries like China, USA, Germany, Southeast Asia etc. For example, very few lift manufacturing companies can be seen in Australia who manufactures lifts. This results in quality issues in the MEP system (Mostafa et al., 2018). Blockchain based monitoring system supports to track the MEP system from manufacturing stage to installation stage ensuring that MEP systems are up to the required standards (Agrawal et al., 2022; Angrish et al., 2018).

- An automated, Blockchain-enabled system can help monitor maintenance procedures for the building. This system can easily and accurately manage maintenance requests, procurement processes, product delivery, payments, and more, thanks to the use of smart contracts (Xu et al., 2021). Its transparency also ensures that everyone involved from the occupant to other parties is kept up to date on the status of a maintenance request, from the beginning of the process to the completion of the work. Also, it enables maintenance managers to recognise who supplied and installed any building component at what cost at any given time (Li et al., 2019; Zakhary et al., 2019).
- Integration of Blockchain and Building Maintenance System (BMS) technology allows for the creation of a Decentralised Autonomous Organisation (DAO) to manage the lifecycle of a structure. This DAO is powered by multiple smart contracts, which can be used to automate the placement of maintenance work orders and the release of payments upon verification that the work is complete. The DAO can handle every aspect of a building's lifecycle, from design and construction to operation, maintenance and demolition, with the smart contracts working together to ensure that these processes are carried out in a cohesive and autonomous manner (Perera et al., 2020; Shojaei, 2019).
- A large number of stakeholders involved in the process of procurement and management of MEP systems lead to coordination issues and conflicts among parties. The use of Blockchain has the potential to revolutionise the way contracts and transactions are handled. It could reduce the costs associated with these activities while improving their security. Furthermore, it could lead to efficient coordination among many stakeholders involved in the process of procuring and managing MEP systems by creating new business models (Kim et al., 2020; Xu et al., 2022).
- Utilising product modelling and IT-based product configuration systems which supported by Blockchain allows for greater optimisation of quotation and engineering processes. This leads to a decrease in the costs associated with making a quotation, as well as improved efficiency in other areas, such as increased knowledge sharing, higher quality of quotations, and shortened lead-times (Akhil & Das, 2019). Additionally, Blockchain based product configuration systems can be used to support decision making and provide clarity regarding possible alternatives when configuring a new product (Hvam et al., 2006).
- Blockchain can be used as an immutable distributed ledger where transactions are timestamped into a block, which enables MEP asset tracking, ownership transfer certification and maintains accurate, immutable history records (D. Perera et al., 2021). Also, it ensures that project information is confidentially managed through the Blockchain. As an example, by using a Blockchain system that incorporates smart contracts, all parties involved can easily be notified of MEP drawing

updates (Nakamoto, 2008). This system would allow for the most current information to be readily available and would eliminate potential issues that can arise such as miscommunication of which version of the drawing is the latest, who issued it, and whether it was included with other drawings such as architectural, structural, and services (Perera et al., 2020).

- The use of digital tools enables real-time communication, coordination, collaboration, and sharing of project information and data between participants in project activities. However, the interoperability or incompatibility of different systems and software packages has been recognised as a persistent challenge. Blockchain promotes real-time communication and cooperation across the participants rather than promoting individual execution of computer software (Ibem & Laryea, 2014). Things can quickly go wrong when MEP systems are designed in isolation, rather than in a coordinated manner. That is why it is important to keep your whole team updated on how and where each system is being installed (Hewavitharana et al., 2019).
- Blockchain and intelligent contracts (iContracts) will eliminate the inherent issues in traditional contracts (McNamara & Sepasgozar, 2021). MEP asset management on a Blockchain network helps to solve the problems of dispute resolution and improves the time it takes to solve discrepancies in data. The consensus-based nature of the technology means that updates cannot occur to asset records without agreement from all relevant parties (Teisserenc & Sepasgozar, 2021).
- The core of MEP asset management entails the procedures of registering and transferring possession of an asset as per the provisions of a relevant agreement (Xu et al., 2022). This includes keeping a record of the assets belonging to a particular individual or entity, having a third party manage and administer payments on behalf of the parties involved in a transaction, and performing an atomic exchange of assets based on an amount that has been mutually agreed upon. An asset registry is responsible for maintaining a list of assets that are owned by a certain party. Asset swap is the optimal exchange of assets based on the amount that has been settled by the parties. Blockchain can act as a third party and release the payments when all the obligations of the agreement are fulfilled (Lu et al.; San et al., 2019).
- Blockchain technology offers transparency and trust in the MEP industry, allowing all parties involved to view a chronological record of both monetary and non-monetary transactions (e.g., drawings, property transfer). This visibility is shared among all participants in the transaction, regardless of whether it is financial or informational (Zakhary et al., 2019). The decentralised nature of Blockchain also ensures that all users have the same information, and that this data cannot be altered or deleted. Both the sender and receiver, therefore, have access to more information than is available elsewhere. This traceable and immutable record creates a sense of transparency for users, making them more likely to enter into smart contracts with one another, trusting the automated system rather than relying on an established trust relationship (Kim et al., 2020; San et al., 2019).

4. CONCLUSIONS AND THE WAY FORWARD

MEP systems are frequently a major element of building projects that involve a great deal of stakeholders, have a lengthy lifecycle, and require a great deal of financial expenditure. As a result of their complexity, MEP systems can be subjected to a variety of issues throughout the design to disposal process. Through a critical literature review, this paper examined how Blockchain technology can be leveraged to tackle these difficulties associated with procuring and managing MEP systems. To make it easier to understand, the procurement and management of MEP systems were divided into eight stages based on RIBA Plan of Work (2020). Major issues which identified are high involvement of third parties, poor coordination and clash detection, delay in approvals, lack of transparency, conflicts in contracts, lack of information sharing, conflicts in compliance, warranty leakages, etc. Blockchain was suggested as a solution for solving these issues because of its features such as peer-to-peer network, private key, distributed ledger, hash function and smart contracts. Blockchain could provide minimum third-party involvement, high transparency in contracts, strong verification systems, the immutability of data and auditability of data for the procurement and management of MEP systems.

Very limited studies have focused on finding solutions for the issues in the procurement and management of MEP systems. This paper presents a clear overview of how Blockchain can facilitate MEP procurement and management to develop collaboration among parties, reduce third-party involvement, trust issues, and clashes in contracts, and improve transparency in contracts in an effective manner.

Further investigations should be carried out to identify the stakeholder involvement and process which are related to MEP systems to explore the exact place where Blockchain should be embedded. As a concluding remark, the research outcomes demonstrate that Blockchain and smart contract-powered ICT solutions can significantly contribute to mitigate the issues related to the procurement and management of MEP systems.

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AN IOT-BASED ELECTRICAL AND ELECTRONIC APPLIANCE MANAGEMENT SYSTEM FOR SRI LANKAN RESIDENTIAL BUILDINGS

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ABSTRACT

Sri Lankan household energy consumption was accounted for around 34% of national energy consumption in 2017, and residential applications were accounted for 36% of national energy waste in 2018. Therefore, reducing the energy wastage in the household environment is essential. Researchers from all around the world are working to develop IoT-based solutions to reduce energy wastage, but there are certain challenges in adapting them to the local context as those techniques were developed for foreign domestic usage. As a result, it is crucial to come up with IoT-based solutions which are appropriate for the local environment to assist the reduction. Therefore, this article examines the importance and feasibility of adopting IoT-based electrical and electronic device control systems for household use in Sri Lankan environments. Further, a mobile application was developed to monitor and control the system, which was installed for a residential building after an analysis of the domestic requirements. This system may simply fix into an existing building, making it a cost-effective application for reducing energy wastage in developing countries.

Keywords: *Electrical and Electronic Appliance Management System; Energy Wastage; Internet of Things (IoT); Smart Building.*

1. INTRODUCTION

The population growth has expanded dramatically because of the industrial revolution, technological innovation, and improvements in comfort, resulting in higher energy consumption (Pearson & Foxon, 2012). When global warming causes environmental concerns like climate change, energy supplies are exhausted because of this high energy demand (Owusu & Sarkodie, 2016). Building energy usage has reached an all-time high when compared to other sectors (Anuradha & Halwatura, 2021; Anuradha et al., 2019).

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Throughout its entire cycle, a structure consumes energy in a variety of ways. Construction utilizes about half of all non-renewable materials that humans utilize (energy, water, and raw materials) (Yuksek & Karadayi, 2017). Figure 1 indicates the energy consumption from 2018 to 2031 in Sri Lanka (Sri Lanka Electricity Board [SLEB], 2017).

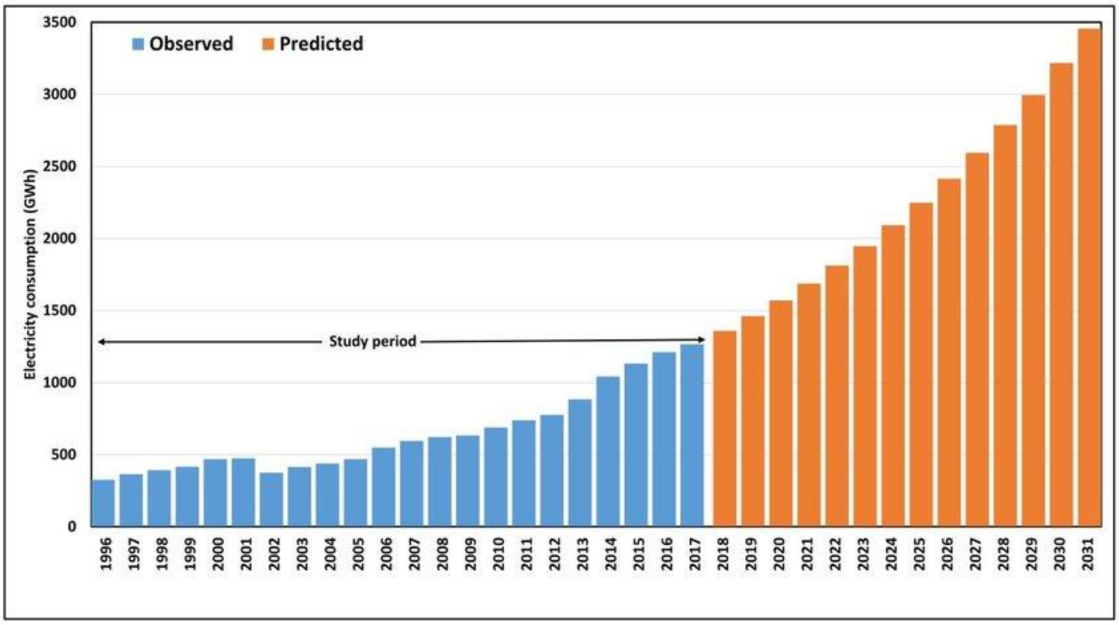

Figure 1: Increment of Energy Consumption in Central province, Sri Lanka (SLEB, 2017)

Figure 1 indicates that the energy consumption from 2018 to 2031 is projected to have a 7% growth rate (Sri Lanka Electricity Board [SLEB], 2017). According to the Energy Conservation Fund (ECF) of Sri Lanka, residential and commercial energy consumption is accounted for around 51.10%, while industrial energy consumption is accounted for around 24.41% (Fernando & Jayasena, 2009). Modern architecture is hampered by several functional needs that must be met to reach a higher standard of living today. Lighting has been a priority in modern architectural designs as a building function that is used to achieve the building's most attractive appearance (Almeida, 2010). Lighting produces a visual environment in a building, and it is a crucial component of energy usage. Lighting energy accounts for around 17% of the electricity consumed by office buildings in United States (Pohl, 2016). When it comes to energy wastage caused by lighting, poor lighting control is the most common cause (Derby, 2006). People make common behavioural blunders by failing to turn off lights when there is an adequate daylight available and when lighting is not necessary for the reticular area. Energy losses caused by the above mentioned human behavioural errors can be considerably reduced with the help of an appropriate lighting control system (Tetlow et al., 2014). The mishandling of electrical appliances and equipment is a major source of energy wastage in buildings when it comes to electronic equipment. According to recent studies, an efficient home appliance system can save up to 30% of total home appliance energy usage (Michaels, 2018). Nevertheless, construction industry is still adapting traditional technologies (Anuradha et al., 2021). This research focuses on using an IoT system to control these devices and assist them to minimise their electrical energy wastage.

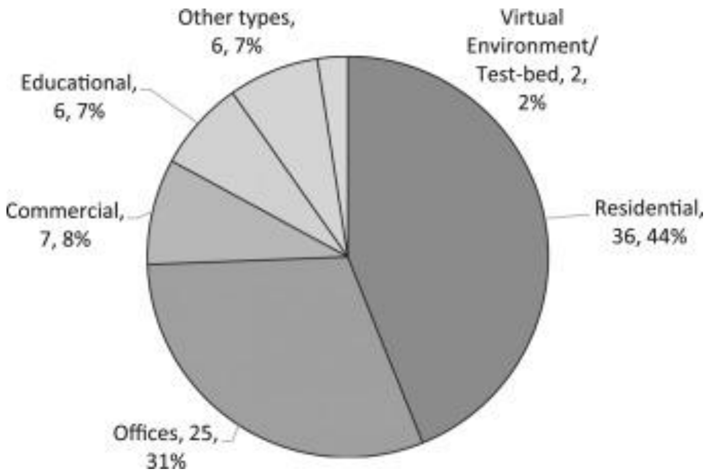

Figure 2: The energy wastage according to the building type (Delzendeh et al., 2017)

One of the most essential aspects of modern civilization is energy conservation. Energy efficiency will likely to become one of the most essential construction elements in future buildings (Acosta et al., 2016). Smart home devices, including smart meters, energy monitoring systems, and connected appliances, provide real-time and detailed information about energy consumption within a household. These devices often come with user-friendly interfaces or smartphone applications that allow homeowners to access and analyse energy-related data easily. The primary goal of this study is to reduce energy wastage in Sri Lankan homes by better regulating the lighting system and home appliances. Building management systems (BMS), currently available in the market are not suitable for the usage in Sri Lankan homes due to several reasons; (I) the majority of the BMS systems have been developed for industrialized countries and not suitable for Sri Lankan set up, (II) those solutions are really expensive and therefore consumers are reluctant to invest more money in such systems, and (III) the dearth of understanding of the people about the field. Thus, the study aims to create an IoT-based lighting and electrical, electronic device management system which is more suited for household use in Sri Lanka. Therefore, the objectives of the study were set up as: (i) to investigate the significance of IoT-based applications in Sri Lanka, and (ii) to develop a lighting control system and an electrical, electronic appliance management system.

2. LITERATURE REVIEW

Based on evaluations of IoT and smart applications, IoT is defined as a network of interconnected devices and systems that collect data from physical components using sensors and actuators, allowing data to be accessed remotely (Ande & Rojatkar, 2017; Sharma & Tiwari, 2016). IoT comes hand-in-hand with the concept of Smart Homes, where electronic systems and products can be automated for easy control by the users to improve comfort, convenience, efficiency and security (Li et al., 2011). According to Busatto et al. (2019), the combination of IoT with Home Automation systems (HASs) is a promising alternative that can guarantee higher energy efficiency. There are comparable functionalities in the smart home devices can be supported to fulfil consumers' specific needs and preferences. The functionality, ease of us, data accuracy, compatibility, energy saving features, privacy and security, and price and value are some key factors to assess how well the devices align with their specific needs, preferences, and long-term goals for energy management and automation. Smart Home Technologies (SHTs) are built from a network of devices, interfaces, sensors and monitors that can work together to enable automation and allow the domestic environment to be controlled locally as well as remotely (Cook, 2012). Lighting systems, hot water systems, fridges, windows, garage doors, curtains, and washing machines are among the most prominent controllable appliances and devices (Robles & Kim, 2010). Several factors influence the impact of lighting on a building's energy consumption (Zhao & Magoulès, 2012). Claddings of a building, percentage of openings are all important considerations. Lighting plays a significant role in the daily lives of people, not only during the night but also during the daytime where artificial lighting is used indoors (Tang et. al., 2017). According to a study by Spyropoulos and Argiriou (2011), lighting energy usage is calculated as a variable percentage of the building's total energy consumption, ranging from 15% to 60%. The Luminous Energy Index (LENI), which quantifies the annual energy consumption of lighting per square meter (kWh/m^2/year), is a criterion for estimating lighting energy consumption (European Standards, 2006). The adoption rate of LED as the main light source has increased in the residential segment due to its high efficiency, long lifespan, and the ability to perform more challenging controls on LED compared to florescent lamps and halogen bulbs (Baumgartner et al., 2012). It is possible to improve living standards in terms of convenience, customizability, ambience and power saving through the use of an LED-based intelligent lighting system (Tang et. al., 2017). Implementing an efficient lighting system can handle the overall problem of optimizing the availability of natural light in a structure, regardless of the metrics used to measure the availability of sunlight in a building (Yu & Su, 2015). Changing energy consumption patterns is critical to reduce energy losses. Nevertheless, changing the behaviour of people is very difficult (Yang & Lee, 2014). A study showed that 15% of the energy consumption in residential buildings was due to artificial lighting (International Energy Agency [IEA], 2015). Daylight harvesting is a process where daylight is used to counterbalance the amount of electrical energy needed to light up a space (Xu et al., 2019). This process can be used to save up to 27% or even 40% of lighting power in regions that receive adequate to high amounts of daylight, respectively (Wen et al., 2006; Tang et. al., 2017). Occupancy control is a common approach for managing lighting use; occupancy sensing control systems turn lights on in a place when motion is detected, then turn lights off after a pre-set interval if no motion is detected (Guo et al., 2010). Electrical appliances in standby mode are one of the most common sources of energy wastage, accounting for up to 10% of total energy consumption in buildings (Olatunji et al., 2019). Providing adequate feedback to building occupants, can dramatically reduce overall energy use in between 5-20% (Derby, 2006). However, relying solely on people's awareness and behaviour is not an effective strategy. Indeed, a recent experimental investigation found that more than 30% of energy savings were achieved after installing a monitoring system in a residential building (Jiang et al., 2009). Philips Hue, LIFX, and OSRAM Lightify are several of the leading smart lighting systems in the market. SHT developers have identified that the most significant barriers towards the adoption of these technologies are the upfront cost, lack of awareness, and concerns regarding privacy (GfK, 2016). A significant issue identified with these products is the lack of closed-loop feedback to control the illuminance level of the space, thereby daylight harvesting cannot be conducted without the use of external sensors (Tang et. al., 2017). Studies related to the users' perspectives have revealed that while there is an interest regarding the energy-saving potential of smart home devices and lighting management systems, there are also market barriers to adoption such as high cost, interoperability of different technologies, privacy, and security loopholes such as the threat of hacking (Wilson et. al., 2017). Research conducted on improvement of smart homes proposed solutions such as connecting the smart homes to the cloud or modifying residential gateways in smart homes to include the home energy management system (Han & Lim, 2010). An IoT-based system which allows the user to control the power supply via a mobile app or the web will result in the user's ultimate happiness while also conserving energy. People are more likely to operate electrical equipment efficiently when they are at their fingertips. When a gadget is not in use but in standby mode, it has become a habit to leave electrical equipment plugged in even when it is not in use. This may not appear to consume a lot of energy, but it has been demonstrated that avoiding this can save the energy wasted.

3. RESEARCH METHOD

This system development is divided into two halves. The first step, the lighting management system comprises the NodeMCU as the lighting management's main processing unit. As well as all sensors (DHT11, LDR, and PIR motion sensor) that may be linked to the NodeMCU. The sensors are connected and operated by the NodeMCU, and it is used to retrieve and process data obtained through the sensors, as well as update it to the cloud via the WI-FI module (Google fire-based MQTT broker). The data from the sensors can be shown via a smartphone app or a Google Fire-based app, as well as a mobile app produced with Kodular App Inventor. Also, NodeMCU performs as a relay module for lighting control. The on-off and timer facility are given to the plug points through the mobile app. When compare with other platforms having costly licensing hooks and closed source practices, the GCP stack is best controller for lighting management system. The key aspects such as compatibility, user interface, functionalities such as voice control, scheduling, and automation are offered in this app.

The next step is the development of electronic appliance management. The mobile app controls the lighting system using a Thing-speak MQTT broker. The MQTT is an emerging and efficient transport protocol has been used the early 2000’s and now with ISO Standard. Further, it will be able to increase velocity and reduce complexity for IoT products and services. The PIR sensor is used to detect their motions and turn the light on, but during the day, it will turn off. The PIR sensor will detect movement if someone enters the area, but the light will not turn on because the LDR sensor determines the time (the daytime or the night-time). When person wants to turn on lights throughout the day, they can do so with the use of a smartphone app. A timer to turn lights on and off can also be set via the mobile app.

The hardware components required for the development are NodeMCU, PIR motion sensor, LDR sensor module, power supply, relay module, and voltage converter unit. Arduino IDE, and Kodular app invertor can be listed as the required software in this step. Further, for remote access purpose, connection for online service is essential. This technology is designed to manage the lights efficiently. This has been built as a one-box assembly to make installation easier. Therefore, there is no need to modify the existing electrical wiring during installation in the building. The main unit in this circuit is the NodeMCU which is directly connecting with all sensors and other subcomponents. The mobile application facilities turn on and off motion detection and regulate lighting. As a result, the motion detection sensor and the NodeMCU have been connected. Even if the room is inhabited, keeping the lights on will waste energy due to adequate daylight.

The LDR sensor will be used to check the presence of sunshine in the room, and only when there is no proper sunlight, the motion-detecting sensor is activated. An LDR sensor has been used to connect the NodeMCU to the PIR motion sensor. The relay module controls the lighting. The LDR sensor outputs a 5v DC signal, but to operate the lighting, it must regulate a 230v AC. Therefore, the PIR motion sensor output is connected in the terminal to the 5v-230v relay module supply. Then the schedule is done. The D8 pin on the NodeMCU ESP8266 is connected to a 5v-230v relay. When a current is allowed to pass at the precise time, the D8 pin will stop allowing the current to flow when the timer expires. The current passing will activate the relay via the D8 pin. The relay will be connected to the lighting. As a result, the lighting will be controlled by the current travelling through the D8 pin. Next in order to control the IoT base, the ESP8266 D9 pin is set as the switch in the mobile app. When the light is turned on via the mobile app, a signal is sent to the NodeMCU. The D9 pin sends a current to the relay module to turn on the light when the app sends a signal to do so.

Developing an electronic appliances management unit for time scheduling, the D10 pin on the NodeMCU ESP8266 is connected to a 5v-230v relay. When a current is allowed to pass at the precise time, when the timer expires, the D10 pin will stop allowing the current to flow. The current traveling will activate the relay via the D10 pin. The relay will be connected to the lighting. As a result, the lighting will be controlled by the current travelling via the D10 pin. Next, the ESP8266 D11 pin is set as the switch in the mobile app for the IoT base control. When the light is turned on via the mobile app, a signal is sent to the NodeMCU. The D9 pin sends a current to the relay module to turn on the light when the app sends a signal to do the same.

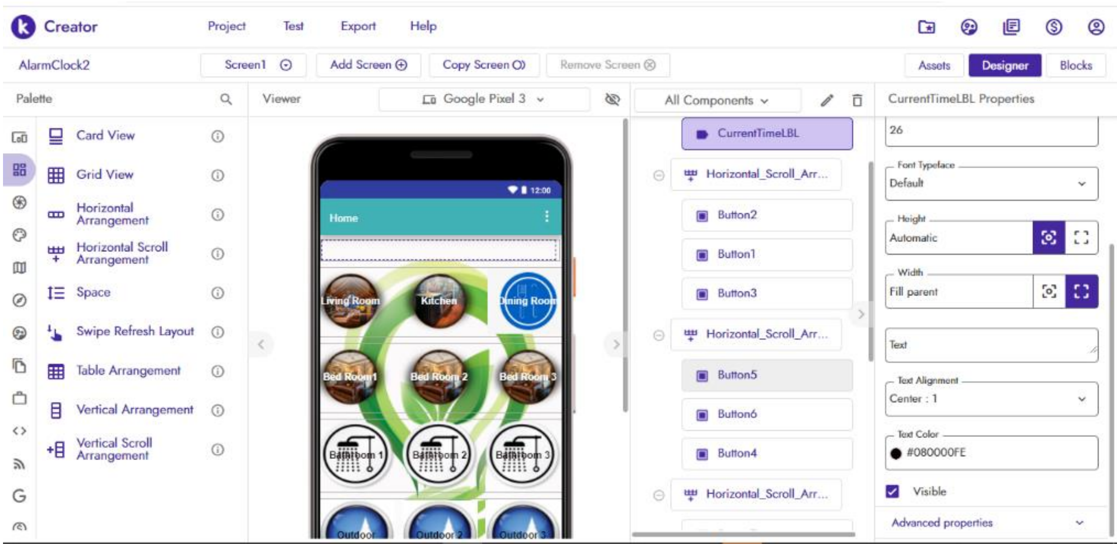

Figure 3: Development of main screen of mobile app

3.1 MOBILE APP DEVELOPMENT

The mobile application for this system was created using the Kodular application maker tools. The main screen shown in Figure 3 had then to be created first. The main screen's basic sketch design was developed using palettes. Buttons, labels, text boxes, a clock, a firebase database, horizontal arguments, a time picker, and other elements were added as palettes to the main panel.

The designing stage of the process ends after adding the palettes to Figure 1. Then, in the portion of the block, the backend development had to be completed.

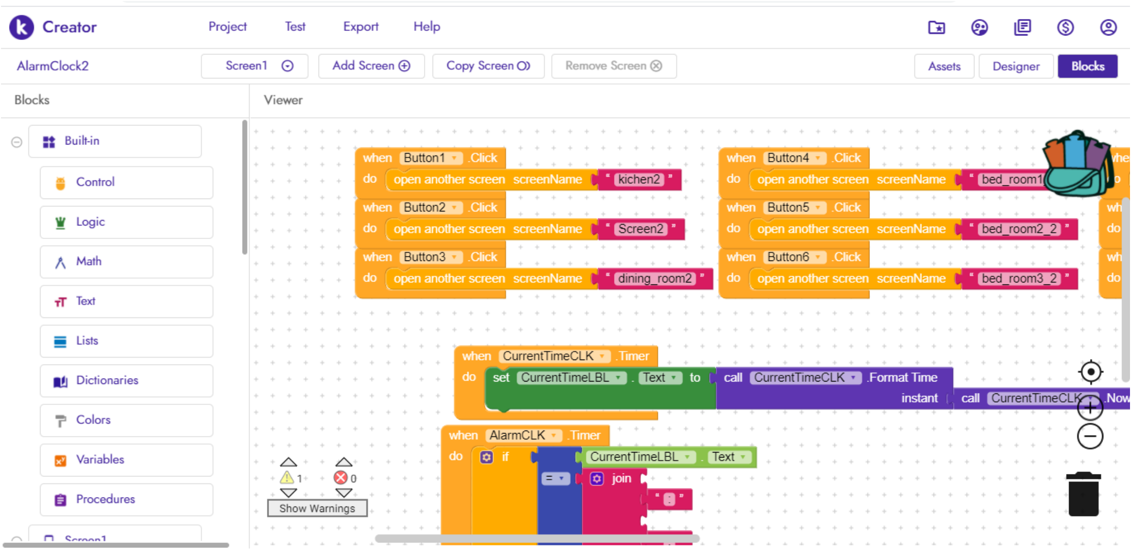

Figure 4: Backend Development of the Mobile App

The functionality of the pre-set palettes was coded at this point, as were the logical arguments for the relevant functions. The mobile app includes the occupancy control and IoT control for Lighting control by switching to turn on and off the occupancy control. The ESP8266 will be instructed to transmit a current through the D7 pin by turning on the mobile app.

3.2 LINKING THE SYSTEM

The mobile application and the NodeMCU were linked using API Key and Firebase URL. Therefore, the API key and firebase URL have been added to that palette. The switch is turned on, the value '1' will be printed in the relevant database. If the switch is turned off, the database will print '0'. The API key and a firebase URL are also provided in the NodeMCU ESP8266 coding. NodeMCU reads the relevant sub-database when it runs. The number '1' is then printed in the database, and the current is then passed through a pre-set digital output. If the sub-database prints '0,' the current will stop flowing.

3.3 IMPLEMENTATION OF THE SYSTEM

This assembly has been simplified as much as possible to reduce the installation cost. The device installation requires little extra effort. It is necessary to install the lighting management unit on the top of the ceiling, and it is preferable to install the unit in the middle of the coverage area for optimum sensor functionality. There are two connecting points: one for line in and one for line out. The existing system does not require any changes. The system only must be connected to the centre of the light and the physical switch. The NodeMCU should then be connected to a wireless network. If there is an open network, the devices will connect to it automatically. When network is secured, the NodeMCU should be given the password and username while coding. When NodeMCU is running, it communicates with a specific device. Firebase database by Google, the program should then be installed on the phone. The gadgets are controlled by a smartphone app. The details of the same Google Firebase database are coded into the mobile app. The program should then be installed on the phone. The gadgets are controlled by a smartphone app. The details of the same Google Firebase database are coded into the mobile app.

4. DISCUSSION

The choice between a commercial smart home device and NodeMCU depends on the requirements, technical expertise, and budget. A plug-and-play solution with convenience and support, a commercial smart home device may be a better option. However, if you enjoy tinkering, have programming skills, and want full control over your smart home system, NodeMCU provides an affordable and customizable platform.

The NodeMCU was coded with the password and username of a Wi-Fi network. When the network is available, ESP8266 Wi-Fi module automatically signs into the network and accesses the google firebase database which was given instructions to access when programming.

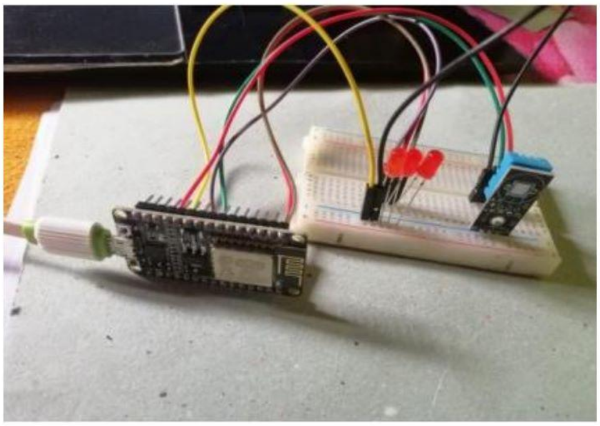

Figure 5 (i): NodeMCU connected with LED

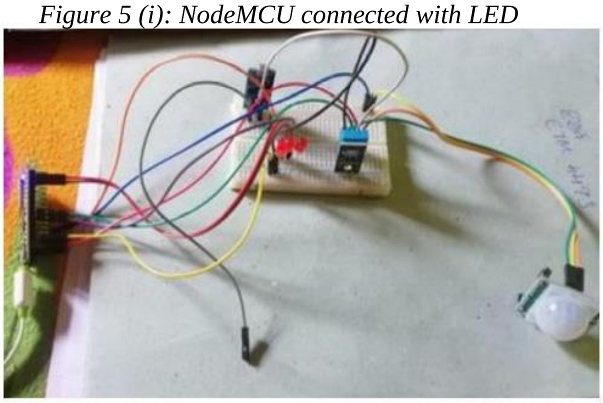

Figure 5 (ii): Motion Sensor Connected Circuit

The Google Firebase database login information was provided by the mobile application given in Figure 6. The living room was selected for the experiment. When light 01 was turned off, the associated LED to the light 01 output was also turned off. The LED turned on when it was configured to turn on light 01 from the phone. The ability to control lighting and electronic appliances with a single touch of the fingertip has undoubtedly increased convenience. As shown in Figure 7 the motion sensor was enabled automatically. Further, it was subsequently established that this system also protects the home from electrical risks. The light then began to react to the movements it had sensed.

A timer was inserted into the mobile application. The NodeMCU functioned as expected when the timing was set by the mobile application. The timer option as display in Figures 8 and 9, is set to 15.32.44, and the LED will switch off at that moment.

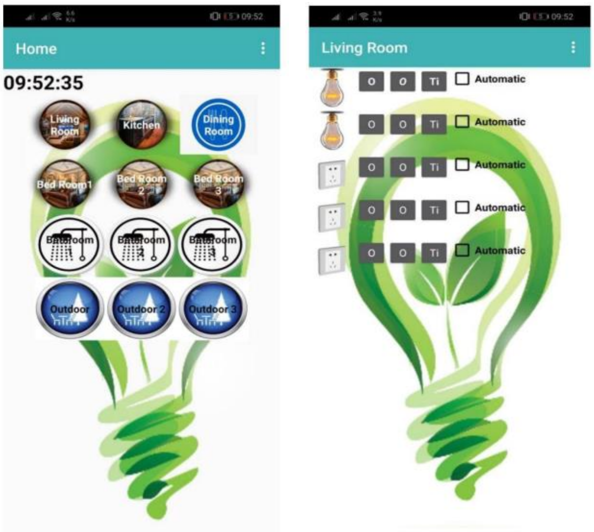

Figure 6: Comparison of Screen 1 (left) of Mobile App and Screen 2 (right) after clicking the living room icon

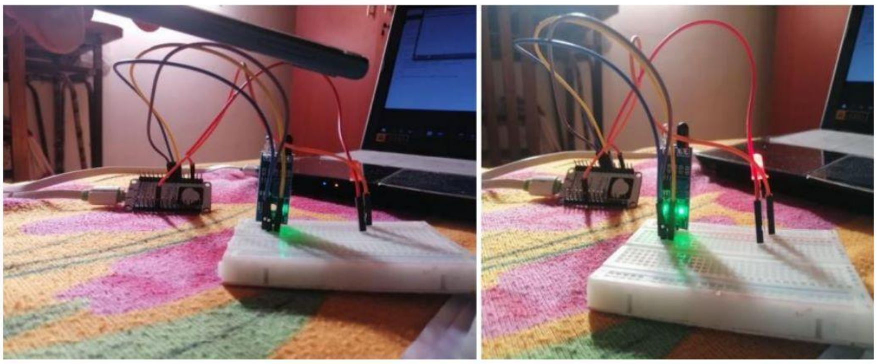

Figure 7: Motion Detection functioning LED acting accordingly

Figure 8: Timer Function

Figure 9: Timer Setting

Because the lighting control system considerably increases occupant safety and comfort while also achieving the primary aim of energy saving, it is clear that this technology is not only practical but also a tremendous step in the right direction for sustainability. This method has countless practical applications, and with the attention and cooperation of stakeholders, it may be used throughout a project to support renewable energy and energy efficiency. By enabling users to contribute to the objective of energy saving, a system like this not only encourages sustainability but also has the potential to increase productivity and mental pleasure of residents.

5. CONCLUSIONS

The automation control and mobile application are key advantages of IoT based system. Further, the extent of energy savings and cost reduction achievable with NodeMCU depends on the specific applications you develop, the devices you integrate, and how effectively you optimize and manage your smart home system. The comfortability comes as a benefit of this system when reducing the power energy waste. The ESP8266 Wi-Fi module is a low-cost device that runs on extraordinarily little power. The prototype developed in this study uses extraordinarily little energy. Additionally, this system is designed to be installed without requiring any changes to current electrical wiring. This system provides a platform for innovation and customization, allowing you to explore various possibilities to achieve energy efficiency and cost savings in your smart home setup. Further, it is most suitable for overcoming the behavioural mistakes that lead to electricity energy waste. These systems also allow users to use a mobile application to keep track of the electricity system in the house. Furthermore, because of this mobile app and ESP8266 module is linked through the Google Firebase database, this system can work over the internet. It is conclusive that the benefits of this system far outweigh any potential misgivings that users may have when it is first introduced. Even with regards to concerns about the additional cost and effort of installing this system into existing buildings, users can rest assured that the long-term benefits and cost-saving potential of this system significantly exceed the initial investment. Users' capacity to contribute to the system's greater sustainability objective as well as its inhabitants' well-being may serve as a powerful incentive for them to use it. This technology may be pushed as a means of minimizing the energy waste that occurs on a regular basis in residential buildings in Sri Lanka.

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ANALYSIS OF BARRIERS TOWARDS IMPLEMENTING CIRCULAR ECONOMY IN SRI LANKAN BUILT ENVIRONMENT

Panchali Weerakoon[1] and M. Thayaparan[2]

ABSTRACT

All over the world, environmental pollution has become a major environmental issue at present. As the construction industry extracts a high amount of natural resources compared to any other industry, it can be known as one of the significant causes of environmental pollution. In order to protect the environment from harmful human activities, there is a massive demand towards sustainable construction practices. Circular Economy (CE) concept has been identified as a way forward to sustainable construction practices. It has been identified that implementing CE in the construction industry has many barriers, enablers and drivers. Hence, this study aims to qualitatively analyse the relevance of the barriers identified through a literature survey in the global context towards circular economy implementation of the Sri Lankan context. Semi-structured interviews were carried out among industry experts and academics who have experience and knowledge of the CE concept. The findings of this study indicate that the practical implementation of CE in Sri Lankan built environment has many barriers as it is still in an early stage. This study concludes that the construction industry stakeholders should be aware of these concepts, and primarily the authorities should focus more on this concept to move forward with a sustainable construction industry and protect the environment.

Keywords: *Barriers; Circular Economy; Construction Industry; Implementation; Sri Lanka.*

1. INTRODUCTION

Environmental pollution is one of the substantial global problems that attracts both developed and developing countries because of its long-term effects (Kampa & Castanas, 2008). It can be identified as a result of humankind's unfavourable activities directly or indirectly towards the environment (Rai, 2016), such as rapid increment of waste production, malicious use of natural resources, urbanisation, and technical and industrial evolution (Kampa & Castanas, 2008). Investing on constructing of new residential, office, factory, school, hospital and infrastructure in order to support urbanisation and social changes has become urgent needs of the society (Vaduva-Șahhanoğlu et al., 2016). Therefore, the construction industry can be considered as one of the significant contributors to uplifting the three-dimensional aspects of a developed

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or developing country (Rajabi et al., 2022). Even though this industry significantly elevates a country's social and economic well-being, it consumes considerable natural resources (Omole & Ndambuki, 2014), specifically fresh water, wood, sand and limestone. One of the major reasons towards this is that the construction industry mainly focuses on "take, make, consume and dispose of ", the liner chain of supplying materials (Ellen Macarthur Foundation [EMF], 2015). In order to reduce these environmental effects through this liner method, the current trend in the construction industry is to replace reclaimed materials with alternative sources for construction materials (Behera et al., 2014). Hence, sustainable construction practices have rapidly increased worldwide recently (Lima et al., 2021).

In comparison to the liner chain of supplying materials, another prominent concept in recent years is the Circular Economy (CE), which is centred on better management of resources (Pomponi & Moncaster, 2017). Further, according to Nodehi and Taghvaee (2022), CE has become a trend in modern society, especially in construction waste management. Despite the development of Sri Lanka’s building sector happened recently, the country is increasingly suffering from environmental challenges caused by unsustainable construction methods (Athapaththu et al., 2016). Further, Athapaththu et al. (2016), stated that unsustainable practices in the Sri Lankan construction industry are now being acknowledged. However, according to Wijewansha et al. (2021), in fulfilment of international sustainable construction (SC) criteria, Sri Lanka remains to be a long way to go. Even though the application of the CE concept in Sri Lanka has been addressed by various scholars (Bekchanov & Mirzabaev, 2018), it is still regarded as a novel concept due to the industry's poor adaptability (Liyanage et al., 2019).

2. LITERATURE REVIEW

In any country, the construction industry is known as of one the most crucial indicators towards the economic development of the country (Alaloul et al., 2021; Makoye et al., 2022), as it makes a significant influence towards the increment of employment (Al-Bayati et al., 2019; Strout, 1958) and regional development (Nodehi & Taghvaee, 2022). Over the past decade, it has become increasingly clear that the rate of production and consumption and technological progress has led to severe environmental and social problems in the world, threatening the sustainability and continuous growth of societies (Bamgbade et al., 2022). The current Linear Economy model has produced approximately 25% of solid waste in the construction industry and extracted more than 30% of the world's natural resources (Benachio et al., 2020). With the increase in the demand for construction materials, the shortage of materials and the growing concern for the environment, the efficient construction of resources has been the subject of intense debate worldwide in, particular after the development of the concept of the CE at various levels of government, industry and academia in recent years (Hossain et al., 2020). According to EMF (2015), CE can be identified as “an industrial economy that is restorative or regenerative by intention and design”. Furthermore, the fundamental aims of CE in the construction sector CE are to preserve the value of constructions and their associated parts while minimising construction and demolition waste to the greatest extent possible (Torgautov et al., 2021). On the other hand, Tseng et al. (2020) have identified that the CE has a broader economic advantage than initial material costs savings or resource optimisation to reduce waste, recycling, reuse or re-manufacturing, as all resources can produce multiplier effects, resulting in higher value generation based on CE principles of maximisation. However, according to Adams et al. (2017) and Ghisellini et al. (2018) implementation of CE in the construction industry has hindered due to various barriers and challenges.

In developing countries, generally, along with a high growth rate, ecological degradation growth is also considered in a high range (Lee et al., 2020), Sri Lanka's construction industry has grown considerably over the past decade. At the same time, as a developing country, Sri Lanka is suffering more and more environmental problems due to unsustainable construction practices (Athapaththu et al., 2016). Researchers like Athapaththu et al. (2016), Liyanage et al. (2019) and Wijewansha et al. (2021), have established strategies that have affected the Sri Lankan construction industry to take into account CE as a sustainable construction industry strategy, such as selecting materials to promote sustainable, environmentally friendly, green materials, acquiring supplies from certified green vendors, planning for the site of use, calculating quantities before ordering materials, and implementing CE. Governments and businesses all around the world have put the adoption of CE on the agenda to address significant environmental problems since it benefits the construction industry (Roy et al., 2022). Nevertheless, significant barriers hinder the construction sector's circular supply and materials recovery (Torres-Guevara et al., 2021). Table 1 elaborates the barriers towards implementing CE in the construction industry.

Table 1 - Barriers towards CE implementation in construction the construction industry

Barriers	**Sources**											
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**
No guarantee on economic benefits	✓		✓								✓	
Lack of understanding/ awareness/information /technology		✓	✓		✓	✓	✓	✓	✓			✓
Lack of policy and regulations		✓	✓		✓	✓		✓		✓		
Limited stakeholder collaboration				✓		✓					✓	
Lack of supportive infrastructure and market to facilitate reuse/recover	✓		✓		✓		✓			✓		✓
Economical/Financing related barriers				✓		✓				✓		✓
Lack of standardised practices		✓	✓		✓			✓			✓	

Source: [A] Yu et al. (2021); [B] Grafström & Aasma, (2021); [C] Ogunmakinde et al., (2021); [D] Charef & Emmitt, (2021); [E] Mahpour, (2018); [F] Cantú et al., (2021); [G] Al Hosni et al., (2020); [H] De Jesus & Mendonça, (2018); [I] Acharya et al., (2018); [J] Sarja et al., (2021); [K] Wijewansha et al., (2021); [L] Al-Raqeb et al., (2023)

The barriers to adopting the Circular Economy concept in the construction sector are shown in Table 1. These are, lack of a proper understanding, lack of awareness and information about the CE concepts, and lack of technology to implement CE concept. Moreover, it can be identified that the second most common barrier towards CE implementation is lack of policy and regulations. The next section outlines the methods used in this research work to determine the significance of the aforementioned barriers to the Sri Lankan building sector.

3. METHODOLOGY

The circular concept has been discussed in a worldwide context in principle during the last few years. According to Liyanage al. (2019), CE adaptability in the Sri Lankan construction industry is poor. This has led to a limited number of industry practitioners who possess adequate knowledge of the CE. Hence, the necessity to have in-depth discussions with those experts demanded a qualitative research approach for this study. According to Ritche et al., (2013) qualitative research represents a specific set of people's views, experiences, beliefs, and attitudes and is ideal for research on emerging conceptions through in-depth investigations .

15 semi-structured interviews with experts from academic and industry practitioners were conducted. The number of interviews was limited to 15 due to data saturation. By the 12th interview, the collected data got saturated and in order to confirm the saturation 3 more interviews were carried out. In qualitative research, “saturation” is the point at which incoming data does not provide any new facts, whcih is accepted as a benchmark for defining sample size (Guest et al., 2006; Guest & MacQueen, 2008). To guarantee that the experts chosen for the interviews have enough expertise and experience with CE in the Sri Lankan construction industry, purposive sampling was employed. According to Bernard (2017), purposive sampling is when a researcher decides what information is needed to know and then find people who can and are capable to supply it due to their knowledge or experience. The profile of each respondent is given in Table 2. The collected data was analysed through content analysis.

Table 2 - Respondent's profile

Respondent No	Designation	Experience with green buildings	Total years of experience
R 01	Deputy General Manager	10	25
R 02	Quantity Surveyor/Academia	10	24
R 03	Environmental Engineer	8	15
R 04	Project Manager	15	48
R 05	Managing Director	12	28
R 06	Senior Lecturer/Green AP	4	8
R 07	Senior Professor	13	30
R 08	ASHRAE Distinguished Lecturer/Director	12	46
R 09	Senior Professor	18	18
R10	Energy Efficiency Specialist	6	8
R11	Senior Energy Consultant	20	30
R12	Architect	10	15
R13	Quantity Surveyor	10	15
R14	Site Engineer	8	12
R15	Project Coordinator/Green AP	5	7

4. RESEARCH FINDINGS ON THE BARRIERS TOWARDS CE IMPLEMENTATION

The level of implementation of the Circular Economy in Sri Lanka is inadequate due to several barriers. The barriers identified using existing literature (Refer to Table 1) are further analysed using primary data in this section to explore the relevance of such barriers in the Sri Lankan construction industry context.

4.1 NO GUARANTEE OF ECONOMIC BENEFITS

Construction Industry is a profit-making industry. Stakeholders will only take over the risk of implementing a new concept if they know the benefits, they can gain from it. According to the perspective of R07, R10, and R11, there should be a proper guideline for the investors and the clients to refer to the benefits of their investment. Further, they suggested that this guideline quantifies the economic benefits using different parameters at different construction project phases. Respondents stressed that the first step of implementing the CE concept is ensuring that investors clearly understand the economic benefits of investment because implementing this concept is possible with the investor's consent.

On the other hand, R07 argues that industry practitioners should fulfil their corporate social responsibility towards the development of social, economic and environmental factors. Hence, through research and development, the stakeholders can identify the actual economic benefit of this concept and introduce it to the industry. Confirming this fact, R09 stated that *"Sri Lankan construction industry practitioners should consider collaborating with academia for further developments of the industry like this"*.

4.2 LACK OF UNDERSTANDING/AWARENESS/INFORMATION

In general, employers working at the site level in construction companies are unaware of concepts like sustainability and circular economy. In particular, the site-level employees of small and medium-sized contract companies face these scenarios for various reasons. R01, R02 and R03 highlighted that in Sri Lanka, lacking knowledge regarding these kinds of relatively new concepts has caused many problems during the design and post-contract stages. Further, they stated, *construction stakeholders do not bother to learn new concepts but practice the same old conventional methods and make profits out of it, which will be harmful to the environment in the long term*. R14 and R15 emphasised that as the CE concept has to be implemented from the design stage, awareness about this concept among all the stakeholders is crucial in the long do.

As stressed by the respondents, **the relevant parties and authorities should take the necessary actions to mitigate this barrier as it has led to negative environmental impacts due to the unsustainable construction activities by many parties.** Sri Lanka is a country blessed with many natural resources. However, with the population increase and the development of the construction industry, natural resources have become scarce. Due to the complete extraction of natural resources, the country is also facing natural hazards. Even though the situation is considerable, the attention towards these problems from the authorities needs to be improved.

4.3 LACK OF POLICY AND REGULATION

Even though many respondents agreed that lack of policy and regulation is a barrier to CE implementation, R02 and R15 brought up a counter-argument that implementing CE at a policy level will increase the improper activities in the industry as well as at the policy-making level in the country; hence they believe this change should happen along with the change of people's thinking pattern but not through rules and regulations. The respondents who agreed with a policy-level change stated, as Sri Lanka is a developing country, without policy Sri Lanka will go nowhere. Contradictory to this fact, R01 stated, with 25 years of experience, that it is doubtful, even with Policies, whether Sri Lanka will move forward with a concept like this as Sri Lanka's situation is getting worse daily with more corruption in every sector.

Political influence for policy implementation – In Sri Lanka, even though there are different existing policies towards environmental protection and sustainability related to the construction industry, implementing these policies is deplorable. Respondents highlighted that Sri Lanka does not have a proper system to implement the policies. Further, they highlighted that corruption takes place at various levels by the officers might be the main reason for this. While more than two-thirds of the participants agreed with this fact, they also highlighted that only a policy would not change Sri Lanka.

4.4 LACK OF SUPPORTIVE INFRASTRUCTURE TO FACILITATE REUSE/RECOVER

Most respondents agreed that Sri Lanka needs a supportive infrastructure to facilitate reuse/recovery. The main reason respondents mentioned, How the second-hand market can give an assurance about their goods? When some sellers price second-hand products higher than the price of purchasing or manufacturing them from scratch, it reduces the demand for second-hand markets. Also, some shop owners keep products longer without selling them, making them look antique and trying to sell them for a higher price than it costs. On the other hand, a few respondents stated that a part of the Sri Lankan community does not tend to reuse due to their different beliefs.

4.5 LIMITED STAKEHOLDER COLLABORATION

Construction projects are unique and complex. To implement the circular economy concept, construction projects should welcome strong stakeholder collaboration, even though it might lead to a more complex scenario, which on the other hand, will make the project harder to manage. R07 highlighted that *"making a construction project more complex might end up with huge losses"*, whilst R08 stated that *"making a construction project complex will not be an issue as long as best practices like RIBA plan of work implemented at project level"*. Moreover, respondents mentioned that stakeholder collaboration could have both positive and negative impacts on the project completion, and the interest of the stakeholders might not be the same; in that case, even with the stakeholder collaboration, the project might not be able to be implemented CE up to the expected level.

4.6 LACK OF STANDARDISED PRACTICES

This was identified as one of the major reasons for failing to implement CE in Sri Lanka adequately. The authorities should guide the stakeholders in the construction industry with proper practices. Few respondents stated that what does it have to do towards implementation of CE was a common question from their experience in the industry. Towards lack of standardised practices, the participants were given mainly two reasons;

Not spending adequate time in the design stage of a project – It has been observed that most of the construction projects in Sri Lanka spend minimal time during the design stage. Hence, the changes during the post-contract stage due to lack of planning and designing are vital in the construction industry. There should be proper planning for obtaining and selecting materials for the CE implementation.

Lack of skilled labour – In the Sri Lankan construction industry, most labourers have no qualifications to work even as labour. Thus, they have been working in the industry for decades as it is their family occupation. Without proper education, understanding the skills which are needed for CE concept implementation will not be able to obtain from them.

Barriers towards Circular Economy implementation in Sri Lanka are mostly common to the barriers which were identified in the worldwide context. And it was recognised that there are other barriers are linked with the main barriers which are more specific to the Sri Lankan context as it is a developing country. Among these barriers, the most highlighted barrier by the participants was “Lack of Policy and Regulation” in Sri Lanka. As the sub-barriers related to this barrier; political influence, fraud activities and corruption in government were identified.

5. SUGGESSIONS TO OVERCOME THE BARRIERS TOWARDS CE IMPLEMENTATION

To overcome the barriers to implementing CE in the Sri Lankan construction industry, industry and academic experts in CE have suggested different solutions. The participants of the interview were given more suggestions as mentioned in Figure 1 to overcome the barriers towards CE implementation.

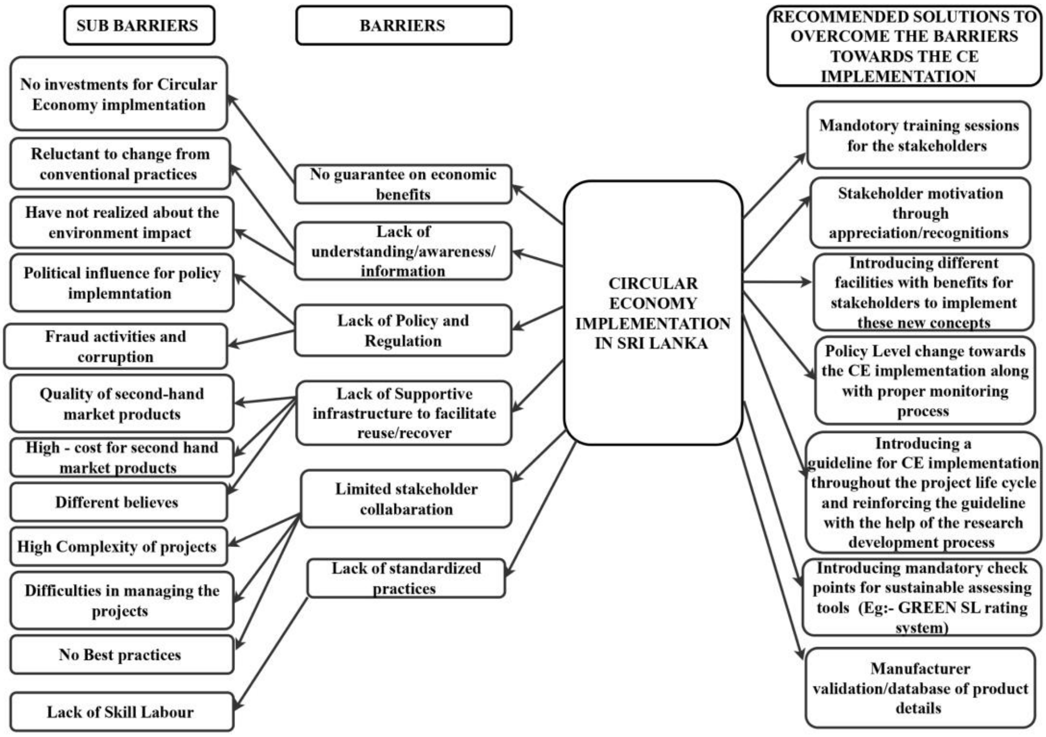

Figure 1 - Circular Economy Implementation in Sri Lanka

Mandatory training sessions for construction stakeholders - To make construction stakeholders aware, brainstorming sessions and compulsory training sessions should be implemented at the authority level. Introducing a minimum qualification level for construction workers was also suggested as a part of this recommendation.

Stakeholder motivation through appreciation/recognition – Government authorities related to the construction industry and environmental protection can introduce special benefits schemes for the construction stakeholders as appreciation for working towards sustainable development. Furthermore, respondents indicated that Sri Lanka could attract more investors from different sectors to invest in Sri Lanka.

Introducing different facilities with benefits for stakeholders to implement these new concepts – It was suggested by the interviewees that the government should play a vital role towards implementing this concept as it has numerous benefits towards the country's development. The suggested facilities by the respondents that the government can provide for the betterment of this implementation are; loan facilities with interest-free and tax exclusions.

Policy Level change towards the CE implementation along with proper monitoring process - The industry experts suggested that a policy level change should adhere in Sri Lanka as it is still a developing country and the knowledge and the consequences of environmental pollution have not been understood by the general public and even by some governing parties. Therefore, improper activities for example, issuing permission to cut trees, are still happening in Sri Lanka. A proper monitoring process should also be introduced to the stakeholders to mitigate improper activities.

Introducing a guideline for CE implementation throughout the project life cycle and reinforcing the guideline with the help of the research development process - It was recommended to introduce a guideline for the Circular Economy implementation with the collaborative inputs of experts in academia and industry. This guideline may include standard practices to implement CE in the construction industry.

Introducing mandatory checkpoints for sustainable assessing tools (e.g., GREEN SL rating system) – As there is a trend of obtaining GREEN SL rating system in Sri Lanka aiming different marketing perspectives, respondents suggested introducing mandatory checkpoints within the GREEN SL system as it can value the rating system as well and it will help for the CE implementation also.

Manufacturer validation/database of product details - To motivate the **reuse** principle in the Circular Economy concept, respondents suggest; manufacturer validation about the quality, life cycle, and carbon emission from the product.

6. CONCLUSIONS AND RECOMMENDATIONS

As a developing country, Sri Lanka's construction industry continues to improve to meet citizens' needs and develop the country's infrastructure. As the construction industry develops, the construction industry consumes a large number of natural resources, and environmental degradation also occurs. CE has been identified as a solution to the sustainable construction industry. Implementing the CE concept in the Sri Lankan construction industry has faced numerous barriers. As a conclusion while Sri Lanka's construction industry focuses on developing facilities, stakeholders should pay attention to minimising environmental pollution. Implementing the CE concept will benefit the stakeholders and protect the environment. The Sri Lankan government should facilitate towards these concepts as it has social and economic benefits for the nation.

Based on the findings of this paper, further studies can be adopted on; formalised path-way of achieving the circularity within a construction project indicating the cost-benefits through implementation this concept.

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APPLICABILITY OF BIM TECHNOLOGY FOR ENHANCING THE LEAN CONSTRUCTION PROCESS IN SRI LANKA

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ABSTRACT

Building Information Modelling (BIM) is widely implemented in construction industries around the world, providing many benefits. BIM has brought significant improvements in productivity, accuracy, and efficiency. Lean is an innovative construction management method that is closely linked to the overall lifecycle of a project to ensure its success. Lean and BIM are two different concepts used to enhance the value and quality of overall construction projects. The combination of these two concepts has been used to eliminate waste and encourage a streamlined workflow ensuring the delivery of value to the customers. But still, there is a lagging that can be identified in the applicability of BIM for enhancing the lean construction process in local scenarios. Therefore, the study explored the applicability of BIM technology for the lean construction process in Sri Lanka. Accordingly, a comprehensive literature survey and three case studies were conducted to collect data. Subsequently, the collected data were analysed using content analysis with the use of NVivo software. The study indicates that 12 lean techniques which have been implemented in local construction projects and 9 BIM-related software encourage the establishment of lean principles. The study further revealed, 7 common challenges while integrating of Lean-BIM and 9 solutions to overcome the challenges identified. Finally, a framework was developed based on the research findings to identify the current situation of the applicability of BIM technology for enhancing the lean construction process in Sri Lanka.

Keywords: *Building Information Modelling; Construction Industry; Collaboration; Lean Construction.*

1. INTRODUCTION

The construction industry is one of the key industries which contributes to the country's economy (Onyango, 2016). In a developing country, construction is crucial because it creates a path for the country's economic growth and is also very complex in its nature (Aljahdali & Alsulami, 2017). Hence, it has become a very challenging task to achieve the project requirements and constraints (Cheung & Yiu, 2006). According to Issa (2013), lean construction is a philosophy oriented toward construction administration which was developed from Toyota`s production system. Also, it sets productive flows in motion to

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develop and control systems to reduce losses throughout the construction process. Reduced cost of implementation, improvement of continuity, minimising waste, and finishing the output within the agreed period are some of the advantages of lean construction (Li et al., 2020). According to Johansen and Walter (2007), lean principles have been used in developed countries such as Australia, Denmark, Finland, Singapore, the United Kingdom, and the USA, to get the best value for their projects. With the technology development, the concept of Building Information Modelling (BIM) came into place. BIM helps to minimise wastage, and errors to carry out the construction process effectively and efficiently as well as reduce the life cycle cost and gain the quality of the output (Epasinghe et al., 2018). BIM is used for this lean construction process in parallel (Guerriero et al., 2017). Most European countries and the United States have obtained progressive popularity in BIM technology. Over the last few years, BIM usage has risen dramatically over the world, particularly in industrialised countries such as Australia, China, Denmark, Finland, and Singapore, Sweden, the United Kingdom (Ullah et al., 2019). However, it has previously been observed that the Sri Lankan construction industry has poor records in completing projects within the given time, allocated cost, and expected quality targets (Halwatura & Ranasinghe, 2013; Perera et al., 2021). Sri Lanka is still in the initial stage of lean practice and BIM technology. Based on the "Bew-Richards UK BIM Maturity Model," the Sri Lankan construction industry is classified as being in "Phase 0.". Hence, this research paper identifies the significance of BIM's applicability to the lean construction process in Sri Lanka.

2. LITERATURE REVIEW

2.1 LEAN MANUFACTURING

The lean process involves adding value to the production to get a high return on investment in manufacturing (Salem et al., 2006) and combines both workflows of the organisation with the organisational techniques to achieve a higher quality outcome by using minimum resources (Katayama & Bennett, 1996). The lean manufacturing system has encouraged by five principles which are identifying value, mapping the value stream, creating flow, establishing pull, and seeking perfection. Lean production principles were successfully used for TOYOTA product manufacturing in 1950 in Japan (Abdelhamid & Salem, 2005). Those principles boost creating better production flow and improve the culture continuously. According to Kelendar (2020), there are three main concepts in lean thinking including eliminating waste, creating values, and continuous improvement which can be used to identify value-adding activities, non-value-adding activities which can be eliminated, and non-value activities which cannot be eliminated in the process. Those non-value activities which can be eliminated are called 'waste'.

2.2 LEAN CONSTRUCTION

Even though lean was developed for the manufacturing industry, it has had a significant impact on many other industries all over the world (Abdelhamid & Salem, 2005). There are significant differences between the construction industry and other manufacturing industries. According to Salem et al. (2006), the construction industry deals with larger units in which end products cannot be transported whereas the manufacturing industry deals with the end products which can be moved as a whole. Further, the researchers have highlighted that some of the other differences are on-site production: productions are site position manufacturing, One-of-a-kind production: customer decides the final output, complexity: completion of construction projects are very complex, unique, and dynamic systems (Koskela & Howell, 2002). Even though there are differences between the construction industry and other manufacturing industries, the objectives of every project are the same. According to Howell (1999), it is a common scenario when it comes to the goal of delivering a project meeting specific customer requirement in zero time. According to Koskela (1992), lean construction techniques have become a foundation for project management because it views the construction process without focusing on individual activities. According to previous studies, the countries such as Australia, Brazil, Chile, Denmark, Ecuador, Finland, Peru, Singapore, South Korea, the UK, the USA and Venezuela are the leading countries which have adopted lean construction (Albalkhy & Sweis, 2021; Ballard & Howell, 2003; Johansen & Walter, 2007; Jørgensen & Emmitt, 2008). With time, many instruments have been created to materialise the application of the lean construction philosophy more systematically, they are minimising waste, maximising value, and continuous improvement.

According to Marhani et al. (2013), the implementation of lean construction has a profound impact on construction schedules and overall project performance. It effectively enhances workforce productivity, fosters effective coordination and communication, and reduces defects and rework. One of the most significant positive outcomes of embracing lean principles in construction projects is the timely delivery of completed projects to clients. Furthermore, the adoption of lean principles has led to an increased rate of innovation within the construction industry (Meng, 2019).

2.3 BUILDING INFORMATION MODELLING

Like all the other industries, the construction industry also gets benefited from a range of information and communication technology (ICT) solutions in the project delivery process (Bui et al., 2016). It has proved that the construction industry is more productive with ICT applications (Bryde et al., 2013). The most prominent example of an effective ICT application using in the construction industry is BIM (Eadie et al., 2013). BIM is widely seen as a stimulant for innovation and productivity in the global construction industry. In the current industry practices, BIM is commonly used to design, construct, and maintain approaches for projects (Bryde et al., 2013). BIM integrates people and technology to reduce time and costs and increase efficiency in projects. Unlike other ICT applications used in the construction industry, BIM can create realistic models of the building. In the design, construction and operation process, BIM is used to create and manage the data and represent it in a cloud-based real-time collaboration platform. IFC enables the interoperability between BIM software and uplifts collaboration with the professionals involved in the construction industry (Tse et al., 2005). It enables data visualisation, rapid generation of alternative designs, automated assessment of model reliability, generation of comprehensive reports, and accurate forecasting of building performance (Ullah et al., 2019; Sacks et al., 2010). Further, in the construction phase, a project team can monitor the progress, coordinate meetings, integrate RFIs, change orders and punch list information using the BIM models (Al-Yami & Sanni-Anibire, 2021).

As Ullah et al. (2019) demonstrate, in recent years, there is a significant increase in the adaptation of BIM in developed countries, whereas most Asian countries have used BIM for all their public projects. However, whether it was used the BIM technology for numerous purposes, and individually use the BIM and lean concepts competitively for construction industry development, no research has been conducted to investigate the applicability of BIM technology for enhancing the lean construction. Thus, the following methodology has been taken to find out the applicability of implementing BIM technology to enhance the lean practices in the Sri Lankan construction industry.

3. METHODOLOGY

In this study, a comprehensive literature survey was conducted to identify the lean construction principles in the construction industry and then, BIM and its uses in the construction industry. Correspondingly, the case study approach was followed under the qualitative research method to identify the application and practical issues of implementing BIM and lean applications in the Sri Lankan construction industry. Due to the limited number of BIM projects in the Sri Lankan context, a purposive sampling method was used to select individuals who were most relevant to the research objectives. It enables to increase the accuracy of the data by allowing the researcher to gather in-depth and focused information from the selected sample. Accordingly, three case studies which used BIM-related software applications were selected, and under each case study, nine respondents were interviewed. Then the collected data were analysed using content analysis with the use of NVivo software. The profiles of the case study projects are summarised in Table 1.

Table 1: Case study profiles

Description	Case A	Case B	Case C
Project Type	Educational	Infrastructure	Office
Contract Sum	LKR 1.6 billion	USD 550 million	LKR 5 billion
Project Duration	2 years	3 years	3 ½ years
Procurement Type	Measure & Pay	Measure & Pay	Design & Build
LOD level	LOD 350	LOD 350	LOD 400
BIM Maturity Level	Level 2	Level 2	Level 2
Used BIM Software	CubiCost, Sketchup	SketchUp, Revit, CubiCost	BIM 360, Revit, CostX, Navisworks
Other Software	Zoom, MS Project	Zoom, MS Project	Asana, MS Teams, MS Project

From three case studies, each case was interviewed by three professionals. All nine respondents' details are shown in table 2.

Table 2: Respondents' Profile

Respondent	Title	Type of Org.	Experience (years)		Professional Qualification	Scope of Work
			Industry	BIM		
A1	Quantity Surveyor	Consultant	3	2 ½	BSc QS	Quantification, communication, collaboration, cost management
A2	Director (Quantity Surveyor)	Consultant	16	5	Charted QS	Reduce cost & manpower, cost estimates, communication & collaboration

Respondent	Title	Type of Org.	Experience (years)		Professional Qualification	Scope of Work
			Industry	BIM		
A3	Project Quantity Surveyor	Contractor (CS2)	3	2	BSc. QS	Quantification, Managing the team, Checking the models & drawings, Collaboration
B1	External BIM Advisor	Consultant	3	1	BSc (Hons) QS	Introduce BIM to the project, Identify LOD in the Pre-contract stage
B2	Director (QS)	Consultant	30	5	Charted QS	Pre-Tendering works, Cost Estimation, Cost Planning
B3	Quantity Surveyor	Consultant	4	2	BSc. QS	Quantification, Cost estimates
C1	Senior QS (BIM Team Leader)	Consultant	10	5 ½	Charted QS	Construction and rectification of defects, Quantification, Managing the team
C2	Senior Architect	Consultant	15	5	Charted Architect	Modelling
C3	Engineer	Consultant	8	3	BSc (Hons) Electrical	Modelling electrical drawings

4. ANALYSIS AND FINDINGS

4.1 IDENTIFICATION OF LEAN WASTES IN THE CONSTRUCTION INDUSTRY

Respondents were asked to provide information about the lean wastes which they have experienced during their past projects. All nine respondents mentioned that they had identified all eight lean wastes during their past projects. According to A1, most sites don’t have a proper waste disposal system. They had to transport materials to another land from the construction site to dispose of, which results in additional costs for the project. Supporting this argument, B2, B3, and C3 also highlighted the presence of waste in construction and transportation. C3 further explained that in cases where low-quality materials are ordered or inadequate storage facilities are available, particularly in MEP sections, the replacement has to be done due to damages. B1 states *“the motion waste comes up with poor coordination, miscommunication, and poor documentation. Labours’ carelessness and the supervisors’ ignorance make more motions in the site. To find specific equipment site labourers have to walk through the site and waste time”*. Not only in the sites but also in the consultancy firms motion waste can be identified.

According to C1, *“most architects' workspaces and equipment tend to be messy, and it makes very difficult in locating documents and tools”*. This lack of organisation can lead to wasted time and delays. Another form of waste identified in lean construction is excessive inventory. C3 expressed that the ordering and purchasing of materials to address damages can result in an accumulation of excessive inventories, which ties up capital and contributes to waiting waste. C1 specifically highlighted that waiting waste is most commonly observed in MEP sections. Additionally, B1 and A1 identified that delays in drawings also lead to waiting waste. While A2, B1, and C1 mentioned that waiting waste can be caused by client decisions. B2 emphasised that it can also occur within the team itself. C1 further explained *“when purchasing orders are not placed in a* *timely manner as per a procurement plan, it results a considerable time waste"*. Delays can occur if purchasing orders and requests are not submitted promptly. A1 further stated that most of the defects can be identified from the site due to poor quality of work, damaged material, rework, or punch list items.

As reinforcement is one of the major materials, which has a high-cost, waste of reinforcement is a major issue in the construction industry. A3 mentioned that since labours who are in the bar bending yard cut reinforcements according to the schedule provided, changes in these schedules result in material waste. B2 and C3 also mentioned that overproduction can happen on the sites. According to the data collected, over-processing was highlighted only by respondents B2 and B3. However, B3 stated that poor communication, coordination, and task management will lead to over-processing waste.

Moreover, the drawing changes were highlighted as common in the construction industry. B1 and B2 explained that these drawing changes often require a reassessment of quantities, resulting in wasted skills. A2 further illustrated that variations in the project also contribute to the misuse of skills, estimating it to be around 7% of his experience.

According to the data analysed, waste occurs throughout the entire project in the Sri Lankan construction industry. Most of the waste identified by the respondents is related to waiting, such as waiting for approvals, waiting for drawings, and sub-contractors waiting for others to finish their tasks. These waiting periods significantly impact project efficiency. However, the analysis reveals that the construction industry experiences all eight lean wastes during the construction process.

4.2 LEAN PRACTICES WITH BIM-RELATED SOFTWARE IN SRI LANKA

Respondents were asked about the software and the lean techniques that they have used for their projects. According to their opinions in Sri Lanka, there has no 100% BIM or lean projects. They have used other software and techniques to implement lean in their organisation. Table 3 shows the techniques which have been used with BIM software.

Table 3: Lean techniques with BIM software

Lean Technique	BIM Software
Visual Management	Revit, CubiCost, BIM 360, Viskar, CostX, Navisworks, SketchUp
Integrated Project Delivery	MS Project
Target Value Cost	CostX, CubiCost
Pull Approach	MS Project, Primavera
Effective Analysis	Primavera
Last Planner System	MS Project, Primavera, Navisworks
Just in Time	Navisworks
Value Stream Mapping	Navisworks
Target Value Design	Primavera
Line of Balance	Primavera

In addition, companies implemented lean techniques using other software. Table 4 presents the non-BIM software used to implement lean.

Table 4: non-BIM software with lean techniques

Lean Technique	Non-BIM Software
Kanban	Asana
Daily Huddle Meetings	Zoom, MS Teams

4.3 CHALLENGES OF BIM TECHNOLOGY FOR LEAN CONSTRUCTION IN SRI LANKA

In case A, A1, A2 and A3 expressed that since the BIM technology is still not established in Sri Lanka, the knowledge and practice regarding the adaptation of lean using BIM technology are relatively low here. They have identified a lack of professional knowledge and the influence of the traditional education system as significant factors affecting this situation. A3 also points out that the unwillingness to embrace change is a challenge, as many traditional professionals are reluctant to adopt new technologies. A2 specifically mentioned the absence of a BIM culture in Sri Lanka, while A3 emphasises the resistance towards technological advancements.

A1 has highlighted the lack of expertise and limited commitment to research and development regarding lean practices and BIM technology in Sri Lanka as another barrier. As a developing country, one significant obstacle in Sri Lanka in implementing BIM technology is the high initial costs associated with BIM-related software applications, which are often difficult to afford for most contractors, consultants, and employers in the country. Further, the limited availability of resources and financial constraints make it difficult for the construction industry in Sri Lanka to fully embrace BIM due to the high upfront investment required. A1 mentioned that *"Government involvement in the advancement of modern technology is very poor"*. Further, A3 stated that Denmark, Finland, and the UK have better BIM implementation because of the strong involvement of their government. As the respondents emphasised, compared to those countries, Sri Lankan government involvement is significantly lower. It can be inferred that the limited government involvement in imposing guidelines and the absence of adequate standards and protocols for BIM contribute to the challenges faced by Sri Lanka in effectively implementing BIM in the construction industry.

Consequently, in case B also, B1, B2 and B3 emphasised the lack of experience in the use of BIM technology and lean as a key barrier. Additionally, there is a common perception among professionals that tasks performed using BIM can be accomplished using traditional methods as well. This mindset hinders the adoption of BIM and prevents the exploration of its full potential. Furthermore, if organisations aim to implement BIM alongside lean practices, the need to invest in staff training and provide opportunities for hands-on practice were recognised as demotivating factors. Alongside software expenses, the requirement for high-performance computers further adds to the financial burden. Additionally, it was found challenging for more experienced professionals to adapt to new technologies like BIM as they are not familiar with computer technologies.

4.4 MEASURES TO OVERCOME CHALLENGES FOR IMPLEMENTING BIM TECHNOLOGY FOR LEAN CONSTRUCTION IN SRI LANKA

When considering the lack of knowledge and less commitment to education among construction professionals in Sri Lanka, A1 suggested to engage foreign experts to increase the awareness of them. This could involve organising continuous professional development (CPD) programs, webinars, and seminars. Additionally, A1 proposed that universities should incorporate comprehensive educational programs for undergraduates right from the beginning. Consequently, B3 stated that open BIM centres will help to get education about BIM and lean.

Additionally, government support emerged as a significant factor, as suggested by the respondents. A2 emphasised that "*one way the government could support the industry would be to establish specific organisations to provide education, training, and resources to professionals in the industry"* This would facilitate the dissemination of knowledge and expertise in BIM technology and lean principles. In contrast, B2 recommended encouraging the use of BIM technology and lean principles by providing funding for pilot projects which demonstrate their benefits in the Sri Lankan context. The third suggestion put forward by the respondent A1 was the introduction of guidelines and regulations that either mandate or incentivise the use of BIM technology and lean principles in specific construction projects. Such measures would promote their integration and create a standardised approach within the industry. In addition, B1 proposed offering tax incentives to encourage investment in necessary machinery and provide a trademark or recognition to organisations who are implementing BIM technology. As the same respondent explains, *"this could be similar to the rating system in sustainable construction, where organisations receive grades such as gold or platinum based on their performance".* This grading system could be extended to include BIM and lean construction, providing a clear evaluation framework.

As the respondents mentioned they had to spend the high cost of the computers and the purchasing software. Other than that, organisations must train their staff and they have to hire those who have knowledge about BIM and lean practices, and after purchasing software they had to renew their licences and maintain the cost of computers. C1's opinion about the cost of purchasing items was *"if you want to use BIM, you have to buy the software and machines which are required"* or he suggested, *"we can charge from it from the client"*. To do that A2 and B2 mentioned that they must promote BIM and lean technologies among the clients.

Figure 1 represents the identified wastes in the construction sector, the lean tools that can be used, and the BIM application for each lean technique to minimise construction waste in Sri Lanka. Further, the above-discussed challenges and solutions to overcome those in BIM technology and lean implementation are discussed in Figure 1.

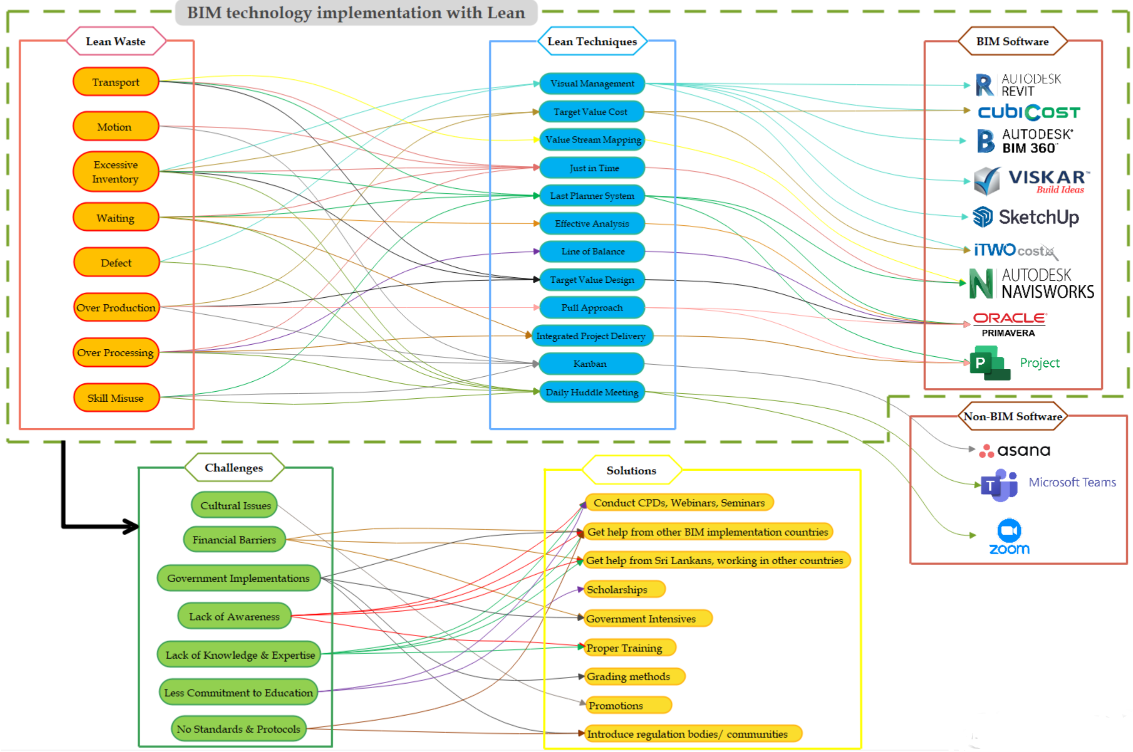

Figure 1: Framework of applicability of BIM technology to enhance lean construction in Sri Lanka

5. CONCLUSIONS

In conclusion, numerous lean techniques, such as just-in-time, the last planner system, Kanban, target value cost, daily huddle meetings, and pull approaches, can be applied directly and indirectly in the construction industry. By adopting these techniques, most countries could achieve significant benefits. The study identified how Building Information Modelling (BIM) technology is utilised in the construction industry and the purposes it serves. Standards and protocols for creating, managing, and using BIM models offer rules and best practices throughout a building or infrastructure project's lifecycle. BIM software enables collaboration on a project and real-time information sharing between architects, engineers, and construction workers, enhancing communication, and lowering errors. Subsequently, combining lean construction and BIM models is an approach that seeks to enhance productivity, minimise waste, and improve quality in the construction sector. The study conducted interviews with three industry professionals who are currently utilising BIM technology and lean practices in their projects. The data collected highlighted how BIM technology can be used to identify and minimise lean waste. For a developing country like Sri Lanka, integrating BIM and lean project management practices can lead to high-quality project outcomes in the minimum possible time.

The study further identified the challenges of implementing BIM technology to enhance lean construction in Sri Lanka. Accordingly, financial barriers, government implementation, lack of awareness, and lack of knowledge were identified as the most critical challenges. Therefore, it is recommended to get the support of other countries, and Sri Lankans working in other countries who have engaged in BIM practices to overcome the challenges and to enhance lean construction through BIM in Sri Lanka.

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APPLICABILITY OF BLOCKCHAIN TECHNOLOGY IN THE SRI LANKAN CONSTRUCTION INDUSTRY

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ABSTRACT

Construction is one of the most significant drivers of economic growth for any nation. In addition to contributing heavily to economic development, it is one of the world's biggest industries. The industry's productivity or effectiveness has often been in doubt whether the industry is productive or effective. To upgrade the standards of the construction industry, different digital tools and software have been introduced. Among numerous innovative technologies spreading across the construction industry, blockchain is emerging as a breakthrough in streamlining the structure and development of various processes. Therefore, this research tends to study how blockchain technology can improve the key performance indicators in the construction industry via various blockchain applications that can be utilized in the construction industry. The correlation and the impact between the applications of blockchain and the construction industry performance were analysed through statistical analysis via SPSS software. A qualitative expert opinion survey with ten construction experts who have experience in blockchain technology, selected through purposive sampling to collect data in Sri Lankan context, was conducted to collect suggestions and recommendations to implement blockchain in the Sri Lankan construction industry. The gathered data was analysed using the content analysis method. The barriers that Sri Lanka must overcome to adopt blockchain technology and the way to mitigate them were included in the study. How can Sri Lanka be prepared to adopt blockchain technology and what applications can be applied in the Sri Lankan construction industry were discussed in this study.

Keywords: *Blockchain Technology Application; Implementation; Key Performance Indicators.*

1. INTRODUCTION

National economic growth relies heavily on the construction industry. As a result, many jobs and income are created for overall society due to the infrastructure provided by it. This includes infrastructure for health, education, and transportation. Collaborative operations pose many challenges for the construction industry. Several failed projects around the world are caused by poor performances. Unfortunately, a substantial percentage of project activities (e.g., prefabrication) are conducted off-site or offshore, resulting in the loss of management control. In the construction business, numerous

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disputes and litigation problems have arisen about payments withheld, quality fraud, and data authentication. Researchers and practitioners have recognized that construction project business processes lack transparency and accountability.

Supply chain developments in the construction industry are being handicapped by a drop in mean value and a rise in transactions. In construction supply chains, low trust has been an ongoing problem for a long time because of decentralised teamwork. Through digital technology, it may be possible to achieve the criteria of centralised teamwork with high transparency. It is the primary purpose of these technologies to increase trust, visibility, and traceability as well as strengthen partnerships among key stakeholders regarding the sustainability of the materials. With blockchain technology (BCT), knowledge exchange and transactions can be streamlined and protected. An ever-increasing collection of data records is preserved in blockchain technology through a central archive fund. Building a supply chain that utilizes blockchain technology is a relatively new concept.

The problem in the industry based on this study is that the construction industry in Sri Lanka still suffers from poor project performance. This is due to a lack of well-defined practices and strategies and the complex nature of work. Hence, the construction industry in Sri Lanka is yet to be improved with ways for implementing Blockchain Technology to improve. In this research paper, a way of supporting and upgrading the construction industry's performance through digitalization is being researched. Blockchain technology is new to adopt, so this study suggests suggestions for implementing blockchain technology in the Sri Lankan construction industry. This study was done to identify the factors that affect the performances in the Sri Lankan construction industry, to identify the application of blockchain technology, to determine the correlation of blockchain applications with the improvement of performances and evaluate the impact of the application of blockchain in the construction industry and propose suggestions to implement blockchain in the Sri Lankan construction industry.

Many applications of this technology have been proposed and recently discovered in. the construction. industry, including enhancing energy demand and supply, connecting with Building Information Modelling (BIM), and ensuring cyber safety (Khan et al., 2021).

The purpose of this paper is to identify the factors affecting the construction industry in Sri Lanka, as well as how blockchain technology can be applied to the industry. There have been recommendations made for implementing blockchain in the Sri Lankan construction industry based on the evaluation of the application.

2. LITERATURE REVIEW

As a major contributor to the national economy, the construction industry provides substantial employment to many people (Murari et al., 2021). For a project to be successful, it's critical to consider factors like cost, timing, quality, health, safety, and environmental concerns, as well as the effective use of resources (Ahsen et al., 2021). According to the findings, the 10 key performance factors (KPIs) are Time, cost, quality, safety & health, internal stakeholders, external stakeholders, client satisfaction, financial performance, environment, information, technology and innovation (Soewin & Chinda, 2018).

As a major contributor to Sri Lanka's economic growth, the construction industry plays a crucial role. Although the industry faces unique challenges and difficulties, it also faces significant challenges (De Silva et al., 2008). The current context in Sri Lanka shows that many construction projects have not achieved their cost targets and goals. There have been various project control techniques developed over the past few years (Cooray et al., 2018). As with the Construction Industry, companies have been trying their best to reap the benefits of technology disruption and bring a sense of innovation into an industry that was largely hardwired to the analogue era previously (Narayanan et al., 2016). To achieve process improvement, the concept of digitalization is used to minimize costs, time, and resources. In construction, it is also referred to as digital transformation for operational excellence (Zhang & Zou, 2017). The Block chain technology was introduced simultaneously with Bitcoin. A document titled "Bitcoin: A Peer-to-Peer Electronic Cash System" was published in 2008 by Satoshi Nakamoto. To remain anonymous, the paper was published under Satoshi Nakamoto's name. The author wished to remain anonymous, so no one knows who he is to this day (Lemieux, 2016).

A blockchain preserves transparency and builds trust among its users by consolidating public information and creating checks and balances. As a technology, blockchains are fundamentally about trust optimization (Zheng et al., 2017). Blockchain technology features a central archive function that maintains a growing collection of data records. As a result, blockchain technology can facilitate knowledge exchange and secure transactions (Nakamoto, 2020). According to Royal Institution of Chartered Surveyors (2021), blockchain can be categorized into five types open blockchain, Private blockchain, permissioned blockchain, Hybrid architectures and off-chain storage & Cross-chain interoperability. As a decentralized network, Blockchain eliminates the need for a reliable third party to manage the network or to verify, record, and validate transactions. Due to its distributed nature, blockchain technology automatically shares information between nodes (Okazaki, 2018). As a decentralized network, Blockchain eliminates the need for a reliable third party to manage the network or to verify, record, and validate transactions. Due to its distributed nature, blockchain technology automatically shares information between nodes (Okazaki, 2018).

Blockchain technology has brought to life a key innovation, smart contracts. It is a digital contract that is executed automatically when predetermined conditions are met (Buterin, 2014). By design, smart contracts are unambiguous because they are computer programs. If the input is the same, the output is predictable and deterministic. Further, smart contracts are encoded in computer programs, so users cannot disagree over the contract. As a result of adding a contract to the blockchain, it becomes immutable with one interpretation. Depending on the time, conditions, or the presence of another device, it can be triggered automatically or by defined inputs. In an off-chain system, assets connected to a contract may be moved or transferred (stocks, fiat currency, vehicle titles, etc.).

In the construction sector, blockchain technology has emerged as a breakthrough in transforming the content and expansion of supply chain connections (Khan et al., 2021). Khan et al. (2021) mentioned that construction supply chains benefit from BCT's facilitation of transparency, traceability, information exchange, and trust, which improves supply chain management. It is explored how smart contracts and BCT may help deliver projects (E SUB, 2018). Using blockchain technology, a lack of confidence between the parties would not be a cause for confrontational contractual relationships (Shojaei, 2019).

3. METHODOLOGY

The main research philosophy for this research is mainly positivism, which is based on the opinions of the people (professionals). To accomplish the study's goals, primary data were gathered thorough a questionnaire survey and semi-structured interviews. A preliminary questionnaire was conducted to obtain data for preparing the expert interviews and a preliminary interview was conducted to obtain data for the preparation of the questionnaire.

Preliminary questionnaire and the main questionnaire were prepared with including the structured and unstructured questions. questionnaire was developed and distributed among the professionals in the constructions industry and familiar with blockchain technology.

The preliminary interview and the expert interview were conducted by using purposive sampling who are experts in the construction industry and familiar with both the Sri Lankan construction industry and blockchain technology.

The preliminary questionnaire was distributed for collecting further data and for gather data required to prepare the expert interview questions. The preliminary interviews were conducted prior to preparing the main questionnaire. The expert interview was conducted with ten experts and the questionnaire was responded by 35 persons. Questions were formed based on the research problem, research objectives, variables, and sub-variables. The following conceptual framework illustrates the relationship between dependent and independent variables.

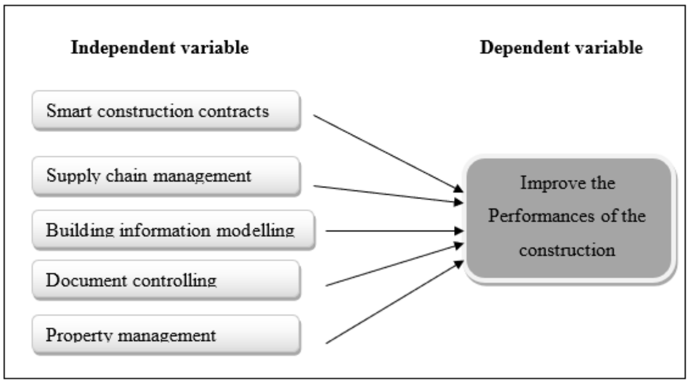

Figure 1: Conceptual Framework

For the expert interviews, professionals representing all disciplines of architecture, quantity surveying, engineering, project management, researchers and academic lecturers who are familiar with blockchain technology and the construction industry were selected. Each interviewee was coded, and they all referred to by their respective code names as shown in Table 1.

Table 1: Details of interviewees

Code	Profession	Experience range
EX1	Researcher / Lecturer	15 – 20
EX2	Researcher / Lecturer	10 – 15
EX3	Quantity Surveyor	Less than 5

Code	Profession	Experience range
EX4	Project Manager	10 – 15
EX5	Engineer	5 – 10
EX6	Quantity Surveyor	5 – 10
EX7	Architect	Less than 5
EX8	Quantity Surveyor	Less than 5
EX9	Engineer	15 – 20
EX10	Project Manager	Above 20

4. DATA ANALYSIS

Preliminary questionnaire data were analysed through a relatively important index analysis. To analyse the data collected from 35 respondents for the questionnaire survey, correlation analysis, and regression analysis were carried out using SPSS Software. After determining the validity of the data, a correlation analysis was conducted to identify how independent and dependent variables are related. Multiple linear regression was used to analyse the independent variables' impact on the dependent variable. Content data analysis was carried out through all the objectives of this study.

5. FINDINGS

5.1 FACTORS AFFECTING THE PERFORMANCE OF THE CONSTRUCTION INDUSTRY

According to the literature survey, there are these ten key performance factors (KPIs) time, cost, quality, safety and health, internal stakeholders, external stakeholders, client satisfaction, financial performance, environment, and information, technology and innovation (Soewin & Chinda, 2018). Those KPIs were used in this study to examine the order of importance. Likert scale accordance with the importance was used for that purpose. RII values for the factors are given in Table 2.

Table 2: Results gained by RII analysis.

Factor	Frequency					Total no of respondents	Total weight	Relative index	Rank
	VI	I	MI	LI	NI				
Time	29	5	1			35	168	0.960	1
Cost	29	4	2			35	167	0.954	2
Quality	29	3	3			35	166	0.949	3
Health & Safety	16	17	2			35	154	0.880	6
Internal Stakeholders	7	22	2	1		35	131	0.749	10
External Stakeholders	5	23	5	2		35	136	0.777	9
Client's satisfaction	20	15				35	160	0.914	4
Financial performances	18	15	2			35	156	0.891	5
Environment	11	20	3	1		35	146	0.834	8
Technology & innovations	11	20	4			35	147	0.840	7

As per the Table, time, cost, and quality are the most important indicators among all the KPIs. This data outcome helped to determine what should highlight in asking questions in the expert interview and what should highlight when analysing the third and fourth objectives.

5.2 APPLICATION OF BLOCKCHAIN TECHNOLOGY

As per the experts, Blockchain technology allows for more automated and autonomous operations than manual human intervention. The main things that differentiate blockchain technology from other technologies are the characteristics of a peer-to-peer network, high security, high transparency, trust, high immutability, high auditability, and high reliability. Some blockchain applications are still used in the construction industry, but many are still in the research stages. The application of BCT to smart contracts, supply chain management (SCM), Building Information Modelling (BIM), facility management, sustainability, contract management, Blockchain-enabled equipment leasing, document management and property management was identified through secondary data.

5.3 CORRELATION BETWEEN BCT APPLICATIONS WITH THE IMPROVEMENT OF THE CONSTRUCTION INDUSTRY

As all the significant values are <0.001, correlation analysis shows that there are relationships between the independent and dependent variables. Results are shown in Table 3.

Table 3 : Results from correlation analysis.

Correlations

		ASCC	ASCM	ABBM	ADCM	ABPM	AABC
ASCC	Pearson Correlation	1	.757**	.657**	.614**	.474**	.509**
	Sig. (2-tailed)		<.001	<.001	<.001	.004	.002
	N	35	35	35	35	35	35
ASCM	Pearson Correlation	.757**	1	.510**	.475**	.484**	.613**
	Sig. (2-tailed)	<.001		.002	.004	.003	<.001
	N	35	35	35	35	35	35
ABBM	Pearson Correlation	.657**	.510**	1	.606**	.424*	.673**
	Sig. (2-tailed)	<.001	.002		<.001	.011	<.001
	N	35	35	35	35	35	35
ADCM	Pearson Correlation	.614**	.475**	.606**	1	.636**	.586**
	Sig. (2-tailed)	<.001	.004	<.001		<.001	<.001
	N	35	35	35	35	35	35
ABPM	Pearson Correlation	.474**	.484**	.424*	.636**	1	.451**
	Sig. (2-tailed)	.004	.003	.011	<.001		.007
	N	35	35	35	35	35	35
AABC	Pearson Correlation	.509**	.613**	.673**	.586**	.451**	1
	Sig. (2-tailed)	.002	<.001	<.001	<.001	.007	
	N	35	35	35	35	35	35

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

ASCC – Application of BCT in Smart construction contracts

ASCM - Application of BCT in Supply chain management

ABBM - Application of BCT in BIM

ADCM - Application of BCT in Document management

ABPM - Application of BCT in Property management

AABC – Improvement of the construction industry performances.

5.4 REGRESSION ANALYSIS - IMPACT OF BCT ON THE CONSTRUCTION INDUSTRY

The regression analysis was employed to identify the impact between these two variables through the SPSS software. The results are shouwn in Table 4.

Table 4 : Results of regression analysis

Coefficients						
Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	.030	.682		.044	.965
	ASCC	.375	.214	.367	1.752	.090
	ASCM	.603	.213	.514	2.828	.008
	ABBM	.536	.178	.489	3.007	.005
	ADCM	.279	.181	.273	1.543	.134
	ABPM	.005	.176	.004	.026	.980

a. Dependent Variable: AABC

As per the results, the construction industry improves its performance by 37.5% by implementing BCT in smart construction contracts, 60.3% in supply chain management, by 53.6% in BIM, by 27.9% in document management and 0.5% by implementing BCT in property management.

5.5 CORRELATION BETWEEN BCT APPLICATIONS AND THE IMPACT OF THE APPLICATION OF BCT IN THE CONSTRUCTION INDUSTRY

According to the experts, all the performance indicators of the construction industry can be improved with adopting to the blockchain technology. Other than the KPI’s, as 'Trust and Transparency' are also mentioned throughout the Project Management Body of Knowledge (PMBOK) as significant aspects to be followed, the management process in the construction sector is also can be improved with adaptation to blockchain technology.

As per the experts, there are very few blockchain applications used in construction industry. However, there are many proof-of-concept projects, or prototype systems being developed.

5.6 SUGGESTIONS AND RECOMMENDATIONS TO IMPLEMENT BCT IN THE SRI LANKAN CONSTRUCTION INDUSTRY

5.6.1 Sri Lanka’s Readiness for Applying BCT

According to the experts, Sri Lanka is not in an appropriate level to adopt blockchain technology. The main barrier is there is no policies established regarding using blockchain technology. Resistance to change could be a big barrier too because people don’t like to change from what they are used to.

BCT is not only for use by one single company. It’s a more ecosystem. That means, everybody should use it. To get the full advantage of blockchain, every party should use BCT. The knowledge gap is also a big barrier and the lack of capability of technical feasibility. The initial cost of implementing can be expensive. Those barriers can be found in Sri Lanka that effects to block the implementation of Blockchain technology.

5.6.2 Suggestions and Recommendations to Implement Blockchain Technology in the Sri Lankan Construction Industry

As per the experts, construction companies should avoid ad hoc behavior and implement most of the practices that Project Management Body of Knowledge (PMBOK) mentions to stay on the right track prior to implement an advance technology like blockchain technology.

According to some respondents, a proper knowledge regarding blockchain technology should be given in organizational level and undergraduate level. If there's a need to use Information Technology (IT) professionals to do some jobs, it is preferred to go for joint ventures or collaborations with companies. As parties can exchange knowledge and construction professionals can benefit from each other's experience, integrating with another company could be cost-effective. IT companies can develop the system.

Another comment that came up is Involved in research and development. Another thing is, the client should get an idea about blockchain concepts and what are the advantages of that. Again, from the contractor's point of view, they should be able to deal with this one. Even if the clients are ready for that, if the contractors are not ready to use it yet, it still cannot be done. Another thing is the government should apply or create relevant legal policies to allow blockchain to be used in the Sri Lankan context. Stakeholders should then be informed that changes need to be made. They should understand what the challenges in the construction industry are and how they can be mitigated through blockchain concepts.

After the above suggestions fulfilled, the experts recommend in starting to apply blockchain for payment handling system. The respondents mentioned that after a payment handling system is adopted, then quality tracking in the supply chain can follow. BCT can be used to track the certification of raw materials and intermediate products. In this way, it can solve supply chain management problems very well.

One respondent said further about the areas that can adopt BCT as document management. Trust in the documents, maintenance, facility management, and asset management are the prominent areas in the Sri Lankan construction industry which can use BCT for future implementations.

6. CONCLUSIONS AND RECOMMENDATIONS

The study has identified the performance indicators that affect the improvement of the construction industry.

Preliminary interviews conducted among four experts in the industry who are familiar with blockchain technology indicated how blockchain differs from other technologies and what the characteristics of BCT benefit the construction industry. Some visible and research-level blockchain applications were identified are possible to apply in the construction industry. The analysis proved that there is a relationship and impact between variables.

The main outcomes that were obtained are, about the characteristics of BCT that will benefit to improve the KPIs with the performances of the construction industry and the BCT applications that are used in the world in construction.

The main outcomes of the expert interviews are:

1. About the reasons for not using blockchain in Sri Lanka's construction industry,
2. About the readiness of Sri Lanka to adopt BCT,
3. About the barriers to implementing BCT in the Sri Lankan construction industry, and
4. suggestions and recommendations of professionals on what solutions can be put into practice by the Sri Lankan construction industry to implement BCT.

Through the findings and outcomes gained from this study, it is clearly shown that the Sri Lankan construction industry can be improved with the implementation of blockchain applications on it. As per the findings, before implementing blockchain applications in the country following are recommended to get the surrounding that suits to implement BCT:

1. Must establish Government policies regarding using BCT and its applications,
2. It's better to have more research studies regarding BCT and its applications in the construction industry relating to Sri Lanka,
3. Must mitigate the fear of technology in peoples' minds. For that training sessions, workshops or other programs can be followed at the organizational level,
4. The country should produce IT professionals with also having the construction industry practice,
5. Avoiding ad hoc behaviours in the construction industry practices. For this aspect, good management practices should be followed. It is recommended to follow the PMBOK, and this should follow at the organizational level,
6. The financial capacity should be assessed, and
7. It is recommended that the government must allow blockchain to be used in the central bank.

After these recommendations are fulfilled even up to an adequate level, the following recommendations can be given regarding implementing BCT in the Sri Lankan construction industry:

1. At first, Blockchain applications should be developed according to the construction industry in Sri Lanka or must observe what applications can be bought and adopted with Sri Lanka,
2. Sri Lanka must produce more Blockchain developers,
3. It is better to adopt the applications that have been practiced earlier in construction companies if there's a lack of capacity for risk-taking, and
4. The applications that are in use overseas can be adopted by configuring their pros, cons, and nature. Those applications that can be recommended are BCT to supply chain management, BIM and financial management (payment processes) when considering the Sri Lankan context.

Blockchain technology is an upcoming topic, and it is gaining traction in developed countries. The study focused on Sri Lanka's construction industry and provided suggestions for implementing BCT applications. The study illustrates several areas in the construction industry where the blockchain concept can be easily adopted. As a result of this study, it has been demonstrated that the use of BCT has a significant influence on the performance of the construction industry. BCT can be implemented in the construction industry as a great parameter for improving performance. It is therefore important for Sri Lanka's construction industry to follow such a concept. Further development of this research has been identified in the following areas.

- Regarding the digitalization of the country

As the world rapidly develops with digitalization, it's better to adopt that wave to the construction industry in Sri Lanka also. When technologies like BCT appear in the world, Sri Lanka must have the environment to adopt them as the first thing. It is therefore possible to conduct further research on that subject as follows. How to build Sri Lanka that is technologically dense, in terms of its capability to adopt such technologies, and feasibility studies relevant to the adoption of BCT.

- Regarding adopting BCT in the construction industry in Sri Lanka.

Processes related to payment, administration, document handling, supply chain management, and BIM applications can be followed to analyse how these applications adapt to Sri Lanka. In addition, the impact they have on the construction industry can be discussed.

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APPLICABILITY OF DRIVE-THRU BANKING FACILITY FOR THE NEW NORMAL SETUP: A CASE OF COVID-19 PANDAMIC IN SRI LANKA

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ABSTRACT

Banks play an important role in economic growth and social welfare enhancement. However, the COVID-19 epidemic had an unanticipated significant impact on enterprises and organisations. Nonetheless, due to the crucial nature of their services, banks should continue to operate. As a result, to increase efficiency and profitability, the banking industry has embraced cutting-edge technology and access techniques. One of the most popular methods in the worldwide banking sector is drive-thru banking. However, in Sri Lanka, no particular emphasis has been paid to this type of facility, and there has been no adequate study on this topic addressing the applicability of drive-thru banking facility. A detailed literature analysis was conducted to review the concept and important components of drive-thru banking, as well as elements of the banking business globally and regarding to the Sri Lanka. Case studies and a survey were used to continue the study using the qualitative research approach. The study examined how each of the implementation factors, such as enablers, barriers, benefits, limitations, requirements, and customer perspectives on this facility, affected the applicability. Accordingly, certain factors such as high initial costs, supplier and maintenance constraints, carparking limitations, queue control, and accessibility need to be addressed. The study concludes that by considering these implementation variables, drive-thru banking can yield positive outcomes for both customers and bankers. The study recommends that banks in Sri Lanka explore the potential of drive-thru banking facilities and adopt them as a means of improving their services and meeting customer needs in a changing landscape.

Keywords: *Barriers; Benefits; Drive-Thru Banking Facilities; Enablers; New Normal Situation; Sri Lankan Banking Sector.*

1. INTRODUCTION

Banks play a key role in the process of economic growth and social welfare enhancement by mobilising and investing most society's savings. Thus, maintaining banking system efficiency remains a critical concern in raising economic growth in the bank-dominated Sri Lankan financial system (Kumara & Yasushi, 2010). However, unexpectedly, the

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COVID-19 pandemic had a significant impact on businesses and workplaces. Therefore, it is necessary to keep social distance as a configuration to prevent pandemic outbreak among individuals. Although banks continue to operate due to the critical nature of their services (KPMG in Sri Lanka, 2020). Hence, there have been fewer customer visits other than the essential services. Nevertheless, the same energy consumption is required to continue the bank operation. Therefore, bank cost was higher than the revenue (Robinson & Kengatharan, 2020). As a result, the banking sector has adopted innovative technology and access methods to increase efficiency and profitability required to address long-term goals (Kobika, 2019). The drive-thru banking facility is one of them, in the global banking industry, this is a very popular method, and it was a more applicable method to provide essential and other banking services to consumers safely during the COVID-19 pandemic situation (Sergeant, 2020). Since most of transactions at banks with a teller drive-thru take place outside the bank (Platt, 2016).

While some banks in Sri Lanka have already implemented drive-thru ATMs in populated areas (CBSL, 2021), the applicability of the drive-thru banking facility to the wider Sri Lankan banking sector in the new normal situation remains largely unexplored.

The identification of the applicability of drive-thru banking facilities in the Sri Lankan banking sector during the COVID-19 pandemic is crucial for increasing efficiency and productivity (KPMG in Sri Lanka, 2020). Despite the significance of this topic, only a limited number of studies have been conducted in this field, such as those by Baxter and Stafford (1985), Lay (2007), Gupta (2015), and Kaur, et al. (2020), along with some urban development reports. However, these studies primarily focused on identifying different aspects of drive-thru banking and exploring existing facilities, without specifically addressing the Sri Lankan context. Consequently, there is a clear research gap in the evaluation of drive-thru banking's applicability within the Sri Lankan banking sector, particularly in the context of the "new normal" situation. Thus, there is a need to conduct an in-depth exploration of the drive-thru banking facility in Sri Lanka to fill these knowledge gaps. This research area holds great potential and is a critical requirement for determining innovative access methods, such as drive-thru banking, that can provide customers with more secure and convenient services during the ongoing COVID-19 pandemic (KPMG in Sri Lanka, 2020). Therefore, it is crucial to initiate research in the Sri Lankan context to bridge this gap and ascertain the suitability of drive-thru banking, making it a worthy and timely researchable area in the banking industry.

A comprehensive literature review was conducted to explore various aspects relevant to the research topic, including the banking industry's contribution to the economy and the challenges posed by the COVID-19 pandemic. The review also examined the implementation, enablers, and barriers of drive-thru banking facilities. By analysing existing literature, this review aims to provide a solid foundation for understanding the current state of the banking sector in Sri Lanka and the potential applicability of drive-thru banking. Additionally, the research findings will be discussed, further contributing to the existing knowledge gap in this area.

2. LITERATURE REVIEW

The banking sector plays a major role in the economy, and it is often called the backbone of the financial system. The necessity of stability in the banking sector in a financial system was highlighted by various scholars during the recent financial crisis (Tafri, Rashidah, & Normah, 2011). Because domestic and foreign payments are exchanged through the banking system, a well-functioning banking system is required for the smooth operation of economic activity (Kumar & Bird, 2020).

2.1 THE IMPORTANCE OF THE BANKING SECTOR FOR THE SRI LANKAN ECONOMY

The banking sector plays a crucial role in the Sri Lankan financial system, serving as a key player by providing liquidity to the economy and adjusting asset risk characteristics. By mobilising and investing a significant portion of society's savings, the banking sector contributes to economic development and progress in social welfare (Kumara & Yasushi, 2010). Preserving banking system efficiency is of utmost importance in promoting economic growth within Sri Lanka's bank-dominated financial system. The Banking Act of 1988 empowered the Central Bank of Sri Lanka (CBSL) to implement tighter regulations and controls over the banking industry following a series of reforms in both the banking sector and the economy (Thilakaweera, et al., 2016). As of the end of 2020, the banking industry accounted for 72.5% of the financial sector's assets. The sector's asset base witnessed significant growth, reaching Rs. 14.6 trillion by the end of December 2020, an increase of Rs. 2.1 trillion and representing a year-on-year growth rate of 17.1%, surpassing the 6.2% reported at the end of 2019 (CBSL, 2021).

The profitability of the banking sector is critical in overcoming economic disruptions (Panayiotis, et al., 2008). Profitable banks are more likely to attract capital from investors and generate additional capital through retained earnings, as highlighted by the European Central Bank (2016). Furthermore, Trujillo-Ponce (2013) emphasised that bank profitability is crucial for the long-term viability of the financial system, as profitable banks can inject capital into the economy through lending activities. In line with this, the policies introduced by the CBSL to promote the regional dispersion of bank branches aim to enhance broad-based and equitable access to finance. Policymakers in developing countries widely support the expansion of the banking sector, as it improves regional reach of banking services and facilitates increased access to funding, which are crucial for achieving strong and sustainable economic development (Thilakaweera, et al., 2016).

2.2 IMPACT OF COVID-19 ON SRI LANKAN ECONOMY AND BANKING INDUSTRY

The spread of COVID-19 represents an unprecedented global shock, with both the disease itself and mitigation actions, such as social distancing measures and partial or national lockdowns, significantly impacting the economy. According to the World Health Organisation (2021), a pandemic is defined as an epidemic that occurs worldwide or over a wide area, crossing international boundaries and affecting a large number of people. In the aftermath of the initial outbreak, the financial sector, particularly banks, were expected to play a crucial role in mitigating the shock by providing essential loans to corporations and households (Demirguc-Kunt, et al., 2020). As a result, banks have been disproportionately affected by the rapid global spread of COVID-19 compared to other sectors (Aldasoro, et al., 2020). Supply chain disruptions have also contributed to the economic impact of the pandemic. These disruptions arise from workers' inability to go to work, border closures, travel bans, and limitations on the movement of goods, people, and capital. As a consequence, production and trade have been significantly affected, particularly in import-dependent countries (Roshana, et al., 2020). The explosive growth of the COVID-19 pandemic has become a major global economic issue that has garnered significant attention worldwide (Roshana, et al., 2020). Developing countries, in particular, face increased vulnerability due to lower economic immunity.

Unfortunately, the new dynamics that COVID-19 has ushered in will drive banks' cost bases up rather than down. The implications of COVID-19, including its impact on security, user patterns, and other aspects, have had a short-term effect on retail and commercial banks (KPMG in Sri Lanka, 2020). A probably higher level of arrears and collections, necessitating additional staff, increased on-shoring and multi-sourcing of suppliers to bolster operational resilience, lower staff productivity due to reduced demand for traditional accounts and products, higher insurance and telecoms costs with more staff working from home, and higher fraud costs are among the factors driving this increase (Aldasoro, et al., 2020).

The rapid global spread of COVID-19 has had an unprecedented impact on the economy, affecting various sectors through the disease itself and mitigation actions like social distancing and lockdowns. In the aftermath, the banking sector was expected to play a vital role in absorbing the shock by providing crucial loans to the corporate sector and households (Demirguc-Kunt, et al., 2020). Consequently, banks have been significantly affected by the pandemic compared to other sectors (Aldasoro, et al., 2020).

The economic impact during COVID-19 has been further amplified by disruptions in the global supply chain due to border closures, travel bans, and restrictions on movement of goods, people, and capital. These disruptions have severely affected production and trade, particularly impacting countries that heavily rely on imports (Roshana, et al., 2020). Furthermore, the rapid growth of the COVID-19 pandemic has emerged as a major global economic issue, particularly for developing countries with lower economic resilience (Robinson & Kengatharan, 2020). In response to these challenges, central banks and governments worldwide have implemented various policy measures to ensure liquidity and support credit flow. However, the potential impact of these countercyclical lending practices on the stability of the banking system as well as the resilience of banks' enhanced capital levels since the global financial crisis, remain significant policy concerns (Demirguc-Kunt, et al., 2020).

In Sri Lanka, precautionary measures were strictly enforced, including social distancing interventions, suspension of public transportation and marketplaces, closure of schools and universities, island-wide curfew, and work from home policies (Hewage et al., 2020). Unfortunately, the new dynamics brought about by COVID-19 have increased banks' cost bases rather than reducing them. Factors such as higher arrears and collections, increased staffing needs, bolstering operational resilience through on-shoring and multi-sourcing, reduced staff productivity, higher insurance and telecoms costs, and increased fraud costs have contributed to this rise (Aldasoro, et al., 2020). Additionally, Robinson and Kengatharan (2020) highlight that certain activities cannot be effectively conducted remotely or from home, underscoring the importance of IT infrastructure, workforce considerations, fiscal status, and the nature of the business in maintaining smooth operations. Similarly, Omary et al. (2020) found that working from home has negatively impacted operational efficiency, reduced productivity due to social distancing measures, and curtailed production levels.

2.3 DRIVE-THRU BANKING FACILITY

The concept of drive-thru facilities, originally designed for fast-food restaurants and coffee shops, found its way into the banking sector. As customers faced the complexities of traditional banking, including long wait times and interactions with tellers for simple transactions, the need for faster and more convenient services became evident (NCR Globle, 2021). Drive-thru banking is allowing customers to drive up to the bank and carry out transactions without leaving their vehicles (Bartlett, 2017). As a result of banking complexity, customers had to take hours out of their day to prepare their financial information, travel to the bank, wait in long lines and speak with an individual teller. Customers who wanted assistance with simple transactions (such as cashing a cheque) were ushered into the same lines as those who needed assistance with more complicated transactions, such as mortgages or business loans (NCR Globle, 2021). Furthermore, it is stated that the old banking system was simply unsustainable as people demanded faster and more efficient services to fit their faster-paced lifestyles. As a result, there was a growing need for faster, more convenient banking services that decreased difficulties and saved time, and drive-thru service became available. A lane exists where a customer can do a transaction through a window. As well as voice Artificial Intelligent (AI) systems can even be used to replace humans in drive-thru banking. Its conversational AI innovation can understand orders and make corrections in the discussion if participants have language problems or heavy accents (Kaur, et al., 2020). Even there can be seen customers are flocking to use drive-thru banking facilities to accomplish a range of transactions. However, these operations entail more than just cashing a cheque or depositing money. Since then, cash withdrawals, cardless cash facilities, credit card settlements, utility bill payments, mobile cash facilities, loan payments, balance inquires, cashiers' cheques/money orders, master card/gift cards, ordering checks, changing orders, and many other services are provided (FCB, 2020).

A drive-thru facility has become a crucial component of modern banking, with most banks incorporating multiple lanes, including a dedicated lane for commercial and large transactions (Lay, 2007). Pneumatic tubes system, drive-thru windows for ATMs and counters are all examples of ways to employ drive-thru banking facilities. Although the processes remain the same, the usage method differs (Baxter & Stafford, 1985; WSP, 2020; NCR Globle, 2021). In terms of service times at drive-thru facilities, observations have shown a negative exponential distribution, with an average service time of 1.96 minutes based on 676 instances. Approximately 88% of service times were below 4 minutes. The process when a customer goes through while waiting in line to be served, the total amount of time spent in the drive-thru system was separated into waiting time and service time components (Baxter & Stafford, 1985). Furthermore, the authors stated the cost of inside service at a financial institution is calculated by adding the value of personal time to the cost of fuel required to start a vehicle engine. The time it takes to use an inside facility can be broken down into five parts: (a) time to park and exit the vehicle, (b) time to walk into the facility, (c) time to complete the transaction (including waiting in line), (d) time to return to the vehicle, and (e) time to get back into the vehicle and start the engine. By adding the various components of time that would be utilised to compute user charges connected with the inside service, a value is obtained. The total time required for using inside service at financial institutions was found to be 3.9 minutes on average during off-peak periods and 4.7 minutes during peak periods. The cost of time to the customer was estimated at USD 0.325 during off-peak periods and USD 0.39 during peak periods, assuming a conservative valuation of a person's time at USD 5.00 per hour.

3. RESEARCH METHODOLOGY

The research process is known as the comprehensive plan of research development, which illustrates a defined series of stages in a logical order that will guide the research to efficiently accomplish the intended goals (Babin, et al., 2012). Furthermore, it could be identified as a systematic process that typically consists of a background study, literature review, data collection, data analysis, conclusion, and validation of research findings (Bradbury, 2015). A literature review and a theoretical model were conducted following a background study to determine the aim, objectives, and research problem. Further, study was conducted using a qualitative approach.

Case studies were used as the research strategy, and semi-structured interviews were used as data collection procedures in each case. The banks, which were selected based on the availability of drive-thru ATMs, established the study’s boundary, as the applicability of drive-thru banking facility was assessed using drive-thru ATMs. According to the selection criteria, Cases A and B are banks with drive-thru ATM facilities (context 1), and Cases C and D are banks without drive-thru ATM facilities (context 2). To collect data, respondents were selected from both the management and supervisory levels. Managerial level respondents were selected based on their involvement in the bank's operations. As a result, the applicability of drive-thru banking facility identification was implemented in two independent cases for this study due to drive-thru ATMs' availability and unavailability. Content analysis was determined to be the best data analysis technique. In the data analysis process, the NVivo software was employed to facilitate computer-aided content analysis.

4. RESEARCH FINDINGS

4.1 IMPACTS OF THE PANDEMIC TO THE BANKING SERVICES AND OPERATION

The case study discusses the impact of the pandemic on banking services and operations, highlighting various modifications that were necessary. These changes included adopting the work-from-home concept, employing a restricted number of essential personnel, and adjusting banking rules to meet evolving customer needs. However, these adjustments led to a gradual decline in bank income, prompting efforts to lower overall maintenance costs. Technical involvement played a critical role in navigating the challenges, with banks relying heavily on technology to maintain smooth operations and ensure data security. Queue control became crucial, necessitating strategies to enforce social distancing. Additionally, space allocation was required for sanitisation, raising pandemic awareness, and addressing supply chain disruptions. While these modifications incurred additional costs, prioritising safety and delivering essential banking services remained paramount during the pandemic.

The similarities between two cases of operating bank procedures during the pandemic situation. Despite differences in the cases and the types of respondents, the majority of respondents agreed that the bank's operational costs should be reduced due to energy consumption and maintenance. However, bank income was reduced due to restrictions on services and central bank policies. Similarly, the branch operations might have different operating costs due to lower energy consumption. The pandemic has caused additional operating costs due to increased sanitation, pest control, and provision of hygiene facilities. Supply chains have also been disrupted, affecting core and non-core business activities because of island wide lockdown and boarder closure. In context 01, drive-thru ATMs have proved to be popular and beneficial in reducing customer queues and wait times, while in context 02, there were queues outside the bank that put people at risk of exposure to the pandemic.

4.1.1 Drive-Thru Banking Facility's Appropriateness with Current Bank Practices

The drive-thru banking facility has emerged as an appropriate addition to current bank practices, addressing the need for faster and more convenient transactions. With the aim of providing a secure environment for financial activities, drive-thru banking has gained popularity and is being integrated into upcoming development projects. In today's fast-paced lifestyle, time-saving has become crucial, and drive-thru banking caters to this demand by offering quicker transactions.

The traditional banking system was unsustainable in meeting the growing demand for faster, more convenient banking services that reduced difficulties and saved time. Drive-thru banking can add value to the bank and the city by moving with people's faster lifestyles, providing an efficient banking service, and reducing energy consumption. However, the adoption of drive-thru banking may require more time for adaptation due to various factors. These include initial costs, limited space availability, data protection concerns, and the need for staff training and maintenance. Despite these challenges, drive-thru banking is seen as a viable solution to reduce energy consumption, improve customer experiences, and align with the evolving banking landscape in the new normal situation.

4.2 ENABLERS AND BARRIERS OF IMPLEMENTING THE DRIVE-THRU BANKING FACILITY IN THE SRI LANKAN BANKING SECTOR

4.2.1 Barriers of Implementing Drive-Thru Banking Facility

The identified barriers include high initial costs, limited space availability, the need for moderately expensive technology, data protection challenges, staff training, and system maintenance. Additionally, obtaining approval from relevant authorities can be a lengthy and challenging process. The lack of sufficient lanes to accommodate drive-thru traffic and design issues can also be barriers. Cities and towns must consider the impact on traffic flow, noise pollution, and potential traffic snarls. These barriers can be categorised into two groups: internal barriers related to the internal banking environment, and external barriers associated with the external environment and conditions. The barriers to implementing the drive-thru banking facility in Sri Lanka are shown in Figure 1.

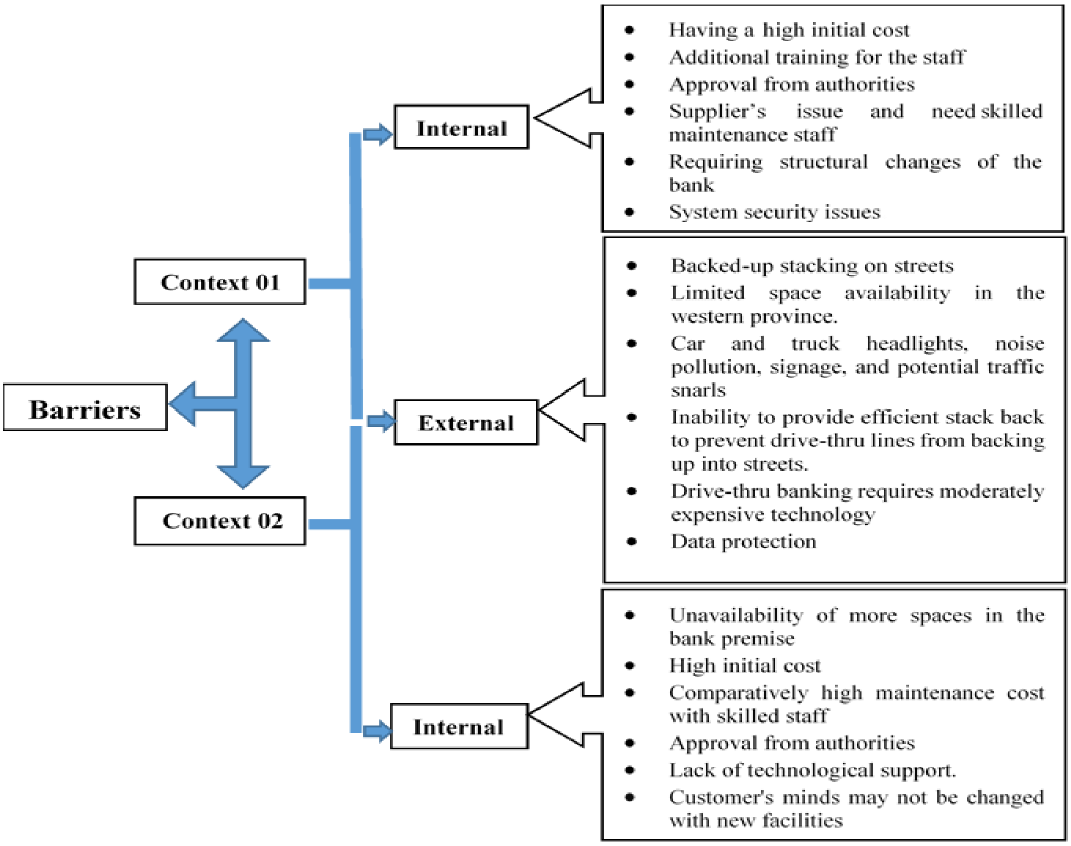

Figure 1: The barriers to implementing the drive-thru banking facility in Sri Lanka

The barriers to implementing the drive-thru banking facility in Sri Lanka under contexts 1 and 2 were determined separately, as shown in Figure 1. Then, because the external barriers to implementing drive-thru banking facilities were similar in both contexts, the external barriers were identified together.

4.2.2 Enablers of Implementing Drive-Thru Banking Facility

It is mentioned that most banks have similar layouts and forms, and implementing a drive-thru facility would provide more secure procedures during a pandemic situation and reduce customer gathering inside the bank. Furthermore, implementing a drive-thru facility would help address parking space challenges, decrease energy consumption, and bring added value to ongoing development projects in the western province. Enablers were categorised as internal and external, with internal enablers originating from the internal banking environment, and external enablers stemming from external conditions and factors. The enablers for implementing the drive-thru banking facility in Sri Lanka are shown in Figure 2

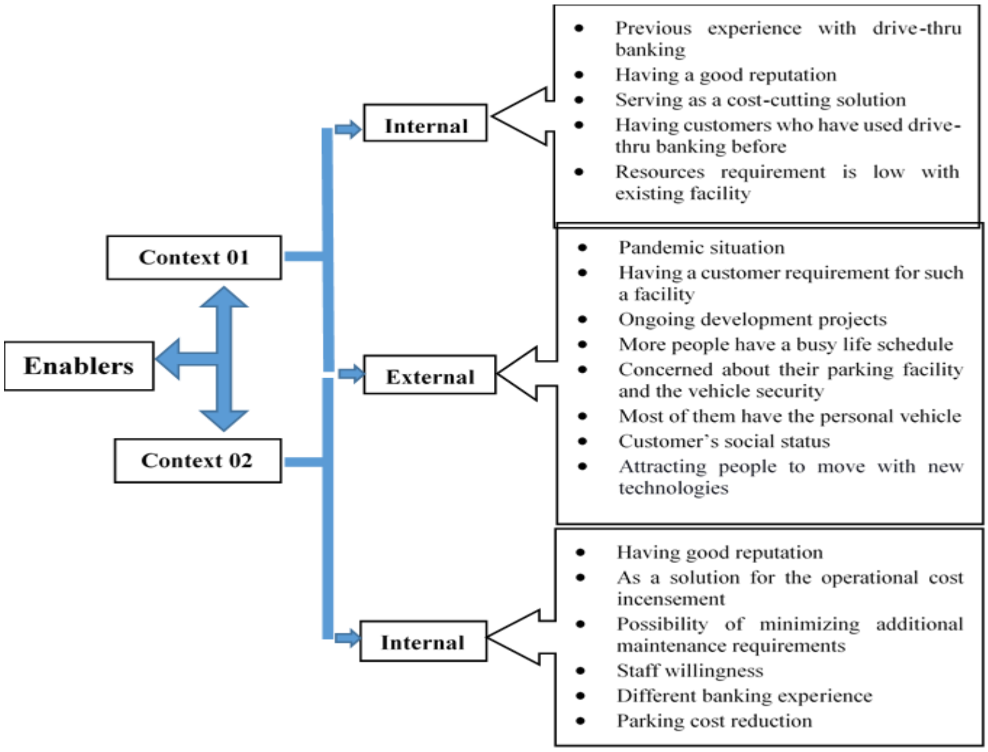

Figure 2: The enablers to implementing the drive-thru banking facility in Sri Lanka

The enablers for implementing the drive-thru banking facility in Sri Lanka under contexts 01 and 02 were determined separately, as shown in Figure 2. In the subsequent analysis, the external enablers for implementing drive-thru banking facilities were identified collectively for both contexts, as they exhibited similarities across the two contexts.

4.2.3 Benefits of having the Drive-Thru Banking Facility

Drive-thru banking facilities offer several advantages, as highlighted by professional respondents. These include improved accessibility for all customers, reduced queues and wait times, enhanced security and privacy, decreased human interaction, high customer attraction, reduced traffic congestion, fast and efficient service delivery, cost savings for banks, minimised breakdowns and system errors, and the potential for marketing and branding. These benefits make drive-thru banking a convenient, time-saving, and customer-centric solution, while also providing operational efficiencies for financial institutions. The total time consumed for a transaction is estimated to be between 3.9 and 4.7 minutes, with a cost ranging from USD 0.3 to 0.4. Additionally, respondents emphasised the convenience, accessibility, and reliability offered by these facilities. Figure 3 provides a summary of these benefits.

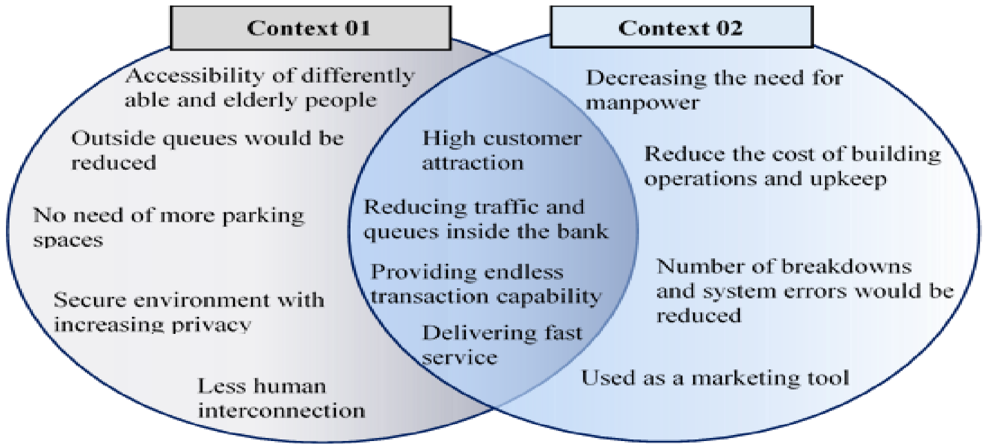

Figure 3: The benefits of implementing the drive-thru banking facility in Sri Lanka

4.3 OVERALL ANALYSIS OF THE APPLICABILITY OF DRIVE-THRU BANKING FACILITY FOR THE SRI LANKAN BANKING SECTOR

The applicability of a drive-thru banking facility was assessed based on the identified criteria of time savings, convenience, cost savings, accessibility, and reliability. The views of 35 customers' responses in the Sri Lankan banking industry were checked against 16 statements about drive-thru banking facilities identified in the literature and applied to the Sri Lankan banking system. The level of concurrence was measured using a five-point Likert scale: 1-"Strongly disagree," 2-"Disagree," 3-"Neutral," 4-"Agree," 5-"Strongly agree." Furthermore, descriptive statistics were used to analyse the data.

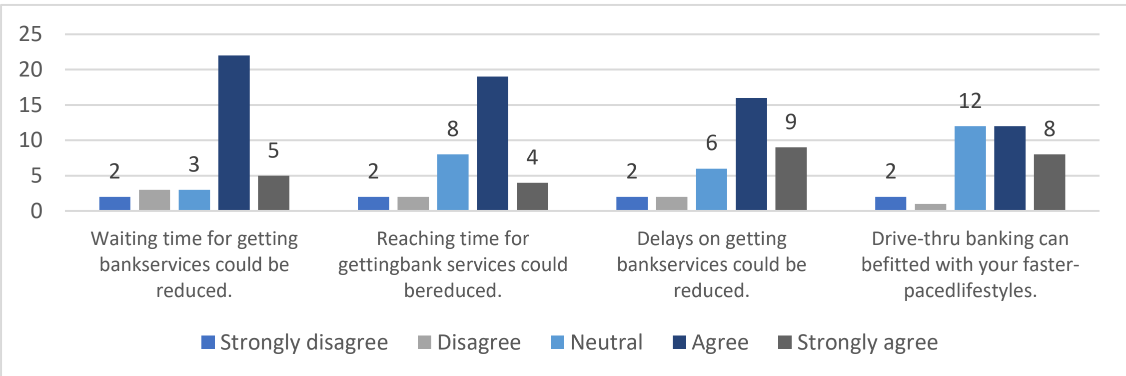

Figure 4: Time saving

When examining the timesaving benefits of a drive-thru banking facility, multiple time-related factors were taken into account, such as waiting time, reaching time, delays, and alignment with a faster-paced lifestyle. Figure 4 depicts the favourable reception of a drive-thru banking facility based on its ability to save time. Furthermore, there seems to be an increase in the neutrality of response under match with the faster-paced lifestyle, reflecting the same equal value as the agreed responses.

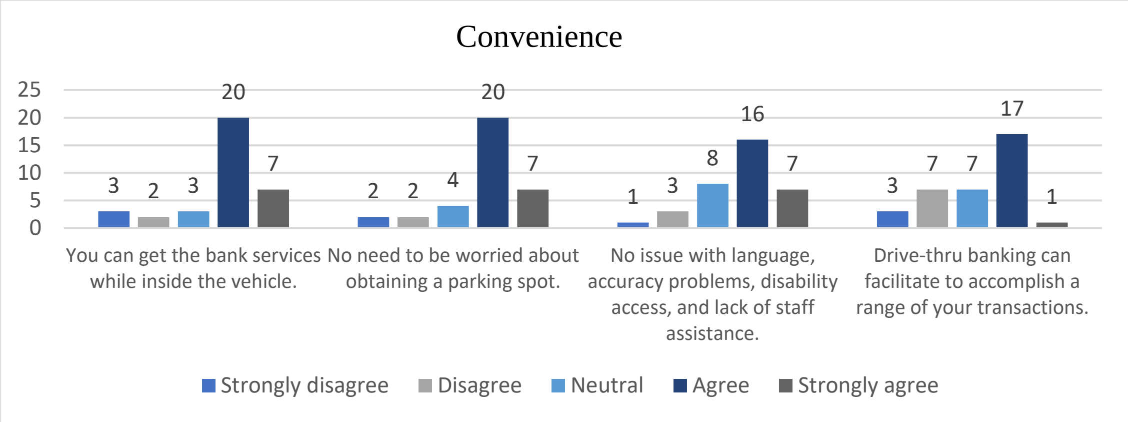

Figure 5: Convenience

The convenience of a drive-thru banking facility was evaluated based on various factors that enhance the customer experience. These factors include the ability to access services while remaining inside the vehicle, eliminating the need to search for parking, alleviating concerns about language barriers, ensuring accuracy of transactions, receiving staff assistance, and providing ease of access for individuals with disabilities. According to figure 5, the neutral response appears to increase under the final factor of variety of transactions. However, it was not having a significant impact on making a decision on that factor.

Cost Benefits

The cost benefit of a drive-thru banking facility was assessed based on various factors, including waiting time and parking expenses, additional costs for bank services, energy consumption, and document preparation costs. Figure 6 displays the responses, indicating that the drive-thru banking facility offers substantial cost benefits, as the majority of responses were positive. However, when compared to other cost factors, additional costs and document preparation elicited a higher number of neutral responses.

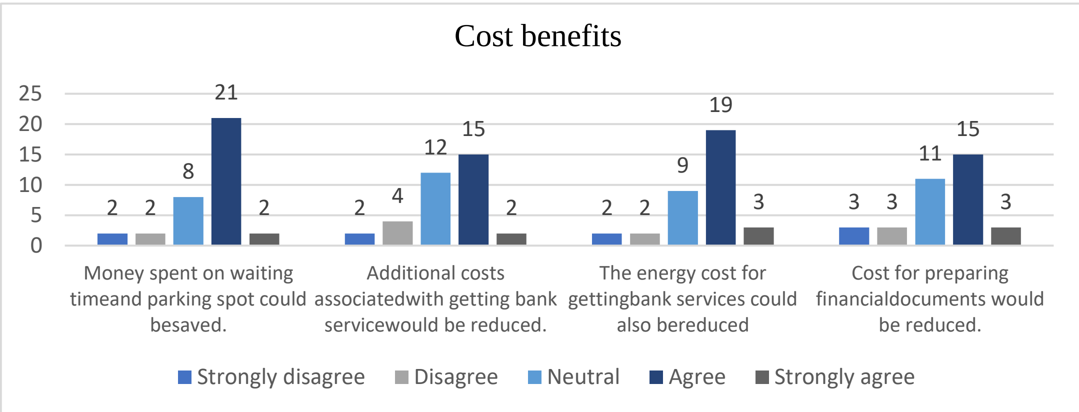

Figure 6: Cost benefits

Accessibility and Reliability

Drive-thru banking's accessibility and reliability were assessed using factors such as difficulty in digital banking, reliability in comparison to digital banking, having a secure environment, and accessibility difficulty. Figure 7 illustrates responses for drive-thru banking facilities under the accessibility and reliability criterion, and it was shown to have a similar pattern for all four factors.

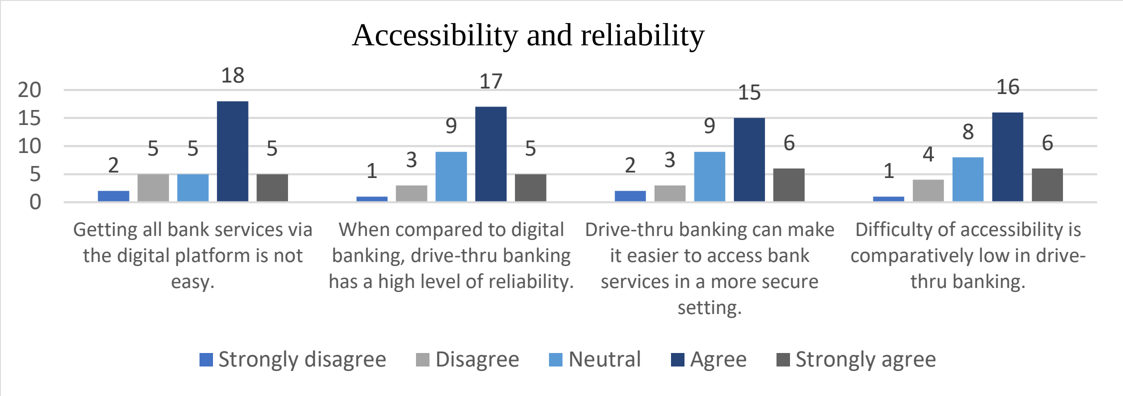

Figure 7: Accessibility and reliability

5. DISCUSSION

The findings highlighted the applicability of drive-thru banking to the Sri Lankan context as evidenced by case studies, as well as evaluated the applicability of drive-thru banking to the Sri Lankan context using the identified criteria via a questionnaire survey. The literature review and objectives were re-examined in order to arrive at a critically evaluated final outcome. As a first step, evaluate the influence of COVID-19 on the bank operation process in Sri Lanka and critically assess how it affected general banking procedures, which has been further elaborated as maintenance and the additional cost arising from supply chain disruption, restrictions on working procedures, reduction of the bank's income, and rearrangement of the banking process. As a result, digital banking became widely used, but it had some issues from the perspective of both customers and employees, including reliability, connectivity, security, and access difficulties, which were critically assessed to determine the need for drive-thru banking in the Sri Lankan banking context. With that concern, it moved on to determine the applicability of drive-thru banking by identifying its benefits, enablers, barriers, limitations, requirements, and customer feedback.

When it came to requirements, the major requirements for drive-thru banking implementation were determined to be space, investment, legal approval, and technology, as well as other requirements such as staking lanes, noise, and access, which were determined through the literature. Furthermore, it has some limitations in that it would not be used for certain banking services that require a lengthy process to verify the information. Furthermore, customers' positive feedback has been demonstrated through criteria including time savings, convenience, cost savings, accessibility, and reliability on the drive-thru banking facility. Moreover, key finding showed the applicability of drive-thru banking facilities with the impact of a pandemic situation. Digital banking and drive-thru banking were the options most of the banks followed globally in order to face the pandemic situation. With that, here mainly focused on the drive-thru banking facility, which was evaluated by determining the requirements, barriers, enablers, limitations, benefits, and customer opinions as briefly described with the key findings. Finally, it can be concluded that the use of a drive-thru banking facility should place a greater emphasis on properly managing the banking system by providing a better banking experience in order to achieve customer satisfaction through a secure banking process in the new normal situation.

6. CONCLUSIONS

The COVID-19 pandemic is regarded as a major disaster that is wreaking havoc on people all over the world. Similarly, the business community in Sri Lanka was impacted by the pandemic as a result of the lockdown and supply chain disruption. Furthermore, the banking sector was hit harder than other sectors as a result of the economy's decline and the inability to recover loans. However, there was a digital banking enhancement that had some limitations due to a lack of knowledge and resources. With that in mind, determining the applicability of a drive-thru banking facility would be preferable to meet this challenge while ensuring a secure environment for both customers and employees. As a result, the research aim of determining the applicability of drive-thru banking facility by understanding community needs and the banking system in Sri Lanka was achieved by completing four main objectives.

The banking sector is critical to economic development and is a key player in the Sri Lankan financial system because it provides liquidity to the economy as a whole while also adjusting asset risk characteristics. Similarly, it contributes to economic development and social welfare progress by mobilising and spending the vast majority of society's savings. Furthermore, banks' operations have grown to include a variety of loan grant and deposit schemes, leasing, investments, foreign exchange operations, and international trade facilitation, all of which contribute to the country's economic growth. The COVID-19 pandemic's rapid spread is a major global economic issue that has drawn widespread attention. The vulnerability of the pandemic in developing countries is increased due to lower economic immunity. To help with this, central banks and governments around the world have implemented a variety of policies to increase liquidity and support the flow of credit. In addition, the cost of sanitisation, pest control, PPEs, and the provision of self-hygiene facilities, as well as the rearrangement of workplaces following health requirements, increased the cost of maintenance and operating costs in the Sri Lankan banking system. Similarly, the island-wide lockdown and border closure disrupted supply chains, affecting the bank's ability to survive operations with supporting materials for the core and non-core business activities.

When comparing the two contexts, drive-thru ATMs provide a better opportunity to control the queue because customer gathering inside the bank is reduced, and it also helps to reduce energy consumption, which aids in the reduction of pandemic spread and operational costs. Similarly, drive-thru banking can address the parking issue because most customers are concerned about their parking facility and the security of their vehicle, even if they used a third-party vehicle, which would charge for the time spent waiting. Furthermore, it would add more value to the ongoing development project in the western province as well. When it comes to barriers, drive-thru banking necessitates a technology that is moderately expensive; data protection is another challenge for drive-thru banking adoption; and bank employees must be trained in all drive-thru practices because it is a new concept that customers will take time to adopt. Furthermore, due to the limited space availability in the western province, the initial cost of achieving the system and space requirements for the facility was high. in the country's new normal situation, drive-thru banking is a viable option for lowering energy costs as well. When comparing the two contexts, banks that do not have the drive-thru ATMs have reservations about their applicability to current banking practices when considering their various products. However, a questionnaire survey revealed that drive-thru banking has a positive impact on customer perspective when considering time savings, convenience, cost savings, accessibility, and reliability.

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APPLICABILITY OF RECYCLING AND RESOURCE RECOVERY FOR SOLID WASTE OF SRI LANKAN SUPERMARKETS

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ABSTRACT

Every day, supermarkets create municipal solid waste, which makes up about 25% of all solid waste made in urban areas of Sri Lanka. Poor waste management in Sri Lankan supermarkets can have a big effect on greenhouse gas emissions, climate change, and public health by contaminating water, soil, and the air. To address this challenge, recycling, and resource recovery are two of the best sustainable waste management practices. Hence, the study aims to investigate the applicability of recycling and resource recovery techniques for Sri Lankan supermarket solid wastes. The research choice adopted in this study was a mixed method with a questionnaire survey and semi-structured interviews. A questionnaire survey with 70 participants from top-level management, middle management, and the front-line staff was conducted to identify waste types and management practices, and a semi-structured interview with three professionals who have experience in this field was conducted to validate the survey. Further statistical analysis and manual content analysis were used to analyse the data. The findings revealed that the main waste types generated by Sri Lankan supermarkets are food, plastic, polythene, paper, and cardboard. Biogas and composting were found to be the most applicable on-site resource recovery techniques for these types of waste, and other techniques such as gasification, deinking for paper recycling, and recycling of plastic and polythene waste required the involvement of third-party resource recovery plants. The study can aid researchers, practitioners, and policymakers in coming up with and using waste management policies, laws, and guidelines for Sri Lankan supermarkets and other similar contexts.

Keywords: *Recycling; Resource recovery; Solid waste; Sri Lanka; Supermarket.*

1. INTRODUCTION

Solid waste management has become a significant challenge in Sri Lanka, where inefficient waste management practices are causing environmental damage and health risks (Saja et al., 2021). Over 7,000 tonnes of solid waste are generated in Sri Lanka every day, but only 20% of that waste is collected by local authorities, and only approximately

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5% of that waste is recycled. The balance of the waste is disposed of in open dumps or landfills (Nishanthi & Kaleel, 2021). One of the main places where solid waste is produced in Sri Lanka is supermarkets (Reitemeier et al., 2021). According to the Central Environmental Authority (CEA, 2021), supermarkets make up about 25% of all the solid waste made in urban areas of Sri Lanka. The increasing consumerism and changing lifestyles of people have resulted in more packaging waste, food waste, and other types of waste generated by supermarkets (Diaz et al., 2017). The amount of plastic waste that supermarkets produce is one of the biggest problems in Sri Lanka. Gunaruwan and Gunasekara (2016) support the idea that plastic bags, containers, and wraps used to package food are a big part of the country's waste problem. The authors also said that because there aren't enough waste management facilities and methods, a lot of this plastic ends up in landfills or the ocean, where it hurts the environment. For example, it has contributed to the pollution of several major waterways, including the Kelani River, which provides drinking water to over five million people in the country (Saja et al., 2021; Reitemeier et al., 2021). In addition, the traditional approach to managing this waste has been to dispose of it in landfills, which has proven to be unsustainable and harmful to the environment (Pitawala et al., 2022). For example, organic waste can attract vermin and pests, leading to the spread of diseases. This has created a pressing need for sustainable and effective solid waste management practices in Sri Lankan supermarkets (Gunaruwan & Gunasekara, 2016). Accordingly, there is an urgent need to find more sustainable solutions for managing supermarket solid waste. Recycling and resource recovery techniques have gained widespread attention as sustainable solutions to the solid waste management problem (Rene et al., 2021). The authors mentioned that these techniques involve the collection, sorting, processing, and reuse of solid waste materials. These techniques can be used to reduce the amount of waste generated by supermarkets and divert waste from landfills, thereby reducing environmental pollution (Van Yken et al., 2021). However, a report by the World Bank (2021) states that Sri Lanka has one of the lowest recycling rates in South Asia, with only 6% of the waste being recycled. This is significantly lower than other countries in the region, such as Bangladesh and India, which have recycling rates of 30% and 25%, respectively (Zaman, 2016). These statistics indicate that Sri Lanka is lagging in the adoption of recycling and resource recovery techniques for solid waste. There is a need for the country to prioritise waste management practices that focus on reducing waste generation, promoting recycling and resource recovery, and adopting sustainable practices to manage the remaining waste. Hence, this paper aims to analyse the applicability of recycling and resource recovery techniques for solid waste management in Sri Lankan supermarkets. The following section presents the literature review, followed by the research methodology. Then came the main part of the paper: the research findings and discussion, and finally, the conclusions.

2. RECYCLING AND RESOURCE RECOVERY FOR SUPERMARKET SOLID WASTE

Recycling is the process of collecting, sorting, and processing materials that would otherwise be thrown away as trash and turning them into new products (Soomro et al., 2022). Recycling aims to reduce the amount of waste that ends up in landfills or incinerators, conserve natural resources, and reduce greenhouse gas emissions. In addition, recycling to return waste materials lowers costs and opens new opportunities. Commonly recycled materials include paper, glass, plastic, metal, and electronics (Dias & Junior, 2016). It helps to reduce the amount of waste that is sent to landfills or incinerators, which can have negative environmental impacts (Oshodi et al., 2020). When waste is recycled, it is transformed into new products, reducing the need to extract and process virgin materials from the earth, conserving natural resources, reducing greenhouse gas emissions, and helping to protect ecosystems (Van Yken et al., 2021). On the other hand, this uses less embodied energy as the recycled materials have already been extracted and processed (Zaman, 2016). For example, recycling aluminium cans uses 95% less energy than producing new aluminium cans from raw materials. Accordingly, it plays an important part in sustainable waste management and has a critical role in protecting the environment and conserving resources (Gunarathne et al., 2019).

Resource recovery is the process of getting materials or energy out of the waste that would otherwise be thrown away (Lag-Brotons et al., 2020). It involves collecting, sorting, and processing trash to get valuable materials that can be used again or recycled, such as metals, plastics, and organic matter. It also includes making energy from waste, such as by making biogas from organic waste or burning waste to make electricity (Velenturf & Purnell, 2017). Resource recovery can create economic opportunities by creating new markets for recycled materials and by generating revenue from the sale of recovered energy. This can help to support local economies and create jobs in the waste management industry (Dias & Junior, 2016). The goal of resource recovery is to reduce the amount of waste sent to landfills or incinerators, conserve natural resources, and minimise the environmental impacts of waste disposal. Resource recovery helps to conserve natural resources by reusing and recycling materials that would otherwise be discarded as waste (Dawson, 2007). This can help reduce the demand for virgin materials, such as minerals and fossil fuels, that are used to produce new products. It is a key strategy for sustainable waste management and is an important part of the circular economy (Gunarathne et al., 2019). Table 1 summarises the types of waste generated in supermarkets along with their overall contribution and the method of waste management applicable to each type of waste.

Table 1: Types of waste in supermarkets and applicable waste management methods

Type of waste along with their overall contribution (%)	**Recycling and resource recovery Methods**							**Source**
	Recycling	**Anaerobic digestion**	**Composting**	**Dark fermentation**	**Gasification**	**Pyrolysis**	**Dissolution**	
Food (48%)		✓	✓	✓	✓	✓		[1] - [4]
Paper and cardboard (20%)	✓							[5] - [9]
Glass (12%)	✓							[10] - [13]
Plastic (8%)						✓	✓	[14] - [16]
Wood (7%)	✓		✓					[17] - [19]
Non-ferrous metal (3%)	✓							[20] - [21]

Sources: [1] (Rashid & Shahzad, 2021); [2] (Oshodi et al., 2020); [3] (Lukajtis et al., 2018); [4] (Filimonau & Gherbin, 2017); [5] (Ma et al., 2016); [7] (Gunaruwan & Gunasekara, 2016); [8] (Dias & Junior 2016); [9] (Ozola et al., 2019); [10] (Nishanthi & Kaleel, 2021); [11] (Velenturf & Purnell, 2017); [12] (Lag-Brotons et al., 2020); [13] (Dias & Junior 2016); [14] (Gunarathne et al., 2019); [15] (Gunaruwan & Gunasekara, 2016); [16] (Armenise et al., 2021); [17] (Velenturf & Purnell, 2017); [18] (Saja et al., 2021); [19] (Berger et al., 2020); [20] (Reitemeier et al., 2021); [21] (Brooks et al., 2019)

3. RESEARCH METHODOLOGY

This study aims to investigate the applicability of recycling and resource recovery techniques for Sri Lankan supermarket solid wastes. Initially, a background study was undertaken to determine the research problem. After that, a comprehensive literature review was done to identify the different types of solid waste that supermarkets produce and the ways that those wastes are managed around the world. This study adopted a survey strategy to get an overall idea of Sri Lankan supermarket solid waste generation and management and particularly to check whether recycling and resource recovery is applied in the Sri Lankan context. Accordingly, an online questionnaire survey using Google Forms was carried out among 70 participants, who are operations managers, facilities executives, and housekeeping labours of supermarkets in the Colombo Municipal Council area based on convenience sampling, which is a non-probability sampling technique where the entire population is not considered in selecting the sample (Dawson, 2007). The respondent rate is 82.9% (58 respondents). To analyse the survey data, descriptive statistical analysis techniques were applied. Measures such as means, standard deviations, and frequency distributions were calculated to summarise the quantitative data obtained from the questionnaire responses. Following that, an expert interview was conducted to validate the questionnaire survey and to gain additional knowledge about recycling and resource recovery, with three professional experts who have experience with recycling and resource recovery of waste as mentioned in Table 2. Manual content analysis techniques were then applied to analyse the qualitative data. This involved systematically reviewing the interview transcripts, identifying recurring themes and patterns, and deriving meaningful insights from expert perspectives.

Table 2: Profile of expert interview respondents

Respondent No	Designations	Experience in the Waste Management sector
R1	Director - Waste Management Authority	More than 15 years
R2	Director - Central Environmental Authority	More than 25 years
R3	Engineer - Central Environmental Authority	More than 11 years

4. RESEARCH FINDINGS AND DISCUSSION

This section includes three sections which are types of Sri Lankan supermarket solid waste, current recycling and resource recovery techniques used in Sri Lanka, and the applicability of identified recycling and resource recovery techniques on Sri Lankan supermarket solid waste.

4.1 TYPES OF SRI LANKAN SUPERMARKET SOLID WASTE

The percentage of solid waste types generated in the supermarket according to the literature (section 2) slightly differs from the Sri Lankan perspective. The questionnaire survey allows for the involvement of a larger number of participants, such as supermarket managers, operations staff, and other relevant stakeholders and this provides a broader perspective on waste generation and management practices in Sri Lankan supermarkets. Hence the solid waste types generated in the supermarket which is collected using the questionnaire survey is illustrated in Figure 1.

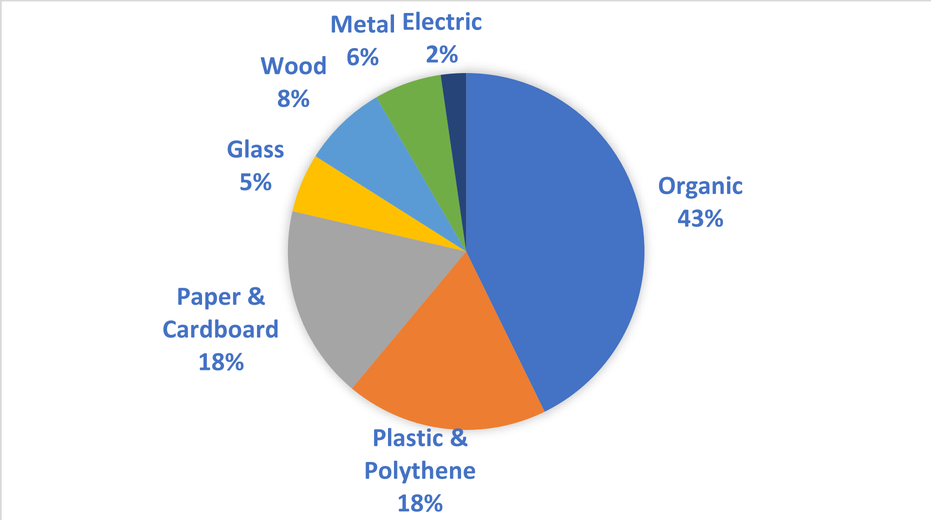

Figure 1: Types of Sri Lankan supermarket solid waste

Organic foods include food waste, fruit and vegetable scraps, and other biodegradable waste generated in supermarkets. The significant contribution of organic waste, including food waste and biodegradable materials, aligns with findings from previous studies. Accordingly, it is estimated to contribute around 30% to 50% of the total waste generated in supermarkets (Rashid & Shahzad, 2021). On a similar note, as per the findings, it is estimated that organic waste contributes to about 43% of the total waste generated in supermarkets. Further, supermarkets use a lot of plastic and polythene packaging material for their products, including plastic bags, bottles, and containers, and is estimated to contribute to about 18% of the total waste generated in supermarkets. Further, supermarkets also generate a significant amount of paper and cardboard waste from packaging boxes, bags, and receipts. According to the literature, supermarkets generate a significant amount of paper and cardboard waste from packaging boxes, bags, receipts, and other paper-based materials. This waste stream is estimated to account for approximately 10% to 20% of the total waste generated in supermarkets (Ma et al., 2016). Similarly, the questionnaire findings revealed that this waste contributes to about 18% of the total waste generated in supermarkets. In addition, the wood waste in supermarkets can come from a variety of sources, including packaging crates, pallets, and shelving units. While the contribution of wood waste in supermarkets may vary, it is estimated to be a relatively small percentage (8%) of the total waste generated. On the other hand, hazardous wastes such as electrical waste, metal waste, and glass waste are generated in very fewer amounts.

To conclude, the targeted waste types for recycling and resource recovery of supermarket waste were identified as food waste, plastic and polythene waste, and paper and cardboard waste. Due to the high quantity of weekly waste generation, these three waste types were selected as the main treatable waste types. Though glass waste, metal waste, wood waste, and E-waste were identified in the supermarket facilities due to the inconsistency of the generation of waste, four waste types were excluded from on-site recycling or resource recovery.

4.2 CURRENT RECYCLING AND RESOURCE RECOVERY TECHNIQUES USED IN SRI LANKA

The recycling and resource recovery techniques that have been used for different types of supermarket solid wastes in Sri Lanka are shown in Table 3.

Table 3: Recycling and resource recovery techniques used in Sri Lanka

No	Recycling and Resource Recovery Techniques / Types of Waste	Incineration	Biogas	Gasification	Pyrolysis	Composting	Recycling
1	Food waste		30/58			28/58	
2	Plastic and polythene	18/58		5/58	5/58		30/58
3	Paper and cardboard	23/58					35/58
4	Glass	50/58					20/58
5	Wood						58/58
6	Metal						58/58

According to the literature, for food waste, composting and anaerobic digestion are commonly used methods. Similarly, the questionnaire findings revealed that biogas and composting are the techniques used for managing food waste, as they can convert it into useful resources like energy and fertiliser. Recycling, biogas, and gasification are all effective techniques for managing plastic waste. Plastic waste can be recycled to produce new products, while biogas and gasification can convert it into energy. Incineration can also be used for plastic waste, but it can produce harmful emissions. Recycling and pyrolysis are used to manage paper and cardboard waste. Recycling can turn paper waste into new products, while pyrolysis can convert it into energy. Incineration and biogas are not recommended for paper waste. Further, recycling is the most common technique for managing glass waste, as it can be melted down and used to produce new glass products. In addition, composting and pyrolysis are used to manage wood waste. Moreover, recycling is the most common technique for managing metal waste, as it can be melted down and used to produce new metal products. Further, out of the resource recovery techniques found in the literature, biogas, gasification, pyrolysis, and composting were found to be current resource recovery techniques in Sri Lanka. Subsequently, the respondents were asked to rate the resource recovery and recycling techniques concerning profitability and environmental impact, as depicted in Table 4. A rating system was used, where the profitability and environmental impact of each technique were rated on a scale of 1 to 5, with 1 indicating the lowest profitability/low impact and 5 indicating the highest profitability / high impact.

Table 4: RII of profitability and environmental impact

No	Recycling and resource recovery method	RII	
		Profitability	Environmental impact
1	Recycling	3.57	1.00
2	Incineration (WtE)	3.14	3.00

No	Recycling and resource recovery method	RII	
		Profitability	Environmental impact
3	Gasification	3.00	1.29
4	Pyrolysis	2.71	1.71
5	Biogas	1.85	1.43
6	Composting	1.57	2.14

The investigation has determined that recycling is the optimum method for recovering resources or energy. This is due to the profitability's high RII value and low environmental impact, which have a total score of 3.571 and 1.0 out of 5, respectively. This is likely since recycling has many environmental benefits, such as reducing waste volumes, conserving natural resources, and reducing greenhouse gas emissions associated with the production of new materials. In addition, the availability of different waste recycling plants in Sri Lanka which are both profitable and the impact on the environment by those plants are low. Yet the environmental impact by the recycling plants is low the greenhouse gas emissions and consumption of fossil fuels due to waste transportation cannot be neglected. Even though the RII values of incineration are higher than those of gasification, the environmental impact of incineration is nearly double that of gasification. However, it is important to note that incineration and gasification methods are not as environmentally friendly as recycling and can lead to emissions of greenhouse gases and other pollutants. Incineration was perceived to have the highest environmental impact among the recycling and resource recovery methods considered. Some of the reasons for this belief are worries about the emissions from incineration, such as air pollutants and greenhouse gases, and the possible risks of dumping incineration ash. However, gasification was also perceived to have a moderate environmental impact. Gasification can have environmental benefits, such as reducing waste volumes and producing syngas that can be used as a fuel, but it can also produce air pollutants and requires energy inputs. Other methods get the lower places in the order of importance for resource recovery, such as pyrolysis, biogas, and composting, indicating that they are less important. All three methods were perceived to have a moderate environmental impact. This is because biogas production has some positive environmental benefits, such as reducing methane emissions from organic waste, but it also requires energy inputs and can produce some greenhouse gas emissions during production. Pyrolysis has some environmental benefits, such as reducing waste volumes and producing biochar that can be used as a soil amendment, but it also requires energy inputs and can produce some air pollutants. Composting has environmental benefits, such as reducing methane emissions from organic waste and producing a nutrient-rich soil amendment, but it can also require significant land use and energy inputs. However, it is important to consider the specific context and waste materials being used when evaluating the effectiveness and suitability of each method.

4.3 APPLICABILITY OF IDENTIFIED RECYCLING AND RESOURCE RECOVERY TECHNIQUES ON SUPERMARKET SOLID WASTE

According to the experts interviewed, the only methods that can be used are anaerobic digestion (biogas) and composting, which were chosen by seven and five out of seven respondents, respectively. None of the respondents mentioned any other techniques. All of these people agreed that anaerobic digestion (biogas) is a way to reuse resources that can be done on-site with waste from supermarkets. It is easier to turn food waste into biogas on the site of a supermarket than to collect food waste and move it to a different place. Also, by using biogas produced by the supermarkets themselves or by selling it to third parties, profits could be earned. Moreover, the reduction of food waste handed over to the municipal councils by the supermarkets will be reduced through the application of on-site biogas units. Respondents who agreed with composting said that composting food waste on-site is a good way to reuse resources because you don't need a lot of technology to start the process. This makes composting easier to use than biogas systems. R1 and R2, on the other hand, stated that composting is not applicable in the Sri Lankan context because R2 highlighted that "*composting attracts flies, leeches, and creates an odour that is not suitable for a supermarket area. These disruptions have the potential to harm supermarket business*".

Plastic sand brick is a plastic and polythene waste recycling technique that is currently not used in Sri Lanka. Two respondents, R3 and R4, agreed that plastic sand brick is a recycling technique that applies to supermarket plastic and polythene waste. According to R3, "*plastic and polythene waste generated in supermarkets can be recycled into plastic sand bricks. The relatively small area required for the process and the fact that waste generation is not massive is an advantage in terms of space*". Whereas with daily small collections of waste, the recycling process can be continued once a week, which would not require a large area. Yet respondents R1 and R2 were against the applicability of plastic sand bricks. According to R1, "*It is not safe to construct a recycling plant near a supermarket. The gases produced by the heating of the plastic will have an impact on both the environment and people's health*". This explains why plastic sand brick an applicable recycling method in an urban area is not. Considering the arguments of R1 and R2 and considering the negative impacts on the surrounding environment of plastic sand bricks, it can be concluded that plastic sand brick is not an applicable on-site recycling technique.

In the literature review, both gasification and pyrolysis were identified as resource recovery techniques that can be used on food waste and plastic and polythene waste. The respondents revealed that although in the Sri Lankan context gasification and pyrolysis are used only for plastic and polythene waste processing, these techniques cannot be used on an on-site supermarket basis. The reason for this is that a daily bulk waste quantity of 300 metric tonnes should be used in continuous operation gasification and pyrolysis plants, which supermarkets lack. Also, the literature review emphasised that the capital investment for a gasification plant or a pyrolysis plant is comparatively high. Even though gasification and pyrolysis were rated as moderately economical techniques by all three respondents, due to the lack of waste generation, they can be categorised as non-profitable investments for investors. Apart from that, the space needed for a plant is moderately higher than for biogas or composting. Where in the supermarket premises is the lack of space the main concern?

The technology for precipitation/dissolution is not yet familiar in Sri Lanka. This is why all three respondents responded that precipitation/dissolution is not an applicable resource recovery technique for the Sri Lankan supermarket context. This can be elaborated by the statement in R2 that "*we do not use precipitation or dissolution as a waste management technique in Sri Lanka*". Moreover, R6 stated that "*implementing an unknown technology when there are known alternative technologies is a risk*". This can lead to the conclusion that precipitation/dissolution is not yet ready for use in Sri Lanka. Further, as discussed in the literature review, dark fermentation is a resource recovery technique that still has few practicalities with its initiation from an engineering point of view. Similarly, all seven respondents stated that dark fermentation cannot currently be used in Sri Lanka. R3 stated that the "*dark fermentation process cannot be applied on an on-site basis at supermarkets due to the lack of technology and lack of knowledge by its users*".

According to all three waste management experts, converting paper waste into building material is an environmentally friendly recycling technique for paper and cardboard waste that cannot be applied to supermarket waste. According to the literature, paper waste can be recycled up to ten (10) times before it loses its quality. Where the paper and cardboard waste collected in supermarket premises has not been recycled before, this poses an issue in the recycling of paper waste into building materials. R2 emphasised this issue, stating, "*The paper used in supermarkets is of high quality." Making building material from high-quality paper when it can be recycled is a waste*". The supermarket does not have such a space." Which highlighted the need for space for the recycling of paper waste into building materials. This concludes that converting paper waste to building material is not applicable due to the quality of the waste and lack of space.

All seven experts in waste management agreed that deinking paper to recycle it is not something that can be done in a supermarket. The main problems with using the on-site paper deinking process were that there wasn't enough space and there wasn't enough paper waste. According to their responses, the paper waste generated from a single supermarket is not enough for the processing of a deinking plant. Accordingly, deinking of paper waste on the premises of supermarkets is not an applicable recycling method. Furthermore, selling paper waste to recycling third parties could be more profitable. Paper waste converted into bioethanol as a resource recovery technique for paper waste was denied as an applicable resource recovery on-site supermarket by all respondents. Bioethanol production by paper waste is not a resource recovery technique currently used in Sri Lanka, which makes the technology unknown to waste management experts. With the responses of the seven respondents, it can be concluded that bioethanol production from paper waste on-site is not an applicable resource recovery technique.

Hence, anaerobic digestion (biogas) and composting were identified as on-site resource recovery techniques for food waste. Plastic and polythene waste can be recycled with the assistance of a third party, and it can also be a gasifier. Paper and cardboard waste can be recycled into pulp with the help of a third party. Finally, a framework is created based on the research findings shown in Figure 2.

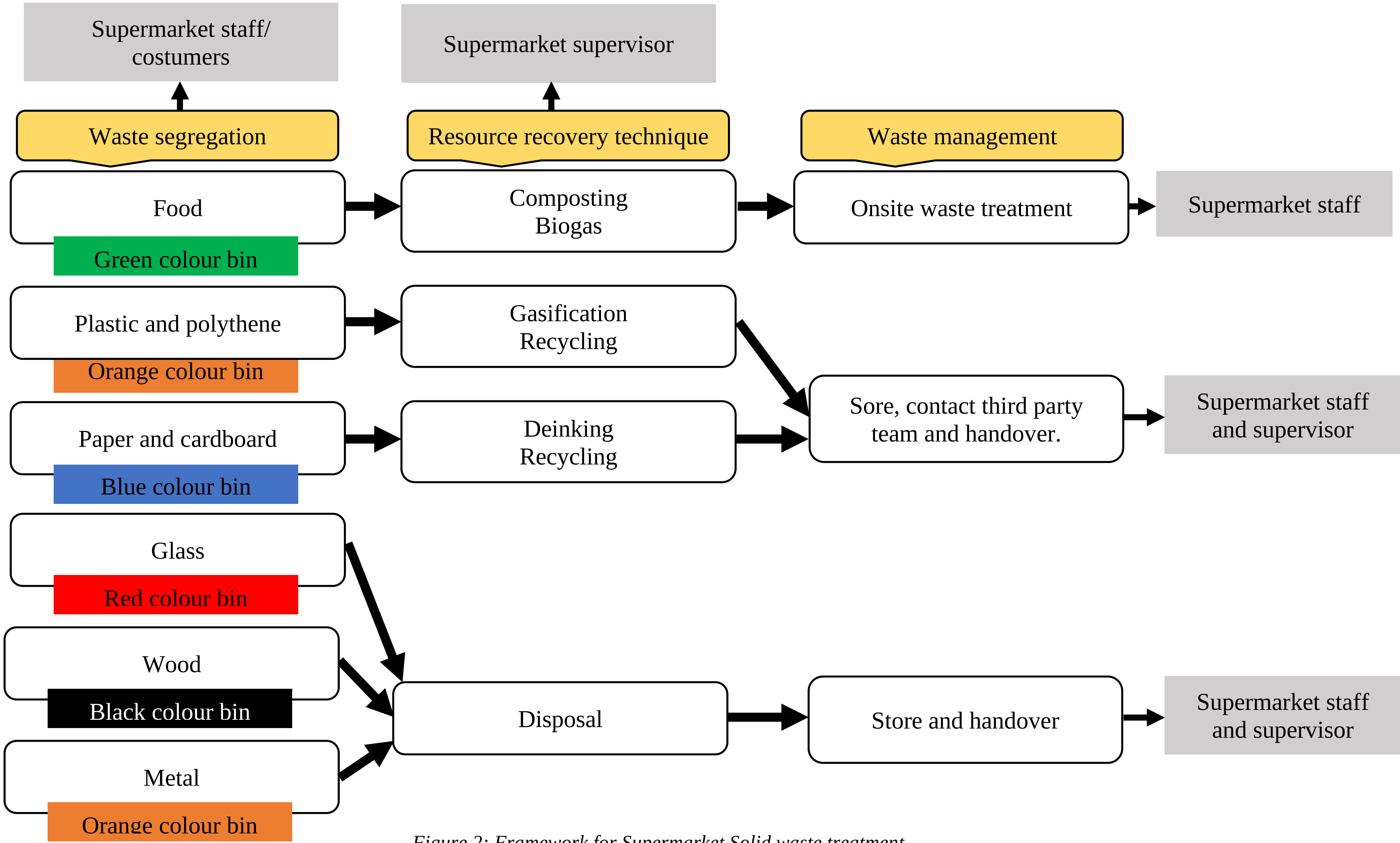

Figure 2: Framework for Supermarket Solid waste treatment

5. CONCLUSIONS

This study conducted a survey to identify the types of waste generated by supermarkets in Sri Lanka and examined the recycling and resource recovery methods currently employed to manage these wastes. The study revealed that food waste, plastic and polythene waste, and paper and cardboard waste are the primary treatable waste types in supermarkets. In Sri Lanka, the common resource recovery techniques used for waste management include biogas production, gasification, pyrolysis, and composting. The study also evaluated the profitability and environmental impact of these techniques and found that recycling is the most profitable and environmentally friendly method for managing most waste types, followed by gasification and pyrolysis, as per the ratings provided by waste management experts. Biogas production and composting were identified as effective techniques specifically for managing food waste. By identifying the predominant treatable waste types in supermarkets, industry practitioners can prioritise the implementation of effective recycling and resource recovery techniques for managing these wastes. Furthermore, the research findings can assist industry practitioners in understanding the most viable and environmentally sustainable techniques for managing different types of waste. This research can serve as a valuable guide for developing effective waste management strategies that reduce waste, enhance environmental sustainability, and increase profitability within the supermarket industry. Additionally, the study's insights can contribute to the development of theoretical frameworks and models for waste management in the supermarket sector. Importantly, it is worth noting that this study solely assessed the profitability and environmental impact of waste management techniques in Sri Lanka. The study is limited to the supermarkets in the Colombo Municipal Council. Additionally, the study might not account for potential variations in waste generation and management practices among different types or sizes of supermarkets, which could affect the applicability of the recycling and resource recovery techniques suggested. Future research should compare the effectiveness of different waste management techniques employed in other countries or regions. Moreover, conducting detailed cost-benefit analyses of various waste management techniques would provide a more comprehensive understanding of their economic feasibility. Overall, this study offers valuable insights for policymakers, waste management authorities, and supermarkets in Sri Lanka, aiming to improve waste management practices and foster a transition towards a more sustainable and circular economy. By implementing the findings from this research, stakeholders can contribute to mitigating environmental impacts, reducing waste generation, and promoting sustainable practices within the supermarket industry.

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APPLICATION OF EXPERIENTIAL KNOWLEDGE AND PERSONAL CONSTRUCTS INTO CONSTRUCTION CLAIMS MANAGEMENT

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ABSTRACT

Construction industry is known as a knowledge-intensive, where much of construction knowledge is tacit in nature based on experience. Nevertheless, sharing and applying of Experiential Knowledge (EK) and Personal Constructs (PC) to managing construction projects is lacking. Construction projects will inevitably involve claims, where due to presence of knowledge deficits of professionals in the industry, Claims Management (CM) has become a challenging task for contractors. Thus, the research aimed to explore the applicability of integrated EK and PC approach within the organisational culture towards successful CM practice. A qualitative approach inclusive semi-structured detailed expert interviews was attained in pursuing the research aim as the data collection tool. Data collection was limited to Grade C1 and above contractors in Sri Lanka. Literature findings disclosed the significance of applying previous project experience, role of organisational culture and role of PC in the construction industry. Expert interviewees established that CM is a knowledge-intensive core practice in the construction sector. Accordingly, the research study developed a framework indicating the relationships and applicability of Experiential Learning (EL), PC, Knowledge Sharing (KS) and Shared Learning concepts along with reusable project knowledge and EK towards each phase of CM process within the knowledge centred organisational culture.

Keywords: *Claims Management; Experiential Knowledge; Experiential Learning; Personal Constructs; Shared Learning.*

1. INTRODUCTION

Knowledge is the "lifeblood of an organisation" (Asrar-ul-Haq et al., 2016) and is generated by transforming experience (Battistutti & Bork, 2017). Knowledge of individuals gained from experience has a connection with various applications in the construction industry (Johansson, 2012; Liu et al., 2019). Therefore, management of knowledge is crucial (Asrar-ul-Haq et al., 2016) to overcome the challenges in construction projects (Safaei et al., 2020). The knowledge that is gained in a project needs to be transferred to an organisation's memory for reuse on other projects (Owen et al.,

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2014; Zhou et al., 2022). Hence, sharing experience and information among the people in the project team is an important task to improve the work performance compared to the past (Terzieva & Morabito, 2016). According to Alroomi and Jeong (2012) and Love et al. (2018), developing a learning culture can improve the project outcomes in the construction industry. Experiential Learning (EL) is based on the notion that the best way to learn something is by doing it. Western Governors University (2020) stated that EL is the dominant learning style in the construction industry. Yap and Shavarebi (2019) explained that EL and project personnel's personal constructs (PC) will be an important part of reusable project knowledge. Xiao and Boyd (2006) argued that the PC of the project management team must be challenged to increase their ability to learn to handle difficulties.

Due to the exclusive, vibrant and diverse nature in the construction industry, there have been situations where claims are inevitable (Apte & Pathak, 2016; Seo et al., 2021). Disputes arise when the contractor claims are not effectively managed (Khekale & Futane, 2015; Mehany et al., 2018). To address this challenge, claims management (CM) process is required and established by the industry contractors (Shaikh et al., 2020). CM is the process of employing and coordinating resources to progress a claim from identification and analysis through preparation, and presentation, before it proceeds to negotiation and settlement (Kululanga, 2001). However, construction CM is not a simple task and raises a variety of challenges for contractors like reaching amicable settlements (Lew et al., 2014; Parchami et al., 2020). Safaei et al. (2020) claims that there is a significant relationship between CM and knowledge management as a response to the aforementioned challenge. In fact, the knowledge deficit of professionals relating to managing claims constitutes a threat to the effective management of claims (Bakhary et al., 2015).

Numerous studies have been conducted on KS (Sanboskani et al., 2020; Senaratne et al., 2021), EL (Yap & Shavarebi, 2019), and PC (Simić et al., 2017; Vukelić et al., 2021) for the construction industry. However, there is a gap in integration of the above three concepts that relate to the application of CM practices in the Sri Lankan construction industry. Existing challenges in knowledge management that affect the successful CM practices can be fixed by the integration of EK and PC of the project team members with a proper collaborative organisation culture in contractor companies. Therefore, this research attempts to address the effective CM practice with the application of integrated EK and PC concepts within a collaborative learning culture. The structure of the paper consists of a critical evaluation of literature findings on the concepts of EK, PC, Shared Learning and CM, a study of research methodology and key findings from expert interviews on how integrated EK and PC concepts apply to the CM process.

2. LITERATURE REVIEW

2.1 PERSONAL CONSTRUCTS

Personal constructs (PC) are mental representations used to interpret events (Eiroa-orosa et al., 2019). The personal construct theory (PCT) developed by Geoge Kelly, examines people’s personalities, and explains their behaviour (Xiao & Boyd, 2006). Kelly’s PCT concerns that everyone develops a unique perspective on their living environment (Xiao & Boyd, 2006). PC serves as mental frameworks to interpret new difficult circumstances (Xiao & Boyd, 2006) because PC are methods by which individuals gather information, access them, and create interpretations. Love et al. (2018) emphasise that the aforementioned theory helps to understand the environment, solve issues, and utilise the memory of the people effectively.

2.2 APPLICATION OF EXPERIENTIAL LEARNING AND EXPERIENTIAL KNOWLEDGE IN THE CONSTRUCTION PROJECTS

Experience is an important role in decision-making and learning (Yap & Shavarebi, 2019). Ability to learn and acquire knowledge through experience is a key to personal development (Eraut, 2011). "The process of learning through experience" (Felicia, 2011, p. 1003) is called Experiential Learning (EL) which is significant in developing the competencies of professionals. Koskinen (2012) stated that learning from past project experiences improves project management skills in project-based organisations (Kokkonen & Alin, 2015). Moreover, Blume (2017) defined Experiential Knowledge (EK) as the knowledge gained through EL. Yap and Shavarebi (2019) highlight that learning from individual's and others' mistakes and viewing these failures as opportunities for improvement is a part of the learning process. Therefore, the application of EK to construction practices prevents repetitive mistakes, minimises rework, and omits reinventing the wheel (Yap & Shavarebi, 2019).

2.3 ROLE OF SHARED LEARNING (SL) CONCEPT IN THE CONSTRUCTION INDUSTRY

Shared Learning (SL) is the process of cooperating to accomplish a common goal (Sustainable Energy Advice Ltd., 2012). Information and knowledge gained through professional experience, training, business knowledge etc. (Lin & Lee, 2004) can be shared among the project teams in an organisation (Nguyen & Malik, 2020) allows organisation-wide learning (Ganguly et al., 2019), especially in the construction industry (Fong & Chu, 2006). Sharing knowledge among teams is important because SL enables KT across different projects that helps in acquiring knowledge for future projects (Ma et al., 2008; Nguyen & Malik, 2020) and for knowledge creation (Nguyen & Malik, 2020; Owen et al., 2014). Formal shared learning methods are project report database, assigning same employee to different projects, and flagship projects (Mueller, 2015). Working in a KS environment helps employees to enhance their creativity (Malik et al., 2020; Wang & Noe, 2010), problem-solving and productivity (Hung et al, 2021).

2.4 REUSABLE PROJECT KNOWLEDGE

An effective strategy that fits project's needs is to adapt or adopt reusable project knowledge (Tan et al., 2010). This strategy can save cost and time by eliminating the reinvention of the same specific knowledge (Baxter et al., 2008). Tan et al. (2007) shows that tacit and explicit knowledge are frequently combined to provide reusable project knowledge which allows for the maximisation of group learning, prevention of knowledge loss and utilisation of the value of the gathered knowledge (Kamara et al., 2003). Knowledge reuse enables better decision-making and creative problem-solving in situations with incomplete and restricted information (Yap & Shavarebi, 2019) via communication and networking.

2.5 KNOWLEDGE CENTRED ORGANISATIONAL CULTURE IN CONTRACTOR ORGANISATIONS

Organisational culture is the beliefs, values, and presumption of an organisation (Heinz, 2022). Organisational culture impacts the decision-making, communication, and working relationships (Naoum et al., 2015; Paais & Pattiruhu, 2019). Job satisfaction and productivity can be increased by fostering knowledge-related activities such as cooperation and learning (Durmusoglu, 2014). Collaborative organisation culture influences the Knowledge Sharing (KS) behaviour among professionals in the construction project team (Nugroho, 2018). Zhang and Li (2016) stressed the significance of collaborative organisational culture in knowledge reuse applications while intra-organisational and inter-organisational communication for better CM processes (Seo et al., 2021). Therefore, organisational culture plays a significant role in informal and formal KS processes among the professionals in the organisation (Papoutsakis, 2009). Yepes & López (2021) reveals that knowledge-centred culture acts as a key influential factor in the knowledge transfer process. The beliefs, attitudes, and behaviours of the organisation's members act as a means of shaping learning culture so that it becomes personal learning (Fernandes, 2018; Rohim & Budhiasa, 2019).

2.6 ROLE OF KNOWLEDGE IN CLAIMS MANAGEMENT

CM is the process of employing and coordinating resources to progress a claim from identification to negotiation (Kululanga, 2001). Accordingly, contractor’s CM process has six phases. Identification comes first, then notification, examination, documentation, presentation, and claim negotiation (Parikh et al., 2019). An efficient CM system is needed due to the rising number of construction claims in diverse and complex construction projects (Seo & Kang, 2021). Improper management of claims leads to disputes such as disagreements over the validity and value of the claim (Mehany et al., 2018). Chovichien and Tochaiwat (2006) and Oyegoke (2006) reveals that the deficit in CM expertise is a threat to effective CM~~.~~ An effective CM should possess a project team who is skilled and experienced in construction law and practices (Apte & Pathak, 2016). Although identifying and presenting claims is easy, substantiation and negotiation of claims are difficult. The above challenge can be addressed by inferring qualified and experienced practitioners that have skill sets in claim procedure, claim presentation and defence along with the CM team (Bakhary et al., 2015). Also, applying reusable knowledge within a cooperative atmosphere can entail better management of claims (Noorzai et al., 2016; Project Management Institute, 2017).

3. RESEARCH METHODOLOGY

The focus of the research is to examine how EL, EK, SL and PC concepts apply to construction CM practice in order to enhance its success from contractor’s standpoint. Qualitative research approach provides opportunities for the researcher to grasp the nature of the matter and develop theories out of practical applications Choy (2014). Since in-depth knowledge and personal opinions of the professionals who are practising CM in the industry are necessary for this research, qualitative approach was adopted to continue the research study. Purposive sampling allows the researcher to collect qualitative responses from the best-fit participants in order to gain a deeper understanding and more precise research findings (Campbell et al., 2020). Subjected to purposive sampling, data was collected from the experts who have more than 10 years of experience in the industry related to CM process. Semi-structured interview is one of the prominent data collection techniques because of its flexibility to the researcher to ask new questions and drop old ones during the interview (Ragab & Arisha, 2017; Kallio et al., 2016). Hence, semi-structured interview was used for data collection. Manual content analysis technique was adopted for this research as the data analysis technique because the number of interviewees and data were within a manageable number, there was no need to resort to automated content analysis.

Interviews were conducted with fourteen (14) construction industry professionals in engineering and quantity surveying profession. All the professionals interviewed have been exposed to CM during their career life and are chartered qualified professionals with intense Sri Lankan industry experience. The profiles of the interviewees are summarised in Table 1.

Table 1: Profile of interviewees

Code	Designation	Experience	Qualification
PE 01	Director	25 years	Chartered Quantity Surveyor, Adjudicator, Claim Consultant
PE 02	Project Director	25 years	Chartered Engineer
PE 03	Project Engineer	30 years	Chartered Engineer
PE 04	Senior Contract Specialist	25 years	Chartered Quantity Surveyor, Claim Consultant
PE 05	Senior Contract Specialist	25 years	Chartered Quantity Surveyor, Claim Consultant
PE 06	Quantity Surveyor	12 years	Chartered Quantity Surveyor, Claim Consultant
PE 07	Quantity Surveyor	10 years	Chartered Quantity Surveyor
PE 08	Director	30 years	Chartered Quantity Surveyor, Adjudicator
PE 09	Director	28 years	Chartered Quantity Surveyor
PE 10	Project Engineer	27 years	Chartered Engineer, Claim Consultant
PE 11	Former Senior Quantity Surveyor	13 years	Chartered Quantity Surveyor
PE 12	Project Engineer	10 years	Chartered Engineer, Claim Consultant
PE 13	Quantity Surveyor	15 years	Chartered Quantity Surveyor
PE 14	Quantity Surveyor	20 years	Chartered Quantity Surveyor, Claim Consultant

4. DATA ANALYSIS AND RESEARCH FINDINGS

4.1 KNOWLEDGE INTENSIVENESS IN CONSTRUCTION CLAIMS MANAGEMENT

All the respondents affirmed that claims management (CM) involves the application of vast knowledge and competencies of construction professionals. As insisted by the interviewees CM is not just a single one-time task but is a continuous process involving series of sub-activities associated with various knowledge applications. As declared by PE 02 and PE 06, a detailed claim document primarily consists of a scenario, legal and contractual facts and quantum. With that, in order to compile above three components together, professionals must be proficient in law (legal principles and case laws), contractual provisions, contract administration, project management, economics, finance, statistics, mathematics, software, modern technologies and site works. Determining documents to be maintained and keeping records also knowledge applicable areas in CM process as proclaimed by PE 15. Nevertheless, PE 08 pinpointed the inferiority of the knowledge of Engineers and Quantity Surveyors in analysing and substantiating claims. Hence, PE 12 emphasised "*CM should be assigned to professionals who have sufficient knowledge in managing claims gained through professional experience and formal education*". Apart from that for CM, variety of professionals are getting involved such as Engineers, Quantity Surveyors, Architects, Lawyers, Financial Experts and others. Therefore, as specified by PE 01 "*it is essential to have an in-depth knowledge and ability to understand different concepts involved with those professions to meet the success of the CM*". The Interviewees believed that without adequate knowledge background in managing claims, professionals are stuck at a point of managing the process of claims.

According to the responses of the interviewees, CM is a unique and complex task in a construction project. Therefore, making the right judgements throughout the CM process is crucial in achieving success for both parties. The interviewees revealed that other than construction project experience and contractual knowledge, having an understanding of legal principles, economics, law, technology statistics and mathematics is beneficial for professionals who are involving in managing claims. By considering all the points and facts discussed above evident knowledge intensity in CM.

4.2 APPLICATION OF INTEGRATED EXPERIENTIAL KNOWLEDGE (EK) AND PERSONAL CONSTRUCTS (PC) INTO CLAIMS MANAGEMENT (CM)

Literature has shown that professionals earned EK through EL. That is taking lessons from earlier projects that people have worked on. According to PE 01, knowledge gained through engaging in professional work is beneficent for each and every phase of the CM process. As PE 06 couched that project team members shall learn from previous experiences gained via engaging in management of claims in order to capture the relevant contractual provisions and legal matters, and to narrowly quantify the extension of time for completion period and the amount of associated cost going to be claimed, during the claim examination stage. Moreover, PE 11 declared "*intending to substantiate the contractor's entitlement, maintaining apposite documents at and off-site with accurate data is a core task in CM process*". Hence, having EK on site-related work will facilitate in determining which documents need to be maintained to prepare the detailed claim and is more advantageous in winning the claim. PE 02 highlighted that, in the local industry, there is no standard format for preparation of a detailed claim document, henceforth devising a claim in a precise and simple format and presenting contractual facts, legal facts and quantification relying on previous CM experience.

Personal constructs (PC) are mental representations used to interpret events. Since PC are unique to the person, people interpret the same event in different forms. PE 01 has opined that application of PC with the integration of Experiential Knowledge (EK) of the project team is essential in the claims preparation and negotiation stage because through sharing their experiences and perspectives, the most advisable delay analysis technique, legal principles and contractual provisions and formulas of computation of associated cost can be adapted with proper justifications for the above selections and claim document can be presented in the most suitable manner with minimum mistakes. Furthermore, bringing different perspectives of the project team members to one specific point enables interpreting an event in numerous ways, which act as a means of suggesting more alternatives under a wide range of contractual provisions, to address the claim comprehensively.

Nearly all of the respondents' points of view and perspectives evidently established that integration of EK gained via EL and shared PC are applicable for all the phases of the CM process.

4.3 APPLICATION OF REUSABLE PROJECT KNOWLEDGE INTO CLAIMS MANAGEMENT (CM) PROCESS

Over time, professionals working in the construction industry go through multiple stages in their career life. All the interviewees confirmed that previous project knowledge of them is utilised for current CM events. PE 04 stressed "*when there was a failed claim event which was handled in the past, some professionals went through them again, studied and analysed why it failed and then learnt by themselves not to make such mistakes or anything wrong again in prospective cases*". Further, they always keen to apply the knowledge grasped via that particular failed claims to manage the future claims effectively.

Significance of the application of reusable project knowledge was re-examined in the practical scenario of CM context. According to PE 02, "*having experience on site work enables early or right time identification of claims*". Further, in the documentation phase of CM process, reusable project knowledge is applied in identifying which documents should be maintained. Detailed claim document is subjective to the organisation due to unavailability of standard format for it. Due to such fact, the format followed to manage the past case can be adapted to the preparation of current claim documents. Experience in negotiating claims in the past enables one to anticipate the opponent party's possible reactions and plan appropriately in advance, ensuring the contractor's right is established throughout the negotiation stage. Moreover, PE 13 specified "*developing defence strategies and making commercial decisions in negotiation stage are done with the assistance of reusable project knowledge*". Accordingly, application of reusable project knowledge is crucial in managing claims effectively.

The framework developed by Yap and Shavarebi (2019) defined the right decisions made by professionals at the right time using integrated EK and PC of the project team members as "Expert Judgement". The responses of the interviewees are evident "Expert Judgement" feature in Yap and Shavarebi (2019) framework is adaptable for all the phases of CM process in the construction industry.

4.4 ROLE OF ORGANISATIONAL CULTURE TOWARDS INTEGRATION OF EK AND PC

The contractor's organisation was encouraged to adopt the organisational culture that would best support the integration of project team members' EK and PC as well as a robust KS strategy. The interviewees agreed to implement a collaborative organisational culture for effective integration of EK and PC. PE 14 believed "*collaborative culture allows employees to freely share their knowledge with others*". According to the respondent's views, it is more appropriate to introduce an organisational culture developed primarily based on collaborative nature, including components of other organisational cultures such as competitive advantage, goal orientation, structuring and profit-seeking, to meet the success of CM in contractors' organisations.

4.5 DEVELOPMENT OF THE FRAMEWORK

The framework was developed to illustrate how the concepts of EK, and PC are able to be integrated in a knowledge oriented collaborative environment to make the claims management practices more efficacious. The strategy of creation of collaborative model comprised of straining the most pertinent elements and characteristics of EL concept and PC concept.

Respondents assured that learning from project failures is the best practice for improving professional knowledge and transferring best practices to prospective projects. Kolb's Experiential Learning Theory (ELT) has defined experience as the core of learning. Adhering to a procedure which has the ability to integrate and share own constructs with each other, creating the potential of addressing unexpected issues in CM in a satisfaction manner. Previous research done by Yap and Shavarebi (2019) has developed a framework indicating how integrated EL and PC apply in expert judgements making, via application of reusable project knowledge to ameliorate the project delivery performance in the construction industry. That developed framework was also adapted to the model development in order to adduce the relationship between PC, EK and reusable project experience.

As revealed in interviews, CM is a knowledge-intensive application in the construction industry. Almost all phases involve professional knowledge and experience applications. Hence, managing knowledge across the project team members who are participants of CM is crucial towards its success. Literature and interviewees substantiated the significance of continuous learning in CM. Figure 1 demonstrates the developed framework for the analysed findings.

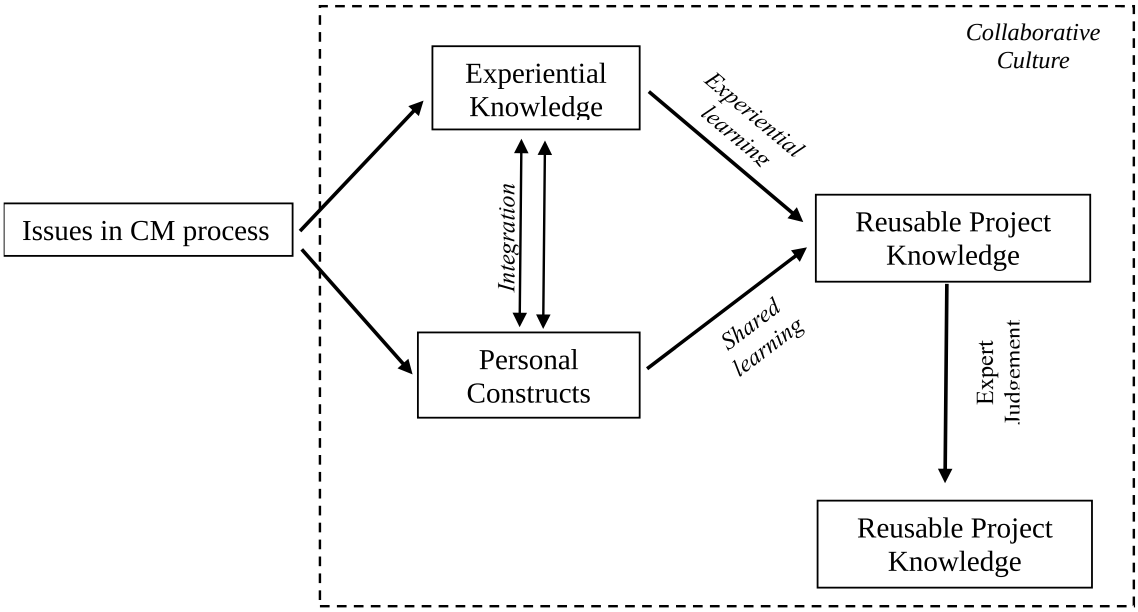

Figure 1: Framework

Use of integrated EK and PC as "Reusable Project Knowledge" within a collaborative environment is vital in making decisions because CM has grown more difficult for practitioners due to a lack of expertise and knowledge. By doing this, it will be possible to solve current CM process issues in an appropriate manner and ensure that the contractor is entitled to the claimed costs and time. The development of a sharing culture also reduces knowledge loss in the construction industry.

As interviewees specified, the framework indicates the interrelationship in between the concepts of EK and PC of the project team members within the knowledge oriented organisational culture. By adhering to this framework, project team members are equipped to make well-informed decisions in response to challenges encountered at each phase of the CM process. Furthermore, the framework facilitates KS among the team mates in contractor organisations, enabling the formation of teams enriched with comprehensive expertise and addressing the knowledge gaps among professionals. This approach ensures that contractors possess the necessary capabilities to meet all requirements and successfully navigate all phases of the CM process. Consequently, it mitigates many of the obstacles faced by CM practitioners, while maximising the contractor's potential to successfully claim costs and time. The process establishes a roadmap for addressing the client's repudiation of contractor claims during claim evaluation and negotiation stages, ultimately minimising the occurrence of disputes and enhancing the overall CM process. Furthermore, the implementation of this framework primarily benefits the parties responsible for managing claims. Initially, this framework is best suited for large-scale contractor organisations within the Sri Lankan context. It is recommended that this framework be applied to local contractor companies registered in the Construction Industry Development Authority (CIDA) as Grade C1 and above, as such companies are more likely to encounter a wide range of claims.

5. CONCLUSIONS

CM, EL, SL, and PC have been interpreted in a various manner over the years by the prior research projects. As a knowledge-intensive sector, the construction industry must adhere to appropriate KM methods in order to remain viable. Though CM process has been established as a knowledge intensive core practise by the experts in the construction industry, literature review defined the CM as a most challenging task to the construction practitioners due to lack of knowledge of the professionals who are involving into the above task. In such a context to create a wide range of expertise professionals, professionals shall adopt to the process of learning from their experience and sharing their such thoughts and experience across their respective team members. Making the best decisions is facilitated by professionals exchanging ideas and information in a collaborative setting. Accordingly, it was hypothesised that following EL and sharing project team members' PCs would enable correct judgments to be made through reusable project knowledge within the knowledge oriented collaborative culture. So developed framework offers guidance to the industry practitioners who are involving in CM, to make CM process more successful and to ensure the contractor's entitlement to claim.

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ASSESSING DELAY CLAIMS IN TERMS OF EXCUSABILITY AND CRITICALITY OF DELAYS IN FIDIC BASED CONTRACTS

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ABSTRACT

Assessment of delays involves complex decision making. Most standard contract forms do not provide guidelines on assessing delay claims; this is left to the professionals who at times tend to make decisions based on experience and subjective judgement. This will not always guarantee consistent decisions. Therefore, there is a need for a mechanism for assessing delay claims in construction industry. Excusability and criticality are the two elements to be considered in assessing a delay. These are governed by the conditions of contract and adopted delay analysis techniques (DATs) respectively. This paper is focused on developing a holistic approach to support the assessment of delay claims in terms of assessing the excusability and appropriateness of DATs. A mixed method approach was adopted for this study with four phases namely; literature review, desk study (based on FIDIC 1999 red book), in-depth expert interviews and a questionnaire survey. Qualitative data obtained through interviews were analysed using content analysis and questionnaire survey findings were statistically analysed. According to the findings, there are 18 major sub-clauses giving rise to excusable delays under FIDIC 1999 red book. In assessing the excusability of delays, the notice requirement, concurrency of delays and the contractor's obligations of mitigating delays are the important aspects to be considered. In the assessment of criticality, window analysis is the most suitable DAT. However, due to the complexity of the window analysis method, as planned vs. as built method is most commonly practiced in the industry which is considered as simple but less accurate.

Keywords: *As Planned vs. As Built; Criticality; Delay; Excusability; Window Analysis.*

1. INTRODUCTION

Claims management is considered as one of the greatest challenges for project stakeholders due to the complex and uncertain nature of construction projects (Amarkhi et.al, 2021). As per Vidogah and Ndekugr (2007), there is tremendous scope for improving claims management practice. This is because; claims management is still performed in an ad-hoc manner, contractors' management information systems are ill designed to support claims and records are often being inadequate even if available. Delays and disruptions to contractors' progress, often resulting in time and cost overruns, are a major source of claims and disputes in the construction industry (Ekanayake & Perera, 2016; Braimah, 2008; Sudeha et al, 2013). Various analytical methodologies have

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been developed over the years as aids to determine the extent of the delay, but hardly any information is available in terms of a holistic approach or procedure to guide practitioners in the assessment of delay claims (Braimah, 2008). Further, majority of contractual regimes do not provide details of the principles governing the assessment of delay claims; this is left to the professionals involved in each project (Kumaraswamy & Yogeswaran, 2007, Croeser, 2010). Banwo et.al (2016) mentioned that assessment of delays involves complex decision making. Conventionally, decision makers tend to make decision based on a blend of their intuition and subjective judgement. This kind of practice does not always guarantee consistent decisions and could be bias. Therefore, there is a need for a mechanism for assessing delay claims in construction industry (Iyer & Banerjee,2001).

There are two major factors to be considered in assessing a particular delay for granting an extension of time. These are: (a) whether the delay is excusable and (b) whether the delay is critical (Ndekugri & Braimah, 2007). Among these two elements, excusability of a delay is mainly be determined by the conditions of contract agreed between the parties while delay analysis techniques (DATs) are used in establishing the criticality and the quantum of delay (Braimah, 2008; Ekanayake & Perera, 2016). However, there are only few previous studies on this topic related to the Sri Lankan construction industry. In the literature, selection of appropriated DATs has been discussed in the recent studies of Dulaimi et al, 2018; Arditi and Pattanakitchamroon, 2018 and Andian et al, 2021. However, not much literature is available in considering both criticality and excusability of delays in assessing delay claims. Hence, the aim of this research is to develop a holistic approach for assessing delay claims in terms of excusability and criticality of delays in FIDIC based contracts. This study is limited to FIDIC 1999 red book due to its prominent usage and the familiarity within the context where research data is collected.

2. LITERATURE REVIEW

2.1 DELAY/EXTENSION OF TIME CLAIMS

Majority of projects overrun the stipulated completion dates. This can be attributed to the nature the uncertainties surrounding building and civil engineering projects (Andian et al, 2021). As such most standard forms of contract permit the extension of completion date where certain stated events tinder the control of or beyond the employer (Alnaas et al, 2014; Murdoch et al., 2015). Alternatively, where the event causing delay is one in the control of the contractor, he suffers damages usually liquidated as stated in the contract (Murdoch et al., 2015; Ndekugri & Braimah, 2007). Delay (extension of time) claims are the most common claims because it is faced by each contractor in almost every construction site (Bordoli & Baldwin, 2008; Braimah, 2013). According to Enshassi and Jubeh, (2020), delays in construction projects are contemplated as one most crucial issue that is being suffered by the current construction industry. Furthermore, Arcuri and Hildreth (2007) stated that construction delays are generally recognised as the most complex, risky and costly matter encountered in construction projects.

An extension of time is not deemed eligible or permissible unless all the causes of the delay are determined and evaluated then check to whether or not the reason is valid for extension of time request as per the contract clauses (Croeser, 2010). After the Contractor evaluates the reasons and causes of the delay and their eligibility for an extension of time; he determines the quantum of time and addition time needed, he then submits the claim into the employer (owner) or his representative (Architect, Engineer or Consultant)

(Murdoch et al., 2015; Ndekugri & Braimah, 2007). Although the reason and causes of an extension of time claim is unique and different for each construction project, the lifecycle and the stages of which the extension of time passes through is typical (Kumaraswamy & Yogeswaran, 2007)

2.2 TYPES OF DELAYS

Evaluation of construction delay claims is, to a large extent, influenced by the type of delay (Ndekugri & Braimah, 2007). A number of studies have attempted to categorise delays in terms of the impact, risk and cause of the delay. An in-depth understanding of the different types of delays is essential for the successful execution of delay-claim analysis.

2.2.1 Excusable and Non-Excusable Delays

An excusable delay can be described as a delay caused by either the client or the client's agents and third parties or incidents beyond the control of the client and the contractor, (Ndekugri & Braimah, 2007; Paray & Kumar, 2020). These culminate into a claim as they impose disruption and delay, as well as, loss and expense to be incurred by the contractor (Ndekugri & Braimah, 2007). A non-excusable delay is defined as a delay caused by the contractor, or any aspect that is within the contractor's sphere of control. The contractor would not be entitled to any additional time or compensation for this type of delay (Paray & Kumar, 2020).

2.2.2 Concurrent Delays

A concurrent delay occurs in a project when more than one type of delay arises at equal time frame and both, either independently or together, which impact the critical path of the project (Menesi, 2007). Subsequently, Paray and Kumar (2020) defined concurrent delay as a delay that is caused by entirely distinct parties at the same time which may impact the completion date of the project. The widely accepted rule in the construction industry is that if delays caused by the owner and the contractor occur simultaneously, last an equal amount of time, and have an equal impact on the critical path to project completion or another milestone date, neither party is entitled to compensable delay damages and neither party is entitled to its actual delay or liquidated damages, unless a specific contractual clause states otherwise {The Society of Construction Law (SCL), 2017}.

2.2.3 Critical and Non-Critical Delays

According to Andian et al. (2021), a delay in progress is not the same as a delay in completion. A delay in progress is a significant shift in the planned timing of a specific activity or activities that could occur at any time. Although the start and/or finish of the activity might differ from the original intent, it is irrelevant, unless it ultimately impacts on the completion date. On the other hand, a delay in the completion date occurs only when the completion date has passed; this can only be caused by a delay to the progress of an activity, which is in the critical path to completion (Croeser, 2010). A critical delay is a delay on the critical path of the project, resulting in the final completion date of the project being delayed, and a non-critical delay is a delay that is not on the critical path and that would, therefore, not impact on the overall completion date (Ndekugri & Braimah, 2007).

Braimah (2008) states that various methodologies have been developed over the years as aids to evaluate the criticality of delays. These methodologies can be divided into different categories (non-critical-path method-based techniques and critical-path method-based techniques) and different types, as are encountered in projects. The methodologies for analysing delay are summarised and categorised in Table 1.

Table 1: Delay Analysis Techniques (DATs)

Name	Description	Literature
As-planned vs. as-built	Compare baseline programme with as-built programme to determine overall delay	Stumpf (2000); Lucas (2002); Lovejoy (2004); Pickavance, (2005); Arcuri & Hildreth (2007); Braimah (2008); Barry (2009); SCL (2017)
As-planned but for	Take the actual as-built schedule and take out the duration of all the excusable delays	Alkass et al. (1995); Pinnell (1998); Braimah (2008); SCL (2017)
Impacted as-planned	Incorporate delays into as-planned (baseline) programme	Trauner (1990); Pinnell (1998); Lucas (2002); Lovejoy (2004) Pickavance (2005); Braimah (2008) SCL (2017); Enshassi and Jubeh (2009)
Collapsed as-built	Eliminate delays from as-built programme	Pinnell (1998); Stumpf (2000); Wickwire & Groff (2004); Lovejoy (2004) Braimah (2008); Barry (2009); SCL (2017)
Window analysis	Divide the programme in a number of time periods and update each window with delays in that period	Lovejoy (2004); Pickavance (2005); Braimah (2008); SCL (2017); Menesi (2007)
Time impact analysis	Establish effect of individual delays on baseline programme and evaluate delays chronologically	Alkass et al. (1995); Pickavance (2005); Braimah (2008); SCL (2017); Menesi (2007); Ng et al. (2004)

3. RESEARCH METHODOLOGY

This descriptive study consist of four phases in which primary and secondary data were obtained using qualitative and quantitative approaches. A comprehensive literature review was carried out to identify various types of delays in construction and commonly used DATs. Primary data collection consists of three major stages as a desk study, in-depth expert interviews and a questionnaire survey. Qualitative and quantitative research approaches were used interchangeably to get the required information and the research therefore had a mixed approach. Creswell (2018) have proved that combined methods give more accurate results as the qualitative findings could be further refined and validated through the quantitative methods.

Desk study was carried on FIDIC 1999 red book in order to identify the contractual provisions giving rise to delay claims, i.e., excusable delays. Desk study findings were refined and validated through the expert interviews. Other major purposes of expert interviews were to identify the practical usage of DATs and factors affecting selection of a DAT. Questionnaire survey was used to identify the relative importance of qualitative findings and to evaluate the appropriateness of commonly used DATs against DAT selection criteria.

Expert interviews were carried out in the form of semi-structured interviews. 06 in-depth interviews were carried out with a panel consisting of two (02) claim/contract specialists, two (02) contract administrators and two (02) adjudicators (referred to as E1, E2, E3, E4, E5 and E6 in the research findings section). Purposive sampling technique was used to select the sample according to criterion formulated by the researcher as; 'construction professionals who are having more than 20 years of experience working for both employer and contractor and having at least 10 years of experience with relate to administration of claims'.

Subsequently, a questionnaire survey was conducted thereafter among Engineers, project managers and quantity surveyors who were involved in delay analysis in construction projects covering both construction and consultant professionals. Questionnaire was designed with two major sections. Purpose of the section I was to identify the relative importance of the factors affecting the selection of a DAT. Purpose of section II was to map the same factors to the identified DATs in order to derive the appropriateness of the DATs. 60 questionnaires were distributed 30 each for professional representing contractor and consultant). Response rate was 85% and 77.5% respectively.

Content analysis was used for analysis of qualitative data while relative importance index (RII), mean weighted rating (MR) and criterion suitability score (CSS) were used to analyse the quantitative data.

$$RII = \sum (W_n) / (A \times N)$$

$$MR = \sum_{i=1}^{n} (Fi \times \%R)$$

$$CSS_i = RII_i \times MR_i$$

RII = Relative Importance Index, **W** = Weighting given to each factor by the respondents, **n** = Frequency of responses, **A** = Highest weight, **N** = Total number of respondents, **MR** = Mean Weighted Rating, **Fi**= Frequency of responses for an attribute, **%R**= Percentage response to rating point of an attribute, **CSS =** Criterion Suitability Score

4. RESEARCH FINDINGS

4.1 ESTABLISHING THE EXCUSABILITY OF DELAYS IN FIDIC 1999

A desk study was conducted based on FIDIC 1999 red book and the findings were refined through experts in order to identify the major contractual provisions for excusable delays. All together 18 sub-clauses, as shown in Table 2, were identified as contractual provisions applicable for excusable delays. 20 sub-clauses were identified through the desk study, however, sub-clause 4.7 [setting out] and 4.24 [Fossils] was omitted since E1, E2, E4 and E6, mentioned that *"delays due to fossils and setting out are rare in contracts"*. Hence following clauses were identified as the contractual provisions giving rise to delay claims under FIDIC 1999 red book.

Table 2: Sub-clauses applicable for excusable delays in FIDIC 1999 red book

No	Sub-Clause No.	Sub Clause Name
1	Sub-Clause 1.9	Delayed Drawings or Instructions
2	Sub-Clause 2.1	Right of Access to Site
3	Sub-Clause 2.4	Employer's Financial Arrangements
4	Sub-Clause 3.3	Instructions of the Engineer
5	Sub-Clause 4.12	Unforeseeable Physical Conditions

No	Sub-Clause No.	Sub Clause Name
6	Sub-Clause 8.3	Programme
7	Sub-Clause 8.5	Delay Caused by Authorities
8	Sub-Clause 9.1	Contractor’s Obligation
9	Sub-Clause 9.2	Delayed Tests
10	Sub-Clause 10.3	Interference with Tests on Completion
11	Sub-Clause 13.1	Right to Vary
12	Sub-Clause 13.3	Variation Procedure
13	Sub-Clause 13.7	Adjustments for Changes in Legislation
14	Sub-Clause 14.6	Issue of Interim Payment
15	Sub-Clause 14.7	Payments
16	Sub-Clause 14.8	Delayed Payment
17	Sub-Clause 16.1	Contractor’s Entitlement to Suspend Work
18	Sub-Clause 19.1	Definition of Force Majeure

The Contractor should demonstrate that the entire delay is excusable under the governing provisions. The notice of claim is to be given within 28 days after the Contractor became aware or should have become aware of the claim related event. In FIDIC 1999 conditions of contracts, a valid claim notice is a condition precedent to submitting a claim. If the notice of claim is not given within 28 days, the contractor is not to be entitled to any additional payment, the time for completion is not to be extended and the Employer is to be discharged from any responsibility regarding the claim related event.

Further, according to FIDIC 1999, within 42 days or other period after the Contractor became aware, or should have become aware of the claim related event, the contractor is to submit the “fully detailed claim” to the Engineer. However, FIDIC is silent on the entitlement of submitting a claim if the contractor fails to submit a valid claim within the stipulated time period. E1, E2, E5 and E6 was of the view that *since FIDIC is silent on the entitlement of submitting a claim if the Contractor fails to submit a valid claim within the stipulated time period, it does not revoke the Contractor’s right of submitting a claim within a reasonable time period.* However, E3 and E4 mentioned that *even though FIDIC is silent on this matter, Engineer should be able to reject a claim if the Contractor submits the Claim after 42 days without a valid reason of doing so.* According to E4 *“an internationally recognised standard form of contract like FIDIC would not stipulate a time frame for submitting a claim without a reason”.* However, all the respondents agreed that as per the International Chamber of Commerce (ICC)’s interim award in 2015, once a proper notice of claim is submitted as per the contract, the Contractor can submit the detailed claim even after passing of 42 days. Further, the respondents highlighted the obligation of delay mitigation by the contractor. According to E5 and E6, although the contractor has a contractual entitlement for a delay claim, if the particular delay could have been mitigated without difficulty, the entitlement may be revoked in arbitral and/or court jurisdictions.

In the case of concurrent delays, according to the respondents, the approach called ‘Malmaison Approach’ [named after the decision in *Henry Boot Construction (UK) Ltd v. Malmaison Hotel (Manchester) Ltd*] which concludes, ‘*where there is concurrent delay the contractor is entitled to an extension of time but is not entitled to loss or expense incurred during the extended period’* is widely adopted in analysing concurrent delays. This is also reiterated in the Delay and Disruption Protocol (SCL, 2017). However, according to E5 and E6, there are approaches such as 'dominant cause' and 'but-for' approaches which are less popular due to the complexity and the subjectivity of their usage.

4.2 Usage of Delay Analysis Techniques in Establishing Criticality of Delays

Respondents were presented with the delay analysis techniques identified in literature. General consensus of experts were that DATs are not being used in a systematic manner in the construction industry. However, all the respondents identified *as planned vs. as built, collapsed as built, impacted as planned, time impacted analysis, and window analysis* as commonly practiced DATs in the local and global construction industries. Further, all the respondents agreed that, as planned vs. as built is the predominantly used technique mainly due to its simplicity. Subsequently, all the five (05) techniques identify in this section are considered in this study.

4.3 Selection of Delay Analysis Techniques

Selection of the appropriate DAT is important for both the Contractor and the Employer in establishing and assessing the delay. Therefore, the experts were asked to identify the most important factors to be considered in selecting a DAT. *E2 stated that "no standard form of contract encourages parties to agree on a particular DAT hence it is mostly up to the contractor to decide which DAT to be used in the given context".* However, all the respondent agreed that time and cost of the analysis, availability of contemporary records, number and nature of delay events, reliability of the outcome and acceptability in dispute boards/arbitral tribunals/courts are important factors to be considered in selecting a DAT. E1, E2 and E4 identified workability of the analysis and skill of the analyst as further important factors while E6 stated that *"although most standard forms of contracts do not recommend any DATs, it is important to look into conditions of contracts for any such provisions"*. Following list consist of all the factors affecting the selection of a DAT as per the interview findings.

- Time taken for the analysis
- Cost of the analysis
- Skill of the analyst
- Nature of the delay events
- Number of delay events
- Acceptability in dispute boards/arbitral tribunals/courts
- Workability of the analysis
- Availability of relevant contemporary records
- Reliability of the outcome
- Conditions of contract

4.4 Importance of DAT Selection Factors

Section I of the questionnaire was aimed to identify the importance of each characteristic which was identified during the expert interviews when selecting a suitable delay analysis technique. Accordingly, respondents were asked to react on a five-point Likert scale in order to determine the importance of each characteristic. Then the findings were ranked based on the RII values as shown in Table 3.

Table 3: Importance of DAT selection factors

Factor	RII	Rank
Availability of relevant contemporary records	0.826	1
Number of delay events	0.784	2

Factor	RII	Rank
Nature of the delay events	0.778	3
Reliability of the outcome	0.766	4
Cost of the analysis	0.685	5
Time taken for the analysis	0.624	6
Acceptability in dispute boards/arbitral tribunals/courts	0.545	7
Workability of the analysis	0.453	8
Skill of the analyst	0.245	9

4.5 MAPPING THE APPROPRIATENESS OF DELAY ANALYSIS TECHNIQUES

Section II of the questionnaire were used to investigate the appropriateness of delay analysis techniques based on their key characteristics that were identified during the expert interviews. A five-point Likert scale was used to gather data from the respondents. Then Mean Rating (MR) values were calculated for every characteristic. Thereafter, the Criterion Suitability Score (CSS) was calculated by multiplying the mean rating value with the relative importance index. Ultimately, CSS was used to evaluate the degree of suitability of each delay analysis technique for a given characteristic as shown in table 4.

4.6 FRAMEWORK DEVELOPED FOR ASSESSING DELAY CLAIMS

Considering the findings with relate to assessing the excusability and the criticality of the delays in delay claims, a framework is developed for assessing delay claims as shown in figure 1 which shows the window analysis technique is highly reliable and more suitable in complex delay scenarios. As planned vs. as built is the simplest technique which can be used with minimum information and lesser time and cost, however less reliable.

5. CONCLUSIONS

Delay claims are common in construction projects and they one of the major sources of disputes in construction contracts. Therefore, it is critical to assess and evaluate these claims efficiently in a timely manner to prevent any retarding impacts on the project progress. Assessment of delays involves scrutinising the excusability and criticality of delays. In terms of assessing the excusability of delays under FIDIC 1999 red book, proper identification and the interpretation of the general and particular conditions of contract is a must. Further, the notice requirement is a condition precedent in submitting a claim. Other important aspects to be considered are the concurrency of delays and the contractor’s obligations of mitigating delays. Specially in the case of concurrent delays, FIDIC 1999 red book itself does not provide any guidance, hence other sources like delay and disruption protocol, arbitral and court decisions need to be referred. However, these external sources not being part of the contract could create challenges in assessing such claims. Criticality of delays need to be established through DATs with essential supporting documents such as properly amended programmes. In terms of selecting a DAT, reliability of the outcome, availability of relevant contemporary records and acceptability in dispute boards/arbitral tribunals/courts are the most important factors to be considered. In that regard window analysis method is identified as the most suitable technique to be used in establishing the criticality of the delay. However due to the complexity of the window analysis method and the poorly prepared baseline programmes in most of the projects, the as planned vs. as built method is most commonly practiced in the industry. The framework shown in figure 1 provides a holistic approach for assessing delay claims in terms of excusability and criticality.

Table 4: Criterion suitability of different delay analysis techniques

Characteristic	As planned vs as built				Collapsed as built				Impacted as planned				Time impact analysis				Window analysis			
	RII	MR	**CSS & Rank**		RII	MR	**CSS & Rank**		RII	MR	**CSS & Rank**		RII	MR	**CSS & Rank**		RII	MR	**CSS & Rank**	
Time taken for the analysis	3.512	0.702	**2.465**	**1**	3.302	0.660	2.179	2	2.744	0.549	1.506	3	2.395	0.479	1.147	5	2.698	0.540	1.457	4
Rank 1: means time taken for analysis is low																				
Contemporary records	2.070	0.414	0.857	5	3.674	0.735	**2.700**	**1**	2.930	0.586	1.717	3	2.791	0.558	1.557	4	3.372	0.674	2.273	2
Rank 1: means requirement of contemporary records is minimum																				
Cost of the analysis	3.302	0.660	2.179	2	3.511	0.702	**2.465**	**1**	3.000	0.600	1.800	3	2.465	0.493	1.215	5	2.837	0.567	1.609	4
Rank 1: means cost of the analysis is low																				
Number of delay events	2.861	0.572	1.636	5	3.326	0.665	2.212	3	3.233	0.647	2.092	4	3.348	0.670	2.243	2	3.698	0.740	**2.737**	**1**
Rank 1: means most suitable when number of delay events are high																				
Nature of the delay events	2.418	0.484	1.170	5	3.122	0.621	1.971	3	2.924	0.407	1.192	4	3.375	0.628	2.120	2	3.651	0.730	**2.665**	**1**
Rank 1: means most suitable when the nature of delay events are complicated																				
Workability of the analysis	3.116	0.623	1.941	2	1.558	0.312	0.486	5	3.349	0.670	**2.244**	**1**	2.628	0.526	1.382	4	2.465	0.493	1.215	3
Rank 1: means the workability of the analysis is high																				
Skill of the analyst	3.465	0.693	**2.401**	**1**	2.163	0.433	0.937	5	2.954	0.591	1.746	2	2.884	0.577	1.664	3	2.512	0.502	1.261	4
Rank 1: means the analyst does not have to possesses higher levels of technical skills																				
Reliability of the outcome	1.768	0.353	0.624	5	3.489	0.698	2.435	3	1.977	0.395	0.781	4	3.907	0.781	3.051	2	4.000	0.800	**3.200**	**1**
Rank 1: means the reliability of the outcome is high																				
Acceptability in dispute courts	2.564	0.483	1.240	5	3.024	0.615	1.861	3	2.968	0.455	1.352	4	3.917	0.792	3.102	2	4.000	0.800	**3.200**	**1**
Rank 1: means there is high acceptability in courts																				

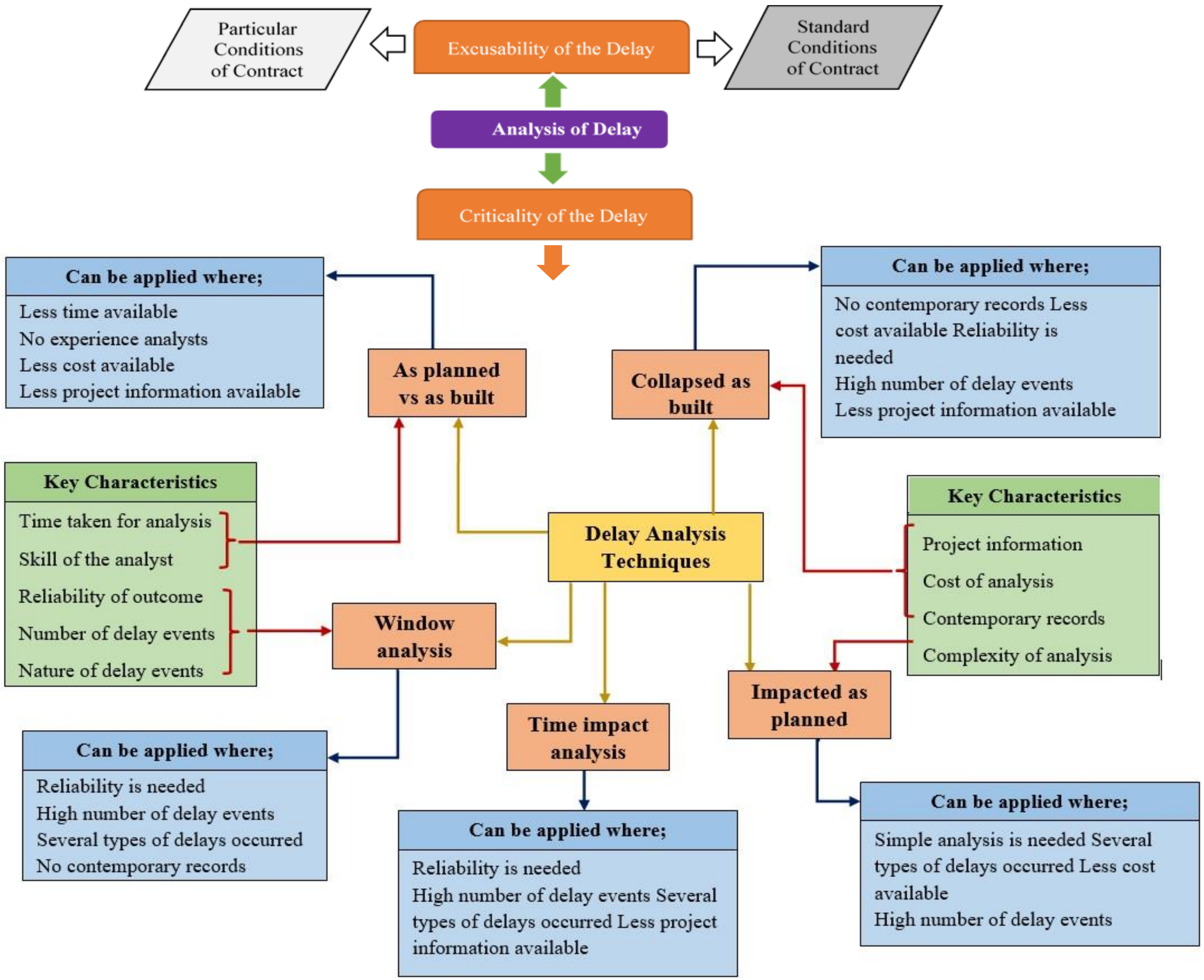

Figure 1: Framework for assessing delay claims

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ASSESSMENT OF DESIGN AND CONSTRUCTION RELATED FACTORS INFLUENCING MAINTAINABILITY OF GREEN ROOFS: A CASE OF HIGH-RISE BUILDINGS IN SRI LANKA

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ABSTRACT

Poor design and construction practices can significantly impact the future maintainability of green roofs in high-rise buildings. While previous studies have focused on green roof construction and design features, this research specifically evaluates the effects of design and construction related factors on maintainability of green roofs, with a focus on high-rise buildings in Sri Lanka. The study begins by reviewing literature on green roofs, their maintainability, and the design and construction factors that influence maintainability. The identified factors were used as a basis for evaluating the effects of design and construction on future maintainability of green roofs. A deductive approach is adopted within a quantitative research design, utilising a survey strategy. A questionnaire survey was conducted among 58 experienced construction professionals, while four expert interviews are conducted to gather additional insights. Data analysis techniques include the Relative Importance Index and content analysis. As derived through analysis, initial cost and roof design were identified as design-related key factors, while cost of construction and availability of machinery and materials were the construction related key factors influencing maintainability of green roofs. Accordingly, the study proposed strategies to enhance the maintainability of green roofs in Sri Lankan high-rise buildings focusing on cost effectiveness, design effectiveness and effective management of green roofs. As a main implication, this research contributes to the development of sustainable and maintainable green roofs in Sri Lanka by providing valuable insights for the construction professionals and policy makers in the country.

Keywords: *Design and Construction; Green Roofs; High-rise Buildings; Maintainability.*

1. INTRODUCTION

The construction industry has a significant impact on the environment, and the building sector has a strong potential to protect it (Sandanayake, 2022). Sustainable construction aims to minimise the environmental impact of a building throughout its lifespan, while

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also improving its economic viability, comfort, and safety (Mahamadu et al., 2016). The principles of sustainable construction have been divided into four pillars: social, economic, biophysical, and technological. According to Vidyaratne and Melagoda (2018), green roofs, which are becoming increasingly popular in Sri Lankan high-rise building and it has gained increasing attention as a sustainable solution for development projects, as they offer numerous environmental benefits such as reducing energy consumption, mitigating the urban heat island effect, and improving air quality. However, poor design and construction can significantly impact the future maintainability of green roofs (Mohanta & Das, 2022). Moreover, one of the critical aspects that need to be addressed is the future maintainability of green roofs, particularly in high-rise buildings (Chew et al., 2019). The maintainability of green roofs refers to the ease of maintenance and the ability to sustain the desired functionality over time. However, the challenge of maintainability is more significant in high-rise buildings due to the added complexities associated with access, logistics, and safety (Ganisen et al., 2015). Therefore, enhancing the maintainability of green roof construction is important since Sri Lanka's construction industry is booming, with luxury apartments, hotels, and shopping complexes being developed in the city and suburbs (Pathirana & Munasinghe, 2021). Further, the government is also promoting sustainable construction to minimise the industry's impact on the environment.

Considering above, this research aimed to evaluate the effect of design and construction on future maintainability of green roofs specialising the high-rise buildings in Sri Lanka. Accordingly, two objectives were formulated:

I. To identify design and construction related factors influencing maintainability of green roofs,

II. To determine the significant design and construction related factors influencing maintainability of green roofs of high-rise buildings in Sri Lanka, and

III. To propose strategies to enhance the future maintainability of green roofs of high-rise buildings in Sri Lanka.

By developing an understanding of the critical factors affecting the maintainability of green roofs, this research will contribute to the development of sustainable and maintainable green roofs in Sri Lanka.

2. LITERTAURE REVIEW

Green roof has been proposed as the sustainable practice to mitigate the adverse effects of urbanisation (Huang & Poullain, 2011). A green roof is a vegetative layer that is intentionally installed on top of a building's roof, either partially or fully, to provide environmental benefits such as reducing urban heat island effect, managing storm water runoff, improving air quality, and reducing energy consumption (Huang & Poullain, 2011). It typically includes a waterproofing layer, a drainage layer, a filter layer, a growing medium, and vegetation. Green roofs properly designed, constructed and maintained, are beneficial socially, environmentally and fiscally (Meulen, 2019).

The green roof operation and maintenance system is considered to be an observable factor, and the lack of maintenance seems to be an additional challenge to the green roof implementation as the roof garden may not function as expected. Maintenance capability is one of the most important factors to consider when designing a building, as it is essential to maximise the overall performance of the building, including quality and cost (Ganisen et al., 2015).

2.1 MAINTAINABILITY OF GREEN ROOFS

Maintainability of green roofs is an essential factor that determines the success of a green roof project in the long term. Maintainability refers to the ease and effectiveness with which a system, product, or process can be maintained or repaired over time (Wang et al., 2016). It is a measure of how easily and quickly maintenance tasks can be performed, how often maintenance is required, and how much effort and resources are needed to keep the system or product in good working condition. Green roofs require regular maintenance to ensure that they remain healthy and functional (Cascone, 2019). Proper maintenance is necessary to prevent damage, enhance the longevity of the roof, and maximise the environmental benefits that green roofs provide.

2.2 FACTORS INFLUENCING MAINTAINABILITY OF GREEN ROOFS

Considerations of the maintenance management of a facility at the planning and design stage are of utmost importance for the facility’s future performance attributes and life cycle cost management (Samaraweera & Gunawardhana, 2020). The demand for modern facilities to strive for higher performance standards means that prudent decisions must be made at the planning and design stage, as they will have a residual effect and vital impact on the facility’s future maintainability. Accordingly, the factors that influence the maintainability of green roofs can be broadly categorised into design-related factors and construction-related factors.

2.2.1 Design Related Factors (DRFs) Influencing Maintainability of Green Roofs

Design related factors (DRFs) can significantly impact the ease of maintenance, the cost of maintenance, and the longevity of green roofs (Allnut et al., 2014). Lack of attention to maintainability considerations at the design stage may lead to difficult and costly operation to users; hence users’ expectation may not be achieved (Huang & Poullain, 2011). It is crucial to identify and address these DRFs during the initial design phase to ensure the long-term maintainability and sustainability of green roofs. By doing so, it can significantly reduce the cost and effort required to maintain green roofs, making them a more viable and sustainable option for high rise buildings. Table 1 identifies the DRFs that can influence the maintainability of green roofs.

Table 1: Design related factors influencing maintainability of green roofs

Factor Code	Factor	Sources
DRF1	Initial cost	[1] [4]
DRF2	Roof design	[3] [4]
DRF3	Roof structure’s lifespan	[4]
DRF4	Design parameters	[2] [3] [4]
DRF5	Material & physical properties	[2] [4] [5]
DRF6	Wastage percentage	[4] [5]
DRF7	Available technological aspects	[3] [4]
Sources:	[1] (Alattyih et al., 2020); [2] (Cascone, 2019); [3] (Chew et al., 2019); [4] (Conejos & Chew, 2020); [5] (Klein, 2018)	

Under DRF4, it has been focused about irrigation system, drainage system, wind exposure and sun exposure conditions when designing a green roof. Apart from that, plant type and soil condition have been considered under DRF4. These factors play a significant role in determining the ease of maintenance, cost of maintenance, and longevity of green roofs. For example, DRF1, which refers to the initial cost, can indirectly influence maintainability (Alattyih et al., 2020). Higher initial costs may allow for the integration of more advanced technologies and efficient design features that can simplify future maintenance tasks. Similarly, DRF2, which pertains to roof design, can influence the accessibility of different roof areas, making maintenance activities easier or more challenging (Chew et al., 2019). By considering these factors, it is possible to design green roofs that are not only aesthetically pleasing but also easy to maintain and sustain over the long term.

In the context of high-rise buildings, specific design considerations may be required to address the unique challenges associated with their height and structural complexity (Vidyaratne & Melagoda, 2018). These considerations may include safe access points for maintenance personnel, efficient water and drainage systems, and appropriate plant selection that can withstand the exposure to wind and sun at greater heights. By incorporating these design-related factors into the planning and design of green roofs in high-rise buildings, their maintainability can be enhanced.

2.2.2 Construction Related Factors (CRFs) Influencing Maintainability of Green Roofs

Construction related factors (CRFs) play a crucial role in the maintenance of green roofs, and their influence should be considered during the planning and installation phases (Conejos & Chew, 2020). In this context, this paper identifies some of the key CRFs that influence the maintainability of green roofs as shown in Table 2.

Table 2: Construction related factors influencing maintainability of green roofs

Factor Code	Factor	Sources
CRF1	Structure and weight of the roof	[1] [3] [5]
CRF2	Cost of the construction	[1] [2] [3]
CRF3	Availability of machinery and materials	[1] [3] [4]
CRF4	Availability of experts related to green roof construction	[3] [4]
CRF5	Risk factors in green roof construction	[1] [3] [6]
CRF6	Rules and regulations	[1] [3]
CRF7	Availability of labour and technology	[3] [4]
Sources:	[1] (Allnut et al., 2014); [2] (Blackhurst et al., 2010); [3] (Carpenter, 2014); [4] (Cascone, 2019); [5] (Rabe, 2013); [6] (Vidyaratne & Melagoda, 2018)	

According to Table 2, considering these CRFs during the design and installation of green roofs can help ensure that they are easy to maintain and provide long-lasting benefits. For example, CRF1, which refers to the structure and weight of the roof, can influence the overall stability and load-bearing capacity of the green roof. Adequate structural support is essential for the long-term maintenance of the green roof in high-rise buildings (Allnut et al., 2014). Similarly, CRF5, which relates to risk factors in green roof construction, is particularly relevant to high-rise buildings (Carpenter, 2014). The construction process at greater heights may involve additional safety measures and precautions to protect both workers and the green roof itself. According to Vidyaratne and Melagoda (2018), to achieve the maintainability complications specific to high-rise buildings, it is essential to consider the unique challenges posed by their height, accessibility, and exposure to environmental elements. This may include incorporating advanced irrigation and drainage systems, employing specialised equipment for maintenance tasks at heights, and implementing monitoring systems to detect and address issues promptly. Addition to that, under the CRF5, there are several types of risk factors that influence the construction and maintainability of green roofs such as structural risk, vegetation risk, maintenance access risk, climate risk, health and safety risk, and waterproofing and leakage risk (Intact Public Entities Incorporation, 2021). Since all these factors affect to the maintainability of green roofs, CRF5 includes all these risk types, highlighting the importance of considering and mitigating these risks during the construction phase of green roofs. In summary, DRFs focus on the planning and design of the green roof, while CRFs focus on the installation and construction phase. Both design-related and construction-related factors are important in ensuring the maintainability of green roofs.

3. RESEARCH METHODOLOGY

This section outlines the research methodology adopted to achieve the aim of developing an effective design and construction strategy for enhancing the future maintainability of green roofs of high-rise buildings in Sri Lanka. The deductive research approach under quantitative research design was adopted for this study as it enables the researcher to quantify the factors influencing the maintainability of green roofs. Survey approach was adapted as the suitable research strategy.

Data collection for this study was done mainly through a questionnaire survey, which was focused on identifying the most significant factors influencing maintainability of green roofs which are associated to design and construction stages. Under the questionnaire survey, Likert scale method was included to identify the DRF and CRF significance level to maintainability of green roofs in Sri Lankan high-rise buildings. The questionnaire was distributed among eighty (80) construction professionals, such as Architects, Engineers, Quantity Surveyors, Project Managers and Facility Managers, who are working in building construction projects in Sri Lanka. The sample of respondents were selected by adopting convenient sampling technique. From 80 distributed questionnaires, 58 were collected with the response rate of 74%. Additionally, 04 expert interviews were conducted with selected respondents to identify strategies to enhance the future maintainability of green roofs. The collected data were analysed by using Relative Important Index (RII) and content analysis techniques.

RII is a type of relative importance analysis that is used to find out the amount of contribution made by a particular variable to the prediction of a criterion variable both by itself and in combination with other predictor variables (Rajgor et al., 2016). Figure 1 shows the formula used to calculate the RII.

$$RII = \frac{\sum(W \times n)}{(N \times A)} \qquad (01)$$

where, W= Weight given by each factor by respondents, n=Frequency of responses, A=highest weight, N= Total frequency of responses (total number of respondents)

Expert interviews were conducted to explore the strategies for enhancing the future maintainability of green roofs in high-rise buildings in Sri Lanka. Semi-structured interviews were conducted with four experts in Sri Lankan construction industry with expertise in green design and construction. Under the semi structured interviews, experts were questioned based on their experiences of maintaining green roofs in high rise buildings and gathered their ideas to improve the maintainability of green roofs. Table 3 presents the profile of expert interviewees.

Table 3: Respondent profile of expert interviews

Code	Interviewee	Experience (Years)
R1	Quantity Surveyor	10
R2	Project Manager	15
R3	Project Engineer	10
R4	Resident Manager	20

Content analysis technique was used to analyse the data collected through expert interviews.

Data analysis and key research findings are presented below.

4. DATA ANALYSIS AND FINDINGS

As per the factors identified under the literature review, this section identifies the critical design related and construction related factors influencing maintainability of green roofs in the context of high-rise buildings in Sri Lanka by analysing the relative importance of the factors. Finally, strategies were proposed by considering the critical DRFs and CRFs related to the maintainability of green roofs.

4.1 DESIGN RELATED FACTORS INFLUENCING MAINTAINABILITY OF GREEN ROOFS OF HIGH-RISE BUILDINGS IN SRI LANKA

Factors identified under Table 1 are ranked as per the relative importance as shown in Table 4. Design-related factors (DRFs) are key considerations that influence the maintainability of green roofs. This section focuses on ranking the DRFs that have the most significant impact on the maintainability of green roofs in high-rise buildings in Sri Lanka. Through the use of a Relative Importance Index (RII), the study aims to provide valuable insights into the relative importance of these factors, enabling architects, engineers, and building professionals to make informed decisions during the design phase to enhance the maintainability and overall performance of green roofs.

Table 4: Ranking of DRFs as per RII

Factor Code	Factor	RII	Rank
DRF1	Initial cost	0.814	1
DRF2	Roof design	0.800	2
DRF3	Roof structure’s lifespan	0.790	3
DRF4	Design parameters	0.786	4
DRF5	Material & physical properties	0.783	5
DRF6	Wastage percentage	0.779	6
DRF7	Available technological aspects	0.745	7

According to Table 4, it is emphasised that the initial cost of the green roof obtained the highest rank (RII=0.814). During the green roof design stage, it is necessary to analyse the maintenance of water, waterproofing membrane, root barrier, drainage layer, filter layer, substrate, and plants. Green roofs involve various new aspects compared to conventional buildings, and initial investment costs need to be considered. The second rank with an RII of 0.800 was obtained by roof design where the lifespan of roof structure received the third (RII=0.79). Under these factors, it considers the load capacity, pitch, shading and rain shadow from adjacent structures, hot/cold air emissions from air conditioning units and other equipment, height of parapet walls, and safe access to install and maintain the green roofs. The fourth rank (RII=0.786) was obtained by the design parameters since it is important to analyse the suitability of the country's environmental impact during the green roof design. The fifth rank and sixth rank were obtained by the wastage percentage (RII=0.783) and available technological aspects (RII=0.779) respectively. Green roofs involve many new aspects compared to conventional roofs and the selection of sustainable materials for a particular design with appropriate physical properties is a necessary factor considered. The last rank (RII= 0.745) was obtained by the availability of machinery, tools, and computer-aided technology. Green roofs are a new concept in many countries, and some necessary tools and equipment may not be readily available.

4.2 CONSTRUCTION RELATED FACTORS INFLUENCING MAINTAINABILITY OF GREEN ROOFS OF HIGH-RISE BUILDINGS IN SRI LANKA

Factors identified under Table 2 are ranked as per the relative importance as shown in Table 5. Construction-related factors (CRFs) are key considerations that influence the maintainability of green roofs. This study focuses on identifying and ranking the CRFs that have the most significant impact on the maintainability of green roofs in high-rise buildings in Sri Lanka. Through the use of a Relative Importance Index (RII), the study aims to provide valuable insights into the relative importance of these factors, enabling architects, engineers, and building professionals to make informed decisions during the design phase to enhance the maintainability and overall performance of green roofs.

Table 5: Ranking of CRFs as per RII

Factor Code	Factor	RII	Rank
CRF1	Structure and weight of the roof	0.790	3
CRF2	Cost of the construction	0.821	1
CRF3	Availability of machinery and materials	0.803	2
CRF4	Availability of experts related to green roof construction	0.786	4
CRF5	Risk factors in green roof construction	0.755	6
CRF6	Rules and regulations	0.769	5
CRF7	Availability of labour and technology	0.741	7

As per Table 5, the cost of constructing a green roof obtained the highest rank (RII=0.821), indicating that it is generally more expensive than traditional roofs due to the various types of membranes, water management systems, technical applications, and proportional involvement required. Availability of machinery and materials obtained the second rank (RII=0.803) since some roof applications and equipment may not be readily available in the industry, and investors may need to import the required items as per their requirements. Structure and weight of the roof obtained the third rank (RII=0.790), while availability of experts related to green roof construction obtained the fourth rank (RII=0.786), as various new concepts and modern technology are applied in green roof construction, requiring the involvement of professionals like architects, engineers, and designers. Rules and regulations acquired the fifth rank (RII=0.769) as high-rise building construction may require special rules and regulations due to the location or security requirements.

Risk factors in green roof construction obtained the sixth rank (RII=0.755) since investors and construction firms in the country may be hesitant to invest in such projects due to the various risks and lack of experience. Finally, the availability of skilled labour and technological aspects in the country obtained the seventh rank (RII=0.741) as the shortage of skilled labour is one of the main issues in the construction industry currently. Accordingly, various strategies were proposed to enhance the maintainability of green roofs of high-rise buildings in Sri Lanka as described subsequently.

4.3 STRATEGIES OF ENHANCE THE MAINTAINABILITY OF GREEN ROOFS OF HIGH-RISE BUILDINGS IN SRI LANKA

As proposed by experts in the industry, various strategies are proposed under 03 key areas: (i) Cost effectiveness, (ii) Design effectiveness, and (iii) Effective management, to improve the maintainability of green roofs in Sri Lankan high-rise buildings. The categorisation of strategies was based on the recommendations and insights provided by experts in the industry. Through the expert interviews conducted as part of this research, professionals with extensive experience and knowledge in green roof construction and maintenance were consulted. These experts identified and suggested strategies that would contribute to enhancing the maintainability of green roofs in high-rise buildings in Sri Lanka. To ensure a comprehensive coverage of the various aspects influencing maintainability, the strategies were organised into these three categories. The categorisation allows for a systematic approach in addressing different factors that can impact the long-term viability and ease of maintenance of green roofs. Accordingly, Table 6 summarises the proposed strategies.

Table 6: Strategies to improve maintainability of green roofs in high rise buildings Sri Lanka

No	Strategies	R1	R2	R3	R4
1	***Cost effectiveness***				
1.1	Properly analysing about size and location of green roof	√	√	√	√
1.2	Select the most effective green roof installation system	√	-	√	√
1.3	Considering life cycle cost (LCC)	√	√	√	√
1.4	Properly analysing the usage of natural resources	√	√	√	√
2	***Design effectiveness***				
2.1	Considering load capacity of green roof systems	√	√	-	√
2.2	Considering reparability of green roof systems	√	√	√	√
2.3	Easy access to the roof	√	-	√	√
2.4	Effective space allocation for green roof	√	√	√	-
2.5	Storm water management	√	-	√	√
2.6	Selecting most suitable plants for the location	√	√	√	√

No	Strategies	R1	R2	R3	R4
3	***Effective management***				
3.1	Finding local and foreign material suppliers	√	-	√	√
3.2	Utilising experienced professionals and skilled man power	√	√	-	√
3.3	Using suitable machinery and equipment in installation	√	√	√	√

During an interview, most of the respondents emphasised the significance of minimising and controlling costs related to green roofs. They unanimously agreed that factors such as size, installation method, and life cycle cost are crucial for ensuring the maintainability of green roofs. Design effectiveness also affects to the maintainability of green roofs and all the experts have highlighted that system reparability and plant selection should be considered when designing the green roof in high-rise buildings. Moreover, majority of the respondents pinpointed the necessity of effective management to improve the maintainability of green roofs of high-rise buildings.

5. CONCLUSIONS

Sustainable construction aims to minimise the environmental impact of a building throughout its lifespan, while also improving its economic viability, comfort, and safety. Green roofs have gained increasing attention as a sustainable solution for development projects, as they offer numerous environmental benefits such as reducing energy consumption, mitigating the urban heat island effect, and improving air quality. However, poor design and construction can significantly impact the future maintainability of green roofs, particularly in high-rise buildings. The maintainability of green roofs refers to the ease of maintenance and the ability to sustain the desired functionality over time. In Sri Lanka, where the construction industry is booming, the government is promoting sustainable construction to minimise the industry's impact on the environment. This study explored the significant design and construction related factors influencing future maintainability of green roofs of high-rise buildings in Sri Lanka. As derived through analysis, initial cost and roof design have been identified as design related key factors, while cost of the construction and availability of machinery & materials were identified as the construction related key factors influencing to the maintainability of green roofs. Finally, various strategies were proposed to enhance the maintainability of green roofs of high-rise buildings in terms of their cost effectiveness, design effectiveness and effective management.

Since, green roofs are one of the effective strategic to reduce these adverse effects of high-rise buildings and provides several benefits to the environment and reduces the impact of the urbanisation, this study has shown that considerations of the maintainability of green roof in green buildings need to be given utmost attention at the design and construction stages. Thus, the outcomes of this study can be used as a basis to let construction professionals in the building industry as well as policy makers to take actions towards implementing a national level strategy for green roof construction in Sri Lanka.

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BARRIERS FOR IMPLEMENTING DISPUTE REVIEW BOARD (DRB) METHOD TO SRI LANKAN CONSTRUCTION INDUSTRY

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ABSTRACT

In Sri Lanka, dispute resolution methods in construction contracts are Negotiation, Mediation, Adjudication, and Arbitration. Although the Dispute Review Board (DRB) method has been successfully used internationally for more than 30 years, it has rarely been applied in domestic contractual disputes. Thus, this research was conducted to identify the barriers hindering the implementation of the Dispute Resolution Board (DRB) mechanism in the Sri Lankan construction industry and to provide recommendations to overcome these barriers. This research was deemed necessary because the current dispute resolution methods could not effectively resolve contractual conflicts. Despite introducing DRB through Dispute Adjudication Boards (DAB), its potential benefits have not been fully realised in Sri Lanka. To achieve the purpose of the study, a comprehensive literature review was conducted first, and then a preliminary survey to identify the barriers to the implementation of DRB in the Sri Lankan construction industry. Subsequently, a questionnaire was administered to 44 professionals engaged in client and contracting organisations. The research findings revealed that the main barriers to the implementation of the DRB mechanism are unawareness of the concept of DRB, clients considering DRB as a burden and hassle for them, additional costs to be incurred, and lack of experience. Accordingly, the study recommends increasing the awareness of the DRB at the national level with the support of authorities to utilise it as a valuable alternative for resolving disputes in the Sri Lankan construction industry.

Keywords: *Barriers; Construction Industry; Disputes; Dispute Review Board (DRB); Sri Lanka.*

1. INTRODUCTION

Construction projects have become increasingly complex and involve many parties with conflicting objectives. The owner, for example, would like a project to be cost-effective and speedy, while the contractor requires to minimise losses and maximise profits (Hardjomuljadi, 2020). Therefore, disputes in construction are inevitable. Vishwanathan et al. (2020) explain that disputes often lead to project failures, loss of time and costs, and damage to stakeholder relationships. Further to the authors, if the disputes are not

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resolved rapidly, they become severe and ultimately lead to dispute resolution proceedings which are time and cost-consuming. In recent years, significant efforts have been made to establish efficient dispute resolution mechanisms, with a particular emphasis on addressing issues related to cost, time, and enforceability. Despite these efforts, the traditional dispute resolution processes still face several limitations in practical applications (De Alwis, et al., 2016).

One of the significant drawbacks of traditional dispute resolution mechanisms is the cost associated with resolving a dispute. In many cases, the expenses involved in litigation, arbitration, or mediation can be excessively high, making it difficult for parties to access. To address these challenges, there is a need to explore new dispute resolution methods that are more efficient, cost-effective, and enforceable. Disputes resolution involves both binding and non-binding approaches, such as; arbitration and litigation as binding, negotiation, conciliation, and mediation as non-binding methods (Chong & Zin, 2012). However, the employers, contractors, and design professionals in the industry have comprehended the hours and dollars as attorney and expert fees, court costs, loss of staff time, and additional overhead expenses due to dispute resolution (De Alwis et al. 2016).

Further, these methods suffer from two significant limitations. First, the trust between parties can be severely tested or even destroyed during the resolution process. Second, the time and expenses involved in resolving a dispute can negatively impact the expected benefits of the project for the involved parties. Consequently, there is a growing interest in exploring alternative approaches to dispute resolution that can be initiated either before or soon after a conflict arises. This trend has emerged as a response to the limitations of traditional dispute resolution methods, with a focus on promoting early intervention, communication, and collaboration between parties in conflict (Gunawansa, 2008). As a result, Dispute Review Board (DRB) has been invented to resolve or avoid disputes and to assist the project parties in mitigating the adverse effects from the beginning of a project. Accordingly, this research aims to critically analyse the applicability of the DRB process to the Sri Lankan construction industry.

2. LITERATURE REVIEW

Construction projects are subjected to prolonged execution periods and diverse stages where economic circumstances and legal and governmental regulations may change unexpectedly. These factors are difficult to anticipate or account for at the time of contract signing, which can impact the management and execution of the project, as well as the contractual obligations of all parties involved (Al-Zwainy, et al., 2018). Consequently, such circumstances often result in construction disputes. In such situations where the disputes cannot be settled amicably, the parties must go to court or consider alternative dispute settlement procedures (Keršulienė, et al., 2010). Litigation involves third parties, such as lawyers and judges, who know the law but may lack of knowledge about construction projects (Alaloul, et al., 2019). However, in the past decades, people have increasingly relied on the judicial system to resolve disputes, which has led to greater trust in its decision-making processes. As a result, there was a significant increase in the volume of cases, resulting in an overload of the courts and a more rigid formalism in judicial decisions (Yaskova & Zaitseva, 2020). Hence, construction experts believe litigation is not a suitable method for dispute resolution in the construction industry, as construction projects are built upon good relationships between parties (Alaloul et al.

2019). Therefore, construction professionals prefer alternative dispute resolution methods to resolve their disputes instead of litigation.

Different ADR methods are available in the Sri Lankan construction industry, including partnering, med/arb, mini-trials, early neutral evaluation, mediation, adjudication, and the deployment of dispute review boards (Illankoon et al., 2022). Amongst, the DRB is identified as an appropriate method as it operates on-site and resolves disputes before leaving the site. According to the Delphi study by Gad and Shane (2012), Asian countries prefer DRB over adjudication, litigation, early neutral evaluation, and mini-trials. Further, the DRB achieved an impressive success rate of 98%, with all conflicts and disputes being resolved before the completion of the contract (Alaloul et al. 2019).

2.1 DRB METHOD IN BUILT ENVIRONMENT

The DRB is a pioneering non-confrontational project management approach aiming to prevent or resolve disputes throughout the project's life cycle. Unlike other alternative dispute resolution methods, this technique intends to proactively avoid conflicts before they occur and promptly address them as they arise. This approach sets itself apart by employing a procedure to minimise disputes and deal with them as soon as possible (Alaloul et al. 2019). The DRB can comprise a single person or a panel of three or five members. It is prudent to keep the number of members to an odd number; so that it is possible to achieve a majority decision where the panel cannot reach unanimity (FIDIC, 2006). When selecting the members, the contractor has to select one member and the employer another, with each approving the other’s choice. Then the two chosen DRB panellists select the third member. Members of the DRB are highly qualified with substantial engineering or construction experience (Harmon, 2003). Harmon (2009) emphasised that the project documents stipulate that DRB panellist must possess a minimum of 10 years of professional experience in their respective fields and significant experience in the particular type of construction involved in the contract. Hence, it has been identified that DRB offers more reliable and appropriate solutions for resolving construction-related disputes compared to litigation and other alternatives.

2.2 BARRIERS TO THE IMPLEMENTATION OF DRB

Oyuela and Bley (2010) identified several barriers to the successful implementation of DRB in Chile, such as resistance to change, lack of knowledge and experience in using DRB, entrenched arbitration or trial processes, and client reluctance to engage in dispute resolution. Clients may perceive dispute resolution as burdensome and restrictive, reducing their margin of movement. Further, Chong and Chong (2009) identified major barriers to implementing DRB in the Malaysian construction industry, which can be categorised under three headings: awareness, cost, and cultural attitude. The lack of awareness of DRB among stakeholders in the construction industry is a significant barrier, as is the perceived high cost of using DRB compared to traditional dispute resolution methods. Moreover, cultural attitudes toward dispute resolution in Malaysia may also hinder the uptake of DRB.

To overcome these barriers, it is essential to increase awareness and education about DRB among stakeholders in the construction industry. It is also vital to provide cost-effective DRB services and to address cultural attitudes toward dispute resolution. Effective communication and collaboration among all parties involved in construction projects can also help to minimise disputes and facilitate the successful implementation of DRB

(Gamage, 2022). As the author emphasised, one of the major challenges was the lack of recent studies related to project communication. Therefore, the literature emphasises the need for context-specific research to better understand the barriers and challenges in implementing DRB as a dispute-resolution method in the construction industry.

3. RESEARCH METHODOLOGY

The research process involved conducting a background study, identifying the research problem, conducting a literature review, designing the research methodology, collecting data, and analysing the data. First and foremost, a background study was carried out to gather information about the research topic: ADR methods and their evolution, the concept of DRB, the DRB procedure manual, the advantages of DRB, and the disadvantages of DRB. Then Barriers to the implementation of DRB were recognised.

A preliminary survey was conducted to verify the literature findings and find new barriers. Altogether 14 barriers were finalised from the preliminary survey. Then a questionnaire survey was conducted to ascertain the views of 44 professionals engaged in the client and the contracting organisations. In this questionnaire, respondents were asked to evaluate the importance of each barrier to implementation by assigning a numerical value based on its perceived criticalness. Data analysis was done by using the Relative Importance Index (RII). This study has identified the most significant barriers to implementing DRB in the Sri Lankan construction industry. Then the interview was conducted with an expert to find possible suggestions to overcome those barriers.

4. ANALYSIS AND RESEARCH FINDINGS

The findings of the questionnaire survey identified 42 barriers in total from the perspectives of client, to implementing DRB in the Sri Lankan context. Those identified barriers were categorised under three main sections; Client, Contractor, and Overall. Overall sector comprised both client and the contractor in equal proportions. Findings are shown in Table 1.

Table 1: Most critical barriers – Client's perspective

Barriers to the Implementation	RII (%)	Rank
Construction industry players from bottom to top-level management are unaware of the DRB	82.73	1
Lack of experience in its use	76.36	2
Clients consider DRB as an additional cost to the project	75.45	3
Clients believe that DRB is going to reduce their margin of movement and that it will become a burden and hassle for them	71.82	4
DRB decisions cannot be enforced in the same way as Arbitration awards are considered	64.55	5
Parties believe that the mere presence of a DRB does not encourage avoiding contractor claims and disputes	60.00	6
Arbitration or other dispute resolution methods are entrenched in practice	55.45	7
There are a smaller number of mega construction projects in Sri Lanka, where DRB service is much more important	55.45	8
Sri Lankan culture prefers negotiating to solve problems rather than refereeing to a third party.	44.55	9

Barriers to the Implementation	RII (%)	Rank
The number of disputes which occur and the seriousness of them is not that significant in the Sri Lankan construction industry	40.91	10
Resistance to change	38.18	11
Clients prefer to postpone the possible dispute resolution	35.45	12
The DRB's mission is limited to the contract's life	34.55	13
Some arbitration institutions in Sri Lanka are adverse to having rules on the use of DRBs	30.91	14

According to the ranking, the most critical barriers to DRB implementation in the client sector were a lack of awareness and knowledge of clients in the construction sector on the DRB mechanism. Moreover, some construction clients believe that having DRB incurs additional cost and burdens to the project. The DRB should be appointed at the start of the project and remain in place throughout the construction period, regardless of whether disputes arise or not. However, this active involvement of DRB through regular site visits, periodic meetings, documentation reviews, and assistance in the potential issues during the construction process leads to fewer disputes. The findings revealed that despite being an established practice, clients in the construction industry still favour arbitration over DRB. Consequently, unlike arbitration, DRB's non-binding decision also discourages employers from proceeding with DRB.

The barriers to implementing DRB were then analysed from the contractor's perspective, and the findings are presented in Table 2.

Table 2: Most critical barriers – Contractor's perspective

Barriers to the Implementation	RII (%)	Rank
Clients believe that DRB is going to reduce their margin of movement and that it will become a burden and hassle for them	80.91	1
Construction industry players from bottom to top-level management are unaware of the DRB	77.27	2
Clients consider DRB as an additional cost to the project	74.55	3
Lack of experience in its use	73.64	4
Clients prefer to postpone the possible dispute resolution	66.36	5
Parties believe that the mere presence of a DRB does not encourage avoiding contractor claims and disputes	65.45	6
There are a smaller number of mega construction projects in Sri Lanka, where DRB service is much more important	63.64	7
Arbitration or other dispute resolution methods are entrenched in practice	62.86	8
Sri Lankan culture prefers negotiating to solve problems rather than refereeing to a third party.	60.00	9
Resistance to change	51.82	10
DRB decisions cannot be enforced in the same way as Arbitration awards are considered	48.18	11
The number of disputes that occur and their seriousness is not that much significant in the Sri Lankan construction industry	40.91	12
The DRB's mission is limited to the contract's life	35.45	13
Some arbitration institutions in Sri Lanka are adverse to having rules on the use of DRBs	32.73	14

Unlike the client, the contractor's key barrier was that they considered DRB as a burden or hassle to them. This perception stems from a lack of knowledge and experience of contractors with DRBs. Many construction industry players, including bottom to top-level management, are unaware of DRBs, making it challenging to introduce and implement them effectively. Moreover, contractors consider DRBs as an additional cost to the project, further discouraging their implementation. This perception can be overcome by educating them on the benefits of DRBs, such as reducing project delays, avoiding costly litigation, and improving project outcomes.

Another significant barrier is the lack of experience in using DRBs. This lack of experience makes it challenging to introduce DRBs and implement them effectively. Training and education programs can help overcome this barrier by providing industry players with the necessary knowledge and skills to use DRBs effectively. Resistance to change is another barrier that must address in the industry. Resistance to change can come from different levels, including both employers and employees in a contracting organisation. Overcoming this barrier requires a clear understanding of the benefits of DRBs and effective communication to encourage acceptance and adoption.

Moreover, the contractors' opinion was that the clients prefer to postpone the dispute resolution, and therefore, they do not encourage having DRB readily available on site. However, they have given a lower ranking to the presence of arbitration, as they believe it is not affected the implementation of DRB in the Sri Lankan context. In Sri Lanka, negotiation is a preferred problem-solving method, making it challenging to introduce and implement DRBs effectively. Educating industry players on the benefits of DRBs and how they complement negotiation can help overcome this barrier. Additionally, there is a perception that DRBs do not encourage avoiding contractor claims and disputes. This perception can be addressed by emphasising the DRB's role in reviewing disputes and providing recommendations to avoid future conflicts. It was revealed that the DRB decisions could not be enforced like arbitration awards, which can discourage their use. Overcoming this barrier requires improving the enforcement mechanisms for DRB decisions, such as incorporating them into contracts and enforcing them through the court system. Nevertheless, clients and contractors have given the lowest ranking to the statement of DRB's mission limited to the contract's life and adverse rules of arbitration institutions in Sri Lanka to the DRB.

Then considering the overall response from both client and contractor in equal proportions, the barriers were reordered in Table 3.

Table 3: Critical Barriers to the Implementation as Overall Response

Barriers to the Implementation	RII (%)	Rank
Construction industry players from bottom to top-level management are unaware of the DRB	80.00	1
Clients believe that DRB is going to reduce their margin of movement and that it will become a burden and hassle for them	76.36	2
Clients consider DRB as an additional cost to the project	75.00	3
Lack of experience in its use	75.00	4
Parties believe that the mere presence of a DRB does not encourage avoiding contractor claims and disputes	62.73	5
There are a smaller number of mega construction projects in Sri Lanka, where DRB service is much more important	59.55	6

Barriers to the Implementation	RII (%)	Rank
Arbitration or other dispute resolution methods are entrenched in practice	59.07	7
DRB decisions cannot be enforced in the same way as Arbitration awards are considered	56.36	8
Sri Lankan culture prefers negotiating to solve problems rather than refereeing to a third party.	52.27	9
Clients prefer to postpone the possible dispute resolution	50.91	10
Resistance to change	45.00	11
The number of disputes that occur and their seriousness is not that much significant in the Sri Lankan construction industry	40.91	12
The DRB's mission is limited to the contract's life	35.00	13
Some arbitration institutions in Sri Lanka are adverse to having rules on the use of DRBs	31.82	14

The findings indicate that the most critical barrier to the implementation of DRB in Sri Lanka is the lack of awareness about the concept of DRB in the country. In the literature also, the lack of awareness was highlighted. Therefore, it can be identified that, not only in Sri Lanka, but also in many countries like Chile and Malaysia, there is a deficiency in the level of exposure, educational programs, and industry practices with regard to the DRB as a dispute-resolution method. Further, the owners and contractors involved in the construction process are unfamiliar with DRB, its benefits, and its operational procedures for resolving disputes. In particular, industry professionals are unaware of the significant advantage of DRB as a mechanism for mitigating disputes. In addition, both the literature and the findings revealed the resistance to change as a barrier to implementing the DRB. However, while the literature mentioned resistance to depart from the established methods such as arbitration and litigation, the findings emphasised resistance as clients view DRB as a burden and an inconvenience. This revealed that the concerns and factors behind resistance to DRB may vary in different contexts. In other countries, since they are more familiar with other dispute resolution methods including arbitration and litigation, and have established processes and procedures for those in place for handling disputes, introducing a new method like DRB would disrupt their existing practices. In Sri Lanka, clients may view the implementation of DRB as an additional step or process which could delay the project progress. They may be concerned about the time and effort required to engage in the DRB process and the potential impact on project timelines, and could stem from the belief that it is hindering the smooth execution of the construction.

Furthermore, the literature identified the high cost of using DRB compared to other dispute resolution methods as a barrier. Consequently, the findings of the study also discovered the additional costs incurred and the lack of experience in utilising DRB contribute significantly to resistance to its implementation in the industry. This could be involving high procedural costs including expert fees, conducting meetings, site visits, reviewing documents, and preparing reports. Moreover, the findings reveal that clients and contractors believe the DRB is more appropriate for mega projects. Since there are relatively few mega projects in Sri Lanka, the perception is that DRB is not widely used in the industry. Further, they have compared it with the arbitration practice in the current industry. Hence, it was noted that the DRB is not widely familiar in Sri Lanka, unlike countries including the UK, USA, Australia, China, France, New Zealand, Bangladesh, Hong Kong, and India. One of the reasons identified for the above is, the DRB decisions cannot be enforced in the same manner as arbitration awards unless it is mandated in the contract. Therefore, the industry practitioners believe that the effectiveness and efficiency of DRB as a dispute-resolution mechanism may be somewhat limited. Despite this limitation, DRB decisions can still serve as valuable evidence in subsequent arbitration or litigation proceedings. Parties' preference to resolve disputes without involving a third party is also identified as a barrier to DRB implementation, although it is less significant compared to other challenges. Additionally, the study identifies that some arbitration institutions in Sri Lanka impose adverse rules that hinder the implementation of DRB in the country.

5. CONCLUSIONS

In line with the literature synthesis, DRB is identified as a well-established dispute resolution method that has unique advantages. As the success of the DRB process became more apparent, it greatly expanded worldwide. Hence, it could be recommended to develop a proper mechanism and incorporate it into the Sri Lankan construction industry. However, 14 critical barriers to the implementation of DRB in the Sri Lankan context were identified through the analysis. Amongst, the lack of awareness in the industry regarding DRB application is at the top. Therefore, organising awareness programs and owner-contractor forums is recommended to enhance the knowledge and attentiveness regarding the DRB application and its benefits in the industry. Further, it is suggested to get the support of CIDA to incorporate the mechanism at the national level and to promote and guarantee the convenience of using the DRB in the projects.

The literature review indicates that DRB is an effective dispute-resolution method with unique advantages and has been widely implemented worldwide. However, in the context of the Sri Lankan construction industry, 14 critical barriers to the implementation of DRB were identified. Amongst, the lack of awareness among industry stakeholders about DRB applications is identified as the most significant barrier. To overcome these barriers and promote the use of DRB in Sri Lanka, it is recommended to conduct awareness programs and owner-contractor forums to enhance knowledge and understanding of the DRB application and its benefits. Additionally, it is suggested to seek support from the Construction Industry Development Authority (CIDA) to incorporate DRB mechanisms at the national level and promote its use in projects. By implementing these recommendations, barriers to the use of DRB can be minimised, and the full advantages of this mechanism can be realised. Ultimately, the research highlights the need to address these barriers to ensure the effectiveness of DRB as a valuable alternative dispute resolution mechanism in the Sri Lankan construction industry.

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BARRIERS TO EMERGING SMART SOLUTIONS ADOPTION FOR ENERGY EFFICIENCY IN THE CONSTRUCTION INDUSTRY

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ABSTRACT

Globally, the construction industry (CI) has been blamed to be directly responsible for climate change and its consequential adverse impacts. As a sector known to be energy-intensive and energy-dependent, it is logically right for energy efficiency reforms and strategies to begin in the CI. While energy challenges are largely constituting a hindrance to the accelerated growth and socio-economic development of Africa, the continent continually commits to unsustainable means in meeting its energy demands. Therefore, the adoption of energy efficiency solutions is pivotal for the continent to meet its sustainability agenda. Hence, this study is aimed at identifying the various barriers hindering the adoption of Emerging Smart Solutions (ESS) for energy efficiency in the South African construction industry (SACI). The quantitative research method was utilised in this research study. A questionnaire survey was administered to registered and active construction professionals in the SACI for data collection. Both descriptive and exploratory factor analysis were used to analyse the retrieved data. Findings from the study revealed 17 barriers with high initial cost, lack of financial incentives, and theft and security concerns as the top three barriers hindering the adoption of ESS for energy efficiency in the SACI. The study concluded that a multi-stakeholder approach is embraced to mitigate these barriers so that the potential benefits of ESS can be maximised in the sector. It is recommended that government intervention and support be increased to pave the way for the proliferation of ESS and other energy-efficient strategies.

Keywords: *Africa; Built Environment; Climate Change; Innovative Solutions; Sustainability.*

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1. INTRODUCTION

Several negative impacts have been attributed to the processes and activities of the construction industry (CI). A few of these adverse environmental impacts are carbon dioxide (CO_2) emissions, waste generation, and excessive energy consumption among others (Ahmad et al., 2019; Ahmed Ali et al., 2020; Purchase et al., 2022; Wu et al., 2019). However, the severity of the effect and impacts of energy issues on the human and natural environment seems to outweigh others. As indicated by Tawalbeh et al. (2021), the world's total primary electricity generation in 2017 was majorly through environmentally hazardous means of coal (38.3%) and oil (3.3%). To curb emissions because of the various climate targets established globally, the need for energy efficiency is highly imperative (McAndrew et al., 2021). Energy efficiency is, therefore, a cogent consideration for the implementation of sustainable practices in the CI. As evident in notable green building assessment tools such as the Building Research Establishment Environmental Assessment Method (BREEAM), Leadership in Energy and Environmental Design (LEED), and Comprehensive Assessment System for Built Environment Efficiency (CASBEE), energy efficiency is a core category that a building or infrastructure project must be compliant before it is regarded as sustainable (Kim et al., 2013; Sev, 2011; Sharma, 2018). It is however important that energy efficiency is promoted and well-considered if the CI is to achieve its global sustainability agenda.

Energy efficiency plays an important role by enforcing sustainable consumption, and reducing strain on the energy grid, thereby ensuring an accessible, cheaper, and reliable energy supply (Russell-Bennett et al., 2019). Energy efficiency entails the consumption of less energy to perform the same or higher tasks. The subject of energy efficiency aims to reduce CO_2 emissions, reduce energy consumption, and encourage the responsible and eco-friendly generation and use of energy. In Europe for example, two decrees namely the Energy Efficiency Directive (EDD) and Energy Performance of Buildings Directive (EPBD) were developed by the European Union to achieve energy efficiency within the region (Camarasa et al., 2019). The requirements of these directives are geared towards ensuring all new public and other categories of buildings are nearly zero-energy buildings (nZEB) before the set dates. This concept plays a crucial role in promoting sustainable (social, economic, and environmental) development, improving energy security, and minimising different kinds of emissions in the built environment. Hence, innovative technological options are becoming popular and proliferated to minimise the energy demands of the construction sector. With building automation as one of the key tenets of energy efficiency in the CI, the integration and interoperability of emerging smart solutions (ESSs) are imperative to addressing the energy crisis in the sector. This will ensure energy demands and costs are reduced thereby conserving the continuous depletion of energy resources (Shafie et al., 2021).

Novel technologies, applications, and products integrated with automated controls and sensors to optimise and ensure an effective energy management system are referred to as ESS. These technologies and solutions can be in the form of an embedded part of a product (such as a smart light bulb), a purely digital service (for regulating, monitoring, and analysing energy consumption), or a combination of both among others (Paukstadt, 2019). As further stated by Paukstadt (2019), ESS appears promising for achieving efficiency in energy management due to the proliferation of digitalisation in the sector. ESSs for energy efficiency leverage advanced Information and Communications Technology (ICT) to provide, plan, and manage energy resources for improving, advancing, and achieving the environmental goals of sustainability (Bibri, 2020). Though not exhaustive, ESS for energy efficiency includes smart grid technologies (that utilise real-time data to improve the efficiency and reliability of the electrical grid); artificial intelligence (AI), and machine learning algorithms (that can analyse energy consumption data, identify patterns, and provide opportunities); internet of things (IoT) devices (that allow for remote control and monitoring of appliances at home); building energy management systems (that uses automation, data analysis, and sensors to optimise energy use); energy storage systems (that allow for the storage of excess energy generated renewable sources); electric vehicle charging infrastructure (that uses smart technology to optimise charging and reduce demand on the grid); smart streetlights (that use automated dimming and sensors to control lighting levels based on demand); and power-saving smart home devices such as smart plugs and thermostats.

Despite the need for ESSs, various hindrances prevent the adoption of such solutions in the larger architecture, engineering, and construction industry. As identified in the literature reviewed, there are several hindrances to the adoption of ESSs for energy efficiency. These include a lack of supporting infrastructure, lack of political will, paucity of resources, lack of awareness, cultural barriers, high initial cost, lack of financing and capital, regulatory barriers, resistance to change among stakeholders, paucity of technologies, lack of incentives for adoption and implementation, lack of skilled labour, the complexity of technologies, limited access, lack of assessment tools for the technologies, and lack of technical capability among others (Alam et al., 2019; Brown, 2001; Goodier & Chmutina, 2014; Juszczyk et al., 2022; Oguntona et al., 2019; Palm, 2009; Ratner et al., 2022; Teng et al., 2021; Thollander & Palm, 2012). It is, therefore, crucial to tackle these barriers in a bid to promote sustainability in the CI. Hence, this paper is aimed at identifying the barriers hindering the adoption of ESSs for achieving energy efficiency in the South African construction industry (SACI). This paper is part of a concluded research study that evaluated the adoption of ESSs for energy efficiency in the SACI. The next section presents the research methodological framework adopted in the study, followed by the findings and discussion and lastly the conclusion and recommendations.

2. RESEARCH METHODOLOGY

The study employed the quantitative research method to identify the hindrances to the adoption of emerging smart solutions (ESSs) for energy efficiency in the South African construction industry (SACI). The combination of a literature review (secondary data source) and a questionnaire survey (primary data source) was utilised to present the informative corroboration of construction professionals’ perceptions of the key barriers to the adoption of ESSs in the SACI. To achieve the objective of this study, a questionnaire survey was developed and administered to registered and active construction professionals in the Mpumalanga Province of South Africa, which is the study area. These professionals are construction project managers, construction managers, mechanical engineers, electrical engineers, town planners, architects, quantity surveyors, and civil engineers. From the literature review, a total of seventeen (17) barriers to ESSs adoption for energy efficiency were identified and extracted for use.

Since it was envisaged that the total population will not be able to participate in the survey, a random sampling method was adopted. The first part of the questionnaire survey contained questions that pertain to the background information of the respondents. The second section contained questions aimed at identifying the significant barriers to the adoption of ESSs for energy efficiency based on the respondents' agreement level. The questions in section two of the questionnaire were formulated on a five-point Likert scale (agreement scale). The respondents are required to specify their level of disagreement or agreement with the highlighted barriers in the questionnaire. The completed questionnaire survey was returned and cleaned to ensure they are complete and useful for analysis purposes. The collated data were analysed using both the descriptive and exploratory factor analysis (EFA) methods. The software utilised for data analysis is the Statistical Package for Social Sciences (SPSS). To ascertain the respondent's level of agreement with the identified barriers, the means item scores, standard deviation, and ranking of the seventeen (17) variables were tabulated and presented.

3. RESULTS AND DISCUSSION

This study achieved a Cronbach alpha value of 0.829 for the reliability of the data collection instrument. This value is an indication that the results received are largely accurate and the data collection instrument is trustworthy (Hayes & Coutts, 2020; Schrepp, 2020). Considering the demographics of the respondents, 64.2% are males while 35.8% are females. Civil engineers represent 24.5% of the respondents, mechanical engineers are 20.8%, quantity surveyors are 18.9%, electrical engineers are 15.1%, construction managers are 7.5%, town planners are 5.7%, and architects and construction project managers are 3.8%. Respondents that work for contracting firms are 67.9%, 18.9% work for the government, and 13.2% work for consulting firms.

3.1 DESCRIPTIVE ANALYSIS OF THE BARRIERS TO THE ADOPTION OF EMERGING SMART SOLUTIONS FOR ENERGY EFFICIENCY

As shown in table 1, the mean value and standard deviation ranking of each of the identified barriers were tabulated to reveal the consensus reached by the respondents. All the barriers revealed a mean value higher than 2.50. According to Field (2005), a factor is deemed significant to a study if it has a mean value of 2.50 or more. Based on the findings from the descriptive analysis of the study as presented in table 1, 'high initial cost' ranked first with a mean value of 4.21 and a standard deviation (SD) value of 0.863. Ranked second are 'lack of financial incentives' with a mean value of 4.09 and SD of 0.883 and 'theft and security concerns' also with a mean value of 4.09 and SD of 0.714. Ranked fourth is 'restricting financing options' with a mean value of 4.06 and SD of 0.633 and 'absence of innovation' was ranked fifth with a mean value of 3.94 and SD of 0.842. However, the trio of 'installation complexity' (mean value of 3.55 and SD of 1.030), 'absence of data about existing redesign measures' (mean value of 3.42 and SD of 0.776), and 'obstructions to energy efficiency' (mean value of 3.36 and SD of 0.857) were regarded as the least of the barriers to the adoption of ESSs for energy efficiency in the SACI. A country like South Africa which is known to be one of the most economically developed on the African continent is presently facing energy challenges. There are incessant load-shedding and outages across the country which has subsequently started to cripple all sectors of the economy while the small, medium, and micro enterprises (SMMEs) are badly hit. While the coal-generated energy in South Africa is detrimental to the environment and now unreliable, the recent proclamations by the government on the need to adopt renewable energy sources showed that the government agrees with the urgent need to adopt energy-efficient means and technologies in tackling the lingering energy crisis. The state-owned electricity utility company (ESKOM) faces several challenges such as cash crunch, cable theft, sabotage, corruption, looting, and vandalism while lack of financial incentives and relief for adopting alternative and renewable energy means are widely known to be hindering the adoption of innovative technologies for energy efficiency in the country. The results are in tandem with the realities of the major issues preventing the adoption of ESSs for energy efficiency and are general knowledge.

Table 1: Barriers to the adoption of emerging smart solutions for energy efficiency

Barriers	Mean	Standard Deviation	Rank
High initial cost	4.21	0.863	1
Lack of financial incentives	4.09	0.883	2
Theft and security concerns	4.09	0.714	2
Restricting financing options	4.06	0.633	4
Absence of innovation	3.94	0.842	5
Poor maintenance culture	3.89	0.847	6
Inability to demonstrate investment returns for potential clients	3.72	0.907	7
Disregard for energy efficiency alternatives	3.68	0.827	8
Limited experts	3.68	0.956	8
Lack of knowledge	3.66	0.979	10
Lack of framework and regulations	3.65	0.988	11
Vandalism	3.62	1.042	12
Absence of project consolidation	3.62	1.078	12
Lack of consumer awareness	3.62	1.060	12
Installation complexity	3.55	1.030	15
Absence of data about existing redesign measures	3.42	0.776	16
Obstructions to energy efficiency	3.36	0.857	17

3.2 EXPLORATORY FACTOR ANALYSIS OF THE BARRIERS TO THE ADOPTION OF EMERGING SMART SOLUTIONS FOR ENERGY EFFICIENCY

The data retrieved was further subjected to exploratory factor analysis and the result is presented below. Table 2 shows the results of the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's Test of Sphericity for barriers to the adoption of ESS for energy efficiency. The KMO value of 0.618 indicates that the sample size is adequate for conducting factor analysis, as it is above the recommended threshold of 0.5. This means that the data is suitable for further analysis using factor analysis techniques. The Bartlett's Test of Sphericity result shows an approximate Chi-square value of 341.323, with 136 degrees of freedom and a significance level of 0.000. This indicates that the correlation matrix is significantly different from an identity matrix, and therefore, the variables are suitable for factor analysis.

Table 2: KMO and Batlett's test result barriers to the adoption of ESS for energy efficiency

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.618
Bartlett's Test of Sphericity	Approx. Chi-Square	341.323
	df	136
	Sig.	0.000

Table 3 presents the total variance explained by each component, as well as the initial eigenvalues and extraction sums of squared loadings for each component. The table also shows the percentage of variance explained by each component and the cumulative percentage of variance explained by all components up to that point. The results show that the first component explains 28.542% of the total variance, the second component explains 11.578% of the total variance, and so on. The first five components together explain 65.471% of the total variance. It is important to note that when components are correlated, sums of squared loadings cannot be added to obtain a total variance. The table also shows the rotation sums of squared loadings for each component, which consider correlations between components. These values are provided for reference only and cannot be added to obtain a total variance.

Table 3: Total variance explained for barriers to the adoption of ESS for energy efficiency

Component	**Initial Eigenvalues**			**Extraction Sums of Squared Loadings**			**Rotation Sums of Squared Loadings[a]**
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**	**Total**
1	4.852	28.542	28.542	4.852	28.542	28.542	3.465
2	1.968	11.578	40.120	1.968	11.578	40.120	2.484
3	1.633	9.603	49.723	1.633	9.603	49.723	2.511
4	1.479	8.703	58.426	1.479	8.703	58.426	2.614
5	1.198	7.045	65.471	1.198	7.045	65.471	2.017
6	0.976	5.739	71.210				
7	0.875	5.150	76.359				
8	0.750	4.414	80.773				
9	0.676	3.975	84.748				
10	0.606	3.563	88.311				
11	0.519	3.055	91.366				
12	0.385	2.266	93.631				
13	0.321	1.885	95.517				
14	0.302	1.779	97.296				
15	0.185	1.091	98.386				
16	0.167	0.984	99.370				
17	0.107	0.630	100.000				

Extraction Method: Principal Component Analysis.

a. When components are correlated. sums of squared loadings cannot be added to obtain a total variance.

The scree plot in figure 1 shows the eigenvalues plotted against the number of factors/components extracted for the barriers to the adoption of ESS for energy efficiency. The scree plot helps to determine the number of factors/components to retain in the analysis. In this plot, the first few components have relatively high eigenvalues, indicating that they explain a large proportion of the variance in the data. As we move to the right on the plot, the eigenvalues decrease, and the factors explain less and less of the variance. Based on the screen plot, it appears that the first five components should be retained, as they have eigenvalues greater than 1.0, and they explain a cumulative percentage of the variance of about 58.4%. Beyond the fourth component, the eigenvalues decrease more slowly, suggesting that the additional components explain relatively little additional variance in the data.

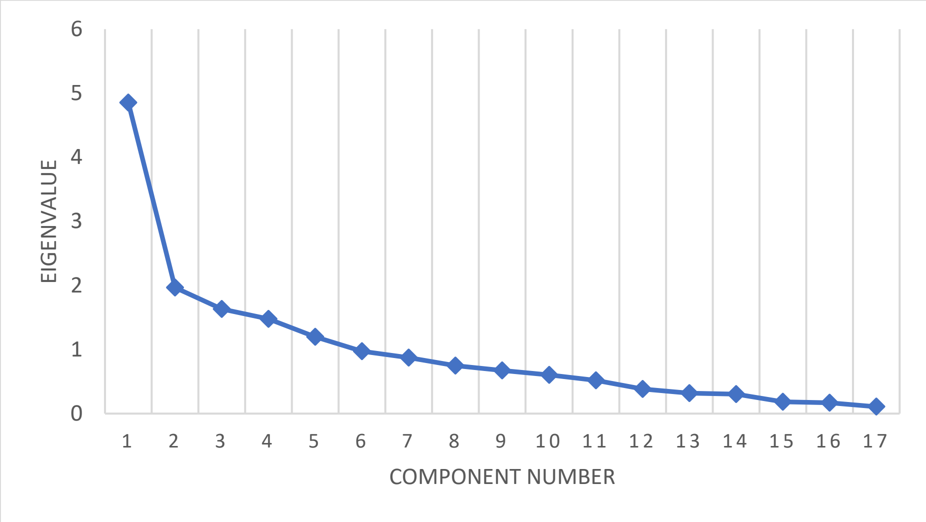

Figure 1: Scree plot for barriers to the adoption of ESS for energy efficiency

Table 4 presents the pattern matrix for barriers to the adoption of ESS for energy efficiency, generated through principal component analysis with oblique rotation. The pattern matrix shows the relationship between the original variables (barriers) and the extracted components. The values in the table represent the factor loadings, which indicate the strength and direction of the relationship between each variable and each component. There are five components extracted in this analysis, and the variables with the highest loadings in each component are as follows:

Component 1: This component is characterised by concerns related to theft and security, as well as vandalism. The variables with the highest loadings in this component are theft and security concerns (loading = 0.809) and vandalism (loading = 0.787). The high loading value for theft and security concerns implies that stakeholders are apprehensive about the security of ESS installations, particularly regarding the safety of energy storage equipment and the potential loss of stored energy due to theft or unauthorised access (Johnson et al., 2020). This perception may arise from the high value and importance of energy systems in general and the consequences of system failure or interruption. Additionally, ESS installations can be targets for theft or vandalism due to their high-value components and remote locations (Azzuni & Breyer, 2018). The high loading value for vandalism implies that stakeholders perceive ESS installations as being at risk of intentional damage, either for malicious purposes or because of accidents. This perception could result from inadequate security measures, insufficient surveillance, or a lack of knowledge about the potential threats to ESS installations (Chua, 2021). The concern about vandalism highlights the need for proper security measures and appropriate location selection for ESS installations.

Component 2: This component is characterised by financial barriers to adoption, including the lack of financial incentives, high initial costs, limited financing options, and the absence of experts. The variables with the highest loadings in this component are lack of financial incentives (loading = -0.878) and high initial cost (loading = -0.675). Limited financing options may make it difficult for potential adopters to secure funding for ESS adoption, while the absence of experts may increase the cost of ESS adoption due to the need for specialised skills and knowledge (Ghobakhloo et al., 2011). These financial barriers to adoption can be significant obstacles for individuals or organisations that may be interested in adopting ESS for energy efficiency. However, there are potential solutions to address these financial barriers, such as government incentives, grants, or subsidies to offset the high initial cost of ESS, or financing options with lower interest rates to facilitate the adoption of ESS (Dowelani et al., 2022). Increasing awareness and access to expert advice on financing and installing ESS may also help overcome some of the financial barriers to adoption (Matsepe & Van der Lingen, 2022).

Component 3: This component is characterised by barriers related to consumer awareness, including the lack of consumer awareness and disregard for energy efficiency alternatives. The variable with the highest loading in this component is lack of consumer awareness (loading = 0.885). A lack of knowledge and understanding about the benefits of energy efficiency measures can impede adoption. Disregarding energy efficiency alternatives may also stem from a lack of awareness or understanding of their benefits (Pelenur & Cruickshank, 2014). This component suggests that efforts to increase consumer awareness and education about energy efficiency measures and their benefits could be a key strategy in overcoming adoption barriers.

Component 4: This component is characterised by barriers related to project consolidation, such as the absence of project consolidation, lack of framework and regulations, and inability to demonstrate investment returns for potential clients. The variable with the highest loading in this component is the absence of project consolidation (loading = 0.804). The absence of project consolidation may stem from the lack of a clear strategy or approach to coordinating various aspects of the project, such as identifying stakeholders, defining roles and responsibilities, and establishing performance metrics (Jeffery, 2009). The lack of framework and regulations may refer to the absence of clear policies, standards, or guidelines that govern the design, implementation, and monitoring of energy efficiency projects. This can make it difficult for project developers and investors to navigate the regulatory landscape and obtain the necessary permits and approvals. The inability to demonstrate investment returns for potential clients can also hinder project consolidation by making it challenging to secure funding and attract stakeholders (Boaz et al., 2018).

Component 5: This component is characterised by barriers related to knowledge and information, including installation complexity, obstructions to energy efficiency, absence of data about existing redesign measures, and lack of knowledge. The variable with the highest loading in this component is the absence of data about existing redesign measures (loading = 0.461). The absence of data about existing redesign measures suggests that there is a lack of information about the impact and effectiveness of ESS in previous projects, making it difficult for potential adopters to make informed decisions (Johnson et al., 2020). The lack of knowledge may refer to a general lack of understanding of ESS technologies and their potential benefits. Obstructions to energy efficiency may refer to existing structural and systemic barriers to the adoption of energy efficiency measures (Boaz et al., 2018). For example, existing building codes and regulations may not support the integration of ESS, or there may be a lack of available expertise to design and implement ESS effectively. Finally, installation complexity may refer to the challenges associated with installing and integrating ESS into existing buildings and energy systems, which may require specialised expertise and equipment (Chua, 2021).

Overall, the pattern matrix shows that the barriers to the adoption of ESS for energy efficiency can be grouped into five distinct components based on their interrelatedness.

This information can be used to develop targeted interventions aimed at addressing the specific barriers that are most relevant to the adoption of ESS for energy efficiency.

Table 4: Pattern matrix for barriers to the adoption of ESS for energy efficiency

	Component				
	1	**2**	**3**	**4**	**5**
Theft and security concerns	0.809				
Vandalism	0.787				
Absence of innovation	0.586				
Poor maintenance culture	0.569				
Lack of financial incentives		-0.878			
High initial cost		-0.675			
Limited experts		-0.530			
Restricting in financing options		-0.449			
Lack of consumer awareness			0.885		
Absence of project consolidation			0.804		
Lack of framework and regulations			0.682	0.311	
Inability to demonstrate investment returns for potential clients				0.752	
Installation complexity				0.680	
Obstructions to energy efficiency				0.654	
Absence of data about existing redesign measures				0.461	
Lack of knowledge					0.669
Disregard for energy efficiency alternatives					0.641

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalisation.
a. Rotation converged in 14 iterations.

4. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the analysis of the barriers to the adoption of ESS for energy efficiency has identified several key factors that limit its widespread use. These barriers include concerns related to theft and security, financial constraints, lack of consumer awareness, barriers to project consolidation, and knowledge and information gaps. The study highlights the need for policy interventions to address these barriers, including the development of frameworks and regulations to promote ESS adoption, the provision of financial incentives, and increasing consumer awareness through education campaigns.

Based on these findings, it is recommended that policymakers, energy companies, and other stakeholders work together to develop comprehensive strategies to address the barriers identified in this study. These strategies should include targeted interventions to address financial barriers, such as the provision of subsidies or tax incentives, as well as efforts to raise consumer awareness and promote knowledge sharing. Additionally, governments and regulators should work to establish clear frameworks and regulations to promote the adoption of ESS technologies, and efforts should be made to increase investment in research and development to drive innovation in this field. By taking these steps, it is possible to overcome the barriers to the adoption of ESS for energy efficiency and pave the way for a more sustainable energy future. Further research can be carried out on the investigation of the specific financial incentives that can be offered to overcome the financial barriers to the adoption of ESS, especially in the construction industry.

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BIG DATA ANALYTICS IN THE SRI LANKAN CONSTRUCTION INDUSTRY: AN ASSESSMENT OF THE CHALLENGES AND STRATEGIES

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ABSTRACT

The increasing complexity of construction projects and the expansion of the construction sector has complicated the data management process by highlighting the need for proper data management tools in arranging and organising construction data. Specifically, countries with developing economies such as Sri Lanka require more advanced data management tools, since the construction sector is the backbone of their economies. In this context, this study aims to identify the challenges to the implementation of Big Data Analytics (BDA) in the Sri Lankan construction sector and the potential strategies which can be adopted in overcoming the challenges for the implementation. Accordingly, a qualitative approach was followed in achieving the aim of the study. A comprehensive literature review was conducted to identify the existing body of knowledge related to the study area. Twelve semi-structured interviews were conducted for primary data collection with experts in the fields of construction and data analytics and the non-probability purposive sampling technique was used to select the experts for the data collection. Data were analysed using the content analysis method. Findings revealed that the requirement of large capital expenditure, resistance from industry professionals and lack of industry awareness are the major barriers to adopting BDA in the Sri Lankan construction sector. Eventually, it was revealed that conducting awareness sessions and educating the industry stakeholders will assist the strategic implementation of BDA in the Sri Lankan construction sector.

Keywords: *BDA; Data Management; Sri Lankan Construction Industry.*

1. INTRODUCTION

The construction industry is the key contributor to developing economies and the construction sector is considered the reflection of a nation's development (Akinrata, 2016). Being a developing nation, Sri Lanka possesses a construction sector which is among the largest contributors to the country's GDP (Jayalath & Gunawardhana, 2017).

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However, the advancement of construction mechanisms is highly challenged in Sri Lanka due to its current economic conditions (Kulatilake et al., 2022). At the same time, the Sri Lankan construction industry is struggling to adapt to novel technologies in order to sustain the quality of the construction mechanisms (Cooray & Coomasaru, 2022). Specifically, data management in the Sri Lankan construction sector is also encountering considerable issues which manifest the need for proper procedures for construction data management in Sri Lanka (Kosala et al., 2021).

Meanwhile, BDA is globally accepted as an efficient data management tool which has the capacity to arrange and organise all types of data in the construction sector (Kostyunina, 2018). Further, BDA is identified as an effective measure in improving the performance of construction projects (Bilal et al., 2019). The vast amount of data generated in the construction sector can be efficaciously managed by utilising BDA and it directly assists in identifying the commercial values indicated by construction data (Wang et al., 2018). Besides, BDA has the potential in revealing the hidden value of data which manifests the importance of BDA towards construction data management (Chen & Lu, 2018). Therefore, this study is aimed at identifying the potential of utilising BDA for data management in the Sri Lankan construction context and this study intends to address the question of "how the Sri Lankan construction industry is challenged in utilising BDA and what are the strategies that could inspire the implementation of BDA in the Sri Lankan construction sector?".

The paper is structured as follows. First, it provides a literature review on BDA in terms of applications in the construction sector. Next, the research method comprises data collection and analysis. This is followed by the findings and conclusions.

2. LITERATURE REVIEW

2.1 DATA MANAGEMENT IN THE CONSTRUCTION SECTOR

Construction data management is a subset of information management which is focused on utilising the information for various purposes in construction mechanisms (Gaith et al., 2012). As Abu-Elkheir et al. (2013) elaborate, data management follows specific practices and data architectures in managing and extracting valuable insights from gathered or available data. Currently, it is a common focus of construction organisations to optimise the use of abundant data which have a massive capacity in improving project performance and other organisational tasks (George et al., 2014). In adhering to the rapid advancement of construction technologies, modern data management tools should also be considered since data management plays a vital role in a construction project (Wang et al., 2018). Accordingly, research has been conducted on the potential of utilising modern applications such as BDA in enhancing the productivity of construction data management (Barbosa et al., 2017; Kostyunina, 2018).

2.2 APPLICATION OF BDA AS A CONSTRUCTION DATA MANAGEMENT TOOL

The main focuses of applying BDA in the construction sector are to predictively assess the data and to comprehend the link between different data available in the construction sector (Fan et al., 2014). Moreover, BDA is used by construction stakeholders in governing project progress and monitoring project performance (Ratajczak et al., 2019). Besides, BDA is used in tracking site operations, tracking material and equipment records, productivity measuring and monitoring labour performance (Yang et al., 2015). Research suggests that BDA has the capacity of fulfilling various data management requirements with the ten (10) features specific to the concept, i.e., 10V's of Big Data (Sadiku et al., 2021). According to Munawar et al. (2022), applications, challenges and opportunities of BDA rely on these specific characteristics of Big Data i.e., value, volume, velocity, variety, veracity, volatility, validity, variability, vulnerability, and visualisation. Figure 1 detailly presents how these characteristics inspire effective data management in the construction sector.

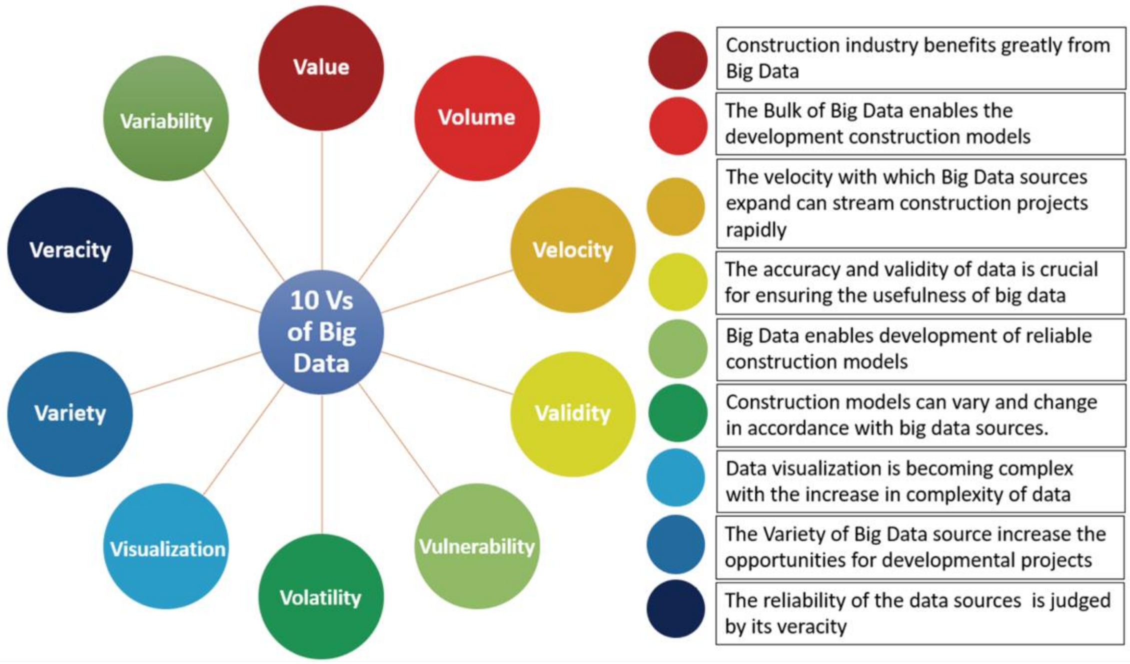

Figure 1: 10V's of Big Data
Source: (Munawar et al., 2022)

As Figure 1 suggests, the characteristics of Big Data should be comprehended deliberately by being specific to the construction sector in order to acquire the maximum benefit of the concept. Eventually, BDA is an important tool because, in the proper application, BDA provides the right information to the right user at the right time within the key parameters of the right volume and right quality (Schermann et al., 2014).

2.3 WHY IT IS IMPORTANT TO IDENTIFY THE POTENTIAL OF UTILISING BDA FOR DATA MANAGEMENT IN THE SRI LANKAN CONSTRUCTION CONTEXT?

The majority of Sri Lankan construction projects encounter time and cost overruns with a lower productivity rate which is mainly due to the poor planning and data management practices of construction projects (Jayalath & Gunawardhana, 2017). Further, most of the construction organisations in Sri Lanka follow traditional procedures for data management which are believed to reduce the effectiveness and efficiency of the overall construction project performance (Epasinghe et al., 2018). At the same time, BDA is well recognised by experts over the globe as a measure in enhancing the performance of the construction industry by optimising data management (Chen & Lu, 2018). Further, proper use of BDA can allow process improvements while maximising the productivity levels of construction projects (Mexas & Quelhas, 2012; Wang et al., 2018).

More importantly, BDA has currently been utilised in other industries in Sri Lanka (Bolonne & Wijewardene, 2020; Samarajiva et al., 2015; Senavirathne, 2022; Surangi & Sellathurai, 2023) and the potentiality has been revealed in utilising BDA in the Sri Lankan context for few other industries even if there is a gap in utilising BDA for Sri Lankan construction context. Further, research has been conducted on using modern technologies such as Blockchain, Building Information Modelling (BIM), and Industry 4.0 for the construction sector in Sri Lanka (Cooray & Coomasaru, 2022; Epasinghe et al., 2018; Gunawardhana, 2018; Kosala et al., 2021), yet there is a gap in existing literature in utilising BDA for construction data management in Sri Lanka. Thus, it is important to address this gap by assessing the potentiality of utilising BDA for data management in the Sri Lankan construction sector as intended by the aim of this study. Specifically, Luthra and Mangla (2018) identify the importance of researching the challenges and strategies as the initial step in implementing new technology in a new context. Besides, when researching the challenges and strategies related to a specific concern, the key focus can be directed to the general challenges and strategies prior to focusing on challenges related to detailed stages (Ahmed et al., 2022). Accordingly, if the overall challenges of adopting BDA in a construction context are properly addressed, it will be conceivable in enhancing the performance of the construction industry through proper data management patterns (Ismail et al., 2018).

3. RESEARCH METHOD

In addressing the exploratory research question, this study adopts a qualitative approach since the qualitative method is considered the most effective approach for exploratory research (Aleixo et al., 2018). Accordingly, the survey method was followed by adopting semi-structured qualitative expert interviews since expert interviews allow researchers to identify the in-depth opinions and views of the survey participants (Priola, 2019). Further, the snowball and purposive sampling methods were followed in defining the research sample to increase the credibility of the collected data (Valerio et al., 2016). Accordingly, Table I presents the profile of the selected experts and the exposure of the experts to the research areas.

Table 1: Profile of the respondents

Respondent	Discipline	Years of Industry Experience	Exposure to the Research Areas	
			Construction Sector	BDA
R1	Ch. Quantity Surveyor	30	✓	✓
R2	Ch. Engineer	25	✓	✓
R3	Lecturer in Computer Science Engineering	20	Partially	✓
R4	IT Consultant	12	✓	✓
R5	Technical Manager in Engineering Software Development	07	✓	✓
R6	Data and Business Analyst	07	Partially	✓

Respondent	Discipline	Years of Industry Experience	Exposure to the Research Areas	
			Construction Sector	BDA
R7	Quantity Surveyor	07	✓	✓
R8	Lecturer in Architectural Software	06	✓	✓
R9	Civil Engineer	06	✓	Partially
R10	Machine Learning Engineer/ Machine Learning Researcher	02	Partially	✓
R11	Data Analyst	02	Partially	✓
R12	Cybersecurity Specialist	02	Partially	✓

The interviews were conducted until the saturation of data on the research question. The content analysis method was used to analyse the collected data for subjective data interpretations (Nayak & Singh, 2015).

4. RESULTS

4.1 CHALLENGES OF UTILISING BDA IN THE SRI LANKAN CONSTRUCTION INDUSTRY

The experts were questioned on the challenges in applying BDA to the Sri Lankan construction industry considering all the phases of a construction project and the results are presented in Table 2.

Table 2: Challenges for implementing BDA in the Sri Lankan construction industry

Challenges	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12
Requirement of large capital expenditure	✓		✓		✓	✓		✓	✓		✓	✓
Resistance from professionals towards modern technologies		✓		✓	✓		✓			✓	✓	✓
Lack of awareness and knowledge by the professionals	✓		✓		✓	✓	✓	✓	✓		✓	✓
Dynamic nature of the construction industry	✓	✓		✓		✓	✓					
Fear of data loss and unauthorised access	✓	✓							✓		✓	✓
Absence of big data analytics culture within organisations		✓		✓		✓				✓		
Lack of technical advancements in the industry						✓			✓	✓		✓
Lack of government support			✓		✓			✓				

As Table 2 suggests Sri Lankan construction sector encounters considerable issues in initiating BDA applications in the construction industry and the findings of the expert survey can be comprehensively presented as follows.

- **Requirement of large capital expenditure**

Most of the respondents identified the requirement of large capital expenditure as one of the major challenges. According to R3, most construction companies are reluctant to adapt to complex data management measures since it requires high-performance computers and other expensive data management software. Further, R5 stated, *"Due to the current economic situation of Sri Lanka, many construction firms are struggling to maintain a positive cash flow"*. Therefore, the R5 mentioned that investing a considerable capital expenditure on data analytics methods will not be possible for many companies. This aspect was further highlighted by R8, who stated that most construction companies are relying on low or medium-performance computers and even the designers and other professionals have mediocre-level devices. R8 further stated that BDA requires high-performance computers and therefore, it can be considered a major challenge.

Moreover, R1 and R6 highlighted that investing in expensive data analytics software may not be possible for all construction companies, especially small-scale businesses. Accordingly, R1 stated that this capital expenditure will only be feasible for large companies and therefore, small, and medium-scale companies will fall back on the competition. As a result of this, R1 further stated that there is a possibility of small businesses being pushed out of the industry while only the large scales businesses remain as competitors. According to the respondent, this inequality is identified in most technological revolutions and R6 stated that this aspect can act as a barrier to any new companies entering the construction sector. However, both R1 and R6 stated that this barrier will disappear with time as the technology becomes less expensive and easily available over time. As an example of the above point, R1 pointed out,

> *"Apple, Microsoft and Amazon are some of the companies that are quick to adopt new technology in other industries and as a result, they have been leading their respective industries. This factor can be applicable to the construction industry as well"*.

Hence, the respondents identified this as a social issue for small and medium-scale companies despite the numerous advantages BDA offers to the industry.

- **Resistance from professionals towards modern technologies**

Based on the interviews, resistance from professionals towards modern technologies was identified as a major challenge in utilising BDA in the construction industry. According to R2 and R4, many of the existing and leading construction professionals in the industry are accustomed to using traditional paper-based methods for data recording and therefore, they will show resistance to transferring to digitalised methods. In R4's opinion, since getting used to new data management software tends to take up some time, most professionals prefer sticking to their familiar traditional methods. In addition, R5 stated, *"To adopt BDA in the construction industry, support from the industry professionals is essential"* and since there is a lack of support from many professionals, it has proven to be a challenge. Moreover, R7 highlighted that most of the established construction organisations have proven and good internal systems in place with traditional methods, and therefore, they may not see an immediate requirement to transition into digitalised data management methods.

- **Lack of awareness and knowledge by the professionals**

Lack of awareness and knowledge of construction professionals towards BDA and its usage in the industry is another main challenge identified by the respondents to the utilisation of BDA. According to R3, most construction professionals do not consider using BDA in the industry since they are not aware of the benefits it can offer to revolutionise the industry. R3 further stated that even if the users are aware of the benefits, they may not be educated on how to use these platforms and achieve the intended benefits. As supporting arguments, R5, R6, R7 and R8 stated that due to the highly technical nature of BDA, only a few professionals will be interested in learning the usage of BDA while only the professionals with advanced IT knowledge will realise the true potential of BDA to the construction industry.

- **Dynamic nature of the construction industry**

The rapidly changing and dynamic nature of the construction industry and its data is another challenge with the utilisation of BDA. As highlighted by R7, data related to construction projects tend to change with the project progression. Therefore, it may be difficult to predict and forecast future outputs with big data as the inputs to the BDA platforms change frequently. As stated by R1,

> *"If we design a retaining wall, and the cost exceeds the budgetary limitations, we might consider changing the design or the materials. Even the structure itself can be changed for this purpose. Therefore, with this dynamic nature of the industry, BDA can have high costs compared to the benefits. if the analysis process takes a lot of resources, and time, it may not be worthwhile to carry out BDA for a project with a large number of changes".*

- **Fear of data loss and unauthorised access**

According to R1, most construction professionals and companies are reluctant to share their databases with other professionals and as a result, there can be a lack of free flow of data which will be a bigger challenge in implementing BDA in construction. In addition, R2 highlighted that most of the companies may not be interested in BDA since, with the digitalisation of work, the number of cybercrimes has also increased. Therefore, the expert argued that the fear of data breaches is another factor that negatively assists the utilisation of BDA. Similar to this point, R2 further highlighted that some parties may have a fear of losing data due to technical problems and system breakdowns in adopting BDA applications.

- **Absence of big data analytics culture within organisations**

As identified by the experts, the absence of a BDA culture within organisations hinders the application of BDA in construction data management. R4 affirmed that organisational cultures mainly affect the resource allocation and the availability of infrastructure in a construction organisation. According to R2, Sri Lankan construction companies mostly follow an outdated culture in technological application which discourages the application of BDA to data management.

- **Lack of technical advancements in the industry**

According to the experts' opinion, there is an apparent lack of technical advancement in the construction industry which negatively affect the use of BDA for construction data management. R9 highlighted that the unavailability of technical advancements significantly affects BDA applications since there are many technical requirements for the smooth implementation of this technology. As per R10 and R12's view, Sri Lanka lags a considerable level of technical advancements which are mandatory to implement BDA applications.

- **Lack of government support**

During the interview survey, it was noted that government support is not sufficiently provided for BDA implementations. R3, R5 and R8 suggest that government provides a minor consideration in stimulating novel technologies and BDA is also one of the technologies that are overlooked by the government.

Likewise, experts provided their opinion on the challenges in utilising BDA applications in the construction sector and followingly, shared their suggestions on the measures which can be followed in favouring a technological transition to BDA applications in the Sri Lankan construction sector.

4.2 STRATEGIES TO OVERCOME THE CHALLENGES IN UTILISING BDA IN THE CONSTRUCTION INDUSTRY

The respondents were asked to suggest strategies related to all the phases of a construction project that can be used to overcome the challenges they identified. Accordingly, Table 3 illustrates the main strategies identified by the respondents in utilising BDA in the construction industry.

Table 3: Strategies to overcome the challenges in utilising BDA in the Sri Lankan construction industry

Strategies	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12
Providing education and training to industry professionals	✓	✓	✓	✓	✓	✓		✓	✓			
Conducting awareness programs for industry professionals	✓	✓		✓					✓		✓	✓
Quantifying the benefits of BDA	✓		✓		✓		✓			✓		
Developing standards and guidelines for proper data management					✓				✓	✓		
Maintaining proper security for collected data						✓		✓				
Getting government support in promoting digitalisation							✓				✓	
Enhancing the technological applications within the industry											✓	✓

Based on Table 3, the key strategies highlighted by the respondents can be comprehensively discussed as follows.

- **Providing education and training to industry professionals**

Most respondents identified that providing education and training to industry professionals on how to use BDA platforms can help override the challenges identified in the previous chapter. In this regard, R3 and R4 stated that education and training can be provided to both fresh and established professionals by conducting workshops, seminars and even by introducing a module to the undergraduate programmes such as Civil Engineering, Architecture and Quantity Surveying. Similarly, R5 stated that by introducing basic software engineering, database management and programming knowledge to university students, they can start creating their own databases and properly manage all those data to enhance construction productivity through BDA. Further, R5 said that this step can be a good strategy for getting young professionals interested in bringing technology to the construction industry. Moreover, R6 highlighted that such education and training can help professionals with traditional mindsets towards new technologies by inspiring them to reconsider their approaches.

- **Conducting awareness programs for industry professionals**

As emphasised by R1, conducting awareness sessions is also important compared to the education and training programs. R11 and R12 mentioned that awareness programs should be conducted in general to all industries via effective platforms such as enterprise social media. R9 elaborated that *"awareness is the most important thing for the implementation of a new technology"* and R9 further emphasised the need for awareness sessions among construction professionals. Further, R2 and R4 affirmed that the awareness sessions should be conducted customising as per the construction organisational cultures and it will help the professionals to grab the essence of the concept.

- **Quantifying the benefits of BDA**

According to R1, the benefits of BDA in construction have not been quantified at present. R1 further stated, *"If we can come up with a strategy to measure the impact to the cost, speed of construction and quality of outputs due to BDA, it will become popular among clients as well as construction professionals"*. Therefore, quantifying the benefits and showing a numerical value in terms of cost or any other aspect can motivate the users to consider BDA adaptation in the construction industry. As a supporting argument, R5 stated that showing the return on investment of using BDA would drive the demand for such technologies. If the increase in the return on investment after utilising BDA can be properly calculated and communicated to the industry stakeholders, they will consider investing in BDA platforms. R5 further stated that example success stories of foreign countries can be shown to the local construction stakeholders.

- **Developing standards and guidelines for proper data management using BDA**

As R9 suggested, data management in the Sri Lankan industry is not standardised in the current context. R9 further argued that if proper BDA frameworks are proposed in utilising BDA in the construction context, it will stimulate the implementation of BDA in the Sri Lankan construction sector. Supportively, R10 suggested that construction professionals who have an in-depth knowledge of BDA can initiate the process of preparing frameworks in utilising BDA in the construction sector. Eventually, R5 commented on the potential of using standardised frameworks for effective construction data management and R5 stated that BDA frameworks will ensure efficiency in construction data management.

- **Maintaining proper security for collected data**

As per experts' opinion, proper data security can ensure a smooth implementation of BDA applications in the construction sector. R8 suggested that construction organisations can outsource services related to data privacy and security, which is essential in accommodating a BDA culture in construction organisations. According to R6, organisations should not be reluctant to adhere to data security measures due to the initial costs since it has one of the major positive influences on the successful implementation of this concept.

- **Getting government support in promoting digitalisation and enhancing the technological applications within the industry**

The experts suggested that government should highly focus on promoting digitalisation. As R11 suggested, the government can allocate a specific budget and get the involvement of professionals in the relevant fields in promoting novel technologies in the construction industry. According to R7, the government can introduce policies and conduct sessions on promoting BDA applications since it will directly affect the advancement of the concept.

Furthermore, the experts suggested that the enhancement of technological applications within the construction industry has a direct impact on the successful implementation of the concept. R11 and R12 affirmed that BDA cannot be individually implemented and that overall technological improvements in the construction sector will strategically stimulate the application of BDA in the construction sector.

5. CONCLUSIONS AND RECOMMENDATIONS

The increasing complexity of construction projects has affected the smooth flow of construction data management while highlighting the need for proper data management tools for complex construction projects. This study reveals that the Sri Lankan construction industry is in dire need of proper data management tools and BDA has the potential in making data management in construction projects more effective. The study suggests that the major challenge which hinders the implementation of BDA in the Sri Lankan construction sector is the large capital requirement which affects developing countries. Moreover, the unawareness and other myths on the security aspects challenge the transition to a BDA culture in the Sri Lankan construction sector. Nevertheless, these can be overcome by proper awareness sessions and education programmes on the use of BDA for construction data management.

Accordingly, this study contributes to the theory by revealing the challenges and strategies in establishing a BDA culture in the Sri Lankan construction sector. However, this study is limited to the general challenges and strategies of applying BDA to a construction project and further studies are directed to the detailed assessment of challenges and strategies related to the application of BDA to different stages of a construction project. Furthermore, it is important to research the feasibility of industry-specific BDA awareness sessions in Sri Lanka. Eventually, future studies are also directed at developing industry-specific BDA frameworks which can be utilised by construction professionals in standardising construction data management in Sri Lanka.

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BUILDING INFORMATION MODELLING FOR CONSTRUCTION PRODUCTIVITY MEASUREMENT

Shandraseharan Archchana[1] and Wei Pan[2]

ABSTRACT

Productivity is a critical performance indicator of the construction industry, and thus warrants effective and efficient construction productivity measurement (CPM). Building information modelling (BIM), a digital representation of the building process, plays a significant role in effective and efficient CPM. Considering the high mandatory requirements for enhancement in construction productivity measurement, this paper aims to review the state-of-the-art literature on BIM-integrated CPM, to identify gaps in the existing body of knowledge and explore future research trends. The aim is achieved through a systematic literature review and bibliometric analysis where the data are retrieved from Web of Science, Scopus, and Google Scholar and proposes future research directions. In total 260 publications were identified from the initial search, and 56 were shortlisted for full-text analysis after several levels of screening including duplication, title and abstract checking. Finally, 21 were narrowed yielded for detailed review for this study. The results mapped the yearly publication trend, publications by source and the co-occurrence of terms. The findings help to identify a suite of BIM-integrated CPM methods used in the construction industry and provide a foundation for future research in CPM. A framework is developed to illustrate the knowledge gap and future directions identified in this study. Accordingly, the findings revealed that existing studies on utilising BIM for CPM are limited to only 3D and 4D BIM. Further, there is a lack of studies on the feasibility of using BIM for CPM, fully automated BIM integrated CPM tools and real-time CPM through BIM.

Keywords: *Building Information Modelling; Construction Productivity Measurement; Systematic Review.*

1. INTRODUCTION

Productivity is a crucial concept since it plays a major role in evaluating the success of the construction industry through quantifying the relationship between construction inputs and outputs. Therefore, statistics on construction productivity are vital for understanding the construction industry in various aspects. Henceforth, productivity plays a major role in formulating and assessing government policy relating to the construction industry. The significance of construction productivity measurement (CPM) is linked to a widely recognised need for productivity improvement in construction at task, project and industry levels (Javed et al., 2018). Indeed, CPM is the first step for realise progressive improvement. Since construction productivity has been measured at different

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levels (e.g., task, project and industry) for various purposes (e.g., labour efficiency, construction efficiency, and economic efficiency) using various methods, such as Single Factor Productivity (SFP), Multi-Factor Productivity (MFP) and Total Factor Productivity (TFP), there is still no universally accepted CPM. Indeed, it is difficult to obtain a standard method to measure construction productivity because of the complexity and uniqueness of construction projects, the fragmented project-based nature of the industry, and the dynamic context of the built environment (Oglesby et al., 1989; Thomas & Mathews, 1986). Therefore, CPM is very elusive and difficult to be conducted.

Traditionally CPM was carried out through text-based manual systems (i.e., daily work reports) to record and obtain various on-site construction data (Cha and Kim, 2020; Ibrahim and Moselhi, 2014; Hildreth et al., 2005). However, the traditional method was considered a poor data capturing technique (Martínez-Rojas et al., 2015; Feng et al., 2010), mainly due to text based information storing system makes difficulty in determining the characteristics (Cha and Kim, 2020), difficulty in recording the information in detailed levels and leads to missing or avoidance of some important information (McCullouch and Gunn, 1993), and huge time and effort required for the on-site productivity data extraction (Xie et al., 2011; Oral and Oral, 2007) and to confirm the captured data is meaningful or useful along with all information (Cha and Kim, 2020).

Technological innovation has a vital impact on construction productivity (Zhan and Pan, 2020; Zhan et al., 2018; Pan et al., 2019). Similarly, advancements in innovation technologies significantly uplift the construction industry, CPM in specific. Various studies have focused on incorporating advanced technologies into the CPM methods to enable the automation of measurement (Arif & Khan, 2020; Ibrahim & Moselhi, 2014; Lee et al., 2017; Poirier et al., 2015a; Zhang et al., 2018). Building Information Modelling (BIM) is a digital representation of the building process and it has been highly acknowledged by researchers for the automation in CPM. Indeed, various studies have been carried out on the use of BIM in the construction process and visualisation, yet in a theoretical manner rather than practical applications. The implementation of BIM has been extensively researched and found to lead to substantial increases in productivity in the construction industry. Several studies have demonstrated the effectiveness of BIM in improving productivity and reducing inefficiencies in the construction process. For instance, a study by Wong et al. (2020) revealed that transitioning from traditional construction methods to a BIM-based approach resulted in substantial gains in productivity. The study found that BIM-based projects are more productive than traditional projects due to better planning, reduced rework, and improved collaboration. The use of BIM as a valuable tool for performance management in construction projects has been highlighted by Cha and Lee (2018). The use of BIM for CPM has also been explored by previous researchers and has been widely discussed in the literature.

Despite the great efforts of the previous studies of utilising BIM for CPM, none of them systematically reviewed the knowledge gap in utilising BIM for CPM. Thus, this present study aims to review the knowledge gap in the use of BIM for CPM by adopting a mixed review methodology of bibliometric analysis and systematic literature review. This study should help researchers to understand the knowledge gap in the use of BIM for CPM and guide future research on this important topic.

2. METHODOLOGY

A systematic literature review was adopted in this paper since it is often seen as an evidence-based approach, helping reduce researchers' subjectivity and biases. The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) 2020 statement was used as a guideline for the systematic literature review. The PRISMA 2020 is a guideline not only to identify and screen the data set but also for transparent, complete, and accurate reporting of systematic reviews (Page et al., 2021).

Initially, a desktop search was conducted across various databases to identify the existing research papers on the domain of automation in CPM. However, this initial search revealed that most of the findings are covered by Web of Science (WoS) and Scopus databases. Various researchers have emphasised that WoS and Scopus are the largest and most robust citation and abstract databases with reasonable availability (Braun et al., 2019; de Oliveira et al., 2019). In addition to this, Alaloul et al. (2022) also used WoS and Scopus databases for a similar kind of study. In addition, a random search has been done in Google Scholar to obtain additional publications in the research context. Further, bibliometric methods were complemented with meta-analysis and qualitative structured literature reviews, so a better review and evaluation of scientific literature can be achieved.

A keyword search query was developed for WoS as "TS = ((BIM OR Building information modelling) AND (construction) AND (productivity) AND (measurement OR calculation OR assessment OR evaluation))" and for Scopus as "TITLE-ABS-KEY ((BIM OR Building information modelling) AND (construction) AND (productivity) AND (measurement OR calculation OR assessment OR evaluation))". Figure 1 illustrates the process involved in identifying the most suitable dataset for this paper.

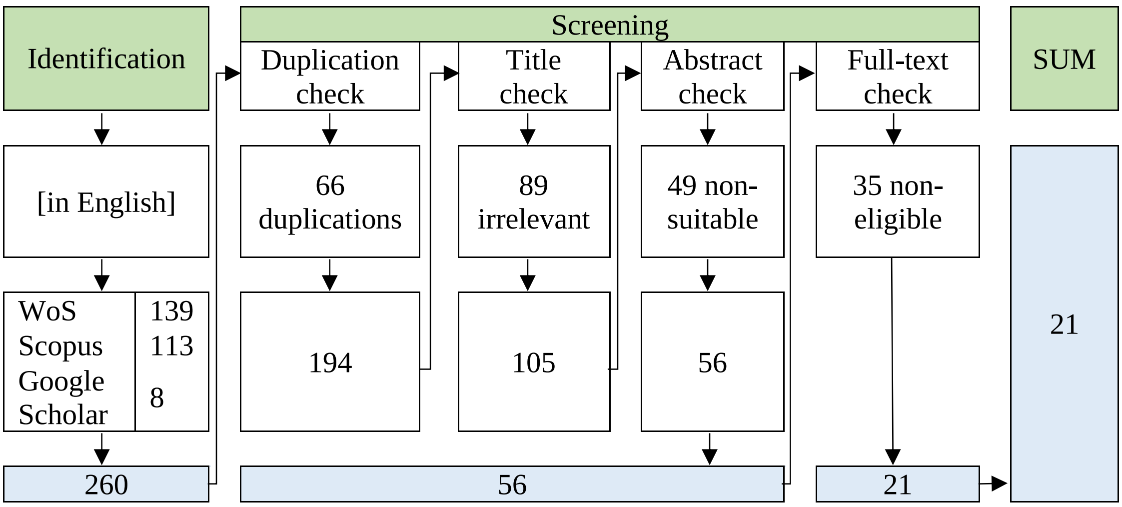

Figure 1: Flowchart of systematic literature review (Adapted from the PRISMA 2020 flowchart by Page et al., 2020)

Under the developed search string 139 and 113 publications were found from WoS and Scopus, respectively. In addition, 8 publications were obtained from a random search in Google Scholar for the publication in the relevant context. In both databases, results were limited to only 'English'. Accordingly, a total number of 260 publications were found from database searching. The initial screening revealed 66 duplicated publications in the findings, hence, at the end of duplication removal, a total number of 194 publications were obtained. The screening was continued with two further levels of filtering such as screening based on title and abstract, which resulted in 105 and 56 publications at the end of each stage respectively. Finally, at the end of a skim reading of the full text, 35 publications were removed, since non-eligible for the focused research domain. Therefore, in the end, 21 publications were found to be suitable for the detailed review of the literature.

Initially, the selected 21 publications were analysed according to the publication year and source. Bibliometric analysis is carried out based on the title and abstract to visualise the connections between terms and the most cooccurred terms. Content analysis of each paper has been done to identify the existing use of BIM in CPM.

3. RESULTS AND DISCUSSION

3.1 PUBLICATIONS DISTRIBUTION BY YEAR AND JOURNAL/CONFERENCE

Figure 2 illustrates the yearly publications output of the publication achieved from WoS, Scopus and Google scholar databases. A maximum number of publications were found in 2016 and 2018. Whereas there was no publication in 2013. The R-square value of the trend line (based on the "Total", y= 0.2333x + 1.1667) was found as 0.3267, which is not sufficient to show the significance. However, since 2016, there is a considerable increase in publications compared to previous years. Even though there were no limitations added to the year of publication in the search string, publications were obtained since 2011 only.

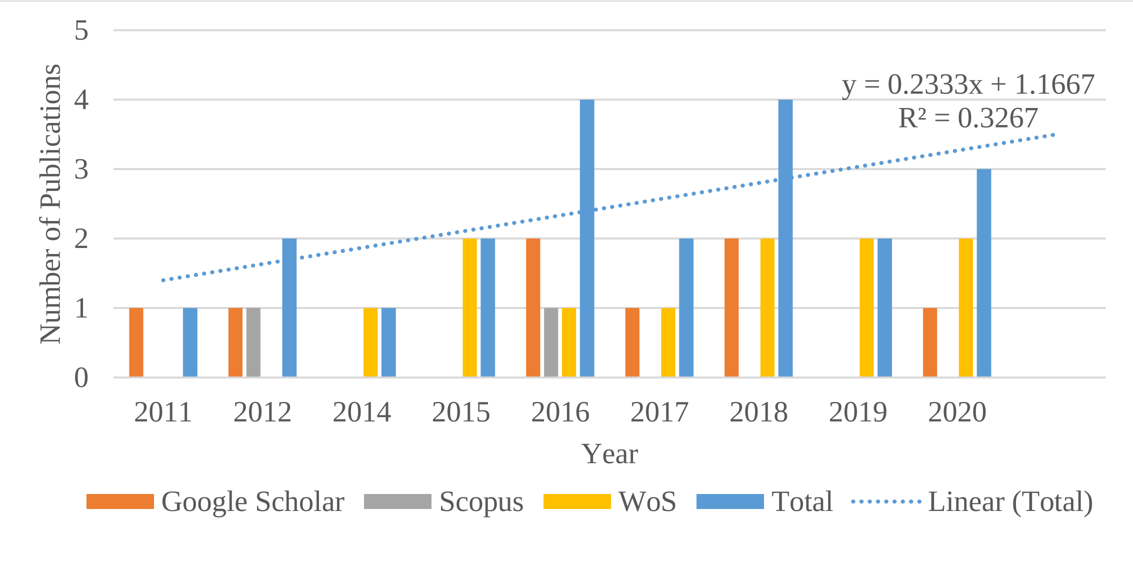

Figure 2: Number of publications from the selected databases over the period 2011-2020

Publications were also analysed based on the sources as illustrated in Figure 3. Accordingly, 21 publications were found from 15 sources, among which 2 were conference papers and the remaining were journal articles. The highest number (6) of publications was found in "Automation in Construction", followed by "Journal of Asian Architecture and Building Engineering" (with 2 records), with the rest of the sources having one record in each only.

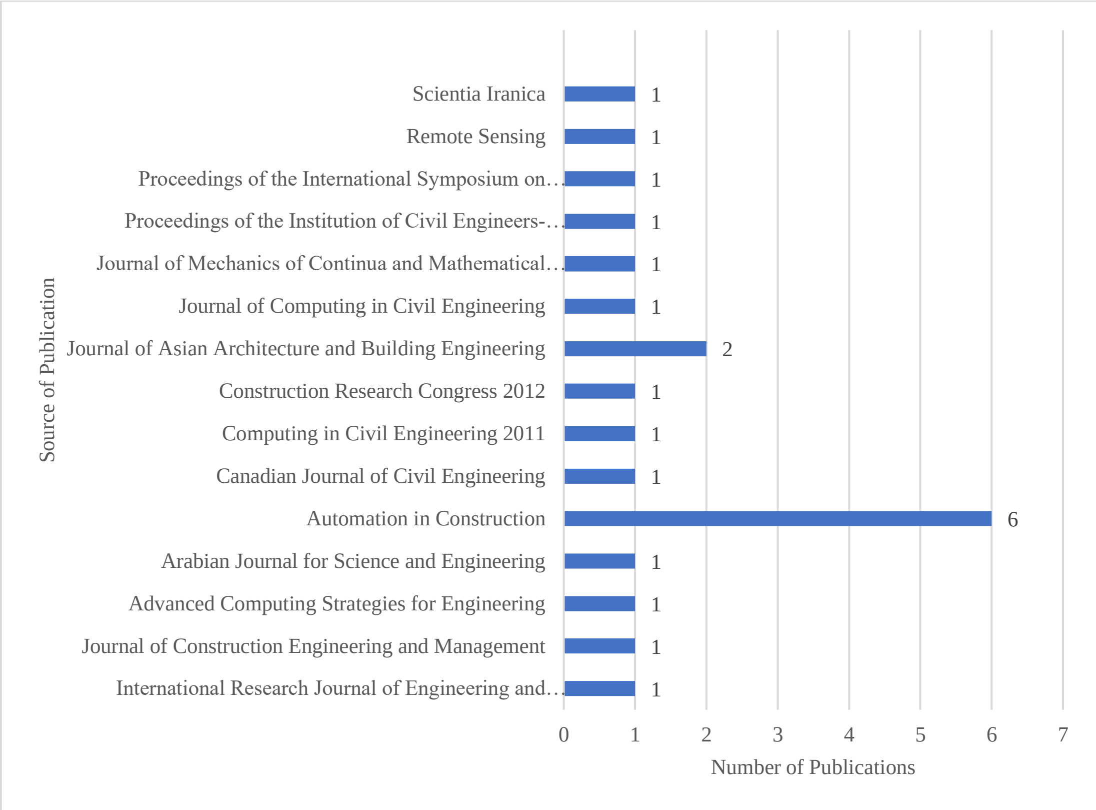

Figure 3: Number of publications per journal/conference

3.2 BIBLIOMETRIC MAPPING

The co-occurrence of text data of publications was analysed using VOSviewer software, to show the inter-closeness among them. Figure 4 illustrates the co-occurring of 26 terms found in the publications.

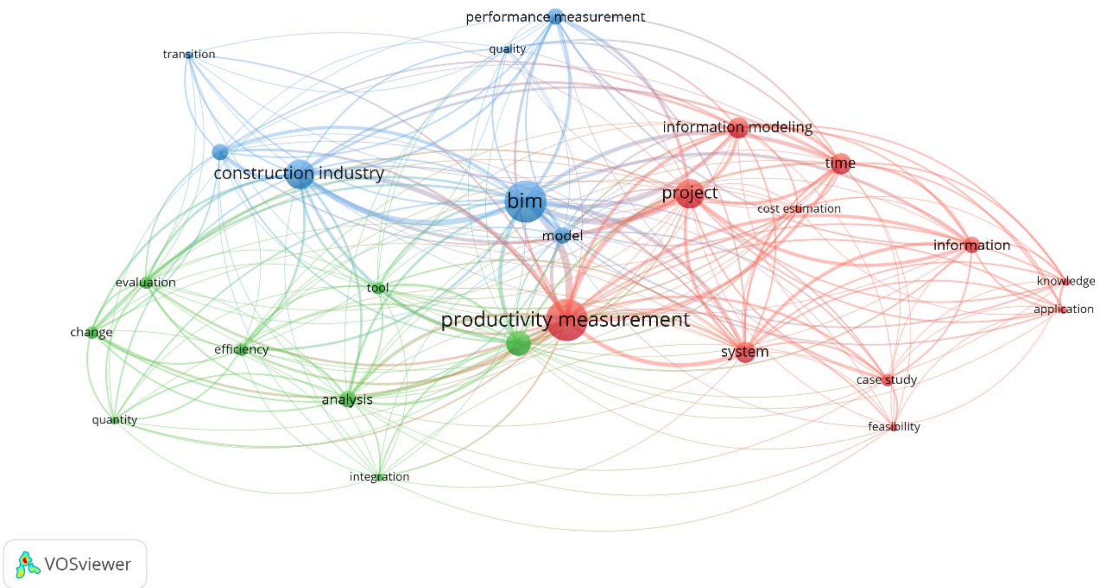

Figure 4: Co-occurrence mapping of terms in title and abstract of publication

By reviewing the bibliometric database files, the minimum occurrence of a text was set to two, 26 terms meeting the threshold point. Instead of analysing the co-occurrence of keywords, the co-occurrence of text data was analysed, since it enables to cover title and abstract of publications. BIM and productivity have the highest occurrence as the node reflects a visual representation of the occurrence of a given term. The thickness of the connecting lines between the nodes indicates the interconnectedness between the terms which indicates the significance of the integration of BIM for productivity.

3.3 BIM FOR PRODUCTIVITY MEASUREMENT

The use of BIM for CPM has been explored by previous researchers and has been widely discussed in the literature. Table 1 summarises the use of BIM for productivity measurement found in the 21 publications considered in this study.

Table 1: Studies on using BIM for productivity measurement

Source	Use of BIM
Abedi et al. (2016)	The proposed CACCBIM can be used as an effective tool for the data collection for the CPM
Arif and Khan (2020)	Typical total station, cloud and BIM integrated framework for real-time productivity measurement
Chan and Kim (2020)	Link 3D objects with a spreadsheet containing detailed daily progress information
Fang et al. (2016)	BIM and cloud-enabled RFID localisation systems enable productivity monitoring through worker location identification and data visualisation
Heigermoser et al. (2019)	The tool allows for a systematic evaluation and analysis of the construction planning in terms of productivity and manpower allocation
Heydarian and Golparvar-Fard (2011)	Framework for monitoring and controlling construction productivity of excavation. Machine learning approach to measure productivity and 4D BIM for a visual representation of the productivity
Khan et al. (2019)	BIM accurately estimates the bill of quantity and cost of the project. Well-documented reports are also generated in the BIM tool (Robot) for the model.
Kim et al. (2020)	Evaluation of project progress was performed through the 3D point cloud and the 4D attributes of BIM
Lee et al. (2014)	New algorithms are proposed for the acquisition of labour data, measurement and analysis of LP, and BIM models were employed for the creation of the LP database
Lee et al. (2017)	Proposed a BIM-based model that could be used for measuring daily LP progress and productivity best-fit line using the proposed BIM-based model
Lin and Golparvar-Fard (2018)	BIM for capturing, communicating, and analysing construction performance
Menon and Varghese (2018)	LP data acquisition method using 3D BIM model. 3D BIM model is used to take off quantities and enhance the accuracy of the LP measurement
Nath et al. (2016)	Fuzzy triangular function to measure construction productivity. Automated scheduling and automated quantity takeoff will automate the productivity measurement
Poirier et al. (2015b)	The findings suggest that BIM has had a positive impact over time on predictability for indicators such as total project cost and labour cost
Poirier et al. (2015c)	Productivity indicator predictability (labour productivity in specific) is becoming easier with BIM implementation
Shan et al. (2012)	BIM as a platform to perform labour productivity studies
Turkan et al. (2012)	3D object recognition technology with schedule information into a combined 4D object recognition system with a focus on progress tracking.
Yarmohammadi and Castro-Lacouture (2018)	A novel approach for automated design productivity measurement, using an API-enabled approach to collect real-time data directly from BIM software

Source	Use of BIM
Yarmohammadi et al. (2016)	Purpose of design log files including information about modelling activities (modeller's interactions with the software) during design sessions
Yarmohammadi et al. (2017)	Extract implicit process information from design log data by implementing a tailored sequential pattern mining approach
Zhang et al. (2018)	Proposed pattern retrieval algorithm which allows identifying the design sequential pattern that is most frequently used in building projects

3.3.1 3D BIM for CPM

Predictability of productivity indicators, especially labour productivity (LP) has been identified as becoming easier with BIM implementation compared to non-BIM implemented projects, thus positively impacting the LP prediction (Poirier et al., 2015b, 2015c). The findings indicate that the use of BIM has a significant positive impact on the accuracy of predicting the LP, compared to projects that have not implemented BIM. Similarly, a fuzzy mapping technique has been proposed and utilised to measure productivity improvement in a BIM-based workflow compared to a precast workflow (Nath et al., 2016). The findings of this study revealed that BIM enables automated scheduling and quantity take-off, which has the potential to automate CPM. This is because the quantity of work done can be used as an output for the CPM. Therefore, BIM allows for accurate estimates of the bills of quantities and costs of the project (Khan et al., 2019). Kim et al. (2020) also highlighted the use of BIM for monitoring the overall project status, such as productivity analysis, progress rate and quality verifications.

Lee et al. (2014) and Lee et al. (2017) conducted research centred around the utilisation of BIM as a tool for collecting data related to productivity measurement. To enhance the recognition of construction site images captured through video, Lee et al. (2014) developed innovative algorithms. These algorithms aimed to improve the recognition of construction site images to better measure the LP and establish a corresponding database. Importantly, BIM models were employed for the creation of the LP database, thus this study primarily focused on using BIM for the creation of an LP database rather than for the direct measurement of LP. In contrast, Lee et al. (2017) proposed a BIM-based model that could be used for measuring daily LP progress. This model was accompanied by a detailed explanation of the prototype. The study also went on to generate a productivity best-fit line using the proposed BIM-based model. While this study was significant in that it directly examined the use of BIM for CPM, it was limited in its scope as it only considered 3D BIM.

In addition, BIM has been utilised for the on-site performance measurement for building construction projects (Cha & Kim, 2020). This system is unique in its ability to link 3D objects with a spreadsheet containing detailed daily progress information, which can provide an accurate and comprehensive view of the project's progress. The proposed database is designed to enhance traditional CPM by incorporating the use of 3D BIM. However, it should be noted that the study by Cha and Kim (2020) is limited in scope, and only focuses on the use of 3D BIM for CPM, similar to the study conducted by Lee et al. (2017). Despite this limitation, the results of these studies demonstrate the potential for using 3D BIM to improve on-site performance measurement. In light of the similar limitations of previous studies, Menon and Varghese (2018) conducted a study that utilised a 3D BIM model for the measurement of LP in a commercial construction project. The study proposed a field LP data acquisition method that integrated the 3D BIM model, which was primarily used to take off quantities and enhance the accuracy of the LP measurement.

3.3.2 BIM Integrated with Other Technologies for CPM

Abedi et al. (2016) proposed a cloud-integrated BIM for precast supply chain management, named context-aware cloud computing building information modelling (CACCBIM). This proposed tool enabled efficient monitoring of the precast supply chain and it can be used to collect data for the CPM. Similarly, BIM has been integrated with cloud and Radiofrequency Identification (RFID) to collect worker location data in an indoor construction environment (Fang et al., 2016). The BIM-enabled system enables data visualisation and offers situational awareness of workers' locations. In addition, this system is capable of storing the historical location data on the server for further data analyses if necessary. Similarly, Arif and Khan (2020) proposed a BIM-based real-time productivity tracking framework that utilises a typical total station and cloud technology. This framework is capable of generating an as-built model for an ongoing construction project through the use of Dynamo programming on a BIM platform and measuring real-time productivity through data-driven BIM models. However, similar to previous studies in this area, Arif and Khan (2020) focused solely on the use of 3D BIM technology, neglecting the potential benefits of incorporating other BIM dimensions, into the framework.

3.3.3 4D BIM for CPM

BIM has been uniquely combined with machine learning to enable monitoring and controlling of productivity in construction excavation operations (Heydarian & Golparvar-Fard, 2011). The authors integrated the use of 4D BIM to provide a visual representation of the productivity of each planned construction activity. Additionally, they applied a machine learning approach to measure productivity. BIM and 4D schedule simulation is also used for labour studies to visually compare the schedule performance as a result of using quick connection systems (Shan et al., 2012). Similarly, the use of BIM for dividing construction projects into work zones, obtaining a fully automated quantity take-off, and offering a colour-coded 4D construction simulation is highly emphasised (Heigermoser et al., 2019). Moreover, location-based 4D BIM models are used to benchmark and monitor workers' location and to document worker hours per task per location (Lin & Golparvar-Fard, 2018). In addition, 4D BIM is integrated with 3D object recognition technology with a focus on progress tracking (Turkan et al., 2012).

3.3.4 BIM for CPM at Design Stage

Productivity measurement at the design stage is comparatively more complex than measuring the construction stage productivity, due to the complexity and variability of the design process, as well as the challenges associated with data collection and analysis (Zhang et al., 2018). Several researchers came up with various methods for the design stage productivity measurement including design hours, number of drawings, number of contractual documents, and project size and type (Thomas et al., 1999).

Even though these methods help to measure the effectiveness of resource utilisation, typically, data collection was manual, which is time-consuming, complex, error-prone, etc. Meanwhile, the integration of BIM technology into the design process provides an opportunity to enhance the efficiency and accuracy of design productivity measurement. By using BIM, design information is digitalised and centralised, providing a comprehensive and accurate representation of the design process. This digital representation enables the automatic collection and analysis of design data, reducing manual effort and minimizing the risk of errors.

Indeed, the utilisation of BIM software has provided construction professionals with access to valuable information about the design process through computer-generated data. For example, design log files stored in Autodesk Revit Journal files (Revit 2017) have been found to contain information about modelling activities, including the modeller's interactions with the software, during design sessions (Yarmohammadi et al., 2016). Further studies have aimed to extract implicit process information from design log data by implementing a tailored sequential pattern mining approach (Yarmohammadi et al., 2017). In a more recent study, Yarmohammadi and Castro-Lacouture (2018) proposed a novel approach for automated design productivity measurement, using an API-enabled approach to collect real-time data directly from BIM software. This approach has the potential to not only streamline the data collection process but also provide more efficient productivity measurement during schematic and design development phases. Similarly, Zhang et al. (2018) proposed a pattern retrieval algorithm to identify the most frequently used sequential patterns in a project by design professionals using BIM log data in the Autodesk Revit Journal files. With this information, baseline productivity can be measured (by averaging the time taken to complete a task), and individual designer performance can be evaluated.

Figure 5 presents the knowledge gaps and future directions identified in this study.

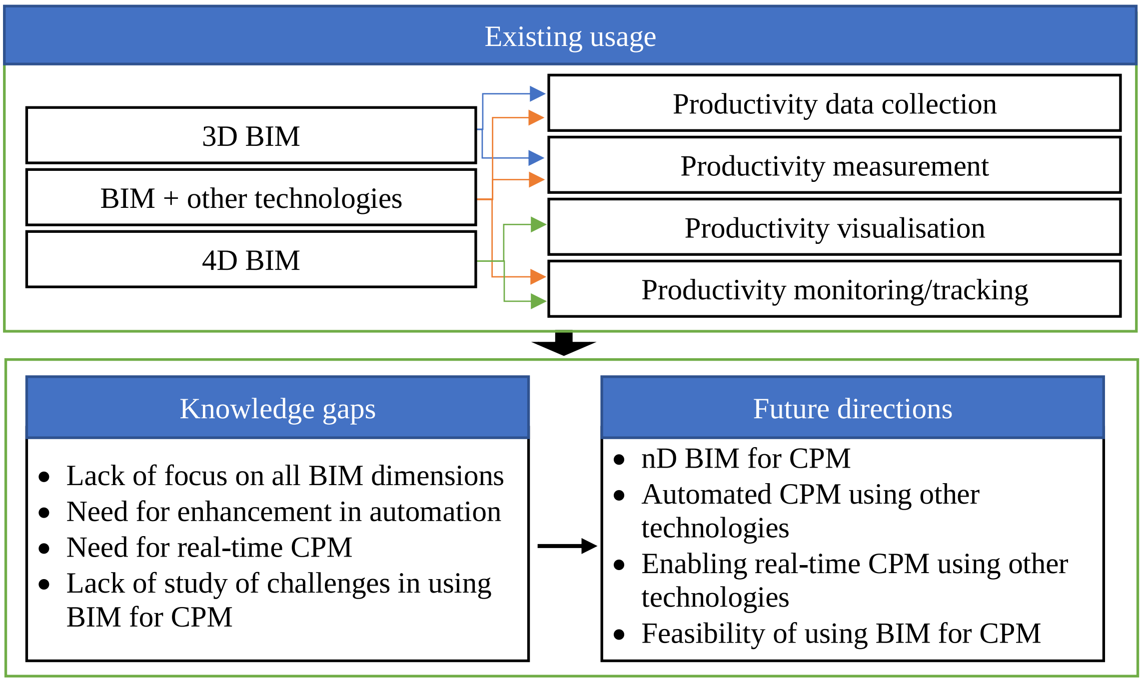

Figure 5: Framework of knowledge gaps and future research direction

4. CONCLUSIONS

Productivity is considered a critical performance indicator of the construction industry since it allows for the overall success of construction projects in terms of time, cost and quality. Therefore, having effective and efficient CPM is vital to improve productivity and to realise the progressive improvement of the construction industry. Traditional CPM was text-based and manual which has various limitations including a huge time and effort for the data collection and analysis. BIM has been identified as one of the technologies that is useful to automate the CPM, since it enables efficiency and effectiveness in the CPM process. BIM has been utilised not only for the CPM at the construction stage but also at the design stage, which is comparatively more complex than CPM. Studies on utilising BIM for CPM focus on identifying the labour data including working hours and worker locations. Furthermore, automated quantity take-off and efficient productivity tracking and monitoring were identified as benefits of utilising BIM in CPM. Therefore, as of now, BIM has been utilised for data collection, analysis, measurement and even visualisation of construction productivity.

While previous researchers have made huge and significant efforts in the use of BIM for CPM, the systematic literature review has identified various knowledge gaps as presented in Figure 5. First, while there are various BIM dimensions, studies on using BIM for CPM are merely focused on 3D and 4D BIM. Therefore, future, studies can focus on the potential and limitations of utilising nD BIM for CPM including 5D, 6D, 7D. and other dimensions of BIM. Especially, 5D BIM, which has the cost information and enables automated quantity take-off, shall be investigated in detail in the CPM context. Second, even though, BIM enables automated productivity measures, it still falls under semi-automation, due to the requirement of manual input. Therefore, there is a need to enhance automation in CPM. This can be achieved by integrating some other advanced technologies such as digital twin (DT) and the Internet of Things (IoT). Third, real-time CPM is still a challenge in the context of BM for CPM. Therefore, enabling real-time CPM shall be investigated by integrating advanced technologies such as DT and IoT. Finally, while BIM has been identified with various benefits in terms of utilising it for CPM it still has some limitations and challenges. Especially, cost overrun with BIM in terms of cost of training, cost of software, lack of financial resources, huge capital investment, and uncertain return of BIM investment are major concerns in adopting BIM. Therefore, there is a knowledge gap in terms of identifying the feasibility of using BIM for CPM. Future research can focus on investigating the above knowledge gaps in utilising BIM for CPM.

5. ACKNOWLEDGEMENTS

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CAN COLOMBO PORT CITY HIGH-RISE TOWER AND PODIUM MORPHOLOGY IMPROVE POLLUTANT DISPERSION AND URBAN VENTILATION?

Malithie Vidanapathirana[1], Narein Perera[2], Rohinton Emmanuel[3] and Shaleeni Coorey[4]

ABSTRACT

A rapid increase in high-rise building clusters within developing cities has led to mounting environmental and climatic issues. This is especially highlighted in Asian cities where extreme tropical climates are accentuated by ad-hoc developments, that in turn create unfavourable urban environments. Traffic emissions and air pollution, directly and indirectly, effect the Urban Heat Island (UHI) factor. Studies show that urban ventilation is a key mechanism to ameliorate UHI, reduce pollution stagnation, improve air quality, and reduce dependence on energy-consuming systems, thereby enhancing future sustainability.

A research gap on the effect of the morphology of high-rise towers, and tower and podium forms as clusters on air pollution dispersion was identified. A high-rise cluster in the proposed Port City in Colombo, Sri Lanka was identified, and possible building forms were designed based on guidelines given by the local authority. Simplified three-dimensional building clusters were simulated using Ansys Fluent and a RANS k-epsilon turbulence model.

Results suggest the addition of a podium has minimal impact on pollution dispersion when compared with only a tower form. Block podiums were found to concentrate pollution within the podium height, while tiered podiums pushed street pollution upwards along the face of a podium. However, more uniform dispersion was seen in tiered podiums, reducing overall pollution concentrations within the study area. Overall, as per requirement and context, it is highlighted that podium forms can be designed to create better-ventilated urban spaces with good air quality, within a high-rise high-dense environment.

Keywords: *Air Pollution Dispersion; High-rise Cluster; Tower and Podium; Urban Sustainability; Urban Ventilation.*

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1. INTRODUCTION

With a projected estimate of 68% global urban population by 2050, rapid urbanisation resulting in adverse climate conditions is an imminent threat. Artificial waste heat, type of land cover and lack of ventilation resulting in trapped hot air are the three main causes of urban warming in cities. Within an urban environment with no industrial emissions, vehicle emissions and poor ventilation is the cause of poor air quality (Kumar et al. 2015). A broad spectrum of health effects is caused by exposure to air pollution by pedestrians and indoor exposure by inhabitants (Blocken et al. 2013). Air pollution also results in faster deterioration of buildings and increased maintenance (Rabl, 1999).

Urban ventilation is the ability to dilute heat and pollutants from an area and is an effective passive cooling strategy to improve urban climate and air quality (Santamouris, 2013). Interactions between building morphology and approaching atmospheric flow directly affect pollution dispersion and ventilation potential Buccolieri et al. 2010). While natural ventilation is a commonly used design strategy, it can become counterproductive in areas with high air pollution as it introduces pollutants to indoor spaces (Wargocki et al. 2000). Poor air quality increases dependence on mechanical systems which are essential preventive measures for improving indoor air quality to maintain the health and comfort of inhabitants. Use of mechanical ventilation systems is expensive to both install and operate (Kaiser et al. 2018) and further increases anthropogenic heat emitted which further intensifies the UHI effect and dependence on mechanical ventilation systems in urban areas (Taha, 1997).

Lack of adequate urban ventilation resulted in the forming of the Air Ventilation Assessment (AVA) system in Hong Kong. This is a comprehensive approach to improve outdoor air quality by optimising and continuously assessing urban planning and building design to promote natural ventilation and reduce air pollution concentrations in outdoor urban spaces. Similarly, the Dutch Wind Nuisance Standard NEN8100 and The National New-Type Urbanisation Plan (NUP, 2014- 2020) in China, were introduced to mitigate the adverse effects of pollution and improve urban ventilation. Employing such standards at the inception of a project such as at Port City, Colombo, will help mitigate any adverse issues arising in the future.

1.1 HIGH-DENSE HIGH-RISE CLUSTERS

High-dense urban living and consolidated services are a part of the solution to reducing the adverse effects of rapid urbanisation (Fincher & Wiesel, 2012). However, high-rise buildings significantly alter wind flow patterns (Hu & Wang, 2005) and the ventilation potential of an urban area. Interactions between building morphology and approaching atmospheric flow directly affect pollution dispersion and ventilation potential (Buccolieri et al. 2010). Pollution dispersion can thus be used as a tool to correlate morphological parameters and flow patterns to improve urban ventilation.

High-rise buildings as defined by the Urban Development Authority (UDA) of Sri Lanka as any building over 12 storeys or 30m in height. Regulations pertaining to the high-rise buildings and podiums have been loosely defined allowing ample room for interpretation by architects and developers.

Podiums are elevated structures or platforms used globally as a transition between different levels of a building. These typically hold all functions which require limited vertical movement and large spatial volumes such as car parks and public recreation. This allows functions such as apartments and offices to be moved to upper floors limiting vertical circulation. While this has proved to be a successful economic model, podiums usually consist of mechanically ventilated autonomous units which have an adverse effect on surrounding climate (Kirchhoff & Low, 2010). Podiums occupy almost 80% site coverage in Sri Lanka and usually form a building complex of its own. A street flanked by towers with podiums creates a unique canyon geometry with a narrow sky view factor and walling effect, deriving unique flow patterns within the canyon.

This paper investigates how tower, podium and tower form, affect pollution dispersion within a high-dense non-uniform high-rise urban cluster, through which urban ventilation can be aided. By understanding the flow patterns surrounding an actual high-rise cluster, urban spaces with good air quality and ventilation can be identified. This would directly and indirectly reduce costs and anthropogenic heat emitted to the environment.

2. METHOD

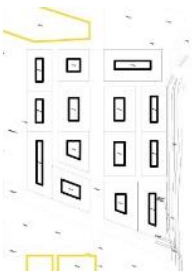
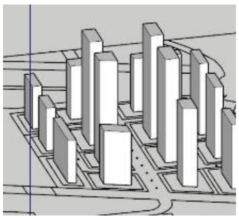
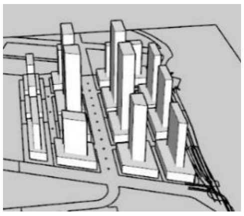
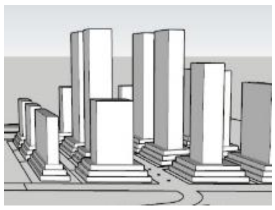
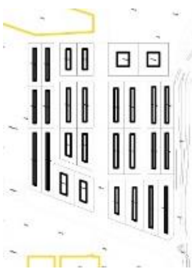
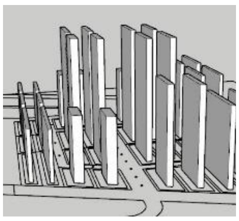
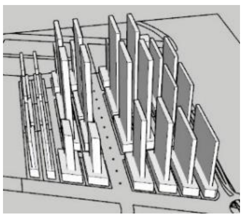
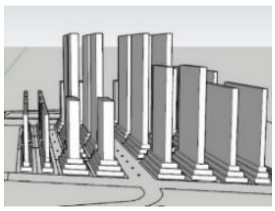
Studies of high-dense high-rise clusters are limited and largely site dependent. The complexities of linking 3D urban forms and wind flow have created a research gap which has been addressed by using computational fluid dynamics (CFD) to model and predict scenarios (Yuan et al. 2014). Local phenomena related to city breathability can be identified by simulating specific urban configurations (Badach et al. 2023). Air flows at the pedestrian level (Ma & Chen, 2020), pollution stagnation zones and airflow structures can be accurately modelled using CFD simulations. As such, for this study, CFD is used to simulate potential building configurations in Port City Colombo, Sri Lanka as shown in Figure 1.

Figure 1: Left - Masterplan of Port City (Source: Port City Authority of Sri Lanka). Right - Selected study area with building plot areas and probe locations marked.

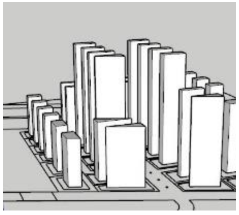
2.1 SIMULATION MATRIX

The simulation matrix was designed taking into consideration the guidelines given for Port City and the current built forms seen in Colombo (Vidanapathirana et al. 2017). Commonly used podium forms in Colombo include the block and tiered podiums with a maximum plot coverage of 80%. All developments are primarily constructed of concrete following simple geometric shapes. Thus, the basis for simulation model development and the different models based on these guidelines are illustrated in Table 1.

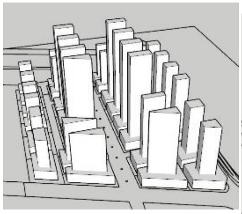
Table 1: Formulating simulation matrix

	Case 1	**Case 2**	**Case 3**
	Tower Only	Tower + Block Podium	Tower + Tiered Podium
Tower	Maximum allowed FAR and height. Same plot coverage across all towers – Average 2519.95m^2. Equal volume (Ground floor area x height) in all simulations.		
Podium	-	Max Height - 30m	5m setbacks every 10m in height to a maximum height of 30m
Podium Plot Coverage	-	80% plot coverage across all podiums – Average 10713.40m^2	
Podium Volume	-	Same podium volume	Different podium volumes due to varying setback tiers and resulting floor area
FAR	Same across models.	Same FAR across models.	Different FAR between models.
FAR	Case 1< Case 3< Case 2		
Scenario 01 	 T01	 TP01	 TTP01
Scenario 02 	 T02	 TP02	 TTP02

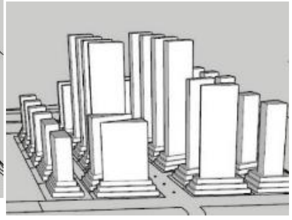
Scenario 03



T03



TP03



TTP03

Following best practices guidelines (Tominaga et al. 2008) models were generated and simulated using Ansys Fluent with RANS K- epsilon as the turbulence model. A continuous pollution source emitting 100% Carbon Monoxide (CO) as an 'inert transport mixture' was given to reduce the complexity and thereby reduce computational capacity. CO is a commonly used divisor to define air quality standards by World Health Organisation (WHO) Air Quality Guidelines and emission standards by the Motor Traffic Authority for vehicles in Sri Lanka. An average vehicle speed of 5m/s was adopted in accordance with the average vehicle speeds of Colombo.

Using data extracted from Ansys CFD-Post, a comparison study was done through a graphical and statistical analysis. Contour maps, volumetric images, streamlines and data from selected probe locations (Refer to Figure 2) were used to analyse and compare the models. Readings at street level and incremental readings along the vertical axis were obtained. CO mass fraction was used to determine air quality while wind velocity was used to quantify ventilation potential.

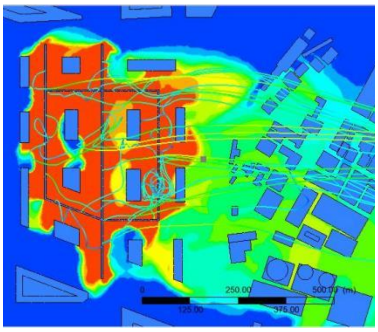
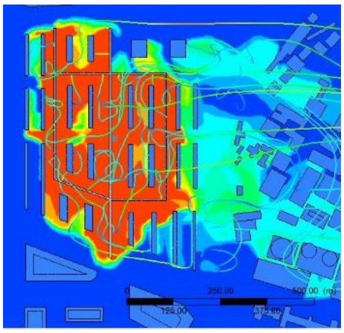
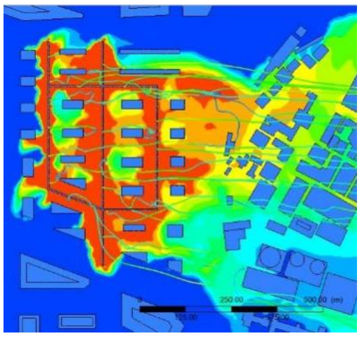
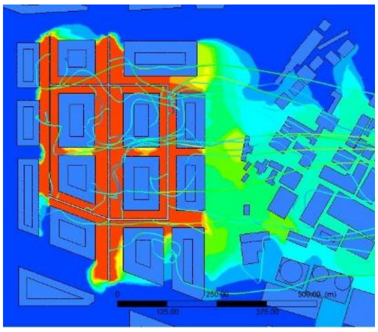
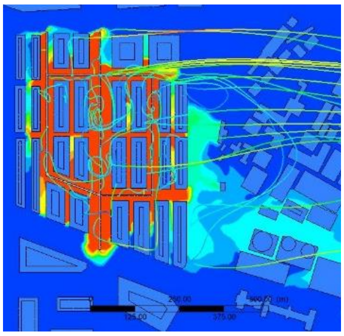
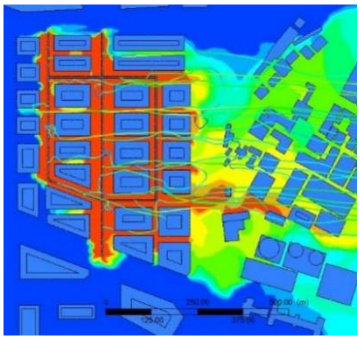
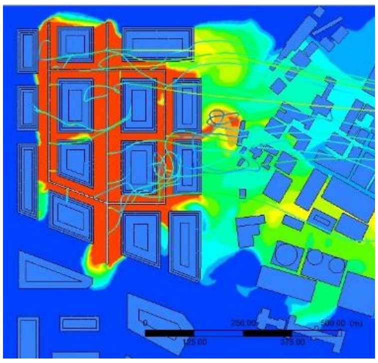
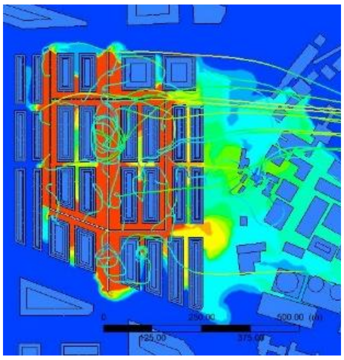
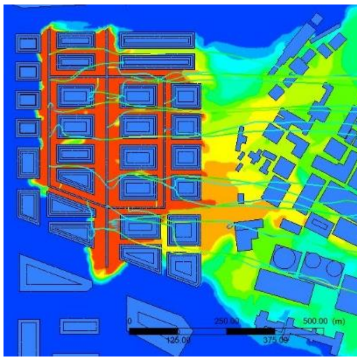
Contour maps depict how variables change over large areas and estimate values at individual points. Vector images and streamlines depict the paths taken by pollutants and its interaction with the built form. Through a graphical study of varying scenarios, the effects to pollution dispersion from the built form were identified.

3. RESULTS AND DISCUSSION

The objective of the paper is to determine the impact of the tower and podium form of a high-rise non-uniform cluster on pollution dispersion. The dispersion patterns of models were thus analysed along the horizontal and vertical axis.

As seen in models T01, T02 and T03 (Refer to Table 2), the building layouts were seen to have an impact on dispersion patterns at ground level. The pedestrian access paths created along the wind direction in Scenario 03 promote ambient wind flow within the study area, thereby pushing the pollution towards existing Colombo, leaving pockets of low CO concentration zones within the high-rise cluster. The opposite is seen in Scenario 02 where the ambient wind is blocked by the building orientation facing the ambient wind direction. Pollution is not pushed outwards, rather it stagnated within the high-rise cluster.

Table 2: Contour map of CO mass fraction at street level of 1.5m and top view of CO mass fraction streamlines (Vidanapathirana et al. 2023)

	Scenario 01	Scenario 02	Scenario 03
Case 1	 **T01**	 **T02**	 **T03**
Case 2	 **TP01**	 **TP02**	 **TP03**
Case 3	 **TTP01**	 **TTP02**	 **TTP03**

The addition of a podium was seen to impede the flow patterns of Case 1 by limiting ambient wind movement and increasing pollution stagnation.

The addition of a block or tiered podium significantly increased the usable plot area at ground level and overall floor areas of each block (Refer to Table 1). While the spacing between buildings was also reduced limiting wind paths, the resulting average CO mass fraction and velocity readings at street level show minimal deviation between Case 1 and Case 2 and a slight increase in Case 3 (Refer to Table 2). The advantages of including a podium thus outweigh its negative effects when considering pollution dispersion.

Table 3: Correlation between CO mass fraction and velocity at 1.5m for each case

	CO mass fraction	Velocity (m/s)	Correlation Coefficient
Case 1 - Tower Only			
T01	0.74	1.85	
T02	0.62	1.73	-0.6901
T03	0.85	1.40	
Case 2 - Tower & Block Podium			
TP01	0.74	1.76	
TP02	0.75	1.84	0.9965
TP03	0.83	2.17	
Case 3 - Tower & Tiered Podium			
TTP01	0.82	1.94	
TTP02	0.80	2.19	-0.8883
TTP03	0.92	1.77	

Cases 1 and 3 show strong negative correlation between CO mass fraction and velocity, where, increased wind speeds result in lower pollution concentrations (Refer to Table 3). This can be attributed to the ambient wind flow pushing pollution out of the street canyons. Tiered podiums show the highest CO concentrations of the three cases. However, if ambient wind flow is encouraged, the built form encourages the dispersion of pollution.

Block podiums record a significant positive correlation (Refer to Table 3) showing the complete opposite behaviour to Cases 1 and 3. Analysis of streamlines of Case 2 shows wind being channelled along the canyon due to its geometry with minimal ambient wind flow. Therefore, higher wind speeds recirculating the pollution within a canyon result in higher pollution concentrations.

3.1 DISPERSION PATTERNS AT STREET LEVEL

When considering the flow patterns formed around podium forms in detail;

In Case 1, two distinct vortices are formed at the foot of each tower on the windward and leeward sides (Refer to Figure 2). Aided by the down-wash along the windward face of the tower and the velocity generated by the pollution inlet, higher CO concentrations are seen on the windward face while the vertical dispersion of pollutants on the leeward face reaches a greater height. This is clearly seen in model T01.

Compared to the tower-only scenario of Case 1, the block podium concentrated street pollution within the podium height (30m). As shown in Figure 2 the podium reduces the width of the street canyon, concentrating the pollution within the street. This pollution plume is pushed towards the foot of each podium on either side of the canyon. Lack of ambient wind along the leeward side of the podium further increases pollution concentration at street level. Within a high-dense narrow canyon as created by Case 2, the dominant velocity source is the pollution inlet and not ambient wind. This further increased pollution stagnation implies that the direction of vehicular movement (pollution source) would strongly affect pollution dispersion patterns as the pollution plume is seen pushed in the opposing direction of ambient wind flow.

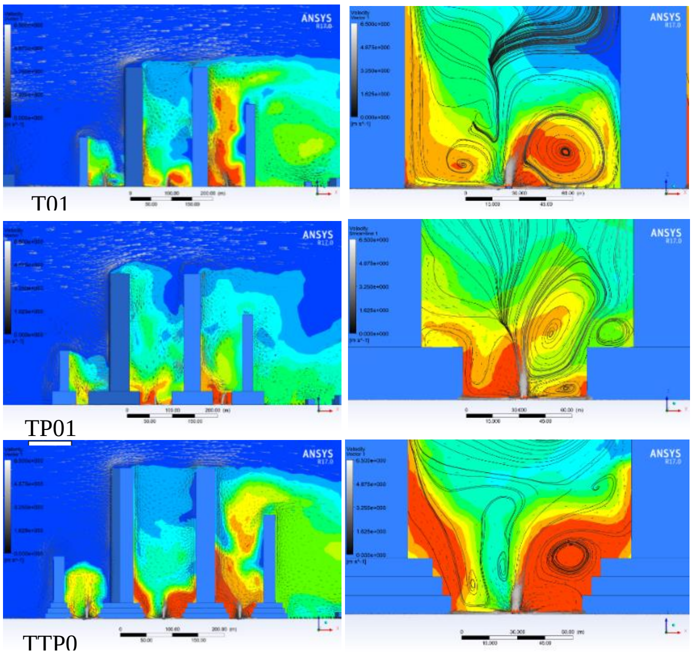


Figure 2: Variation of wind movement and CO mass fraction contour map at street level for models T01, TP01 and TTP01. Variations to flow formation due to podium form can be seen. Right column – Surface streamlines of velocity at same location (Vidanapathirana et al. 2023)

Three distinct vortices are formed in Case 2. The main vortex caused by the pollution inlet takes an elongated shape. The down-wash along the face of the tower reduced pollution concentration at the top of the block podium (Refer to Figure 3) and a second vortex is formed. A third vortex is formed at the base of the podium which causes re-circulation of the pollution at street level and records high pollution concentrations.

The straight edge of the block podium plays a key role in creating these distinct vortices. This is dispersed in the tiered podium form of Case 3. The step formation of the podium appears to divert the plume upwards on both sides of the street with a single vortex formed similar to Case 1. The re-circulation zone formed at the foot of the tiered podium was seen to push the pollution upwards along the face of the podium and tower. This resulted in lower wind velocity and pollutant concentrations at street level (Refer to Figure 2).

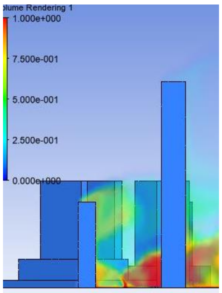
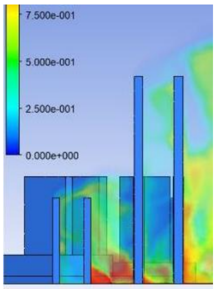
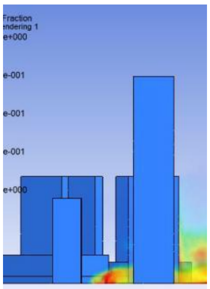
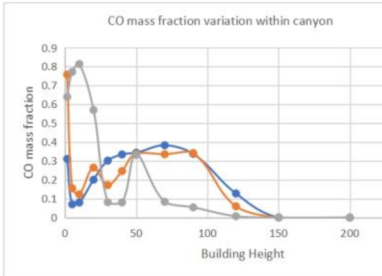
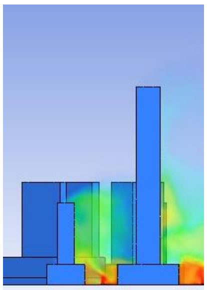
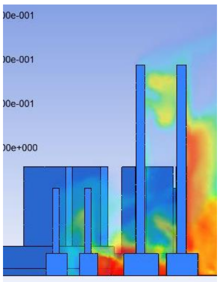
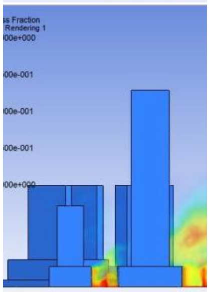
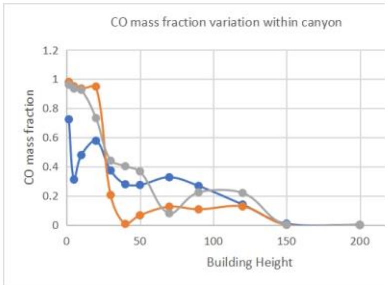
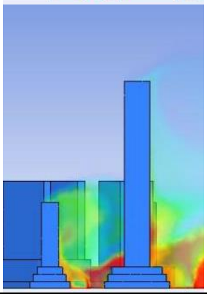
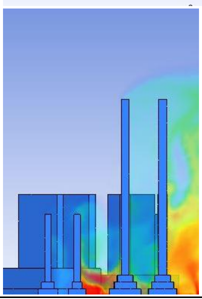
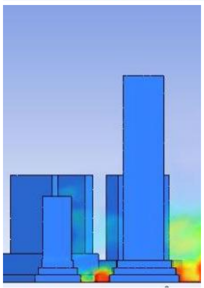
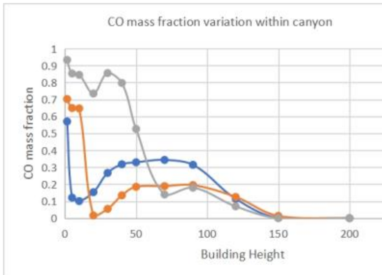
However, the effects of the down-wash along the windward face are reduced due to the tiers, thereby causing more stagnation of pollution along the face of the podium. Similar to the block podium, there is stagnation of pollution along the leeward face of the building.

3.2 VERTICAL POLLUTION DISPERSION

At higher levels such as at 50m and 100m heights, the effects of the podium on pollution dispersion were reduced, but not negligent. Pollution blocked at street level were pushed upwards and dispersed at upper levels. Higher levels of turbulent flows were also seen in block podium models compared to tiered podiums.

Across all models, Case 1 and Case 3 have lower CO concentrations at street level, compared to Case 2. Pollution concentrations remain higher in Case 2 until podium height, after which the rate of dispersion increases compared to other scenarios. Cases 1 and 3 follow similar patterns. While tiered podiums push street pollution upwards along the canyon, pollution concentrations remain lower than Case 1 without a podium.

Table 4: Volumetric sectional image of CO mass fraction dispersion at Probe A

	T01	T02	T03	CO mass fraction
Case 1				
Case 2				
Case 3				

Due to the proximity of buildings within the cluster, a skimming ambient flow is seen over the study area beyond the urban canopy layer (Table 5). Vertical readings at probes confirm that all pollution is dispersed when it reaches the skimming flow. However, within the urban canyon, variations were seen due to different canyon geometries. Between podium height and urban canopy, Case 1 shows higher concentrations than Case 3 followed by Case 2. Further, as a majority, pollution plume of Case 1 models were completely dispersed at a lower height than in other models.

3.3 DESIGN CONSIDERATIONS

As shown by contour maps (Refer to Table 2), flow patterns varied with each building form. However, when comparing between high-rise buildings with towers only and towers with podiums; there is minimal deviation in street level and vertical pollution concentrations. For a developer, the addition of a podium around a tower increases the saleable area of a building significantly. Therefore, the positive impacts of having higher usable space of a podium seem to outweigh its negative impact on pollution dispersion.

Flow patterns were seen to be further altered based on the location of the building, ambient wind direction and canyon geometry. Therefore, close attention must be paid to the functions and location of the building when determining podium form.

Pollution was seen to stagnate within the height in the case of the block podium while pollution was pushed upwards along the face in the case of a tiered podium (Refer to Figure 2). The top of block podiums (at 30m) showed low CO concentrations due to the down-wash along the face of the tower creating a ventilated space. As the streets showed high pollution concentrations, rooftops of block podiums can be used as naturally ventilated public spaces creating elevated walkways to connect the city. This can be further enhanced by including vegetated spaces to create a green link connecting pedestrian spaces.

Tiered podiums were seen to disperse pollution better by reducing overall concentrations of pollutants emitted at street level as the plumes are extended upwards along the face of the podium (Refer to Table 4). Wind speeds were also reduced compared to the block podium. This would suggest that naturally ventilated spaces along the face of the tiered podium may not enjoy good air quality or wind movement and would require mechanical ventilation.

The urban area focused for study was further divided by adding pedestrian walkways dividing urban blocks along the north-south and east-west directions as Scenarios 02 and 03 respectively. Analysis of dispersion patterns show Scenario 02 showed lower concentrations at street level by pushing pollution upwards along the canyon while Scenario 03 has better ambient wind movement which pushed pollution outwards at street level. This results in Scenario 03 recording higher street pollution concentrations, but at very low levels vertically along the canyon.

While the addition of podiums increased overall pollution concentrations at street level, analysis of pedestrian walkways show that they are sheltered from pollution generated within vehicular streets by the podiums. Tiered podiums showed more dispersed pollution concentrations ranging from low to moderate. In comparison to block podiums a higher number of pockets of low pollution concentrations were seen in case 03. Therefore, in an urban environment, tiered podiums were seen to disperse pollution evenly and may be used to enhance the air quality of pedestrian-friendly walkways compared to block podiums.

4. CONCLUSIONS

4.1 SUMMARY OF FINDINGS

The study identified how the addition of a podium and changes to its basic form would impact pollution dispersion generated along a continuous street network within a high-dense high-rise urban cluster. While a standard rule-of-thumb approach to pollution dispersion is not accurately applicable in an actual building cluster, a general pattern can be identified.

Tiered podiums were seen to disperse pollution evenly across large areas compared to block podiums. Block podiums on the contrary limit ambient wind flow and encourage re-circulation of pollution within the street canyons. However, this enabled pedestrian walkways located between buildings to be sheltered from vehicle emissions.

Podiums are commonly used for public functions. By manipulating the podium and tower form to encourage ventilation, spaces with comfortable air quality can be created, thus limiting dependence on mechanical ventilation systems. Similarly, street networks and pedestrian walkways can be arranged at street level or at elevated heights to encourage urban ventilation. Thus, ameliorating UHI intensity and its impact on outdoor thermal comfort and energy use.

4.2 SCOPE AND LIMITATIONS

In order to limit computational cost and time, a simplification of the urban morphology and building typologies to basic forms and materials was necessary. Further analysis using more complex canyon geometries with material properties to reflect actual built forms need to be done. The above study can also be extended by adding buoyancy-driven pollution dispersion (Mei & Yuan, 2022) due to surface temperatures to determine the impact on atmospheric heat islands.

Field testing was not possible as Colombo does not have similar high-dense clusters. Port City is also a unique location at the inception of its development. Further, limitations of using Ansys-Fluent as software to simulate pollution dispersion and wind movement, limited domain size and use of a homogeneous emission source affected the accuracy of the study.

4.3 CONTRIBUTION

The findings of the above study can be used to further refine urban design regulations and passive design strategies to promote pollution dispersion and wind movement. Building forms of Port City will have an impact on the overall climate of Colombo and by employing design strategies, long term impacts of the built environment on the health and comfort of the public can be maintained.

5. ACKNOWLEDGMENTS

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CARGOTECTURE TO MINIMISE PROBLEMS IN POST-DISASTER RECONSTRUCTION PROJECTS IN SRI LANKA

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ABSTRACT

Cargotecture is a sustainable housing solution that has gained popularity in recent years. However, its potential for Post Disaster Reconstruction (PDR) projects has not been fully explored locally and globally. This research aims to develop a framework to overcome the problems in the PDR projects through the implementation of cargotecture in Sri Lanka. A comprehensive literature review synthesises existing research on integrating cargotecture for PDR projects. The research adopted a mixed-method approach. A questionnaire survey was conducted with forty-five construction professionals selected through snowball sampling and data was analysed using RII analysis to identify the critical problems in PDR projects. Then, semi-structured interviews were conducted with ten experts selected through selective sampling. Code-based content analysis was used to identify problems in PDR projects and the benefits of integrating cargotecture for PDR projects. The study revealed 18 problems in PDR Projects, while high time consumption was identified as a significant problem in PDR Projects. Further, the study identified 17 benefits of integrating cargotecture for PDR projects, including reducing construction duration and modularity. The study developed a framework which offers industry practitioners significant insight into the possible use of ISO shipping containers as a sustainable and cost-effective disaster relief housing option. From an academic point of view, the study adds to the current literature on disaster relief housing by investigating the viability of employing ISO shipping containers. The study serves as the foundation for more detailed research on the social and environmental implications of employing shipping containers for disaster relief housing.

Keywords: *Benefits; Cargotecture; ISO Shipping Container; Post-Disaster Reconstruction; Sustainable Housing.*

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1. INTRODUCTION

"Disasters can be defined as an action that causes a threat to life, wellbeing, material goods, and the environment from the extremes of natural processes or technology" (Gunes & Kovel, 2000, p.136). Barenstein et al. (2005) stated that while scientific research on global sensitivity to hazards, risk reduction, and catastrophe resilience is increasing, disasters continue to have serious repercussions, such as fatalities, massive economic losses, and societal upheaval. Disasters have a negative impact on the built environment, resulting in homelessness, widespread population relocation, and higher mortality. Hidayat and Egbu (2010) suggested that Post Disaster Reconstruction (PDR) is restoring the livelihoods of impacted communities by constructing new housing and infrastructure. Disasters have a 20-fold greater impact on the built environment in developing countries than in developed countries (Barakat, 2003), owing to widespread substandard construction, leaving many people in need of housing in countries that are already struggling with their daily economies and housing challenges (Uddin & Matin, 2021).

Hidayat and Egbu (2010) stated that emergency aid, which includes providing food, medical care, and shelter immediately after a disaster, is deemed beneficial, while the reconstruction is often a long-term recovery operation which is slow, expensive, and difficult. Jones (2006) emphasised that PDR may have a permanent influence on a country's development objectives and may be a turning point in the lives of the impacted populations. In Sri Lanka, an investigation by the United Nations Office for Disaster Risk Reduction in 2019 found that 80% of people residing in locations considered to have a high risk of landslides are reluctant to switch from their existing residences (Siriwardhana et al., 2021). Therefore, it is important to be prepared for both disaster situations and PDR. Even though PDR is crucial, earlier studies found several problems. The primary objective of a PDR project is to increase beneficiary satisfaction, yet most projects fall short of this objective as most structures are constructed temporarily rather than permanently (Islam et al., 2018). In contrast to most ordinary construction projects, post-disaster housing projects are more diverse, including social, cultural, and economic requirements, and are also quite dynamic (Alaloul et al., 2019). Le Masurier et al. (2006) stated that because the disasters were on a relatively small scale, there was not much of a difference between the typical building process and the reconstruction procedure overall. In addition, Rotimi et al. (2006) highlighted that it would be difficult to obtain regular resource levels and that there will unavoidably be a lack of skilled individuals to perform impact assessments and consent processes. When natural resources are rare locally, it might be difficult for poorer countries to access resources for post-disaster rehabilitation. Reconstruction efforts following disasters in nations like Indonesia and Sri Lanka are dependent on assistance from outside, including funding from the World Bank and International Non-Governmental Organisations (INGOs) for the importation of labour and supplies (Jayasuriya & McCawley, 2008). Moreover, it is still challenging to create effective communication between resettlement agencies and affected populations (Siriwardhana et al., 2021).

One of the possible alternatives to tackle the problem of slowdown construction of PDR projects is the "shipping container architecture" technique, which uses ISO shipping containers as a building material (Paparella, & Caini, 2022; Radwan, 2015). The reuse of steel shipping containers as a structural element and an architectural envelope that can support a specific purpose or human activity is known as "Cargotecture," which combines the words 'cargo' and 'architecture' (Radwan, 2015). Subsequently, the term "cargotecture" refers to the utilisation of shipping containers in building construction (Al-Khatib et al., 2021). Further, ISO-certified shipping containers are built with identical dimensions to be readily loaded, unloaded, transported, and stacked worldwide (Sun et al.,2017). The ISO shipping container box was created to move trade products from one location to another. These shipping containers are all the same size, allowing easy loading, unloading, transportation, and stacking anywhere around the globe (Wong et al., 2018). Moreover, containerisation is a particularly developed technique for transporting commercial items globally, which is cost-effective (Ling et al., 2020). Furthermore, the use of cargotecture has grown significantly in recent years due to its robust plating, low cost, and ubiquitous availability (Sun et al., 2017). In addition, Shen (2019) stated that cargotecture has various advantages, including lower building costs, faster construction time, and environmental sustainability. There are many types of research have been carried out related to PDR projects in Sri Lanka (Palliyaguru et al., 2008; Gunawardena et al.,2014; Siriwardhana et al.,2021). However, there is a lack of research aiming at the applicability of cargotecture for PDR Projects in Sri Lanka. Therefore, this study aims to provide a significant endeavour in integrating cargotecture for future PDR projects in Sri Lanka. Accordingly, the research aims to develop a framework to overcome the problems in PDR through the benefits of cargotecture in PDR projects in Sri Lanka.

2. LITERATURE REVIEW

2.1 PROBLEMS IN PDR PROJECTS

Following a disaster, reconstruction must address the affected people's contradicting requirements, as well as the need for organisations to develop programmes that address both the immediate need for shelter and the long-term need for permanent housing (Bahmani & Zhang, 2021). Ismail et al. (2014) identified each of the rebuilding activities, which comprise planning, design, purchasing, construction, examination, and completion. Post-disaster restoration operations have particular challenges that extend beyond standard construction issues, and they are prone to creating unsatisfactory building solutions (Siriwardhana et al., 2021). According to Ismail et al. (2014), post-disaster reconstruction projects frequently deal with uncertainty and complexity, with individuals working in disaster-affected region rehabilitation facing the most difficult duties. Safapour et al. (2021) placed the challenges into four categories: general, physical, social, and economic. Table 1 identifies the problems in PDR projects.

Table 1: Problems in PDR projects

No	Problem	References
1	Supply chain dysfunction	[1], [2], [3], [11]
2	Resources shortage	[2], [3], [4]
3	Coordination and communication issues	[2], [3], [4], [5], [6], [10], [11]
4	Infrastructure breakdown	[2]
5	Corruption	[2], [11]
6	Lack of technical and managerial expertise	[5], [10], [11]
7	Lack of guidance	[5], [8], [10]
8	Poor quality of work	[2], [3], [11], [12]
9	Health and safety issues	[3], [12]
10	Political factors	[5], [10], [11]
11	Public policies	[5], [7], [10]

No	Problem	References
12	Financial management	[3], [5], [9], [10], [11], [12]
13	Beneficiary identification and participation	[5], [11]
14	Information and knowledge dissemination	[5], [10]

Source: [1] Celentano et al. (2019), [2] Celentano et al. (2018), [3] Bilau et al. (2017), [4] Alsaadi and Acar (2019), [5] Hidayat (2014), [6] Baarimah et al (2021), [7] Kounnavong et al. (2017), [8] Grimes et al. (2011), [9] Schwartz et al. (2020), [10] Seneviratne (2011), [11] Alaloul et al. (2019), [12] Vahanvati and Mulligan (2017)

According to Table 1, the most identified problems by the authors are coordination and communication issues, financial management, and supply chain dysfunction. Those problems are negatively affecting the speed of the reconstruction process. As a strategy to increase the speed of the reconstruction process, cargotecture technology can be adopted. When it comes to large-scale post-disaster restoration projects, effective delivery has become a major concern (Safapour et al., 2021). According to Alsaadi and Acar (2019), one of the major challenges affecting the success of PDR project performance is the failure to properly manage community cultural continuity while providing development opportunities in PDR projects, resulting in culturally incompatible solutions that are unsustainable in the long run. Celentano et al. (2019) have identified supply chain planning challenges and resource shortages as major bottlenecks in reconstruction projects. Bilau et al. (2017) indicate challenges associated with logistics and supplies as one of the major management issues that arise in large-scale housing reconstruction programmes. Although these circumstances are well known, the strategies required to overcome these difficulties appear to be less clear (Bahmani & Zhang, 2021). The reuse of ISO shipping containers in the construction industry can be innovative and promote a sustainable environment. The provision of ISO container information in an intuitive manner can be convenient for engineers for their design purpose. Such informative data will help to promote container building and thus bring new life to the abandoned shipping container. According to Ling et al. (2020), an ISO shipping container, a standardised steel box used for universal cargo transportation is one of the potential candidates to solve the housing problem. Schwartz (2020) stated that the shipping container is designed to withstand harsh weathering and heavy loading over long-distance transportation, which makes it very durable and suitable for housing purposes. Therefore, it is needed to consider whether the ISO shipping container can be used to overcome the above-mentioned problems in PDR projects.

2.2 BENEFITS OF CARGOTECTURE FOR PDR PROJECTS

Cargotecture provides an affordable way of manufacturing a building module to be repeated, which can reduce the construction cost and time drastically (Amate & Brotas, 2014). Answering the critical issues in the reconstruction process and benefits offered by Cargotecture as a modular housing project can be discussed as follows. Table 2 identifies the benefits of cargotecture for PDR projects.

Table 2: Benefits of Cargotecture for PDR projects

No	Benefits	References
1	Reduce the construction duration	[5], [6], [7], [8], [11], [12], [13], [14], [15]
2	Resource availability and integration	[5], [9], [14]
3	Ability to endure corrosion	[1], [3], [4], [12]
4	High Durability	[1], [3], [4], [12], [14], [15]
5	Economical	[7], [12], [14], [15]
6	Seismic stability	[2], [7], [8]

No	Benefits	References
7	Availability and skills of the workforce	[5], [8], [11]
8	Minimise the involvement of expertise in planning	[5], [7], [8], [11]
9	Overall quality and end-user satisfaction	[5], [7], [11]
10	Promote Sustainability	[1], [4], [10], [11], [12], [13], [14]
11	Reduced site labour requirement	[4], [7], [8], [9]
12	Environmentally less sensitive	[7] [12],
13	Modularity	[2], [11], [12], [13], [14], [15]
14	Transportability	[2], [7], [11], [14], [15]
15	Demountable after use	[2], [10], [11], [13], [14]
16	Low weight	[7], [14]

Source: [1] Ling et al. (2020), [2] Gamón, (2020), [3] Shen et al. (2019), [4] Elrayies (2017), [5] Tas et al. (2010), [6] Weerakoon et al. (2019), [7] Wong et al. (2018), [8] Lawson et al. (2012), [9] Gunawardena et al. (2014b), [10] Gunawardena et al. (2014a), [11] Zafra et al. (2021), [12] Al-Khatib et al. (2021), [13] Sun et al. (2017), [14] Amate and Brotas (2014), [15] Paparella and Caini (2022)

The most identified benefit of the cargotecture for PDR projects is the reduction of the construction duration. According to Wong et al. (2018), in container architecture, the majority of the work is completed off-site (up to 90%, including interior construction), saving time and labour. Further to the authors, the build time of modular construction is typically 50-60% less than traditional onsite construction, and the weight is about 30% of the weight of conventional masonry construction. Steinbach (2022) stated that ports around the world are dealing with a high amount of congestion due to empty shipping containers. Further to the author, the containers have the potential to be repurposed into various types of buildings, such as homes, offices, studios, apartments, schools, dormitories, and emergency shelters. Tas et al. (2010) have identified that 'time' has a much higher rank than the other elements that influence the design of post-disaster permanent housing. Gunawardena et al. (2014) emphasised that the incensement of building supplies prices over time and changes in labour costs over time make the rehabilitation process more expensive than it should have been. According to Zafra et al. (2021), one of the primary characteristics that make modular building a widely wanted new technology is its time efficiency. According to Lawson et al. (2012), many houses can be manufactured at the same time using mass manufacturing facilities, and they can also be put onsite at the same time, reducing construction time. Because of the saved time, the impacted communities would be able to resume their livelihoods considerably sooner.

According to Gunawardena et al. (2014), since a large portion of the modular structure's building process is pre-planned and carried out in a factory environment, even in a post-disaster rebuilding situation, the process of constructing a module from its raw components should not require any major alterations. Further to the authors, because the interiors, façades, roofs, and so on are all pre-built into the modules, the planning required becomes considerably easier. Since the skill required to build a modular housing unit is largely required within the production plant, the site labour requirement can be reduced (Al-Khatib et al., 2021). Further to the authors, when the modules are on site, they will only take a minimal amount of labour to install. Since many home rebuilding procedures are volunteered by local communities, and the knowledge required in the onsite construction of modular houses is little where they can give a better and more efficient service. Since the main resource of cargotecture modules is used shipping containers, the availability of resources is high (Amate & Brotas, 2014). Container buildings have the potential to significantly lessen the burden of resource discovery. According to Paparella and Caini (2022), the benefits of Cargotecture primarily include a decrease in cargo damage and more effective logistical operations, which lead to faster boarding and disembarkation, a rise in worked volumes, and a sharp decrease in handling costs. Additionally, further author stated that since it can be transported in its entirety as a container, can reduce the assembly and disassembly periods. According to Chang et al. (2011), many logistics-related variables may be eliminated by having practically all of the activities conducted under one manufacturing facility. Modular constructions are more ecologically friendly than traditional steel or concrete structures (Zafra et al., 2021). Authors further state that modular construction generates far less trash, giving it an advantage in having a lower environmental effect, which may result in time and cost savings over reduced waste charges. Amate and Brotas (2014) discovered that reusing shipping containers could save more than 80% of the embodied energy in an original steel modular system. It is critical to recognise the benefit given by modular modules, which may be readily dismantled and relocated as needed.

3. RESEARCH METHODOLOGY

A comprehensive literature review was conducted to gather information on problems in PDR projects and the benefits of cargotecture in PDR projects in the construction industry. The mixed method approach is used to achieve the aim of the study. Documentation, interviews, surveys, focus group discussions, observation, participatory arrangements, and qualitative audio-visual material are all methods for acquiring data in qualitative research (Dewi, 2021). Accordingly, the data was collected through two phases. Phase one included the questionnaire survey carried out to collect the data to identify the problems of PDR projects. Accordingly, forty-five construction industry professionals who have knowledge of the PDR project have participated through the snowball sampling method, generally, authors used a sample size of 30 for all validation scenarios (Aithal, & Aithal, 2020). The questions were provided as an online platform. This research adopted RII to analyse the quantitative data collected from the questionnaire survey, using Microsoft Excel. Phase two included the semi-structured expert interview conducted to identify the problems of PDR projects, investigate the benefits of cargotecture in PDR projects and to develop the framework to overcome the problems in PDR through the benefits of cargotecture in PDR projects in Sri Lanka. Ten semi-structured interviews with experts who have experience and knowledge on PDR projects, selected through a selective sampling method were conducted due to data saturation. Code-based content analysis was used to analyse the data collected from expert interviews using NVivo12.

4. RESEARCH FINDINGS

4.1 PROBLEMS IN PDR PROJECTS

The problems identified through the literature survey were sent to the respondents to identify the most critical problems. The validated data gathered by the questionnaire survey was analysed using the “RII approach.” Table 3 summarises the rankings of the problems in PDR projects.

Table 3: Ranking of the problems in PDR projects

No.	Problem	RII	Rank
1	Financial management	0.847	1
2	High time consumption	0.807	2
3	Political factors	0.787	3
4	Coordination and communication issues	0.780	4
5	Supply chain dysfunction	0.760	5
6	Resources shortage	0.740	6
7	Poor quality of work	0.740	6
8	Infrastructure breakdown	0.720	7
9	Corruption	0.720	7
10	Public policies	0.713	8
11	Health and safety issues	0.700	9
12	Beneficiary identification and participation	0.687	10
13	Information and knowledge dissemination	0.673	11
14	Lack of technical and managerial expertise	0.667	12

The results of the questionnaire survey have shown that RII values of the problems of the PDR projects fell between 0.847 and 0.667. Table 3 shows a collection of PDR problems ranked by the RII value based on their perceived severity. With an RII score of 0.847, “financial management” is regarded as the essential concern, followed by excessive time consumption with a value of 0.807. Further, “High time consumption” has been chosen as the second most critical problem in PDR projects and “Political factors” were identified as the third. “Coordination and communication issues” has been identified as the fourth significant problem in PDR projects by the respondents. Political considerations, coordination and communication challenges, and supply chain dysfunction are also prominent, illustrating the complex interplay of social, economic, and political variables in post-disaster reconstruction operations. Additional obstacles include a lack of resources, poor job quality, infrastructure collapse, corruption, and public policy. Health and safety difficulties, beneficiary identification and engagement, information and knowledge transmission, and a lack of technical and administrative competence are all key obstacles that must be addressed in the aftermath of a tragedy. Finally, Figure 1 illustrated the research outcome of problems in PDR projects.

Figure 1: Problems in PDR projects

Through the questionnaire survey, the main problems of the PDR projects were identified. Experts also raised a few problems in PDR projects. The most critical problems identified by experts are discussed in Table 4. Table 4 summarises the main problems in PDR projects. After Validating the identified problems of the PDR projects through the questionnaire survey, those validated problems were further confirmed by the experts during the interviews.

Table 4: Main Problems in PDR Projects

No	Problem	Literature	E 1	E 2	E 3	E 4	E 5	E 6	E 7	E 8	E 9	E 10
1	High time consumption	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
2	Financial Management (Allocation of funds for the project)	✓	✓	✓	✓	✓	✓	✓		✓		
3	Supply chain dysfunction	✓		✓	✓	✓	✓	✓			✓	✓
4	Resources shortage	✓			✓	✓	✓		✓	✓	✓	✓
5	Coordination and communication issues	✓	✓	✓	✓	✓	✓	✓	✓			✓
6	Infrastructure breakdown	✓		✓	✓	✓	✓		✓	✓	✓	✓
7	Corruption	✓	✓		✓	✓			✓	✓	✓	
8	Lack of technical and managerial expertise	✓	✓		✓	✓	✓	✓	✓	✓		✓
9	Lack of guidance		✓		✓	✓	✓			✓		✓
10	Poor quality of work	✓	✓	✓	✓	✓	✓	✓			✓	
11	Health and safety issues	✓	✓	✓	✓	✓	✓			✓	✓	✓
12	Political factors	✓	✓			✓			✓	✓		✓
13	Public policies	✓	✓			✓			✓	✓	✓	✓
14	Beneficiary identification and participation	✓			✓		✓	✓	✓	✓	✓	
15	Information and knowledge dissemination	✓	✓			✓	✓		✓	✓	✓	✓
16	Acquiring a secure land to resettle				✓		✓					
17	Identifying the needs of the victims					✓	✓					
18	Supplying a large number of materials		✓		✓		✓					

All ten experts agreed that high time consumption is a main problem in PDR projects. E2, E4, E6, E7, E9 and E10 stated that the main problem of PDR projects is high time consumption. But E1, E3, E5 and E8 stated that the main problem is allocating funds. E1 stated that *"Most times, the government has to allocate funds for projects. In most cases, the reason for slow construction is the financial issues"*. Acquiring secure land for resettlement was identified as a problem in the PDR project by E3 and E5. E3 stated that the victims need to be re-settled in a land that is located as close as possible to the previous accommodations. E3 further stated that "*There is a principle that the most affecting category of a disaster is low-income population. The reason for it is they are living in the most hazardous places. In most times, their livelihood is related to their living area."* According to E3, supplying a large number of building materials at once for a large-scale reconstruction project is a challenge. E3 further stated that the material prices could be increased due to the sudden demand. According to E4, identifying the needs of the victims of the reconstruction project is also a problem. E5 stated that coordination and communication issues between the authorities are critical. However, E3 stated that *"After* *appointing the Disaster Management Centre (DMC), we were able to resolve those communication issues”.*

4.2 BENEFITS OF INTEGRATING CARGOTECTURE FOR PDR PROJECTS

The benefits of integrating cargotecture for PDR projects were identified through a literature survey and expert interviews. Table 5 summarises the benefits of integrating cargotecture for PDR projects.

Table 5: Benefits of Integrating Cargotecture for PDR Projects

No	Benefit	Literature	E 1	E 2	E 3	E 4	E 5	E 6	E 7	E 8	E 9	E 10
1	Reduce the construction duration	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2	Resource availability and integration	✓										
3	Ability to endure corrosion	✓	✓	✓						✓		
4	High Durability	✓	✓				✓					✓
5	Economical (Less initial cost)	✓	✓			✓		✓	✓	✓		✓
6	Seismic stability	✓						✓			✓	
7	Availability and skills of the workforce	✓										
8	Minimise the involvement of expertise in planning	✓										
9	Overall quality and end-user satisfaction	✓										
10	Promote Sustainability	✓	✓				✓	✓				✓
11	Reduced site labour requirement	✓	✓	✓	✓		✓			✓		
12	Environmentally less sensitive	✓										
13	Modularity	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
14	Transportability	✓	✓	✓	✓		✓	✓	✓	✓		✓
15	Demountability after usage	✓			✓				✓		✓	✓
16	Low weight	✓										
17	Reduce the land consumption		✓					✓		✓		

All the experts agreed that integrating Cargotecture for PDR projects will reduce the construction duration and modularity. Expert 6 stated that “*Obviously, it will take less time compared to conventional buildings, and the cost will also be reduced. Before that, needs to be investigated the geotechnical conditions and have to make proper arrangements.”* Further, most of the experts agreed that integrating Cargotecture for PDR projects helps to reduce initial cost and site labour requirements and provide transportability. However, all the experts argued that resource availability and integration, availability and skills of the workforce, minimise the involvement of expertise in planning, overall quality and end-user satisfaction, environmentally less sensitivity and low weight are not applicable benefits of Integrating Cargotecture for PDR Projects in the Sri Lankan construction industry.

5. DISCUSSION

The research aims to develop the framework to overcome the problems in PDR through the benefits of cargotecture in PDR projects in Sri Lanka. As a result, experts were assigned with matching the path to solving problems in PDR through the benefits of cargotecture in PDR projects in Sri Lanka. Figure 2 depicts the proposed framework for overcoming the problems in PDR projects through the benefits of cargotecture in PDR projects in Sri Lanka.

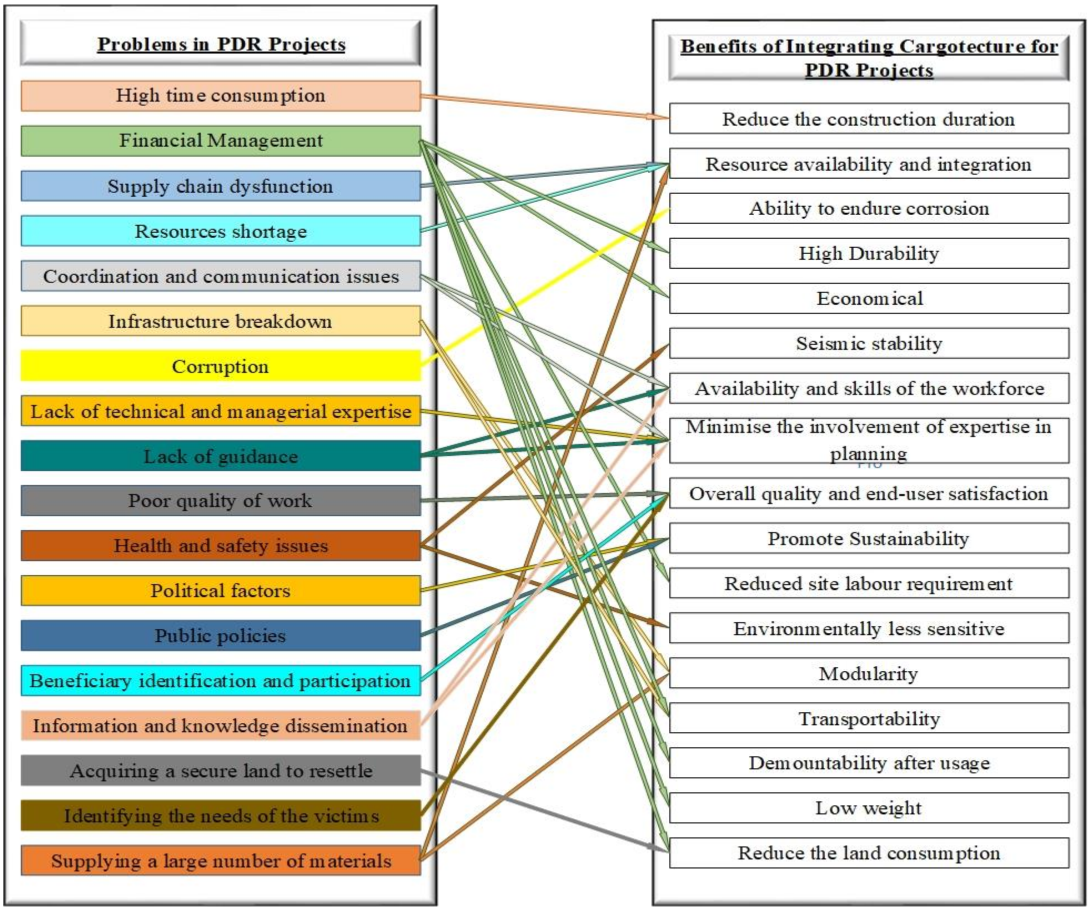

Figure 2: Framework for overcoming the problems in PDR projects through the benefits of cargotecture

As a result, the study found that the majority of the problems in PDR projects in Sri Lanka had been overcome through the use of cargotecture. The literature review of the study identified several problems of the PDR projects. However, during the data analysis, several other problems of PDR projects were identified by the experts. Hidayat and Egbu, (2010) stated that reconstruction is often a long-term recovery operation that is slow, expensive, and difficult. According to the RII analysis of the problems in PDR projects identified through the literature review, the most significant problem was financial management. Tas et al. (2010) identified time to have a significantly higher rank over the other factors, including cost reduction of the project, which affects determine the design of post-disaster permanent housing reconstruction. However, according to the responses, the current study introduces that in Sri Lankan PDR projects, financial management is the most significant problem in comparison to the speed of construction. According to literature findings, coordination and communication issues were one of the main problems in PDR projects. The current study also identifies coordination and communication issues as the main problem. Furthermore, Siriwardhana et al. (2021) and Rotimi et al. (2006) stated that it is challenging to create effective communication between resettlement agencies and affected populations. However, experts of the study stated that this coordination gap often leads to duplications, misallocation of resources, and delays in project implementation. The study identified that to address this challenge, the Sri Lankan government has established the National Disaster Management Centre (NDMC) to coordinate PDR efforts. Le Masurier et al. (2006) stated that if disasters were on a relatively small scale, there was not much difference between the typical building process and the reconstruction procedure unlikely to be a large-scale disaster. Bilau et al. (2017) indicated challenges associated with logistics and supplies as one of the major management issues that arise in large-scale housing reconstruction programmes. In addition, Rotimi et al. (2006) highlighted that it is difficult to obtain regular resource levels after a catastrophic event, and it might be difficult for poorer countries to access resources for PDR. Jayasuriya and McCawley (2008) stated that when natural resources are rare locally, reconstruction efforts following disasters in a nation like Sri Lanka have to depend on assistance from outside. This research also identifies that resource shortage is a critical problem in PDR projects. Industry experts stated that there are several problems in PDR projects, in Sri Lankan projects such as acquiring secure land to resettle, identifying the needs of the victims, and supplying a large number of materials.

Sun et al. (2017), the use of cargotecture has grown significantly in recent years due to its robust plating, low cost, and ubiquitous availability. According to Chen et al. (2016), Gunawardena et al. (2014), and Lawson et al. (2012), the prefabricated modular technology has the potential to significantly reduce the amount of construction time that can be adopted for PDR projects. The findings of this study also agreed that adopting cargotecture for PDR will reduce the construction duration. According to Lawson et al. (2012), labour-intensive builds onsite. According to Pena et al. (2012), cargotecture has been provided temporary home design options that capitalise on shipping containers' natural strengths, reusability, and portability. The current study validated the other benefits of cargotecture, such as demountability after usage, modularity, and transportability, unlike traditional construction. This study further identified that cargotecture would reduce land consumption, which is also a critical problem in PDR. Tas et al. (2010) identified the availability and skills of the workforce and minimise the involvement of expertise in planning as benefits of cargotecture. El Messeidy (2018) stated that cargotecture is an environmentally sustainable solution, as it promotes the use of recycled materials and reduces the carbon footprint of construction. The current study also agrees that cargotecture is a sustainable and eco-friendly building solution that can minimize the environmental impact of construction activities. By repurposing shipping containers, builders can reduce the demand for new building materials and minimize waste.

6. CONCLUSIONS

The aim of the research was fulfilled by conducting a review of the existing literature and collecting data through a questionnaire survey and expert interviews. In Sri Lanka, PDR projects are critical for restoring communities following natural disasters such as floods, landslides, and cyclones. Unfortunately, difficulties have arisen throughout the execution of PDR projects in Sri Lanka. In Sri Lanka, PDR projects suffer from a lack of financing and resources, resulting in delayed execution, limited rehabilitation efforts, and low-quality infrastructure. The lack of competent knowledge of labour and disaster management also hinders the proper implementation of PDR projects. Further, the study identified that cargotecture could offer several benefits in PDR projects in Sri Lanka. Reducing the construction duration, less initial cost, low weight, promotion sustainability, reduced site labour requirement, demount ability after usage, modularity, transportability, and reduced land consumption were identified as the benefits of cargotecture in PDR projects in Sri Lanka in this study. Overall, cargotecture can provide an efficient, cost-effective, and sustainable building solution for PDR projects in Sri Lanka. Finally, the study provided a framework for overcoming problems in PDR projects through the benefit of cargotecture in PDR projects in Sri Lanka. Consequently, the study revealed that most of the problems in PDR projects have been overcome through the benefit of cargotecture in PDR projects in Sri Lanka. The modular nature of shipping containers and their resilience to natural disasters can also provide flexibility and ensure that the built environment remains functional in the face of future disasters.

The study recommended integrating Cargotecture for PDR projects in Sri Lanka to overcome the problem in PDR projects. In addition, the research contributes to knowledge about problems in PDR projects in Sri Lanka and the benefits of integrating Cargotecture for PDR projects in Sri Lanka. Furthermore, this study opens the research area on developing a framework for integrating cargotecture for PDR projects in Sri Lanka to increase cargotecture adoption in PDR projects in Sri Lanka. Thus, the study findings cannot be generalised in the global context since this study only focused on Sri Lanka. Therefore, any other developing nation that is similar in nature to Sri Lanka's construction industries and that shares the same socioeconomic, cultural, and demographic characteristics can conduct further studies to build a framework for integrating cargotecture for PDR projects in their nation to boost cargotecture adoption in PDR projects. However, there were several problems in successfully integrating cargotecture for PDR projects in Sri Lanka when it was implemented to address the problems with PDR projects. As a result, it is recommended that future research focus on the problems associated with integrating cargotecture for PDR projects in Sri Lanka as well as strategies for overcoming these problems. This will help to develop a framework for integrating cargotecture for PDR projects in Sri Lanka and promote cargotecture adoption in PDR projects in Sri Lanka.

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COMPARATIVE COST ASSESSMENT OF DRYWALL TECHNOLOGIES IN DISASTER-INDUCED HOUSING RECONSTRUCTION

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ABSTRACT

The stagnant process of disaster-induced housing reconstruction (DHR) in Sri Lanka (SL) and the reluctance of victims and donors to use expensive technologies for DHR even if disaster-resilient, led to this research. Thus, the research aimed at conducting a comparative cost analysis of different drywall technologies in DHR as alternatives for fulfilling the growing demand for DHR; in doing so, this paper contextualised a mixed research design comprehending a twofold empirical study, which includes a preliminary-expert-interview survey and a questionnaire survey. Content analysis and statistical tools assisted the data analysis. Research outcomes revealed that labour cost-effectiveness, material availability, and sufficiency of unskilled labour are the most influential cost parameters. All ten drywall technologies are effective in terms of the initial cost and can further be tested to choose the best technology for a DHR. Novel aspects of this research are (i) evaluating various cost elements of different drywall technologies for DHR in Sri Lanka, and (ii) presenting research outcomes in a scorecard and a tiered list of drywall technologies, which facilitate choosing economically efficient drywall technologies to accelerate DHR. The scorecard is not restricted to DHR but it is widely practicable for other applications in SL.

Keywords: *Cost; Disaster; Dry Wall Technology; Gypsum Board; MDF Board; Sri Lanka.*

1. INTRODUCTION

Natural catastrophes have affected more than 2.9 billion people globally since 1980, wherein Disaster-induced Housing Reconstruction (DHR) has become a controversial responsibility worldwide (Atmaca & Atmaca, 2016). DHR is a collaborative attempt to deliver houses for victims/families at risk because of long-term natural forces, driven by anthropogenic pressures and natural transformation.

The government/ NGOs finance DHR in most developing countries either as a loan/donation (Lam & Kuipers, 2019). The obligation of paying back the credit-based-funds (Dikmen, 2005); social cost, burden on the public finance from government funding (Dikmen, 2010); and substantial economic loss of disasters exacerbate the financial crisis of the economies in developing countries (De Silva et al., 2021; Froude & Petley, 2018).

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Moreover, both donors and victims are typically reluctant to employ more expensive, as well as unaffordable technologies even if such technologies are disaster-resilient (Kijewski-Correa & Taflanidis, 2012). For example, DHR, after the 2004 tsunami in Sri Lanka (SL), did not adopt tsunami-resilient house designs due to their unaffordability (Batteate, 2006). This leads to evaluating any technology's economic viability before recommending to DHR. Still, the initial cost makes a heavy contribution because the capital cost of DHR is a collective commitment of communities, the government, and NGOs in most developing countries (Froude & Petley, 2018; Batteate, 2006).

On the other hand, victims should be informed of a spectrum of alternative construction materials to avoid causing material shortages during DHR, and to tackle the growing pressure of DHR (Kennedy et al., 2008). Simultaneously, Suarez et al. (2008) specified that DHR continuously focuses on developing appropriate material solutions, so Hulathdoowage et al., (2021) assessed the time-based performance of drywall technologies. Although drywall is not a widespread practice in DHR in the developing context (Hulathdoowage & Hadiwattage, 2021), developed countries have exploited its most significant advantage (Sabau et al., 2018). For example, Barrios et al. (2020) proved that most housing units sustained from Hurricane Harvey (Texas, USA) in 2017, were featured drywall piles. The scientifically-verified positive characteristics of drywall technologies include 5-8 times quicker installation process, less labour requirement, structural cost-saving (Tamboli et al., 2018), decreased cooling demand, and less environmental impact (Mandilaras et al., 2013). Arab et al., (2021) proved that drywall compared to brick wall decreases natural gas consumption by 66.93%, electricity demand by 42.59%, and carbon emissions by 22.54%, and these percentages would be higher in coming years.

Moreover, Khodahemmati and Shahandashti (2020) evaluated construction material cost fluctuation over six years centred on Hurricane Katrina in New Orleans, Louisiana and confirmed that the poor consideration of the capital cost of construction materials leads to budget shortages of DHR. Budget shortages increase the period in temporary huts/ tents for victims. Thus, concerning the benefits of drywall, researchers examined the Research Question (RQ) below:

> *RQ: What are the influential cost elements, and the comparatively efficient drywall technologies in terms of capital cost for DHR?*

A trivial number of scholarly articles are available on the subject. Hulathdoowage and Hadiwattage (2021) established the applicability of drywall for DHR based on a case-study-based analysis. Hulathdoowage et al. (2021) evaluated the time performance of different drywall technologies for DHR. Munasinghe (2018) established the suitability of EPS wall panels for SL concerning thermal comfort. Shamloo et al. (2021) evaluated the effects of four structural systems including drywalls (wood and EPS) on DHR and confirmed that each system fulfils part of DHR needs, e.g. cost and time performance, environmental considerations, and land use. But none of them answers the above RQ. The remaining content of the paper is structured as follows; literature review elaborating on the applicability of drywall technologies for DHR in SL; research methodology; results and discussion regarding a cost comparison of ten drywalls; conclusions of critical findings.

2. LITERATURE REVIEW

This section discusses the applicability of drywall for the host country, SL. However, brick and block walls are still common to SL. Hence, Hulathdoowage and Hadiwattage (2021) compared the performance between block wall and drywall technologies. Similarly, Indian constructions employ brick walls, but new construction techniques are currently emerging, e.g., ferro-cement and gypsum wall panels (Patil et al., 2022).

2.1 NEXUS BETWEEN FINANCIAL BACKGROUND OF DISASTER RELOCATION AND DRYWALL CONSTRUCTION IN SRI LANKA

In 2020, the number of families, which needed to rehabilitate due to the high risk of landslides in SL, was 2,963, and 847 victims were residing in temporary shelters due to flooding and 567 due to landslides expecting permanent residents (Ministry of Disaster Management, 2021). Lethargic characteristics are apparent in most DHR projects in SL, i.e., Hulathdoowage and Hadiwattage (2021) have witnessed victims in tents even after three years of the 2016 Aranayake landslide in SL, which critically obstructs the livelihood of the victims. As per Quarantelli et al. (1995), temporary shelters have already become temporary houses, and there is no sign of permanent houses. Tents arranged for temporary sheltering never fulfil even the very basic needs, irrespective of disaster resilience. Therefore, especially in developing countries, acknowledging quick and affordable construction techniques has more value than in developed countries.

From 1998 to 2012, flooding made the highest cost contribution per year, which was LKR 32 billion and next, and cyclones produced LKR 11 billion costs (Ministry of Disaster Management, 2015). The regular fluvial flooding can transfer tens of thousands of Sri Lankans into transitory poverty, deterring the progress of the country on shared responsibility and poverty eradication (Walsh & Hallegatte, 2019).

ADB (2019) manifested the financial background of DHR in SL in a red zone, further identifying limited financial arrangements, the absence of a national disaster fund, unavailable financing plans, and ineffective insurance strategies. Most of the livelihood opportunities get abandoned for a long-time after a natural catastrophe, such as the lower capacity to carry out fishing due to fragile settings in the community networks in resettlement camps, destroyed crops and lands in agriculture, the need for colossal funding to relocate businesses, difficulties of reinstating tourism (Finucane et al., 2020).

As a critical element, wall construction occupied more than 10% of the total budget of a typical single-house produced after the 2016 Aranayake landslide in SL (Hulathdoowage & Hadiwattage, 2021). Moreover, wall materials are subjected to inflation during the recovery phase (Ghannad et al., 2019; Harris, 2005). Thus, drywall could be a promising solution to fix this matter to some extent because of its cheaper and faster process, and by increasing the number of alternative technologies (Tamboli et al., 2018).

The labour wage rate also rises due to inflation at the recovery phase, i.e., skilled labour rate became almost treble after the tsunami, and finding skilled labours, such as masons, makes the process more difficult (Ghannad et al., 2019; Harris, 2005). Moreover, there is a continuous labour shortage in the Sri Lankan construction sector, especially skilled labours (Pathiraja, 2008; Pathirana, 2021), wherein the labour shortage was 400,000 workers in 2017 (Jayasinghe, 2020). Ghannad et al., (2019) further estimated the capability of modular construction technologies to solve labour-related issues as it ensures higher productivity, lower labour requirement, enhanced safety of construction, quick response to DHR, lower site congestion. Drywall is also a modular technology and provides the same advantages because it demands only on-site assembly.

When choosing materials for DHR, out of the box thinking pattern is more effective to secure cost-effectiveness (Bruen et al., 2021). Hulathdoowage and Hadiwattage (2021) evaluated two case studies induced by 2016 Aranayake GHR and forecasted that three other houses could have been constructed in each case study by replacing block walls with drywall panels (e.g., gypsum board).

2.2 ACCESSIBLE DRYWALL TECHNOLOGIES IN SRI LANKA

Referring to secondary data (Hulathdoowage et al., 2021), the set of ten drywall technologies were adopted for the empirical study concerning the availability for a mass construction such as DHR in SL, encompassing Gypsum board partitions, Cement bonded particleboard (Danane & Wagh, 2018), Expanded Polystyrene Sandwich (EPS) panels (Munasinghe, 2018), Glass fibre reinforced gypsum panel (Bardhan and Debnath, 2018), Cellulose fibre cement composite panels (Ardanuy & Claramunt, 2015), Medium Density Fibber (MDF) board, Paddy straw composite board (DURRA) (Athambawa et al., 2014), Autoclaved Lightweight Concrete (ALC) board, Oriented Standard Board (OSB)-composite material (Chen, 2018), Calcium silicate wall panel board (Si, 2018). Literature sources (Athambawa et al., 2014; Chang et al., 2010) also confirm evaluating local materials to achieve optimum economic viability.

3. RESEARCH METHODOLOGY

Due to the similar nature of both studies, we adopted the methodology followed by Hulathdoowage et al., (2021), who evaluated the time efficacy of drywall technologies.

3.1 DATA COLLECTION

Initially, a series of preliminary interviews with three professionals was conducted to derive a comprehensive set of cost parameters required to assess the initial economic viability of wall construction in DHR and to structure the questionnaire survey. Next, we carried out a questionnaire survey (inclusive of 48 professionals within the sample) for ranking a set of chosen drywall technologies against each cost parameter.

By evaluating the comparative cost performance of different drywall technologies quantitatively with a large sample such as 48, we could avoid the inaccuracies of having a case-dependent comparison and alleviate partial responses to overcome the weaknesses of the previous case study-based studies (Atmaca & Atmaca, 2016). The principal researcher personally visited most of the experts and explained whenever they queried to secure the accuracy of the responses. Responses were weighted based on the experience range of experts to reduce the impact of biased responses.

3.2 DATA ANALYSIS

We analysed interview transcripts subjected to manual content analysis, and questionnaire responses aided on SPSS 20 software package and Microsoft Excel software. Mean Weighted Rating (MWR), skewness, and standard deviation, were the main statistical tools used for the quantitative analysis. Skewness presented the normality of the data distribution. Standard deviation presented the reliability of the data set.

The sample consisted of four groups of experts, i.e. (i) Drywall (20.83%), (ii) DHR (25.00%), (iii) Both (8.33%), and (iii) construction professionals (45.83%). Experts who were having more than 5 years of experience in the respective fields accounted for the first three categories, and the last category was purposefully selected to include professionals who are having some exposure (<5 years) to both drywall technologies and DHR. Moreover, we collected perception-based responses because experts ranked the drywall technologies under each cost parameter. To reduce the biases, responses were weighted based on the experience level, and Gunasena (2010) was followed to justify the weighting decisions.

Subsequently, Equation 1 was utilised to assign scores to the questionnaire responses. The set of ten drywall technologies was assigned MWR as scores and graded under each initial cost parameter of wall construction to develop a scorecard.

$$MWR = \frac{\sum_{i=0}^{N}(W_i \times F_i)}{N} \quad (01)$$

Where, MWR - Mean Weighted Rating for an attribute, W_i - Constant giving to weight each case, F_i - Frequency of responses, N - Number of responses (Hulathdoowage et al., 2021).

Table 1 establishes five levels to interpret MWR values and defines a colour code to improve the visual clarity of data.

Table 1: MWR values interpretation (Gunasena, 2010)

MWR value	Interpretation	Colour code
4-5	Strongly higher feasibility	
3-4	Higher feasibility	
2-3	Average feasibility	
1-2	Lower feasibility	
0-1	Strongly lower feasibility	

Equation 2 was applied to calculate the overall score of each drywall technology representing its comparative economic viability based on initial cost parameters (C1, C2, C3,……., Cx). Equation 2 was derived from Equation 1, wherein the final number of cost parameters (x) was determined from the preliminary-expert-interview survey as six.

$$Overall\ Score = \frac{\sum_{i=0}^{N}\left[\sum_{x=1}^{6}\left(MWR_{C_xDT_i} \times MWR_{C_x}\right)\right] \times 100\%}{\sum_{x=1}^{6} MWR_{C_X} \times K} \quad (02)$$

Where, MWR_{CxDTi}: Mean Weighted Rating of each drywall technology under Cx, MWR_{Cx}: Mean Weighted Rating of Cx, x: Cost parameters, K: The maximum overall score of each technology.

4. PRELIMINARY-EXPERT-INTERVIEW SURVEY RESULTS

We engaged in preliminary interviews to verify the initial cost parameters identified from literature, and to fine-tune the questionnaire. Three professionals having more than 10 years of experience in their respective field (2 – DHR and 1 - drywall) were interviewed. During the interviews, initial cost parameters identified from the literature were thoroughly examined against the characteristics of the recovery phase to derive a description for each parameter (refer to Table 2).

Table 2: Cost parameters along with descriptions

Initial cost parameter	Description	References
Labour cost-effectiveness	The capacity of having a minimum total cost associated with both skilled and unskilled labour components	(Basnayake, 2018; IPS, 2006; Martínez et al., 2020)
Sufficiency of unskilled labour	Capability to fulfil the labour requirement with unskilled labours	(IPS, 2006; Martínez et al., 2020; Zea Escamilla & Habert, 2015)
Material availability	Effectiveness of the supply chain to cater for the material demand for a mass construction	(Hulathdoowage & Hadiwattege, 2021; Zea Escamilla & Habert, 2015)
Material cost-effectiveness	The capacity of having a minimum retail price for materials	(IPS, 2006; Dikmen, 2010)
Transportation cost-effectiveness	The capacity of having a minimum transportation cost via logistical easiness of materials	(Demirli et al., 2015)
Minimum wastage rate	The capacity of having a minimum additional cost due to material wastage at the site	(Bardhan & Debnath, 2018)

5. QUESTIONNAIRE SURVEY RESULTS

The second round of the empirical study was an expert questionnaire survey, wherein the respondents were specialised in a subject area (Kachroo & Kachen, 2018).

5.1 DEVELOPING THE SCORECARD

Respondents ranked the six cost parameters aided on a 1-5 Likert scale to investigate the priority level for DHR and then ranked the list of ten drywall technologies under each cost parameter (C1, C2,..., C6) referring to the same 1-5 Likert scale. Concisely, we agglomerated those two rankings into a scorecard, which is illustrative in Figure 1.

5.1.1 Prioritising Cost Parameters of Wall Construction in DHR

Figure 1 demonstrates that the priority of the first five cost parameters is strongly higher, whilst the last one falls within the “higher range" (refer to Table 1). Labour cost-effectiveness, material availability, and sufficiency of unskilled labour are the most influential cost parameters. To verify, labour shortage, skilled labour unavailability, increments of the labour wages at the recovery stage, and material shortage are frequent issues in DHR projects in SL, further causing delays and disruptions (Ghannad et al., 2019; Harris, 2005; Pathiraja, 2008; Pathirana, 2021). Material cost-effectiveness and transportation cost-effectiveness come next in the order standing within the “strongly higher range”, whereas minimum wastage rate is the lowest.

5.1.2 Prioritising Drywall Technologies Against Each Cost Parameter of Wall Construction in DHR

Figure 1 further distinguishes the effectiveness of different drywall technologies wherein the most feasible drywall technologies under the parameter "Labour cost-effectiveness" are Gypsum Board and Calcium Silicate Panel. Easiness of installing and less labour requirement for assembling gypsum boards diminish the labour cost (Tamboli et al., 2018). Regarding labour cost-effectiveness, EPC panel has assigned to "Higher range" and for sufficiency of unskilled labour, to "Strongly higher range". In fact, EPS panel partitioning utilizes less time, e.g., one and half days of unskilled labour to assemble a 130 sqft room (Munasinghe, 2018). Sequentially, the most available technologies in SL for a considerable demand are MDF panel, gypsum board, and DURRA board. Being scored by 3.4, gypsum board has a minimum wastage rate, which is 5% of the total material required (Condeixa et al., 2015).

5.2 OVERALL INITIAL COST PERFORMANCE OF TEN DRYWALL TECHNOLOGIES IN DHR

The set of ten drywall technologies shown in Figure 1 was manifested in a chart, assigning overall score values (refer Equation 2), illustrating the overall cost-performance of drywall technologies for DHR (refer Figure 2).

Pertaining to Figure 2, two ends represent gypsum board panels (highest performance) and ALC panels (lowest performance). Similar results on the economic performance of gypsum board panels have been assured by Danane and Wagh (2018) related to the Indian construction sector. Overall, all ten technologies have shown more than 50% of the maximum performance.

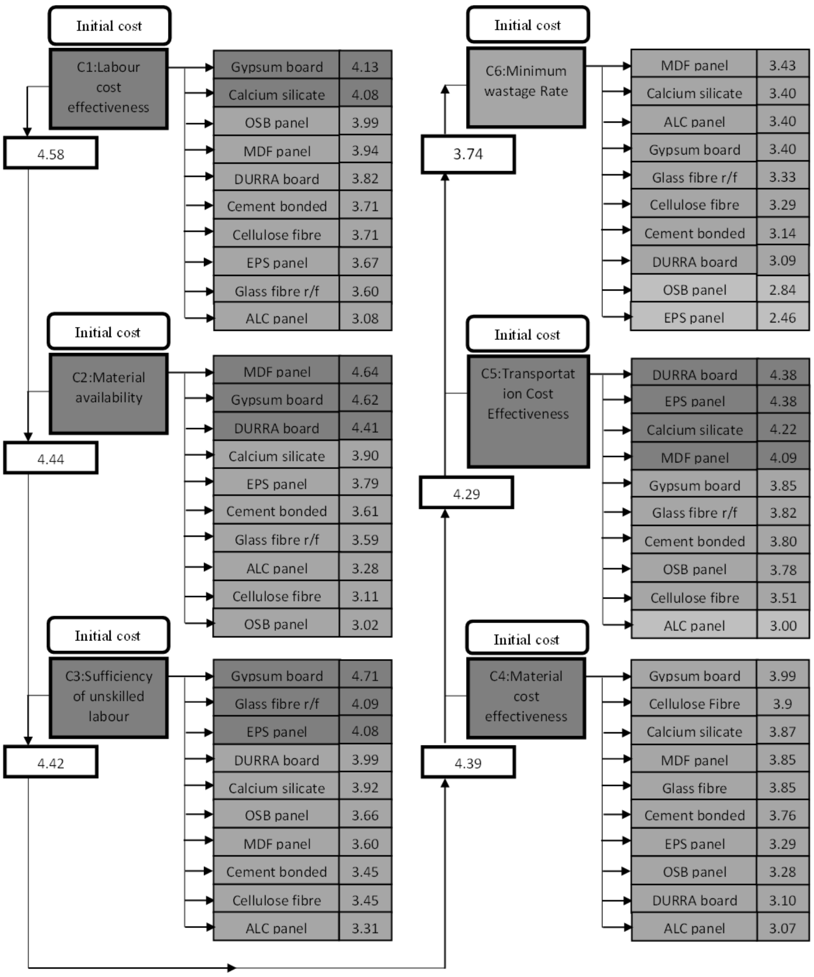

Figure 1: Scorecard regarding the cost performance of drywall technologies in DHR

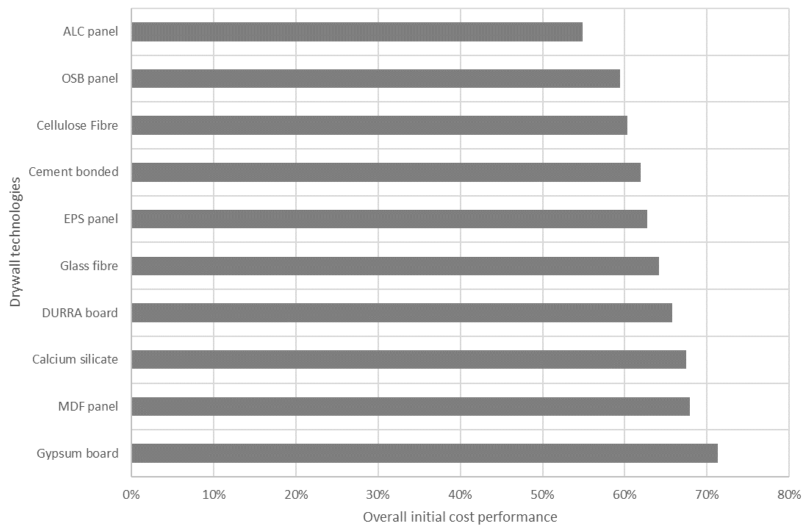

Figure 2: Tiered list of ten drywall technologies in DHR

6. VALIDATION PROCESS OF RESEARCH FINDINGS

Due to the limited number of scholarly articles available on the subject matter, the scorecard (Figure 1) and the tiered drywall list (Figure 2) were presented to two experts of DHR and drywall technologies, respectively holding more than ten years of experience in their relevant field for externally validating the outcomes of the research. Therefore, both Figure 1 and Figure 2 are applicable for DHR in developing countries, struggling with similar difficulties.

Subsequently, prices of drywall panels and material prices for masonry walls were collected from two wholesale companies to further validate the outcomes of the expert questionnaire survey (material cost-effectiveness) (refer to Table 3).

Table 3: Retail prices of 8’×4’ sized wall panels in Sri Lanka in 2022

Drywall technology	Price (LKR)	Thickness (mm)
Masonry wall technologies		
Brick wall	5,692.00	112.5
Block wall	4,732.80	100
Drywall technologies		
Gypsum board	932.00	15
Cellulose Fibre	1,012.00	15
Calcium silicate	1,078.00	22
Glass fibre	1,507.00	15
MDF	2,026.00	12
Cement bonded	2,087.00	18
EPS	2,229.00	75
OSB	2,330.00	25
DURRA	3,920.00	58
ALC	4,559.00	75

Since DHR creates a massive demand for wall materials, prices collected were applicable for purchasing more than 1000 panels. The drywall technologies are more efficient in terms of material cost than masonry wall technologies (112.5 mm thick brick wall and 100mm thick block wall) except ALC panel, which is almost similar to the block wall. However, ALC panels would be even more cost-efficient than block walls when increasing the labour rate during the recovery phase due to inflation (Ghannad et al., 2019; Harris, 2005).

7. APPLICATION OF RESEARCH FINDINGS

The scorecard (Figure 1) and the tiered list of drywall technologies (Figure 2) are particularly applicable for SL but can be applied for similar developing countries by reiterating the same methodology. Rankings of drywall technologies under each cost parameter are not restricted to the disaster context, i.e., material availability for a bulk supply is also a significant analysis for any application of drywall technologies in SL, such as high-rise buildings, commercial buildings. Moreover, the tiered list of drywall technologies is a significant indication to choose the best technology on the initial cost out of several potential technologies.

Concerning Figure 1, Figure 2, and Table 3, all ten drywall technologies are efficient concerning the initial cost, and therefore, this research recommends all ten drywall technologies as alternatives to masonry wall construction in case of fulfilling mass demands of housing construction, such as DHR. Despite this, other factors, such as disaster-resilient requirements should be evaluated to choose the best technology.

To strengthen research in the same direction, further research areas were identified under the guidance of the two experts during the validation process. The same research methodology can be extended to develop a similar set of parameters on the maintenance cost of drywall technologies, finally, comprehending into a scorecard. The applicability of drywall technologies for the interior and exterior should be differentiated when evaluating the resilience against extreme weather conditions. On the other hand, numerous drywall technologies show distinctive levels of resilience under different disaster conditions and the expected resilience level depends on the disaster exposure in the region, so that both factors need to be evaluated in future research. Moreover, Hulathdoowage and Hadiwattege (2021) have explained the future research directions required to implement drywall technologies in detail.

8. CONCLUSIONS AND RECOMMENDATIONS

Capital cost-effectiveness is prominent in DHR due to many funding constraints in developing countries, such as difficulties of paying back the credit-based funds, incapacity of the government, failure to withstand the enormous economic loss of disasters, unfamiliar and expensive insurance programs, and inflation during the recovery period. For counteracting such bottlenecks and as an alternative wall technology to tackle the growing pressure of DHR, this study investigated the comparative cost performance of drywalls in DHR, strengthening the research direction shown by Hulathdoowage and Hadiwattege (2021).

Six cost parameters were empirically assessed, out of which five parameters were positioned in the “strongly higher” range. Labour cost-effectiveness, material availability, and sufficiency of unskilled labour became top influential parameters, further realising the literature on the critical nature of the labour component. Finally, we developed a scorecard that demonstrates a tiered list of ten drywall technologies under each cost parameter. This scorecard facilitates choosing a suitable drywall for wall construction in DHR. The significance of cost parameters has evaluated specifically for DHR. Still, the ranking of drywall technologies under each cost performance would be applicable for other applications as well, e.g., commercial buildings.

This research recommends all ten drywall technologies as alternatives to conventional masonry wall technologies for DHR concerning the overall initial cost performance. Therefore, Figure 1 and Figure 2 can be adapted for the policy development procedure of DHR in SL, such as preparing rehabilitation guidelines, improving the community awareness process of drywall technologies, and conducting further research and development on adopting drywall technologies in DHR.

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COMPARATIVE STUDY OF WORK-RELATED FACTORS AFFECTING MENTAL WELL-BEING OF MALE AND FEMALE CONSTRUCTION WORKERS IN AUSTRALIA

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ABSTRACT

The construction industry is long perceived as physically demanding, and less consideration has been given to the mental well-being of the construction workers. The increasing number of mental health concerns urges the research to expand their focus from work health, safety and accident prevention to the "physio-social effects" on workers' well-being. Hence, this research aims to explore the effect of work-related factors on the mental well-being of male and female construction workers. After a thorough literature review to set the background, a qualitative research approach was adopted as the methodology. Sixteen participants across two cases were interviewed, and the sample is an equal representation of male and female construction workers in Australia. Factors affecting mental well-being are recognised under five themes through the content analysis of the case study results, including the machoism characteristics of the industry culture; the high-risk and fast-paced work environment; financial stability and financial literacy; uneven workload and unconventionally long working hours; and the involvement of the employer's management in reassuring the mental well-being. The key implication is that the same inherent machismo cultural characteristics of the Australian construction industry distinctly affect the mental well-being of male and female construction workers. The unpredictability of casual and contract-based appointments causes low job security and financial stability among male workers leading to financial stress. The current study emphasises that a one-stop approach to address the mental health issues of male and female construction workers is ineffective and proposes further in-depth research under the emerged themes of the research.

Keywords: *Australia; Construction Workers; Female; Male; Mental Well-being; Work-Related Factors.*

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1. INTRODUCTION

Society is one of the three main pillars of sustainability. The concept of social equity distributes well-being over space, ensuring the fair treatment of all members of society and promoting spatial sustainability of a well-being decision (Summers & Smith, 2014). Discussing the socio-economic and cultural implications of built environment sustainability would be prolific when equal consideration is given to people working in the construction industry. As one of the largest industries in Australia, the construction sector has over 1.15 million employees (Australian Bureau of Statistics [ABS], 2020). With its continuous growth, this number will continue to rise. Therefore, the mental well-being of millions of employees is vital to ensure a safe, comfortable and sustainable work environment. However, underlying issues in the construction industry affect the workers' mental well-being, with suicide rates for workers in construction being 80% higher than the general working population (Maheen, LaMontagne & King 2020). From this perspective, this study compares work-related factors affecting the mental well-being of male and female construction workers in Australia.

2. LITERATURE REVIEW

Mental health is “a state of well-being in which every individual realises their own potential, can cope with the normal stresses of life, can work productively and fruitfully, and can make a contribution to their community” (World Health Organisation, 2022). Previous studies identify two avenues of mental health based on the “context-free” and “context-specific” outcomes (Sun et al., 2022). Context-free mental well-being considers the general mental health of an individual. In contrast, context-specific refers to the education or work-related mental health issues governed by specific factors (Sun et al., 2022). The work-related factors of the construction workers can also be considered as the “context-specific” mental health of the individuals in the construction with context-specific outcomes such as job burnout, work-related anxiety, and work-related depression (Schonfeld et al., 2019).

However, mental health and well-being are often overlooked in the construction industry due to stigma and workplace ethos (Hon, 2021). American Society of Civil Engineers (ASCE) identified work-related factors associated with worker well-being, such as job demand, lack of work support, work hazards and workplace injustice (Chan, Nwaogu & Naslund 2020). Similar factors were identified, including low job resources, high cognitive demand, long work hours, and job security (Hon, 2021). Bowen et al. (2014) claim that these factors appear consistent between male and female construction workers and recognise that females face unique challenges due to direct and indirect discrimination. However, Ness et al. (2012) highlight that the mental well-being of female workers requires definite sensitivity, where 99% of the construction workers are from the male population. The specific problem in the construction industry is that mental health and worker mental well-being issues are not openly discussed or recognised to their true magnitude and prevalence for both female and male employees. If the construction industry became proactive and more open-minded about mental health, projects would be more successful as construction workers would have fewer altercations, and communication would be apparent.

This research aims to uncover the work-related factors affecting the mental well-being of male and female workers within the construction industry and provide insight into their effects and severity between the genders. Due to the industry being male-dominated, female workers and their mental well-being are often unrecognised. Hence, the conceptual framework in Figure 1 is used to guide the research.

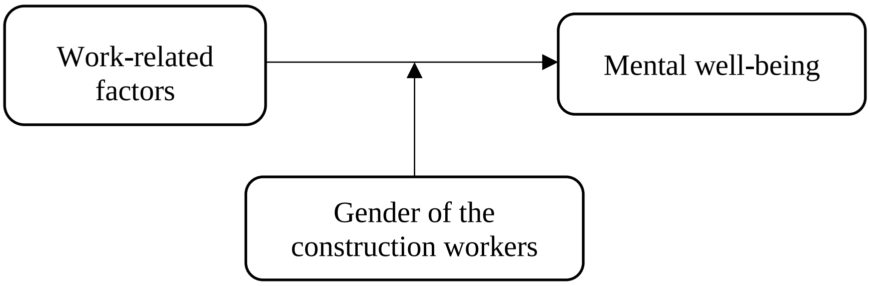

Figure 1: Conceptual model used to guide the case study research

Likewise, the study considers both genders equally and compares the work-related factors affecting their mental well-being. This study aims to highlight and bring awareness to an overlooked issue that may affect thousands of Australian construction workers. Therefore, this study is essential, as it can potentially assist in establishing strategies to improve mental well-being and health and prevent this issue from further affecting the industry and its workers. Hence, the research problem stands as,

"What is the effect of work-related factors on the mental well-being of male and female construction site workers?"

By addressing this issue, the research will increase awareness of the matter within the construction industry. It is anticipated that the findings will assist in developing prevention strategies to improve the mental well-being of workers within the industry.

3. RESEARCH METHODOLOGY

The primary research method was the implementation of explorative case studies. Case studies allow for a deeper exploration and understanding of complex issues (Zainal, 2007). Zainal also explains that case studies effectively present data from real-life situations and provide better insights into the behaviours of the subjects of focus, as they allow researchers to go beyond the quantitative statistical results.

Gustafsson (2017) explains that a multiple case study approach allows researchers to examine various issues to understand the similarities and differences between the points. A survey from Gustafsson (2017) states that findings from multiple case studies are more measured, robust, and reliable. The research team conducted and analysed two cases as part of the explorative case study method. Selection criteria of the cases incorporate that the selected organisation must be a tier 2 construction company; must be a construction company that is building, subcontracting, and managing commercial or industrial buildings; and must be a construction company with projects between $500,000 - $50, 000,000. Two organisations out of the organisations that fulfil all the three selection criteria were considered as the case studies. Criterion ensured that cases with a broader representation of the Australian construction industry were chosen, that the research participants had an in-depth understanding of the work-related factors and culture affecting mental well-being within the construction industry, and that sufficient and quality data was collected. The selected organisations are identified as Cases A and B in the subsequent sections.

Interviews were the primary research method for data collection when undertaking the current research. Interviews were an effective qualitative research method, as they allowed the researchers to learn about the world of others through accurate understanding, which may sometimes be elusive (Qu & Dumay, 2011). Qu and Dumay (2011) also state that a well-planned interview approach can provide a rich data set. Therefore, to implement this method, the research team developed and followed semi-structured interview guidelines. Liamputtong (2019) describes a semi-structured interview as “an interview to obtain descriptions of the interviewee’s world concerning interpreting the meaning of the described phenomena”. In a semi-structured interview guideline, the questions were kept open, and the interviewee could freely express their views while still focusing on the research topic. The demographic distribution of the interviewed participants is demonstrated in Table 1. The research team set out the goal of interviewing 16 participants, 8 participants from each organisation, containing four female and four male participants.

Table 1: Demographic distribution of the participants

	Participant Code	Organisation	Male Or Female	Role	Age	Industry Experience
CASE A	APM1	OA	Male	Concreter	38	20
	APF2	OA	Female	Project Manager	45	24
	APM3	OA	Male	Site Supervisor	45	20
	APF4	OA	Female	Quality Surveyor	59	20
	APM5	OA	Male	Project Manager	36	13
	APF6	OA	Female	Surveyor	25	5
	APM7	OA	Male	Operator	55	6
	APF8	OA	Female	Operator	28	5
CASE B	BPM1	OB	Male	Truck Driver	52	9
	BPF2	OB	Female	Project Coordinator	57	12
	BPM3	OB	Male	Traffic Control Officer	34	10
	BPF4	OB	Female	Boiler Maker	18	6
	BPM5	OB	Male	Accountant	38	9
	BPF6	OB	Female	Electrician	34	11
	BPM7	OB	Male	Electrician	20	7
	BPF8	OB	Female	Project Manager	43	12

Each participant was assigned a code indicating the case and the gender (APM1: Participant No.1 from Case A, Male; APF2: Participant No.2 from Case A, Female). The interview data was qualitative. Hence a thematic analysis was implemented to analyse the data. Braun and Clarke (2021) define thematic analysis as qualitative research used to analyse patterns and themes related to the data. By providing a systematic element to data analysis, a thematic approach allows researchers to accurately determine the relationships between concepts and tell them to the replicated data (Braun & Clarke,2021). The coded interview data was assigned a reference consisting of the participant code and the case (APM1, OA) for the thematic analysis and cross reference purposes.

4. CASE STUDY FINDINGS

The case study findings in the subsequent section provide an embedded cross-case analysis of the construction workers of the two case studies.

4.1 THE MACHOISM CHARACTERISTICS OF THE INDUSTRY CULTURE

Participant from Organisation A indicated that the construction industry has mostly stayed the same over the past years and is still tackling macho culture (APM1, OA). Compared to the past generations, it was expressed that the culture was very 'macho', and males that spoke about their emotions were shown to be '*weak*' or '*feminine*'. APM3 from Organisation A also agreed with APM1 as he explained that in the past years, "*the masculine culture affected the ability for males to talk about mental health, as males were expected to uphold the tough persona*". Participant APF4 further extends on the change of culture due to the interaction of females by conveying that "*males are more alert when females are onsite and tend to watch how they talk and act, to ensure that the females are not offended*" (OA, APF4). While many workers had difficulty overcoming the stereotypical tough male mentality of the construction industry in the past, those of different ethnicities also had to battle the challenges of fitting in. APF2, a male with a Philippine background, expressed that in his early days, due to the industry's lack of diversity and being predominately white, he felt that he did not fit in (OA, APF2). Women in the construction industry find themselves having to adjust to this masculine culture that has been ingrained into the industry over generations of predominately male workers. APM7 said that *"it being such a male-dominated industry, you have to be fairly open-minded, so there is a lot of swearing a lot of cursing"* and *"you can't be too precious, you have to let that slide because that's all these guys have ever known"* (OA, APM7). APF8 support this as she stated, *"it might be a bit confronting or too much, which might lead to them feeling uncomfortable and develop mental health issues"* (OA, APF8). In this statement, she refers to how the masculine culture created by the workers can be confronting and uncomfortable for female workers who are new to the industry and have not been exposed to this type of culture.

The culture that Case B participants experienced followed a trend, with many participants experiencing a toxic culture. Participant BPM3 stated that a "*terrible toxic masculinity problem and had witnessed people breakdown from a combination of bullying and extreme heat*" (OB, BPF2) shows a highly toxic culture within the construction industry. The interviews suggest that there is still an 'old school' culture presence contributing to the toxic culture, with participant BPF4 stating, "*Older bosses are kind of stricter and older traits*" (OB, BPF4, Q5), showing an unaccepting culture towards the new generations of construction workers. This provides an insight that a detrimental culture still exists within the industry and impacts construction workers. When considering the participant responses regarding culture in the workplace, it identified that the 'old school' communication styles and the attitude/empathy towards colleagues are dismal. Participant BPF8 stated, *"I try to avoid comments like that; you need thick skin to work in this industry" (OB, BPF8).* Furthermore, BPF8 stated, *"Management tells me that is who they are, and they cannot modify their behaviour" (OB, BPF8, Q7)*. Both comments are alarming when considering the workplace culture, as acceptance of this behaviour is not the appropriate solution.

In both Case A and Case B the machoism characteristics of the organisational culture are observed. However, in Case B, most participants were aware of the toxicity of the macho culture and demonstrated an interest in changing it for the better. In contrast, in Case A participants find that the culture of their organisation is a constant which they must adapt and adjust.

4.2 THE HIGH-RISK AND FAST-PACED WORK ENVIRONMENT

APM1 works in concrete construction, which involves workers working simultaneously with cranes, concrete pumps, mobile plants, and deep excavation. He explains that the environment is very stressful, high risk and requires workers to move quickly and effectively, which can result in complacency and unfollowing safety procedures. Participant APF2 has the occupation of a site supervisor and expresses that his work environment is very stressful, with the stress originating from "*job responsibility, timeline, client objectives and dealing with a significant amount of site workers*" (OA, APF4). Participants APM5, APM7, and APF8 are involved in civil works and have said their work environment is "*high risk*" and "*demanding*". APF8 stated, "*The high-risk and fast-paced nature of the work environment could also affect people's mental health because they might not handle the pressure very well*" (OA, APF8, Q7). This notion was supported by participants APM5 and APM7, who said they have felt stressed due to their work environment and its high-risk nature. Similarly, the competitive work environment created by other workers can also affect the mental health and well-being of female workers. APF6 has said that "*It is intimidating when I go onsite, I am expected to work as twice as hard as men especially as a woman in a male-dominated work environment*" (OA, APF6). Therefore, the environment created by male workers can be intimidating or uninviting for female workers. APF8 supported this by stating, "*You do the get the odd few workers who are stuck in their ways which might make the environment a bit less enjoyable*" (OA, APF8).

Similarly in Case B, the environments that construction workers are exposed to are often high-risk and harsh; this has the potential to evoke symptoms of stress. This was supported by participant BPM3 who stated a "*high-stress environment that can be unique from other industries*" (OB, BPM3) regarding the work environment; this quote produces an alarming response regarding the stress levels construction workers experience. BPM7 further stated, *"performing activities such as commissioning may look easy and stress-free however, when the equipment is demanded to be placed back into service, then a component fails, the pressure and stress levels become very high"* (OB, BPM7). As stress and pressure impact an individual's mental well-being, there is a link between the work environment and an individual's mental well-being.

Peculiarly, unlike the female participants of Case A the female participants of Case B have not highlighted the harsh, dangerous, and tiring nature of the work environment as a factor that affect their mental wellbeing.

4.3 FINANCIAL STABILITY AND FINANCIAL LITERACY

It was found that financial gain from working in construction was the driving force for the female participants in entering the industry. APF8 stated that *"I think money is* *another factor too because the main reason we are working these long work hours is to make money"* (OA, APF8). On the contrary, the majority of the female participants found that the lack of financial stability due to their work had negative impacts on mental well-being. APF6 stated that *"not making enough money and raising the cost of living definitely affects your mental health, especially if you need to provide for your family"* (OA, APF6). Therefore, financial hardship is a prominent factor affecting female workers' mental well-being, as it limits their ability to provide for themselves or their families. As a result, they are forced to work more hours to increase their income.

This was also found to be a heightened factor in the recent climate of the COVID-19 pandemic, where there were many financial uncertainties factored around the industry, which extended to construction workers. This is shown via participant BPF2 stating, "*It was quite stressful trying to keep the project on budget during the covid pandemic" (OB, BPF2),* representing the financial pressures that would extend to the construction industry workers. The pandemic has placed many financial uncertainties and made the management of projects extremely difficult.

In this light, workers undergoing financial pressures are found to overcommit themselves, place themselves in unsafe environments, and undertake off-the-book tasks for the potential to earn more money. This is a direct result of stress from financial pressure, as the stress can blind workers from making ethical, safe, and acceptable decisions. However, it is important to understand that many unknown factors, such as marital status and lifestyle, have not been considered and can easily influence an individual's mental well-being.

4.4 UNEVEN WORKLOAD AND UNCONVENTIONALLY LONG WORKING HOURS

In conjunction with a shortage of materials and tight project deadlines, construction workers are found to be overwhelmed and experiencing higher levels of stress. APF2 expresses this precisely by conveying, *"All the programs and schedules at the moment are getting tighter and tighter, so it is getting pretty stressful ensuring that all construction activities are on the path" (OA, APM1).* Higher responsibility can result in a higher workload, resulting in longer working hours. Regarding working hours, APF2 elaborates that his occupation does not have a "clock off time" and that his responsibilities are not confined to the project site. He feels obligated to answer phone calls and emails outside working hours to ensure that no critical information is missed. Therefore, it is depicted that long working hours can significantly impact one's mental health as it can impact life outside of work, overwork mental capacities, and cause exhaustion/ complacency. These long work hours can take a toll on the worker's physical and mental health, as described by APF8 who stated that *"I'm working 10-hour days for sometimes 6 days a week, so it's definitely exhausting both physically and mentally"* (OA, APF8). Working 10-hour days consecutively for multiple days affected all participants, as they felt that work was consuming their life. APF6 stated that *"Working the long hours obviously takes away from your own life outside of work and everyone needs that down-time to relax and enjoy life with friends and family"* (OA, APF6). The female participants found the workload coupled with restricted time frames to complete the works to be a major factor in stress and poor mental health. APM5 stated that *"The limited amount of time we can do things and the amount of work that needs to be done, definitely adds* *pressure on an already stressful environment"* (OA, APM5). APF8 also found that *"pressure to meet deadlines"* (OA, APF8).

Participants BPF2 that there often is an "*increase in workloads near the completion of projects to ensure it made its deadline*" *(OB, BPF2),* showing that there can be quite a demand on construction workers sometimes. Participant BPF4 supported this notion stating that "*nightshift limits my ability to have a social life*" *(OB, BPF4),* showing the impacts that long work hours can have on construction worker, especially in their personal lives. Long working hours was not identified as a predominated factor in influencing the mental well-being of the female construction workers, this was predominately due to the role of each female participant. As the participants (BPM5, BPF6, BPM7 and BPF8) were predominately shift workers or 9-5 workers. They did not experience huge workloads for long periods of time.

4.5 THE INVOLVEMENT OF THE EMPLOYER'S MANAGEMENT IN REASSURING THE MENTAL WELL-BEING

Management systems within construction organisations and subcontractors play a vital role in developing a physically and mentally safe environment for all construction workers. APF4 conveys that in his experience, a management system that actively involves subcontracts positively impacts the project outcome and improves individuals' mental well-being, as they feel heard and respected. "*Simple actions from management such as allowing a worker to feel heard and respected significantly improves the work environment, workmanship quality and makes coming to work more appearing*" (OA, APM3). APM1 expresses that his occupation (concreter) is very weather dependent and that it is sometimes challenging to meet organisation deadlines.

All female participants found the management within their company to be supportive and approachable, with no participants voicing any problems regarding the management system. They found the organisation to have adequate support options regarding mental health and found it easy to contact management if they required help. Participants all showed awareness about mental health and often stated that a particular element of their job could lead to poor mental health. A response regarding the management systems from participant BPF2 stated that the "*team leader sometimes mentioned it that support throughout the avenues*" (OB, BPM1). This suggests that there is support offered by the company through the management system. One participant BPM3 stated that they "*have not actually done so I expect better, more supportive results from my outside-of-work friends*" (OB, BPM3). *This* suggests that there is discomfort towards seeking support internally within the industry for this individual. However, from a wholistic approach, an experienced participant, BPF8, stated, "*Due to the size of larger tier 1 construction contracts, the larger construction companies can afford good mental health programs, whereas smaller tier 2/3 construction companies struggle to have the cash flow to invest into mental health programs*" (OB, BPF8). Hence, because of this, smaller construction companies cannot provide adequate mental health programs, which impacts an individual's ability to seek help.

5. DISCUSSION

In contrast to other industries, construction is vastly falling behind in ensuring the social equity of the construction workers, especially on the special sustainability of well-being decisions. The construction industry holds on to the stigma surrounding mainstream forms of treatment for those struggling with their mental health or even depression (Milner et al., 2015). Thus, the industry requires a complete mental and physical commitment to ensure that all construction activities are performed safely and that all workers remain unharmed. The analysis of the case study result features five work-related factors that affect the mental well-being of construction workers.

Regardless of gender, working in the construction industry can typically provide a stressful work environment and concern workers' well-being. As is well documented within the construction industry, it is not uncommon that construction workers can be required to work 12-hour days, six days a week which places a huge amount of strain on an individual (Hon, 2021). The macho and male-dominated construction culture plays a crucial role in the worker's mental well-being, as it can create a hostile, unsafe, and peer-pressured environment. The communication issues with the upper management have left construction workers feeling individually responsible for project progress and dedicated to workload beyond their capacity. These findings are supported by (Powell et al., 2018), who claimed that the masculine culture encourages male and female workers to perceive the notion of enduring pain as necessary and suppress their mental health to adhere to the masculine culture. The management team must also be approachable to allow construction workers to feel comfortable speaking up about site or individual concerns. This approachable relationship can be formed by treating subcontractors equally and conversing with them daily. Powell et al. (2018) convey that long working hours in a union with high cognitive demanding tasks, physical labour and exposure to hazardous activities can leave construction workers feeling emotionally drained. The current study emphasises that this seeps into external factors such as family and lifestyle as male and female workers are left feeling time-poor and exhausted. Eventually, poor worker well-being stemming from work-related factors impacts a worker's personal life, magnifying a worker's negative mindset (Langdon & Sawang, 2018). The findings of the study show that the same work-related factors affect the mental well-being of male and female construction workers differently.

For instance, male construction workers, find the macho culture in the construction industry is a barrier to opening up about mental health issues. Male employees often face a negative stigma that mental health issues are identified as a weakness. The need to prove their masculinity place men in challenging positions, and they tend to take unnecessary risk in the already risky construction work environment. Moreover, male construction workers often express a negative turn on mental health due to financial stress than their female counterparts. Contrariwise, unhealthy mental well-being can cause males to be distracted, sleep-deprived, unstable, unbearable, and inattentive (Boschman et al., 2013), all factors leading to safety incidents and accidents. A common observation is that male construction workers rarely seek management support to handle their mental health-related issues. Hence, Bowen et al. (2014) conclude that while gender can be linked to workers' coping mechanisms.

On the other hand, the exact machoism culture causes sexual harassment, bullying, and role ambiguity among female construction workers in the construction site setting. A previous study (Sunindijo & Kamardeen, 2017) found that females within the industry have a higher impact on mental health through poor relationships with supervisors, bullying, and role ambiguity. In addition to these psychological hazards, female workers are more susceptible to intimidation, confrontation, excessive monitoring, 'fitting in', and sexual harassment due to fighting gender norms within the industry (Hashmi et al., 2022). Moreover, the study outlines that female face lower job satisfaction and experience high levels of conflict balancing work and life commitment.

6. CONCLUSIONS

In essence, this study builds upon knowledge surrounding workers' well-being in the construction industry. It explores the work-related factors associated with worker well-being for male and female construction workers. The key findings of the study are three-fold. The study identifies work-related factors such as machoism cultural characteristics, high-risk work environment, pressure from time constraints and uneven workload as the most popular work-related factors contributing to poor mental well-being for both male and female construction workers in the Australian construction industry. The study elaborates on an important aspect of the machoism culture of the construction industry. Even though the general notion is that male construction workers are comfortable within a macho culture, the study points out that male workers have an added pressure to maintain their "expected behaviour". Lastly, the findings stressed the importance of an accessible management system in organisations that make workers feel heard and respected to improve the mental well-being of individuals.

Hence, it is recommended to develop a better support system specifically designed for construction workers considering the implications of machoism characteristics of the industry culture and the high-risk fast-paced work environment highlighted in the study. The research has also indirectly identified some current management systems that aim to support construction workers. The philosophy is that a more detailed understanding of factors affecting the mental well-being of construction workers will contribute to changing the culture allowing for it to be more inclusive for all.

The research covers a wide array of interviewees with office-based roles and site-based roles. It is a limitation of the current study. Another limitation is the quality of responses provided by the participants, as the research is aimed at a private and sensitive topic, an individual's mental well-being. Some participants were hesitant to provide detailed information regarding their experiences. Further research can be conducted on office or site-based roles and how male or female construction workers perceive work-related factors on their mental health. The research could also be expanded upon by looking into a diverse range of various tiers of construction companies within South Australia. Collecting a range of data from various-sized organisations would build a more accurate picture of the construction industry stemming from small businesses to multinational corporations. This would result in the concluded analysis being broader than the current research's limited representation of the industry and is a recommendation for further research. Other contributing factors which could be used to expand the research would be to further explain the different geographical and cultural variants of the construction industry. The findings within this research were limited to the confines of South Australian projects. They could be expanded to include other states and territories within Australia to provide a more accurate conclusion about the industry within this country.

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COMPARISON OF EMBODIED CARBON ESTIMATING METHODS

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ABSTRACT

The Australian building sector contributes up to 36% of carbon emissions emphasising the importance of carbon management. Embodied Carbon (EC) and Operational Carbon (OC) are classified as two main types of carbon emissions in buildings. Zero carbon projects have gained popularity nowadays where OC is reduced to zero, which enables EC to increase. The focus should have been to reduce overall emissions. The current EC estimating databases and tools could result in inaccurate EC estimates due to various reasons, such as different system boundaries, different geographical locations, lack of standardisation and so forth. To address prevailing shortfalls, a new methodology, Supply Chain based Embodied carbon Estimating Method (SCEEM), has been introduced. This study aims at comparing EC estimates prepared using SCEEM against existing carbon estimating databases/tools. A case study was selected to collect data and estimate EC using SCEEM as well as selected database, Blackbook, and tool, eToolLCD. The results indicated that the EC estimates prepared for the case study was quite high in the selected database/tool compared to the EC values of SCEEM. The percentage difference between SCEEM vs Blackbook and SCEEM vs eToolLCD, was more than 50% for most of the items within the collected data set. The first principles-based methodology considered in SCEEM ensures the accuracy and consistency of estimates prepared using SCEEM.

Keywords: *Carbon Databases/Tools; Carbon Estimating; Supply Chain; Supply Chain-based Embodied Carbon Estimating Method (SCEEM).*

1. INTRODUCTION

Climatic changes have caused a significant impact on the global community resulting in increased temperatures, rises in sea levels, increased water vapours in the atmosphere, and melting of glaciers (Kaluarachchi, 2017; Karl et al., 2009). It is widely believed that climatic changes occur as a result of human activity (Shukla et al., 2019; United Nations Environment Programme, 2009). As the Australian building sector accounts for about 36% of the overall carbon emissions (Huang et al., 2017), it is extremely important to reduce Life Cycle Carbon (LCC) emissions. LCC emissions in buildings can be classified into two main types - Embodied Carbon (EC) and Operational Carbon (OC). Royal

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Institution of Chartered Surveyors (2014) investigated the overall carbon footprint during the operational stage of various kinds of buildings, such as supermarkets, offices and others, to discover that the emissions of OC are comparatively higher than EC. The latest trend is to create zero-carbon projects (Bui et al., 2021), which intend to reduce OC to zero, making the remaining component, EC, more significant (Royal Institution of Chartered Surveyors, 2014; Yokoo et al., 2013). Ashworth and Perera (2015) suggest that in order to reduce the OC component, new materials should be introduced, such as additional layers of insulation, increasing EC. Some buildings possess a short life span and at the same time account for a high percentage of EC emissions when the total environmental impact of the building is assessed (Wolf et al., 2016). EC emissions during material extraction, production, transportation, construction and demolition are irreversible (Wolf et al., 2018). Hence, it is important to reduce net carbon emissions. Green Building Councils worldwide are focusing on introducing roadmaps to improve the focus on achieving net-zero EC (Green Building Council Australia, 2018; World Green Building Council, 2019).

There are various EC estimating databases for early-stage and detailed stage estimating (Victoria et al., 2016). The University of Bath's Inventory of Carbon and Energy (ICE), Waste Reduction Action Plan (WRAP) and Hutchins UK Building Blackbook are quite acknowledged and popular, amongst others. Due to the existence of a different number of EC estimating tools and different system boundaries, comparison of EC calculations is relatively difficult and even within the same system boundary, calculations may differ. Therefore, the accuracy and reliability of these estimating methods are questionable, giving rise to the necessity of developing a methodology to calculate EC accurately and consistently. A new methodology identified as SCEEM has been introduced to estimate EC accurately and consistently (Rodrigo et al., 2021), which is elaborated in Section 2.2.

This study aims at comparing EC estimates prepared using SCEEM against existing carbon estimating databases/tools. In order to achieve this aim, the following objectives were established:

1. To select suitable carbon databases/tools to compare against SCEEM, and
2. To compare EC estimates prepared using SCEEM and selected databases/tools.

Section 2 discusses the literature review carried out while the research methodology followed in this study is shown in Section 3. The findings are presented in Section 4 followed by the conclusions of this research.

2. LITERATURE REVIEW

Construction-related activities contribute to climate change and global warming immensely highlighting the importance of carbon estimating in the construction industry (Baldasano & Reguart, 2014). Therefore, it is necessary to estimate carbon, ultimately to reduce construction industry-related carbon emissions. Currently, there are various carbon databases/tools developed to estimate EC.

2.1 CARBON ESTIMATING DATABASES AND TOOLS

Various carbon databases and tools have been developed by various parties in different countries to estimate carbon (Refer to Table 1). Databases provide carbon coefficients/ factors that could be used for carbon estimating, while tools provide an application that has incorporated carbon datasets and a method to estimate EC.

Table 1: Summary of the EC estimating databases and tools

Type	EC estimating tool	System Boundary	Details	Estimating Method	Type of Application	Publicly Available	Free	Location	Last Updated	Reference
Databases	ICE	cradle-to-gate	EC	Process	Excel Sheet	Yes	Yes	UK	August 2019	Hammond and Jones (2008)
	Hutchins UK Building Blackbook	cradle-to-gate	EC	Process	Book	Yes	No	UK	2010	Franklin and Andrews (2010)
	WRAP		EC	Process	Web Application	For registered users	Yes	UK		WRAP (2018)
	Ecoinvent	cradle-to-gate	LCA	Process	Web Application	Yes	No	Switzerland	Oct 2017	Frischknecht and Rebitzer (2005)
	AusLCI	cradle-to-gate	EPD	Process	Excel Sheets/ XML Format	Yes	Yes	Australia	2016	The Australian National Life Cycle Inventory Database. (2020)
	EPiC	cradle-to-gate	EE and EC	Hybrid	Book	Yes	Yes	Australia	2019	Crawford et al. (2019)
	The GreenBook 2020	cradle-to-end of construction	EC	Process	Book	Yes	No	Australia	Nov 2019	The GreenBook (2020)
Tools	CapIT Online Carbon and Cost Estimator	cradle-to-gate	EC	Process	Published as Hutchins UK Building Blackbook	Yes	No	UK	2011	Mott MacDonald (2018)
	BRE Green Guide Calculator		EC	Process	Web Application	For licensed BREEAM/ EcoHomes	No	UK	Jan 2015	Building Research Establishment (2020)

Type	EC estimating tool	System Boundary	Details	Estimating Method	Type of Application	Publicly Available	Free	Location	Last Updated	Reference
Tools (Cont'd)	BEES	cradle-to-grave	CO_2 cost in $/ton	Process	Web Application	Yes	Yes	US	2010	Fu et al. (2014)
	GaBi Education Software	cradle-to-grave	LCA	Process	Desktop Application	Yes	Yes	Germany	2017	Gabi Software (2019)
	Tally	cradle-to-grave	LCA	Process	Add-on Software to Revit	Yes	No	US	2021	Tally (2021)
	Athena Impact Estimator for Buildings	cradle-to-gate/grave	LCA	Process	Desktop Application	Yes	Yes	US	Feb 2017	Athena Sustainable Materials Institute (2018)
	SimaPro	cradle-to-grave	LCA	Process	Desktop Application	Yes	No	Netherlands	2017	SimaPro (2008)
	EC3	Cradle-to-gate	EPD	Process	Web Application - Beta version	Yes	Yes	US	2019	Building Transparency (2021)
	eToolLCD	cradle-to-grave	LCA	Process	Web Application	Yes	No	Australia	2010	eTool (2018)
	ECE Tool	cradle-to-gate	EC	EEIOA	Web Application	Yes	No	Australia	2019	The University of New South Wales (2019)
	The Footprint Calculator	cradle-to-grave	LCA	Process	Web Application	Yes	No	Australia	2019	The Footprint Company (2019)
	LCAQuick	cradle-to-grave	LCA	Process	Desktop Application	Yes	Yes	New Zealand	2021	LCAQuick (2022)

Source: After Rodrigo et al. (2021)

Table 1 provides a summary of the various databases/tools developed by various researchers and organisations that are popular among practitioners and academics. Though there are several databases/tools introduced for carbon accounting, there are several issues when estimating EC using them. EC estimating databases and tools at present are lacking in transparency, simplicity and accuracy, especially in the way that data are collected (Wolf et al., 2016). As a result, some organisations have begun developing their own in-house EC assessment tools (Wolf et al., 2017). For example, Thornton Tomasetti (2016) developed a tool to estimate EC. Arup developed their in-house EC database, Project Embodied Carbon Database (Wolf et al., 2018), Carbon Leadership Forum has compiled the Embodied Carbon Benchmark database (Simonen et al., 2017), and so forth. Haynes (2010) noted that it is difficult to estimate carbon emissions accurately, and that the calculations are subject to variability. In addition, differences in system boundaries and geographical locations, lack of standardisation, incomplete or outdated data, static nature of data, and assumptions could result in inaccuracies and inconsistencies in carbon estimates prepared using these databases/tools (Rodrigo et al., 2019). Hence, a new methodology was introduced to estimate EC accurately and consistently as discussed next.

2.2 SUPPLY CHAIN-BASED EMBODIED CARBON ESTIMATING METHOD (SCEEM)

SCEEM is a new methodology introduced to estimate EC in Construction Supply Chains (CSCs) by incorporating the value chain concept and blockchain technology (Rodrigo et al., 2021). There are several activities carried out within a construction project involving multiple CSCs. Each activity adds value to the CSC while contributing to EC. SCEEM considers this philosophy and captures EC emissions of each contributor within the CSC and stores in a blockchain (database) to improve transparency, security, trust and accountability among users. SCEEM captures EC emissions considering a first principles-based methodology. For example, it collects data related to fuel usage and electricity usage to account EC emissions of each EC contributor in CSCs. This method provides a more accurate EC estimate as it captures raw data without relying on existing databases/tools which are lacking of transparency, using incomplete or outdated data and many other issues as discussed in the previous section.

3. RESEARCH METHODOLOGY

This research aimed at comparing EC estimates prepared using SCEEM against existing carbon estimating databases/tools. To achieve the objectives and the aim of the study, the methodology demonstrated in Figure 1 was followed.

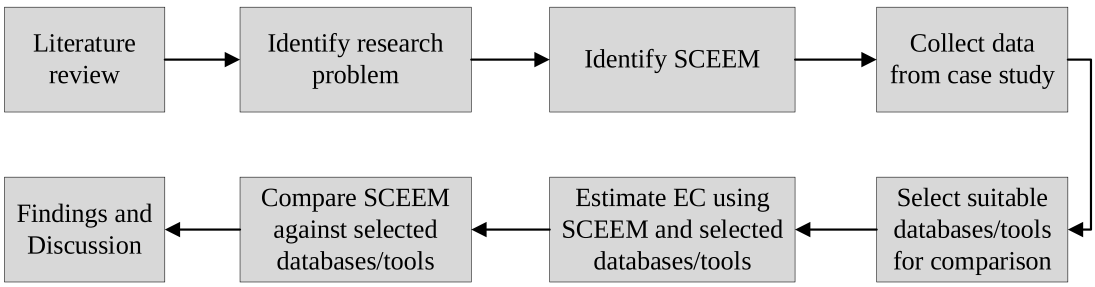

Figure 1: Research Methodology Framework

This study followed the steps shown in Figure 1. Initially, a literature review was carried out to identify the research problem related to inaccuracies/inconsistencies when estimating EC using existing databases/tools (Section 2.1). A more accurate methodology, SCEEM, was identified to resolve this issue (Section 2.2.). It was required to collect data from an actual project due to the calculation steps to estimate EC using SCEEM and other databases/tools, and also to carry out fair comparisons. Therefore, a case study in Sydney, Australia was selected to collect data. Fuel quantities related to a few items within the case study was collected. The next step was to select suitable databases/tools for the comparison. Hence, the currently available carbon databases/tools (Table 1) were evaluated and the results are presented in Section 4.1. Subsequently, the fuel quantities were used to estimate EC using SCEEM and the BOQ quantities were used to estimate EC using selected database/tool. Finally, the comparison between SCEEM and selected database/tool was carried out (Section 4.2).

4. FINDINGS AND DISCUSSION

This section presents the findings of the study.

4.1 SELECTION OF DATABASES AND TOOLS FOR THE COMPARISON

There are various EC databases and tools, as illustrated in Table 1, that can be used to estimate EC in construction projects. A comparison was carried out between the Australian databases, Australian Life Cycle Inventory (AusLCI) database, Environmental Performance in Construction (EPiC), and GreenBook 2020; Australian tools, eToolLCD and Embodied Carbon Explorer (ECE) Tool; and the most popular UK-based databases, Blackbook and Inventory of Carbon and Energy (ICE), to select the most suitable databases and tools for the study. Table 2 presents a justification on the tools that were evaluated and selected.

Table 2: Evaluation of reasons for selection of EC databases or tools

Reason		Selected		Non-Selected				
		Database	Tool	Database				Tool
		Blackbook	**eToolLCD**	**AusLCI**	**EPiC**	**GreenBook 2020**	**ICE**	**ECE Tool**
A	Availability of EC emission factors suitable for the data set	Yes	Yes	No	No	No	No	No
b	Ease of calculations	Yes	Yes	No	No	Yes	No	No
c	Clear and detailed descriptions	Yes	Yes	No	No	Yes	No	No
d	An Australian database/tool	No	Yes	Yes	Yes	Yes	No	Yes
e	Standalone database/tool	Yes	Yes	No	Yes	Yes	Yes	Yes
f	Use of database/tool by previous studies and practitioners	Yes	Yes	Yes	No	No	Yes	No
g	Hybrid Approach	No	No	No	Yes	Yes	No	Yes

Source: Adapted from Rodrigo et al. (2021)

The database, Blackbook, and the tool, eToolLCD, were selected for this study to estimate EC and carry out the comparisons. The other databases and tools have not been considered due to various limitations and issues existent in them. This section elaborates the reasons and justification for the selection or non-selection of databases and tools for carrying out comparisons with the EC values estimated using SCEEM.

a. Availability of EC emission factors suitable for the data set

Blackbook and eToolLCD consisted of EC emission factors applicable for the data set considered in this study. The data collected from the case study was related to civil construction works of a housing development project. The main reason for not selecting other databases and tools to estimate EC in this study is due to non-availability of EC coefficients for the items in the data set. The key items in the data set include excavation of topsoil, stockpile, cut and fill, excavation of trenches, backfill and so forth. However, the databases, AusLCI, EPiC, GreenBook 2020, and ICE, and the tool, ECE Tool, did not have suitable EC emission factors for the items in the data set. Therefore, they were not considered for estimating EC in this study.

b. Ease of calculations

Blackbook, eToolLCD and GreenBook 2020 provide EC values for a variety of items given in the format of a Bill of Quantities (BOQ) related to a building construction project. Therefore, it is extremely easy to estimate EC using Blackbook, eToolLCD and GreenBook 2020. On the other hand, the databases, AusLCI, EPIC, and ICE, and tool, ECE Tool, provide EC emission factors for various materials. Hence, if these databases or tools are to be used, initially the BOQ has to be converted to a bill of material. Subsequently, EC emissions could be calculated. Compared to these databases and tools, it’s easier to use Blackbook, eToolLCD and GreenBook 2020.

c. Clear and detailed descriptions

Blackbook, eToolLCD and GreenBook 2020 provide detailed descriptions for each of the items given in the format of a BOQ. Therefore, a user can easily understand the scope of the item with a clear indication of inclusions and exclusions. This allows the user to accurately calculate EC by using the exact item or else the most suitable item if the exact item is unavailable. However, the databases, AusLCI, EPIC, and ICE, and tool, ECE Tool, provide EC emission factors for various materials. Therefore, it is difficult to consider these databases or tools for the comparison in this study.

d. An Australian database/tool

AusLCI, EPiC, and GreenBook 2020 are Australian EC databases while eToolLCD and ECE tool are Australian EC tools. It is more suitable to use Australian databases or tools to carry out comparisons as data was collected from Sydney, Australia. However, although Blackbook is a UK-based database, it includes location factors that can be used to convert the EC emission factors to Australian values. Therefore, if all other criteria are fulfilled by Blackbook, it can easily be used in the study to carry out comparisons.

e. Standalone database/tool

All the databases or tools, except AusLCI, are standalone. Therefore, they can be independently used for EC estimating in this study. However, AusLCI is still in its development stage, therefore, the developers have enabled the AusLCI database to be accessed through SimaPro or Ecoinvent (The Australian National Life Cycle Inventory

Database., 2020). SimaPro and Ecoinvent have been developed based on the Netherlands and Swiss data, respectively. Therefore, it is difficult to extract Australian-based data through SimaPro or Ecoinvent. Hence, as AusLCI is not a standalone database, it would not be suitable for this study.

f. Use of database/tool by previous studies and practitioners

The EC databases, Blackbook, AusLCI, and ICE, as well as tools, EC tool, eToolLCD, have been used in previous studies. Darby et al. (2011); Fernando et al. (2018); Menzies (2011); and Victoria et al. (2015), have used Blackbook in their research to estimate EC. Teh et al. (2018) have used AusLCI to develop and evaluate a hybrid life cycle assessment framework for recycled materials. Atmaca (2016); Benton et al. (2017); and Din and Brotas (2016), have used ICE to estimate EC. eToolLCD is quite popular among the construction industry practitioners of Australia. A survey carried out by Fouche and Crawford (2015) identified that eToolLCD is the second most popular tool in Australia, being only 4% behind the most popular tool, SimaPro. These databases and tools provide validity and confidence when considering them to be used in the study. However, EPiC, GreenBook 2020 and ECE Tool, being launched only recently, have not yet been used in previous studies.

g. Hybrid Approach

SCEEM uses a process-based bottom-up approach to estimate EC. Hence, it is important to select databases/tools that have followed a process-based method to develop EC emission factors. EPiC, GreenBook 2020 and ECE Tool have each followed a hybrid approach, considering both process-based and Environmentally-Extended Input-Output Analysis (EEIOA) methods. The EEIOA method includes the input-output model of the national economy, where the entire supply chain of material is covered, across the economy, while using detailed and relevant process data as much as possible. This could create double-counting related issues, as some data could overlap one another. Due to these reasons, EPiC, GreenBook 2020 and ECE Tool cannot be used for the comparisons in this research. However, the other databases/tools have used a process-based method, hence, they can be considered.

In summary, Blackbook and eToolLCD were selected to carry out comparisons with EC values calculated using SCEEM. The reasons for selecting Blackbook and eToolLCD are: availability of EC emission factors suitable for the items in the data sets; ease of calculations; including clear and detailed descriptions; being a standalone database/tool; being used by previous studies and practitioners; and, utilising a process-based method.

4.2 COMPARISON OF SCEEM AGAINST SELECTED DATABASE AND TOOL

This section compares EC values calculated for a data set, using SCEEM against Blackbook and eToolLCD. EC values calculated using SCEEM, Blackbook and eToolLCD are illustrated in Table 3.

Table 3: Difference of EC values of the case study estimated using SCEEM, Blackbook and eToolLCD

Item	Item - Description	Quantity	Unit	EC ($kgCO_2e$)			Difference % of SCEEM vs	
				SCEEM	Blackbook	eToolLCD	Blackbook	eToolLCD
A	Strip topsoil (200mm) and stockpile on site	401,724	m^2	77,556	142,794	390,815	84	402
B	Cart from stockpile and spread topsoil (200mm)	314,022	m^2	71,463	35,616	132,684	-50	86
C	Cart from stockpile and spread topsoil (100mm)	29,695	m^2	9,295	3,368	6,274	-64	-33
D	Cut to onsite fill	189,105	m^3	452,004	487,297	919,848	8	104
E	Cut and stockpile onsite	158,384	m^3	159,969	337,453	770,415	111	382
F	Excavate, backfill and compact trenches	16,714	m^3	76,980	96,061	229,765	25	198
G	Cart surplus materials to stockpile	7,713	m^3	18,480	22,459	37,518	22	103

According to Table 3, considering all calculations, the highest EC values were reported from the item, ‘cut to onsite fill’. Similarly, the lowest EC values were resulted from the item, ‘cart from stockpile and spread topsoil (100mm)’. Comparing the percentage difference between SCEEM vs Blackbook, for most of the items, the percentage difference was 50% or more. In almost all of the items, the percentage difference between SCEEM and eToolLCD was more than 50%, except for item C, ‘Cart from stockpile and spread topsoil (100mm)’, which indicated a percentage difference of 33%.

Table 3 clearly demonstrates that Blackbook and eToolLCD provide comparatively higher EC estimates while SCEEM that uses a first principles-based method produces accurate estimates as explained in detail in Section 2.2.

5. CONCLUSIONS

This study aimed at comparing EC estimates prepared using SCEEM against existing carbon estimating databases/tools. There were 2 objectives established to achieve the aim as presented in Section 1. The 1st objective was achieved by identifying and evaluating the available carbon estimating databases (Table 1 and Section 4.1). The EC database, Blackbook, and the tool, eToolLCD, were selected for the comparison. The 2nd objective was achieved by comparing EC estimates calculated using SCEEM against Blackbook and eToolLCD. A case study in Sydney, Australia was selected to collect data related to a few items and carry out the comparisons. The results indicated that the EC estimates prepared for the case study was quite high in the selected database/tool compared to the EC values of SCEEM. The percentage difference between SCEEM vs Blackbook and SCEEM vs eToolLCD, was more than 50% for most of the items within the collected data set. However, the first principles-based methodology considered in SCEEM ensures the accuracy and consistency of estimates prepared using SCEEM. The key limitations of the study were the size and nature of the data set due to the difficulty to collect fuel quantities for various items/activities separately as well as time and resource limitations. The study contributed to establishing the proof of concept, which could be later on tested with more complex CSCs in any type of project. SCEEM is recognised as a better methodology to be used for accounting carbon emissions in CSCs.

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CONCEPTUAL DESIGN OF PORT DEVELOPMENT TO SUPPORT THE LOGISTICS SUPPLY OF INDONESIA'S NEW NUSANTARA CAPITAL CITY

Lusi Aprianti[1], Mohammed Ali Berawi[2], S. Gunawan[3] and Mustika Sari[4]

ABSTRACT

Indonesia is building its new capital city, Ibu Kota Nusantara (IKN), to create inclusive and more equitable economic growth by shifting the center of its economic gravity from Jakarta in Java to IKN in Kalimantan Island. Apart from aiming to become a new economic generator for equal distribution of the national economy, smart and sustainable IKN is expected to trigger new styles of learning, working, and living and encourage a change in Indonesia's development paradigm. IKN covers a total area of 256,000 hectares, with approximately 56,000 hectares of planned urban built areas will be conducted in five stages from 2022 until 2045. One of the challenges faced by the construction phase in IKN is that the existing seaports in Handil and Muara Samboja still cannot provide the support required for the logistics supply of construction materials. To support the development of the IKN, the current seaports and supporting infrastructure must be developed to allow the seamless operation of the logistics process. Therefore, this study aims to propose a conceptual design for logistic seaports in the Simpang Samboja and Muara Jawa areas. Case study is the method used in this study, using both qualitative and quantitative approach. This case study method references previous studies to obtain alternative value-added components. The results of this study show that the proposed logistic areas can facilitate logistic supply in IKN development with value for money.

Keywords: *Conceptual Design; Ibu Kota Nusantara (IKN); Logistic Supply; Seaport.*

1. INTRODUCTION

The President of the Republic of Indonesia decided on the new capital city on August 26, 2019, supported by Law No. 3 of 2022 concerning the State Capital. The new capital city area is developed in East Kalimantan Province, precisely in the North Penajam Paser Regency and Kutai Kertanegara Regency, with a total area of approximately 256,142 hectares and an area of seawater of roughly 68,189 hectares, as shown in Figure 1.

New city development is closely related to the city's economic growth and the economic equity of the region's inland. Furthermore, the role of the port in the city's development

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is crucial, as it has many functions in logistics and supply activities efficiently and connects inland areas (Mangani et al., 2016). The challenges of the logistics supply are the need to link the Nusantara Capital City or *Ibu Kota Nusantara* (IKN) area in North Penajam Paser, East Kalimantan, and the surrounding area to develop urban areas. Therefore, to address those challenges in the goods' traffic flow development, this research proposes a conceptual design of the port infrastructure development by expanding the existing port area through creative, alternative, and innovative ideas utilising Value Engineering (VE).

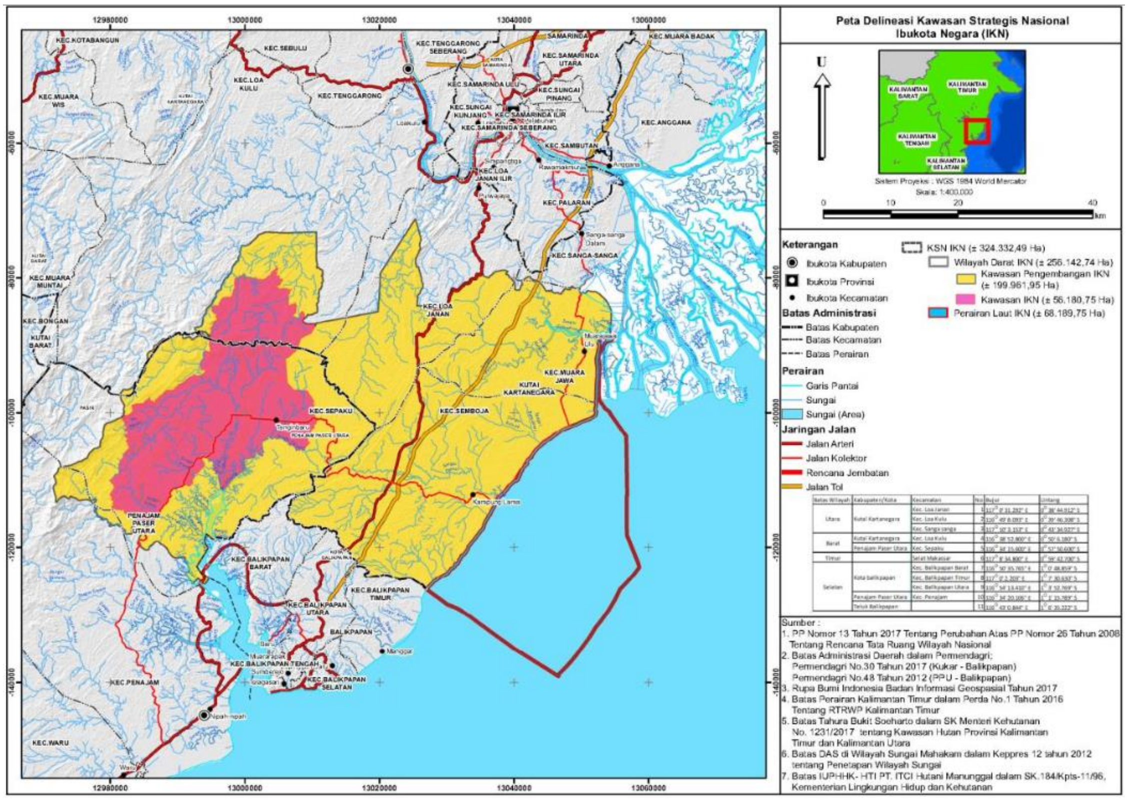

Figure 1: Delineation Map of National Capital City

Source: Law No. 3 Year 2022

2. LITERATURE STUDIES

2.1 PORT DEVELOPMENT

The plan to relocate the National Capital aligns with the vision of making Indonesia a world maritime axis. Infrastructure development in sea transportation is an important concern in planning a new state capital because it affects local economic aspects. Sea transportation is used for passenger transportation and is important in logistics distribution. The location of the new state capital is close to *Alur Laut Kepulauan Indonesia* (ALKI) II, strategic shipping lanes for world ships, so it has the potential to encourage the development of ports in East Kalimantan and eastern Indonesia. Equitable logistics distribution in Indonesia can encourage increased development, evenly distributed in each region (Chyntia et al., 2021).

Ports are protected against waves and equipped with infrastructure and technical facilities, including a pier allowing ships to load and unload (Roa et al., 2013). As a supporting mode of transportation, the port is a hub for modal transportation transfers (land, sea, or air) to support goods supply activities. It is equipped with facilities for ships to sail and dock (Monteiro et al., 2021). Loading and unloading activities at the port create the port to support industrial development by providing checking facilities, warehousing, and local transportation networks in the port area, which impact the regional economy (Arcego et al., 2019).

Based on Indonesia's Government Regulation No. 61 of 2009 concerning ports, in the stipulation of the national port master plan, the hierarchy of port roles and functions is as follows:

a. Main Port is a port that has a function to serve domestic and international sea transportation activities, transhipments of domestic and international sea transportation in large quantities, and as a place of origin for passengers and/or goods, as well as ferry transportation with inter-provincial service coverage,

b. Collector Port has the function of serving domestic sea transportation activities in medium quantities, and

c. Regional and local feeder ports support domestic sea transportation activities in a limited number and act as the feeder of main ports and collector ports with service coverage within the province (regional feeder) or the district (local feeder).

Encourage the three main goals of IKN Development: as a symbol of national identity, a sustainable city in the world, and a driving force for the Indonesian economy in the future, the existence of a main port at IKN is needed as a service for domestic and international sea transportation activities.

2.2 VALUE ENGINEERING

Value engineering (VE), value management (VM), or value analysis were introduced by Lawrence D. Miles in 1961. Miles described value analysis as a problem-solving system implemented using a specific set of techniques combined with an organised, creative approach whose purpose is to generate cost-efficient projects. VE concept broadly focuses on how value can balance time, cost, and quality. Value can be generated from four combinations: (a) maintain function and quality while reducing costs, (b) keep costs low while increasing function and quality, (c) improve function and quality while reducing costs, and (d) improve function and quality while reducing costs (Latief, 2017). Other studies state that a project's or service's value methodology is conceptualised to increase the value of a project through an analysis of its functions (James & Antwi, 2020).

The purpose of the VE concept was to manage and increase systematic innovation to provide a competitive advantage for a product (Amran, 2019). This concept focuses on understanding the function of each product component to be developed using a combination of active verbs and measurable nouns expected to provide the beneficial characteristics of the product. Thus, the VE concept puts function analysis as the main key. The Society of American Value Engineers International (SAVE International) defines value as the ratio between functions and resources:

$$Value = \frac{Fanction\ Performance}{Resouce} \text{ ….. (1)}$$

Source: The Society of American Value Engineers International (SAVE International)

Where, the performance required by the customer can measure the function, and at the same time, resources are measured in the amount of material, labour, price, or time needed to complete the function.

In other words, three basic elements are needed to measure a value (Dell'Isola, 1997). The relationship between the three elements is as follows.

$$Value = \frac{Fanction+Quantity}{Cost} \ldots\ldots (2)$$

Source: (Dell'Isola, 1997)

Where, Function = Specific work that a design/item must do, Quality = Needs, wants, and expectations of the owner or user, Cost = Life cycle cost of a product/project

The VE study stage is a series of activities for an object (project, process, or product). These include defining functions and developing and evaluating ideas that produce VE proposals and are held in workshops (Terouhid, 2022). The stages of a VE study start with preparation, process, conclusions, and reports in the order shown in Figure 2 (Washington State Department of Transportation, 2022).

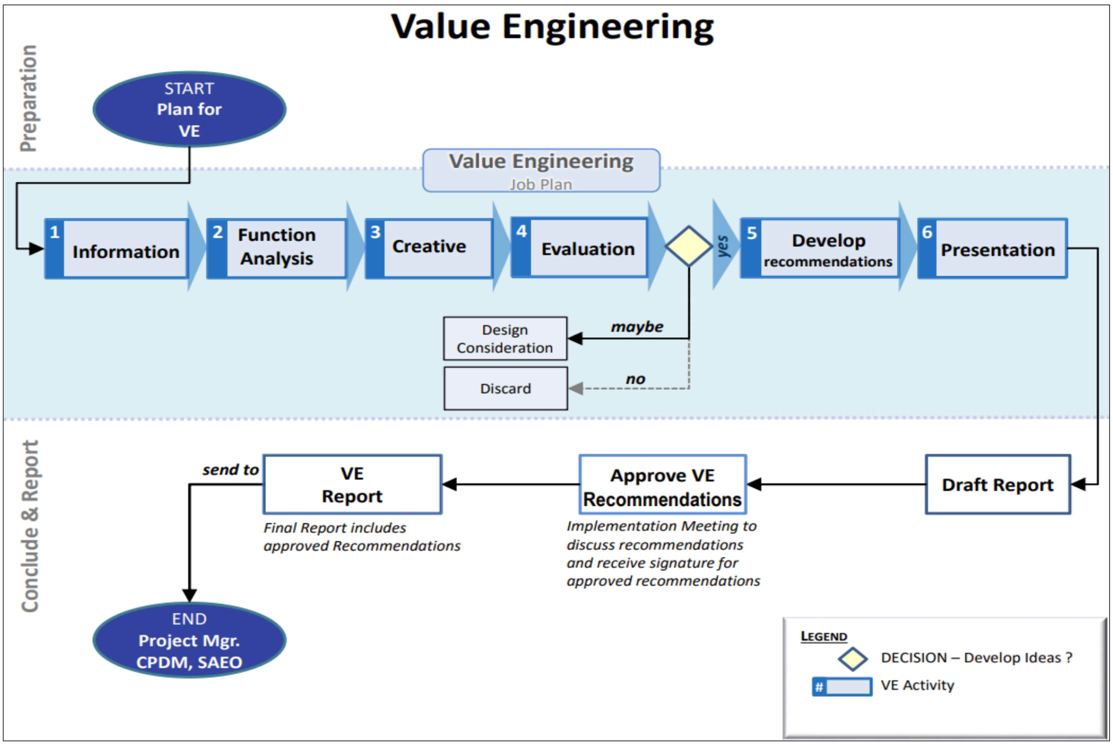

Figure 2: Value Engineering stages
Source: (Washington State Department of Transportation, 2022)

As a systematic process, VE focused on six identifiable steps, including information gathering and criteria setting for decision-making related to selected options (Berawi et al., 2019). While SAVE International is describes the step-by-step Value Engineering Methodology below:

1. Step 1: Information Gathering: This step is all about collecting data and includes the material and scope of the project to understand the project clearly.

2. Step 2: Function Analysis: analyse the functions of the elements identified in the previous step and evaluate their necessity for the project's goals. Once identified, the functions can be explored to be more creative and investigate solutions.
3. Step 3: Creative speculation aims to develop alternative solutions for delivering necessary building functions.
4. Step 4: Evaluation: This step would assess the alternative solutions by questioning the available options.
5. Step 5: Cost Analysis to count the allocation costs of the alternative solutions
6. Step 6: Development aims to develop alternatives with the highest likelihood of success.

The VE concept has resulted in various improvements to projects, systems, and products and the achievement of values widely used in the construction sector, with advantages such as risk reduction, time management, better schedules, quality improvement, and others. (Chen et al., 2010). Implementing VE in infrastructure projects provides many benefits, such as reducing project cost, increasing project performance and efficiency, and increasing project value. VE has also been applied in many developing countries and proven to increase optimal results for construction projects, especially for infrastructure projects with good quality, more advanced technology, and optimum efficiency to archive innovation (Berawi et al., 2019).

Several studies explaining the benefits of implementing VE are summarised in Table 1.

Table 1: Benefits of value engineering

Benefits	**Sources**
Produce project planning with a small Life Cycle Cost (LCC) by concerning cost efficiency	(Chen et al., 2013; Husin, 2022)
The formation of ideas, creations, and innovations derived from the analysis of functions	(Alwerfalli et al., 2021; Fartookzadeh et al., 2018)
Reducing construction costs that are deemed unnecessary.	(HORST Construction, 2020; Seyed Ali et al., 2014)
Application of value for money.	(CFI Team, 2022; Junjie, 2018)
Improving project performance and value.	(Landau, 2022; Terouhid, 2022)
Identify and evaluate construction needs and risks involved.	(Ali et al., 2013; Tong et al., 2022)

By observing the benefits of VE, the implementation of VE is carried out at one of these project development stages: the initial concept phase or the early design phase. During this research, VE was carried out in the early design stage.

3. RESEARCH METHODOLOGY

In order to meet the research objectives, the study will use a qualitative approach by involving experts' concepts, opinions, experiences, and previous studies to generate new research ideas (Cropley, 2023). The value engineering in the study follows the VE job plan and collaborates with a varied background in the process.

The research process commences with identifying the problems that require assessment and formulating research problems. Then the researchers studied related documents, literature, and benchmarking to obtain structural and operational variables for port design supporting regional development. Furthermore, the researcher continued the research with the appropriate literature, standard, or policy study analysis method to achieve the research objectives. Researchers arrange the stages of research to be carried out so that research can be more effective and efficient in producing the expected output.

3.1 INFORMATION PHASE

In this stage, data gathering is practically used to identify the project's justification in more detail. The data and information are generated from the existing government-related port. A Citra Sabut port belongs to PT ITCI Hutani Manunggal (IHM). The port is closest to the core area of IKN, which known as *Terminal Kepentingan Sendiri* (Private Port), where the terminal is located within the scope of the company's work and is used to support all main business activities of the company only (Regulation of the Minister of Transportation Number PM 51 of 2011). With an area of approximately 4,600 m^2 and a 9–13.5-meter shipping depth, this port serves the flow of goods through heavy equipment and the delivery of the company's industrial products. The port is about 8.2 km from the IKN location, with the condition that the road is still a logging road. Existing port facilities include docks where ships dock, loading and unloading areas, and storage warehouses. However, basic facilities, navigation, and loading and unloading facilities are still inadequate (Refer to Figure 3).

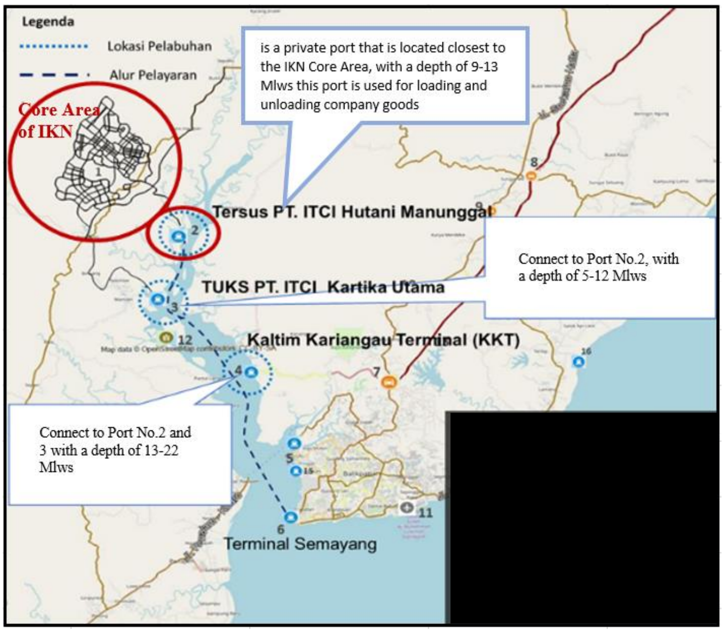

Figure 3: Location of Citra Sabut port
Source: IKN Plan by Ministry of Transportation (2022)

Apart from that, another existing port belongs to the government, which is named Samboja Port in Muara Samboja (Refer to Figure 4). This port would be the object of research because of its location in the development areas of Kuala Samboja and Muara Jawa, which is appropriate for its planning as an industrial center. Later, Kuala Samboja would be prospective as a centre for agro-industry and the food industry, as well as housing. At the same time, Muara Jawa was intended to be a public service centre for agriculture and fisheries as well as residential housing (Presidential Regulation Number 64 of 2022).

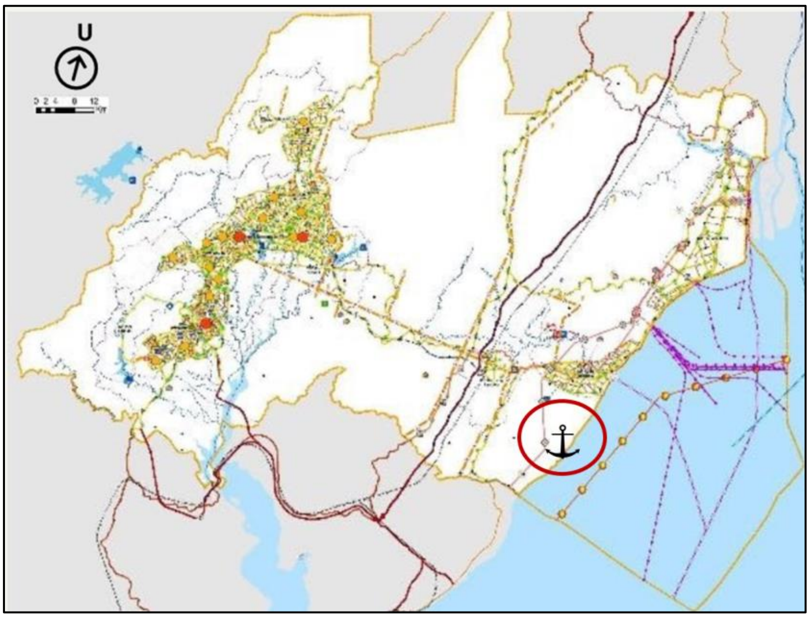

Figure 4: Location of Samboja Port
Source: IKN Plan by Ministry of Transportation (2022)

Samboja Port has a function to support the export and import of crude oil and gas by tankers. With the depth of the shipping lane at 22 meters, this port only has dock facilities and administrative offices, and there is no warehouse or sufficient loading and unloading stacking area (Refer to Figure 5 for actual condition).

Figure 5: The existing condition of Samboja Port in 2022

3.2 FUNCTION ANALYSIS PHASE

Based on existing port data, functional analysis is developed to identify the most beneficial functions for conducting VE studies (Mandelbaum & Reed, 2006). The phase was completed by placing functions by setting up the scope of the problem and ordering functions through a Function Analysis System Technique (FAST) diagram. It is a logical model tool used to identify, classify, develop, and select tasks that contribute to higher value and benefit project development (Refer to Figure 6).

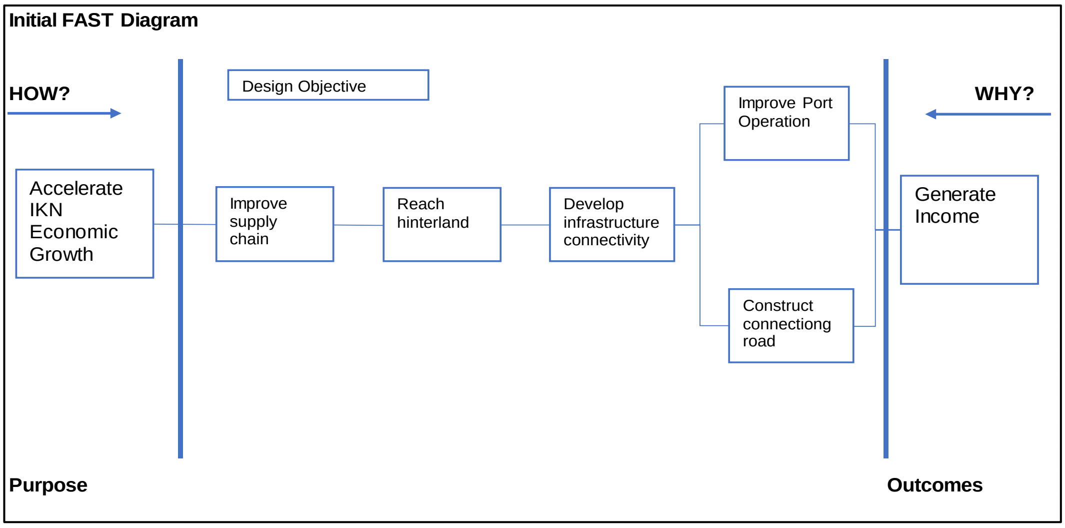

Figure 6: Initial FAST Diagram
Source: Authors (2023)

In the initial stages, researchers conducted a function analysis to accelerate the economic growth of IKN as a manifestation of the National Capital, particularly as a centre for national and international trade that can increase economic growth. To reach these goals, researchers seek to connect the contribution of the supply chain to economic growth in developing countries. Furthermore, it creates opportunities, increases productivity, improves technology and skills, increases employment, and diversifies exports (Solomon, 2013). A supply chain role involves the end-to-end delivery of a product or service. It includes every process from purchasing, manufacturing, inventory management, demand planning, warehousing, transportation, and customer service.

Additionally, efforts to improve the economy should not only be concentrated in certain IKN areas. So economic equality is needed in remote areas. A supply chain of goods or needs can be created if a connected transportation infrastructure supports it. The port is one of the transportation infrastructures with development potential and takes a key role in urban development, starting with local cultural resources and combining economic, logistics, and port industry activities (Louw & Daamen, 2017). Besides that, to reach the hinterlands, ports can be part of a logistics system that connects various logistics facilities and zones (Raimbault, 2019), including access roads. If transportation is built properly, as well as to increase state revenues.

3.3 CREATIVITY PHASE

To generate diverse and innovative ideas that provide the potential for better processes, methods, or services. In this stage, data gathering is practically used to identify the project's development in detail. The data and information are generated from journal articles on port development, as summarised Table 2.

Table 2: Port Facility

No.	Type of Data	Unit of Measurement	References
A	**Structure**		
1	Ship Type	DWT	(Samuel et al., 2009; Sergiu & Alecu, 2020; Yu et al., 2020)

No.	Type of Data	Unit of Measurement	References
2	Quay length	m	(de Boer et al., 2019; Parkison & Kempton, 2021) (Decree of the Director General of Sea Transportation RI, 2019)
3	Water depth	low water springs (lws)	(Decree of the Director General of Sea Transportation RI, 2019; Parkison & Kempton, 2021)
4	Cruise line	m	(Decree of the Director General of Sea Transportation RI, 2019; Pršić, et al., 2011; Samuel et al., 2009)
B	**Port Operational Management**		
5	Administration Building	m^2	(Basanu & Nukina, 2011; George, 2020)
6	Loading unloading area	m^2	(Basanu & Nukina, 2011)
7	Custom building	m^2	(Bichou et al., 2014)
8	Warehouse/storage area	m^2	(Basanu & Nukina, 2011)
9	Connecting Road	km	(Raimbault, 2019)

Following that, functional analysis in the previous stage by considering the project's potential in greater detail. It will update the last diagram of the FAST model by including extended functions and processes. Researchers would carry out creativity analysis to produce many diverse and innovative ideas. The revised concept design is shown in Figure 7.

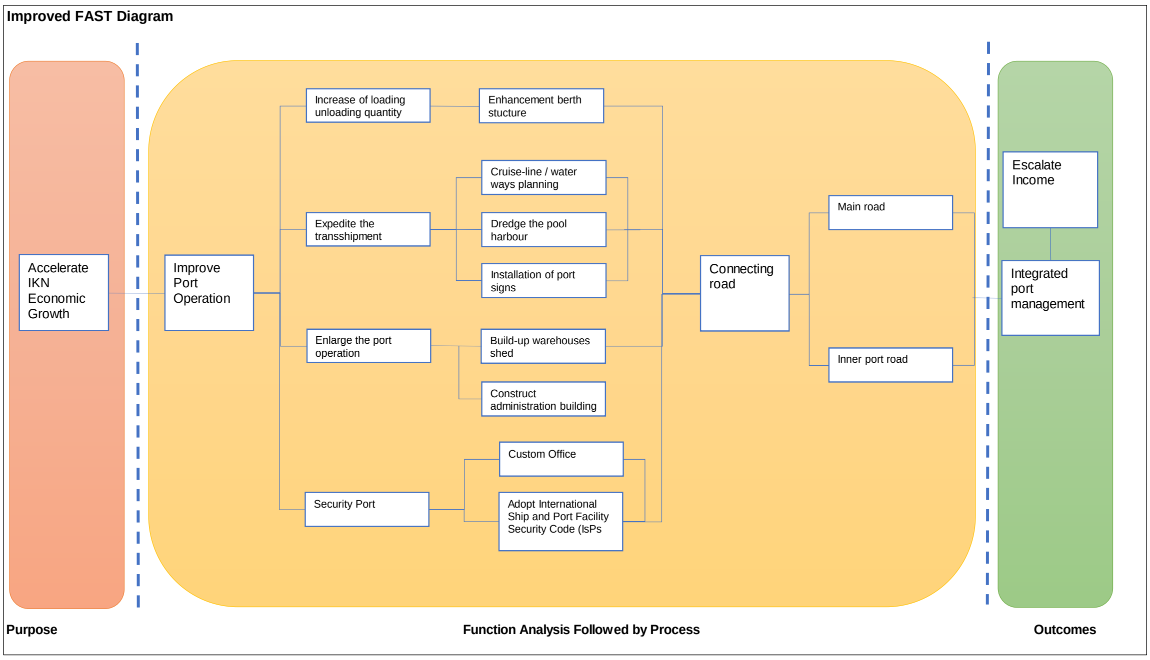

Figure 7: Revised FAST Diagram
Source: Author's processing

In line with the previous initial FAST diagram, in the creativity phase, the author explores by referring to previous research relevant to accelerating the economic growth of IKN related to the outcome of increasing income; it has been formed by the beginning of the study. Based on Table 2, port facilities consist of structural and operational management aspects, both of which are essential to improving the operation of a port.

From these aspects, the researcher analysed the functional approach of each element. Beginning with the structural part, based on the literature, it is stated that the main port requires to be equipped with a quay, shipping lanes, and the depth of the port pool, which supports large ships entering the port smoothly. Then these elements are analysed based on their function to improve port operations that will be developed. The existing quay structure had to be strengthened; this is related to the function of the quay, which is a place for ships to dock and can increase the loading and unloading quantity. Planning for shipping lanes and dredging the water depth will speed up the flow of traffic (entry and exit) of ships and transhipments.

From an operational point of view, the port must also be equipped with several elements to improve port services. Constructing the administration building is expected to carry out the main tasks of office administration, such as recording incoming and outgoing data on transhipments, managing the ship documents, and storing them in a structured manner. Then the port needs to be facilitated by the warehouse. It has the role of storing and moving both raw materials and semi-finished and finished goods that will be sent or received through the port. A warehouse also supports the function of the port as a means of loading and unloading goods. The administration building and the port warehouse have the same function as the port, which is to expand the operation of the port.

The Main Port needs to improve port security in the operational aspect of its function as a national and international trade centre. For this reason, it is necessary to have a customs office to protect revenue and trade facilitation, safeguard society through border control, and provide import and export goods. In addition, adopt the International Ship and Port Facility Security Code (IsPs Code) to establish roles and responsibilities concerning maritime security for governments, local administrations, and ship and port industries at the national and international levels.

However, in terms of validation of the design, a researcher may receive a statement from another researcher and also do the expert judgment procedure, which is a method very often used in the area of risk assessments of complex systems or processes to fill in quantitative data. The expert will be a practical and academic expert with experience in port design and development.

4. DISCUSSION

The development of new marine infrastructure, according to Yu et al. (2020) is relevant to several factors related to sea traffic, such as the type of ship and the size of the structures that will support ship moorings. Another factor mentioned in research by de Boer et al. (2019) and Parkison and Kempton (2021) is that the pier is the most important place or part of the port. This is because the pier is a place to welcome ships to lean on, so there is a close relationship between ships and the pier. When viewed from the flow of sea traffic (Parkison & Kempton, 2021; Pršić et al., 2011; Samuel et al., 2009) shipping lanes are important where it is necessary to pay attention to the waters in terms of depth, width, and other navigational barriers that are considered safe and secure to be navigated by ships. The Port Services function includes: facilities for ship service activities from ships entering, docking, and returning to sail. To support ship service activities, George

(2020) and Basanu and Nukina (2011) state that an area or administrative area in the port is used to ensure that ship loading and unloading operations can be completed efficiently.

Besides that, Port infrastructure in its context supports the number of accommodated logistics, cranes, and terminal areas. In addition to the quality and effectiveness of information systems, the ability to integrate intermodal transportation (roads and rail) and port system management (Tongzon, 2007; Raimbault, 2019). If the volume handled exceeds the port's cargo handling capacity, it will result in port congestion and inefficiency, which can be detrimental to port users. Then the limited access to information on ship arrival will be related to poor information systems, which will slow down the documentation process and port functions. Without the availability of intermodal links, ship users cannot easily move cargo from the port, which can result in delays and high costs.

So that in the end, the entire infrastructure, both in terms of structure and operation, supports the port in its service as a place for loading and unloading goods to support regional logistics dan factor will increase the added value of the port.

5. CONCLUSIONS

The new capital city was decided by the President of the Republic of Indonesia on August 26, 2019, moving the new capital city to East Kalimantan based on Law No. 3 of 2022 concerning the State Capital. The location challenge is to become a logistics supply line connecting the National Capital City (IKN) area in North Penajam Paser, East Kalimantan, and the surrounding area to develop urban areas. By looking at the estimated development of the traffic flow of goods and materials that will occur during the construction and operation of the IKN, it is necessary to plan for the development of port infrastructure.

In the initiation phase, a conceptual design will be carried out. This phase needs to be carried out to understand the actual problems and find solutions for the existing port. This phase is one of the earliest development phases and usually involves creating a number of solutions so that the design direction can be narrowed down slowly (Derelöv, 2009).

Basically, the infrastructure at the port must be ensured so that it can distribute and receive goods effectively, efficiently, and safely because ships are always arriving (Munim & Schramm, 2018). As in the United States, the government is focusing investment on improving port infrastructure in America; this has resulted in the number of vessels doubling over the last 15 years, and tonnage at the top 25 ports grew by 4.4% from 2015 to 2019 due to large carrying capacity ports and harbour operations running efficiently (American Society of Civil Engineers (ASCE), 2021). Therefore, based on the management of previous studies (Table 2), expanding the port area by increasing the area of the warehouse, the length of the quay, and the storage yard would add value to the port.

In addition, to realise the goal of increasing economic growth in IKN, a supply chain development plan is needed that reaches all areas of IKN so that it is connected to a large number of domestic and international trading activities. To support this matter, it is necessary to develop further studies about the relationship between ports and supporting roads as distribution centres and the consolidation of goods according to their function as nodes in the transportation network. Certain activities that can be developed to support the port area include those in the warehousing, industrial, agricultural, or tourism sectors.

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CONFLICTING SITUATIONS AFFECTING PERFORMANCE OF CONSTRUCTION WORKERS AT SITES

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ABSTRACT

The construction industry is labour-intensive, and any conflict involving workers affects the project's overall performance. The present study identified potential conflicting factors and assessed the relative influence of those factors on the performance of workers. A total of nine conflicting factors were identified based on relevant literature. A questionnaire survey was prepared, and responses were collected from workers by visiting four construction sites in India. The data was then analysed using descriptive statistical methods. It was found that payment delay and overworking were the most influential conflicting factors on worker performance. Inadequate resources, lack of communication, lack of education/training, time pressure, and factors related to workplace environments such as noise and dust were also identified as contributing factors to worker conflicts. In contrast, lack of safety and low-risk perception were identified as the least impactful on performance. Addressing these conflicting factors can improve worker performance and job satisfaction, improving the project's overall performance. The study's findings can serve as a guide for employers and managers to create a positive work environment and address the difficulties faced by construction workers at job sites.

Keywords: *Conflict; Conflicting Factor; Construction Sites; Construction Worker.*

1. INTRODUCTION

The construction industry is regarded as the backbone of the global economy due to its significant contribution to global gross domestic product and employment (Tariq & Gardezi, 2022). The construction industry has a substantial impact on job creation. Globally, the construction industry employs more than 220 million people (International Labour Organization [ILO], 2020). Infrastructure development, an output of the construction sector, is a vital indicator of a country's success and global reputation, as it helps fulfilling the population's social demands. The importance of the construction industry to any economy is well documented in the literature (Carvajal-Arango et al.,

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2021; Durdyev & Ismail, 2012; Tariq & Gardezi, 2022). Hence, any issue affecting the construction industry's progress would impact the global economy.

Furthermore, Carvajal-Arango et al. (2021) argued that due to the large amount of manual work involved in the construction industry, it is considered to be a labour-intensive industry. The execution of a construction project takes place at construction sites, which employ human resources at every level. The project managers, site supervisors, safety managers, and construction workers are all essential for the completion of the project within the planned time, cost, and quality. The performance of these critical human resource contributors is determined by their knowledge, experience, skills, and decision-making ability (Hussain et al., 2020) which in turn increases work productivity, quality, and safety.

Although knowledge, experience and communication are essential skills to possess by the individuals at the site, the performance of a project can be hugely impacted by certain conflicting situations (Assaf, 2006). These conflicting situations that occur between the construction personnel at a personal or professional level have a negative impact on project deliverables. Construction sites are often characterized by dynamic and complex work environments requiring workers to navigate competing demands. This can lead to a range of conflicts that workers experience daily. Conflicts arise due to issues in certain aspects of a project, such as time, money, employment, payment, the quality of work, communication, administration, and management (Tariq & Gardezi, 2022). It may be due to differences in individual perspectives, approaches, objectives, and goals. In addition, as the construction industry is a complex and competitive environment in which workers with diverse perspectives, talents, skills, and knowledge collaborate, they set their goals and expectations to maximize their personal and professional benefits in their way. The growing number of workers from diverse cultural backgrounds in the construction value chain means more interactions and disagreements, whether contractual or social, increasing the number of construction disputes (Kumaraswamy, 1998). This can affect work relationships and mutual trust, lowering overall performance (Tariq & Gardezi, 2022) and resulting in adverse outcomes such as project delays, cost overruns, and poor quality of construction. Therefore, it is important to establish a conflict management process in a pre-project planning phase (Yang et al., 2014) that encompasses a wide range of activities, including communication, problem-solving, dealing with emotion, and understanding (Pondy, 1992; Putnam & Poole, 1987; Tinsley & Brett, 2001).

This study addresses the subject of conflict among construction workers through the following two research questions:

- What is considered a conflict for a worker on construction sites?
- How influential is each conflicting factor in impacting construction workers' performance?

The answers to the above-mentioned research questions will lead to identifying the conflicting factors and how each factor affects worker performance. The present study does not explore the issue of workplace conflict from the management perspective, such as considering the perception of managers on worker conflicts or exploring the effects of worker conflict on top management. Instead, this study focuses on identifying factors based on relevant literature and assessing them using the workers' opinions. Interpreting the influence of potentially conflicting factors for a worker will allow the construction industry to identify the shortcomings and further implement remedial steps to improve the performance of the construction workforce. For example, an organization can use the findings of this study to pre-plan and mitigate possible conflicts among workers. This will benefit project managers to keep running the projects on time by mitigating the conflicts among construction workers amicably.

2. LITERATURE REVIEW

2.1 CONFLICT

Conflict is defined as 'to be in opposition to one another'. It refers to disagreements between people or members of an organization. Such disagreement is inherent in relationships between all human beings (Thakore, 2013). Rauzana (2016) defined conflict as a dispute between elements or opposite thoughts in a project. Further, Brown (1993) highlighted that doubt, questioning, opposition, incompatible behaviour, controversy, antagonistic interaction, and disputes constitute a conflict. The impacts of these conflicts on workers can be significant, leading to adverse outcomes such as reduced job satisfaction, stress, and burnout (Jaffar et al., 2011). In addition, conflicts can also have broader impacts on construction projects, such as delays and cost overruns. Addressing these conflicts requires a proactive approach that involves understanding the root causes of conflicts, developing effective communication and conflict resolution strategies, and creating a culture that prioritizes worker safety and well-being.

Conflicts can be internal or external. Internal conflicts arise when workers experience conflicting goals or values within themselves (Aubert, 1963). For example, workers may struggle to balance their safety with job responsibilities, leading to anxiety and stress. Similarly, workers may experience conflicts between their values and work demands, such as when asked to cut corners on safety procedures to meet project deadlines. On the other hand, external conflicts arise when workers experience conflicts with others within their work environment. This can include conflicts with supervisors, co-workers, clients, or the general public. For example, workers may experience conflicts with supervisors over working conditions or safety procedures or with clients over project timelines or specifications. Workers may also experience conflicts with the general public, who are impacted by construction activities, such as noise or disruptions to traffic.

Although conflicting situations in a workplace inhibit the performance of at least one of the parties involved, Rauzana (2016) proposed that conflicts also have certain advantages. One suggested advantage is that conflict can provide information and new ideas, ultimately improving decision-making quality. Furthermore, it can force the parties involved to think about and reconsider their perspectives while bringing previously interred problems to the surface, allowing the leadership to assist in finding the best solution for the project. Lastly, it can also teach mutual understanding and respect for differing viewpoints.

2.2 CONSTRUCTION WORKER PERFORMANCE

As mentioned, the construction industry's major problems are declining productivity and a lack of performance standards for construction workers (Shehata & El-Gohary, 2011). The numerous factors that affect worker performance can be classified into three types: factors related to the industry, factors related to management, and factors related to workers. Design factors include repetition and complexity, building codes, construction technology, laws and regulations, job factors (job duration, size of the job, and type of job), environmental factors (adverse, uncertain weather and seasonality), and site location are all industry-related factors. Next, management-related factors include planning and scheduling, leadership, motivation, and communication. Lastly, labour skills, motivation, and availability are all worker-related factors. Workers must have the ability and knowledge to perform the task skilfully, and the unavailability of a trained workforce will undoubtedly affect labour productivity (McNally & Havers, 1967).

Improvements in project performance due to advances in labour skills have long been sought after in the construction industry. It is well accepted that project performance is predicated on the capabilities of the labours during project execution, whose talents and abilities can affect project progress to varying degrees. A study by Tabassi et al. (2019) analyzed how conflict resolution can improve performance in such contexts by mediating the level of team collaboration. As conflicts among workers impact their ability to perform well, it is essential to analyze worker conflicts with the aim of enhancing worker performance at sites.

2.3 CONFLICT IN CONSTRUCTION

Assaf (2006) conducted a questionnaire study that identified the causes of delays in a construction project. Payment delays, change of orders and suspension of work by the owner were a few direct situations that reduced the efficiency of workers, causing the delay. Some indirect problems faced at the worker level were the nationality of workers, personal conflicts among workers, low productivity level among workers, labour shortage, and lack of skilled workers. Some external factors involved were effects of subsurface conditions, delay in obtaining permits from the municipality, hot weather effect on construction activities, rain effect on construction activities, unavailability of utilities on site, the effect of social and cultural factors, traffic control at the job site and accidents during construction.

The high cost of conflict resolution in projects is a critical characteristic of the construction industry. Ng et al. (2007) discussed the dynamic nature of conflicts in terms of their evolution and escalation within a project and the interaction between conflicts and dispute avoidance and resolution techniques. The study explored conflicts under two broad categories – organizational and uncertainty, which were further split into the process and people involved. In the process category, various situations observed were due to performance, quality, payment, and poor communication. In the people category, misunderstandings, culture, language, communication, work habits, and lack of team spirit were identified as the major conflicting situations. Some uncertain areas were further divided into external or internal factors. Social impacts, weather, and unforeseen site conditions were considered external factors. In contrast, the workmanship was considered a source of internal conflict.

Carvajal-Arango et al. (2021) discussed the aspect of the workplace well-being of construction workers, as it has proven to be precarious during the construction process. Most approaches to construction workplace well-being have been top-down, objective rather than subjective, and excluded perceptions and opinions of workers about their work. Construction workers were observed to be more socially and economically vulnerable due to their work-life imbalance, increased risk of accidents on site, long hours of repetitive work, occupational diseases, and, ultimately, poor quality of life (Carvajal-Arango et al., 2021). Moreover, it was suggested that manual construction is intensely physical and fatigue-inducing. This can lead to muscle and joint pain and poor working posture creating ergonomic risk and ultimately resulting in poor productivity and efficiency. The main reasons for these unfortunate but avoidable outcomes are lack of supervision and inadequate safety conditions on site. This generates a potential risk of accidents and deterioration of physical and mental health. Some work sites conditions like noise and air pollution, unhygienic environment, continually changing climatic conditions, and poor eating habits lead to alcohol/drug use, putting workers' health at risk. In addition, other factors like excessive workload, inadequate salary, and disinterest in work lead to conflicts. In interviews conducted by Carvajal-Arango et al. (2021) with construction workers, one of the statements was, *"I have to work in construction, but I don't like it. My colleagues also think that because they have to, not because they want to, as they say"*. Therefore, most workers' opinions regarding their sense of work are negative, mainly due to the lack of choice to work in sectors other than construction.

3. RESEARCH GAP

In summary, the literature review indicates that although conflicting situations involving workers considerably affect their performance, only a limited number of studies have evaluated conflict-oriented factors in construction. Few studies assessed conflict outcomes at the management level in construction but not at the workers' level (Alazemi & Mohiuddin, 2019). In addition, some studies that identified conflicting situations at the workers' level are based on theoretical constructs (Thakore, 2013). Furthermore, data-based studies on conflicting factors, specifically at construction sites, involve the perception of managers and engineers rather than the opinions of site workers, which poses a significant research gap. This study attempts to address the research gap by identifying the conflicting factors for workers and evaluating the impact of those factors on worker performance by involving the construction workers and gathering their insights. As a result, the effect of workers' conflict on project performance can be thoroughly understood for the project to be executed under the given constraints.

4. RESEARCH METHOD AND ANALYSIS

4.1 IDENTIFICATION OF CONFLICTING FACTORS

Scopus and Google Scholar repositories were used to select research articles for a literature review. A three-level keyword screening structure method (Cong et al., 2022) was adopted to search for the relevant studies: the first-level context keywords defined the search context, i.e., the construction sector; the second-level topical keywords narrowed the scope, i.e., conflict and related terms; and the third-level subject keywords limited the search to target subjects, i.e. workers.

With the help of the screening method, a set of 21 peer-reviewed English language articles were obtained. Initially, 25 factors were identified as potential 'conflicting factors' based on a thorough review of the articles. A discussion on the 25 factors was carried out with four experts, including two academicians and two construction managers, each having more than 15 years of experience in construction. The discussion aimed to check the appropriateness of the identified factors and ensure no significant factors were left out. Many factors were identified during the discussion as repeated or depicting the same meaning, which were omitted or grouped to make one factor. For example, training, illiteracy, and education were clubbed together under the same factor, *lack of training*. At the end of the discussion, the 25 identified factors were narrowed down to 12 conflicting factors that were exhaustive, and the experts suggested no further changes.

Subsequently, the 12 factors were classified into internal and external conflicts based on the characteristics of a conflict (Aubert, 1963; Thakore, 2013). An internal conflict is a conflicting situation that arises within an individual (I1), whereas an external conflict is a conflict that occurs between multiple parties (E1). The four experts who narrowed down 25 factors to 12 conflicting factors have further categorized the 12 conflicting factors into internal and external factors. The experts have set the parameters, based on the outcome of the conflict, for categorizing the factors into internal and external conflicting factors. Three parameters – affects well-being (I2), work constraints (I3), and lack of clarity (I4) – were identified for internal conflict. On the other hand, two parameters – opposition to one another (E2) and motive to frustrate (E3) – were recognized for external conflict. A factor should satisfy at least one parameter to be classified as an internal or external conflict. When a factor satisfies parameters under both the internal and external classifications, the number of satisfying parameters is counted. If a factor satisfies more parameters under internal than external, the factor is classified as an internal factor, and vice versa. If the factor satisfies the same number of parameters under internal and external classifications, the factor is termed an internal-external conflicting factor. In addition, if the factor does not satisfy any of the parameters, that factor is removed for further analysis. Using a brainstorming approach, all the experts have classified all the 12 factors into internal, external, and internal-external factors based on the developed method. The results of the classification are shown in Table 1.

Table 1: Classification of conflicting factors

Sl. No.	Conflicting Factors	Internal			External		Source(s)
		I2	I3	I4	E2	E3	
1.	Payment delay[2]	✓			✓	✓	(Assaf, 2006; Carvajal-Arango et al., 2021)
2.	Inadequate resources[1]		✓	✓	✓		(Tariq & Gardezi, 2022)
3.	Lack of communication[3]		✓	✓	✓	✓	(Ng et al., 2007)
4.	Lack of training[1]		✓	✓			(Barriuso et al., 2021)
5.	Workplace environment[3]	✓				✓	(Choi et al., 2021)
6.	Overworking[2]	✓			✓	✓	(Carvajal-Arango et al., 2021)
7.	Time pressure[3]	✓	✓		✓	✓	(Assaf, 2006; Mashwama et al., 2019)
8.	Low-risk perception[3]		✓		✓		(Wong et al., 2020)
9.	Lack of safety[3]	✓				✓	(Wong et al., 2020)
10.	Uncertain site conditions						(Ng et al., 2007; Mashwama et al., 2019)
11.	Unsafe behaviour						(Zhang et al., 2023)
12.	Labour strikes						(Mashwama et al., 2019)

[1]internal conflict, [2]external conflict, and [3]internal and external conflict

Table 1 shows that out of 12 factors, only nine were classified under internal, external, or internal-external factors. The three factors – *uncertain site conditions*, *unsafe behaviour*, and *labour strikes* – were identified as an outcome of a conflicting situation rather than a conflicting factor by itself. Therefore, based on the discussion, nine 12 potential factors were retained as conflicting factors for further analysis.

4.2 DATA COLLECTION USING SURVEY

The data was collected from construction sites in and around Guwahati, India, through purposive sampling. The sampling unit considered for this study was construction workers. Before circulating the questionnaire among all the workers, the language and understanding of the question statements were pilot-tested at the site with three construction workers. Four construction sites were visited, and 50 workers (semi-skilled and unskilled) were surveyed from January to March 2023. The construction workers primarily belonged to one of the three trades: bar benders, carpenters, or masons. Most of the surveyed workers were male, and only four were women. 56% of the workers were between the age of 18-24 years, 40% were between the age of 25-35 years, and only two workers were above 40. Over 75% of the workers had a site experience of 1-5 years, and 16% had an experience of 5-10 years working at sites. Two workers had an experience of less than one year and more than 15 years, respectively. All the workers involved in the study were working 10-hour shifts. Since most of the workers were unlettered, the respondents were assisted in filling out the questionnaire by their supervisors in the presence of the authors. This was done to ensure effective communication of the survey questions, even in the local language.

A two-part self-administered questionnaire was used as the survey instrument to collect data on the impact of the conflicting factors on workers' performance. Part 1 consisted of demographic data such as age, experience, and gender. Part 2 consisted of statements based on the conflicting factors to measure their impact on worker performance using a 5-point bipolar Likert scale. The responses in Part 2 were measured on a scale of 1 to 5, where 1 = strongly disagree and 5 = strongly agree. An option of 'no opinion' was also provided so that the workers do not feel compelled to answer a question if they do not understand it. This helps to avoid nonresponse bias in the data. The question statements were framed starting with the conflicting factor (along with a description, for example, if necessary), followed by "…affects my performance at the site." For instance, for the conflicting factor *payment delay*, the statement was "Untimely or inadequate payment of wages affects my performance at the site." Similarly, another conflicting factor is the *lack of communication*; the statement was, "Improper communication with management and co-workers affects my performance at the site." An extract of Part 2 of the questionnaire is shown in Figure 1.

Please select an option to rate the following conflict factors with respect to their impact on your performance as a worker on construction sites. Ratings are to be given on a 5-point bipolar Likert scale from 'strongly disagree' to 'strongly agree'.

S. No.	Conflict factors ("…affects my performance at site")	Strongly disagree	Disagree	May or may not agree	Agree	Strongly agree	No opinion
		1	2	3	4	5	
1	Untimely or inadequate payment of wages						
2	Unavailability of proper resources to carry out my job						
3	(Statements based on factors as given in Column 2 of Table 1)						

Figure 1: Extract of Part 2 of the questionnaire

4.3 DETERMINATION OF RELATIVE WEIGHT OF CONFLICTING FACTORS

This study used the median to measure the data's centrality. It is considered a more accurate measure for relatively smaller data sets due to its resistance to outliers (Karakhan et al., 2021). Furthermore, the standard deviation values were generated to measure the agreement of the responses, that is, to check whether the responses were within an acceptable level of dispersion. According to a study by Karakhan et al. (2021), a standard deviation value of 1.64 was adopted as the permissible limit. If the standard deviation of a conflicting factor is 1.64 or below, it is considered that the responses are in consensus. Table 2 shows the nine conflicting factors' median and standard deviation values.

Table 2: Influence of conflicting factors on construction worker performance (n = 50)

Sl. No.	Conflicting Factors	Level of Influence		Relative Weighting Factor
		Median	Standard Deviation	
1.	Payment delay	5	1.13	1.66
2.	Overworking	5	0.54	1.66
3.	Lack of training	4	1.03	1.33
4.	Inadequate resources	4	0.83	1.33
5.	Lack of communication	4	0.82	1.33
6.	Workplace environment	4	0.62	1.33
7.	Time pressure	4	0.62	1.33
8.	Lack of safety	3	0.95	1.00
9.	Low-risk perception	3	0.85	1.00

Based on the values in Table 2, it can be observed that consensus was reached for all of the factors. In addition, the relative weighting factor (RWF) (Karakhan et al., 2021) was used as the metric to assess the level of influence of conflicting factors on worker performance. The RWF for a factor is calculated by dividing its median value by the lowest median value among all the factors. This value gives the level of influence of a factor relative to other factors on a worker's performance at construction sites. The last column of Table 2 reveals the values of RWF for the conflicting factors. In this study, a factor with RWF of 1.00 is considered as moderately influential, and factors with RWF of 1.33 and 1.66 are considered highly and extremely influential factors, respectively.

5. FINDINGS AND DISCUSSION

The study identified the conflicting factors affecting the performance of construction workers at the site. Table 2 shows that the relative weighting factor (RWF) value for the two factors – *payment delay* and *overworking* – is 1.66, which is the highest. This indicates that these factors have an extreme influence on workers' performance at the site. It also shows that the influence of *payment delay* and *overworking* on worker performance is 1.66 times that of factors such as *risk perception* and *lack of safety*, which have an RWF of 1.00. From Table 2, it is evident that along with the two factors: *payment delay* and *overworking*, five conflicting factors have a high influence on worker performance: *inadequate resources*, *lack of communication*, *lack of education/training*, *workplace environment*, and *time pressure*. The following paragraphs provide a detailed discussion of the identified conflicting factors.

Payment delay (RWF = 1.66) is identified as an extremely influential conflicting factor for workers. Delay in payment or inadequate wages is a stressful situation for workers as it is their primary source of income. It places the workers in a conflicting situation with themselves and their employers. The uncertainty of payment date and compensation amount makes it unsettling for workers; hence, they cannot put in their best effort during work. Workers may feel unvalued or disrespected if wages are consistently delayed. This can lead to conflicts if workers doubt management's intentions or think they are being mistreated, which can motivate their frustration. A possible solution to this would be to contractualise the employment of workers with proper clauses highlighting the details of compensation for delay in payment.

Furthermore, *overworking (RWF = 1.66)* leads to physical and mental fatigue, which increases the risk of accidents and injuries. Hence, overworking is a factor of undue influence that workers must be relieved of to improve their performance. Overworked workers experience stress, anxiety, and other adverse health effects, which lead to conflict with their employers. Overworking makes it difficult for workers to balance their work and personal lives. It leads to burnout, a state of emotional, mental, and physical exhaustion caused by prolonged stress. Workers who are experiencing burnout become demotivated and thus less productive. To counter this, employers should set realistic targets for workers and expand the workforce by hiring more diverse and skilled workers. In case overtime is unavoidable, specific incentives may be offered.

It was further found that *inadequate resources (RWF = 1.33)* highly influence worker performance. Shortage or unavailability of resources required to carry out a task puts the worker in an idle position which may lead to internal and external conflict. The worker will then have to either work overtime or increase the work pace, which compromises the safety and quality of the project. When resources are scarce, workers may be forced to prioritise specific tasks over others. This can create conflicts if the tasks are all important and require immediate attention. When resources are limited, workers may be forced to cut corners or compromise on quality to complete tasks. To mitigate this, resources should be prioritised based on critical tasks, and managers should have contingency plans in case resources are unavailable. The schedule of workers may also be decided based on the resource schedule so that the majority of workers can be engaged in tasks. Communication is a crucial part of a project, and lack of it leads to delays, errors, and poor-quality work. The results show that worker performance is highly influenced by a *lack of communication (RWF = 1.33)*. For example, if workers do not communicate effectively about hazards or safety requirements, it can lead to accidents and injuries. Poor communication can lead to mistakes in the construction process. For instance, if workers are not communicated effectively about the specifications or requirements of a particular task, they may end up making mistakes that could have been avoided. Some workers stated that their supervisors briefed them about the work once at the beginning and then were unavailable during the entire task. In addition, if workers do not understand their responsibilities, it can lead to disputes among themselves over who is responsible for specific tasks. Thus, poor communication not only leads to conflicts between the workers and management but also among the workers as well.

Similarly, workers who do not receive feedback or recognition for their work may feel undervalued and demotivated. Lack of communication is closely associated with *time pressure (RWF = 1.33),* another highly influential factor on performance. Workers experience a lack of clarity when they are given conflicting priorities, such as being asked to complete multiple tasks simultaneously. Furthermore, *lack of training (RWF = 1.33)* was acknowledged by workers to be highly influential on their performance. Workers who lack the necessary education or training lack the skills to perform their job effectively. This makes them less aware of standard procedures and safety concerns at the site, making them less competent. Workers not trained in proper safety procedures are at a higher risk of accidents or injuries, which can create conflicts if these incidents impact other workers or management. Lack of education or training also limits growth opportunities for workers as they will not have the necessary knowledge and skills to advance in their careers. This can create internal conflict if workers feel they are being held back or not given opportunities to grow.

Additionally, construction sites are often noisy due to heavy machinery, tools, and equipment use. Exposure to high noise levels causes hearing damage and reduces workers' ability to communicate effectively, increasing the risk of accidents and mistakes. Noise also induces fatigue, stress, and irritability, negatively affecting workers' performance. Sites are also often dusty due to using concrete, cement, and other building materials. Exposure to dust causes respiratory problems such as asthma and bronchitis, which negatively affect workers' health and well-being. Dust also causes eye irritation, skin irritation, and other health issues. Therefore, *workplace environment (RWF = 1.33)* is also revealed to be a highly influential factor for worker performance at the site. Exposure to a harsh physical environment can distract the worker from the task, leading to lowered performance. This is being addressed by the rising safety concerns of project managers and the increasing awareness of site safety over the years, which has led some to preventive measures such as providing workers with PPE.

Lastly, workers do not receive adequate safety training and are not provided with the necessary safety equipment. This puts them at a higher risk of accidents or injuries. However, the results found that *lack of safety (RWF = 1.00)* does not impact workers' performance on construction sites. This can be alluded to the workers being comfortable and used to working without safety equipment. This may also be due to workers' lack of awareness of the importance of safety at the site. Moreover, workers who perceive high levels of risk tend to be more cautious and take appropriate safety precautions (Arezes & Miguel, 2008). In contrast, workers who perceive lower levels of risk are more likely to take risks and engage in unsafe behaviours. For example, one such behaviour is the non-usage of PPEs like helmets and gloves. This may be because the workers feel familiar with the work due to its repetitive nature; hence, their perception of risk associated with that task is reduced. Therefore, workers identified that *low-risk perception (RWF = 1.00)* could moderately influence their performance. Lack of training and communication are some of the causes of their low-risk perception of potential hazards.

6. CONCLUSIONS

The occurrence of conflicting situations at sites has an impact on project performance. The present study addresses two research questions: first, what is considered a conflicting situation for workers on construction sites? And second, how influential is each conflicting factor in impacting construction workers' performance? A thorough literature review was conducted, and nine conflicting factors were finalised using expert opinions. This step addressed the first research question. Next, a questionnaire survey was conducted with workers from four construction sites in Guwahati, India, to answer the second research question. The worker's responses were analysed, revealing three conflicting factors based on the relative weighting factor: extremely, highly, and moderately influential on worker performance. It was found that payment delays and overworking are the most significant factors that can put workers in a conflicting situation with themselves. Inadequate resources, lack of communication, lack of training, workplace environment, and time pressure were identified as the moderately influential conflicting factors on worker performance. Further, the conflicting factors that least influenced worker performance were low-risk perception and lack of safety.

In conclusion, practitioners should target to provide solutions to the conflicting factors, especially those that have extreme and high influence on worker performance, as it leads to a much-improved performance of construction workers on site. Presently, these factors associated with workers are neglected by site managers as they believe it does not contribute much to the success of a project. As a result, workers cannot work at their full potential.

7. LIMITATIONS AND FUTURE RESEARCH

It is important to acknowledge certain limitations of this study. Firstly, the survey was conducted with a few workers in very few construction sites in one region. It may be possible that replicating the study in other geographical areas and with a larger sample can produce additional conflicting factors other than in the present study. Secondly, the results are based on the first-hand opinions of the workers rather than empirically measured data concerning the effect of conflicting factors on performance. The findings of this study will significantly benefit site managers and practitioners in gaining a better understanding of the conflicting situations that workers face at sites. This effort can also open avenues for further studies to explore the conflicting factors in other contexts, such as financial performance, schedule, cost, and working style of upper management.

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CONSTRUCTION AND DEMOLITION WASTE MANAGEMENT ISSUES IN BUILDING PROJECT LIFE CYCLE STAGES: A CASE OF SRI LANKA

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ABSTRACT

The construction industry is rapidly growing in Sri Lanka, leading to an increase in the amount of waste generated from building projects. This waste often ends up in landfills or is disposed of in an unorganised manner, causing environmental and health hazards. While there is a growing body of research on Construction & Demolition (C&D) Waste Management (WM) including Zero waste, there is lack of studies available on the management of WM issues according to the life cycle of building projects in Sri Lanka. Hence, this study aims to investigate the C&D WM issues in Sri Lanka according to the life cycle of building projects. The study adopts a qualitative approach that involves conducting two rounds of expert interviews following the Delphi method and using manual content analysis to analyse the collected data. According to building life cycle, WM issues are categorised as Preconstruction; Construction and Building Renovation; Use and Operate; Demolitions and Repurpose and Material Recovery and Production. The research is significant as it provides insight into the current issues of C&D WM in Sri Lanka and offers recommendations for improvement. By categorising the issues based on the different stages of the project life cycle, it becomes easier to identify where in the process the C&D WM issues are most prevalent and to develop targeted solutions to address them.

Keywords: *Building Project; Construction and Demolition (C&D); Life Cycle Stages; Waste Management (WM).*

1. INTRODUCTION

The building construction consumes up to 40% of global raw materials (Darko & Chan, 2016), generates about 40% of waste (Nasir et al., 2017), and emits about 25% of carbon dioxide (Mahpour, 2018). Hence, it implies the construction industry is one of the highest waste generators globally (Bilal et al., 2020), a sign of unsustainability of the sector (Núñez-Cacho et al., 2018). These issues could be traced to the unsustainable economic approach of "take, make, dispose", otherwise known as linear economy, entrenched in the building construction industry (Bilal et al., 2020). Construction waste generation has been identified as a major issue due to its direct impacts on the environment as well as

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the efficiency of the construction industry (Formoso et al., 2002). A study conducted by Ameh et al. (2013) found that on average 21–30% of cost overruns occurred in construction projects due to material wastage (Udawatta et al., 2015). Currently, the European construction sector produces 820 million tonnes of C&D every year, which is around 46% of the amount of total waste generated.

Furthermore, WM issues have also been increasingly advocated in dealing with C&D waste generated from construction due to global urbanisation and urban renewal. This is particularly urgent in emerging countries where economic development must be sustained by construction activities, while the massive amount of C&D waste generated and accumulated as a grand challenge that the economies have not experienced before. Their capability for waste treatment is meagre given the huge amount of waste generated by the construction sector. The key to tackling the issues arising from C&D waste is to integrally apply the building life cycle (Bao et al., 2019). Moreover, WM issues handling is a significant consideration in sustainable construction (Park & Tucker, 2017).

There is a lack of WM issue categorisation in the life cycle of building projects, despite several studies that have focused on circular economy (CE) and Zero Waste concepts to reduce WM issues. While CE and Zero waste approaches have gained significant attention, there is a gap in understanding how WM issues vary across different stages of a building project's life cycle, which is critical to develop targeted and effective WM strategies. This research aims to address this gap and provide a comprehensive understanding of WM issues in the context of life cycle of building projects in Sri Lanka. This paper is structured as follows. First, it provides a comprehensive literature review on C&D waste management and issues. Next, the research method, comprising data collection and data analysis is elaborated. This is followed by the findings and conclusions.

2. LITERATURE REVIEW

2.1 CONSTRUCTION AND DEMOLITION WASTE

The production and manufacture of building components, along with the construction process itself, involves the extraction and movement of 6 billion tons of basic materials annually, or 40% of extracted materials in the US (Kibert & Kibert, 2008). In addition, the US construction industry contributes to a large amount of waste to the municipal solid waste stream (Yuan et al., 2012). Building related C&D waste in US was estimated to be 143 million metric tons. As a result of waste generation, contractors have to bear loss of profit due to the involvement of additional overhead costs and delays, loss of productivity due to additional time involvement for cleaning and considerable waste disposal costs. Construction waste generation not only has cost implications for handling processes but also consumes valuable land due to disposal activities (Hao et al., 2007). Furthermore, the industry cannot continue to practice if the environmental resources on which it depends are depleted. Thus, the significance of WM needs to be understood in order to encourage stakeholders to achieve goals related to WM (Manowong, 2012).

2.2 CONSTRUCTION AND DEMOLITION WASTE MANAGEMENT IN CONSTRUCTION INDUSTRY

C&D WM have become one of the major environmental problems in both developed and developing countries. It has been a pressing issue in Hong Kong since the late 1990s.

Tremendous amounts of C&D waste have been generated from ongoing new construction works, as well as renovation and demolition work (Hao et al., 2007). The C&D waste has been increased which has been resulted from the extensive building and infrastructure development projects as well as redevelopment of old districts. The quantity of construction waste has increased from 8,000 tonnes in 1991 to 20,000 in 2004 (Hao et al., 2008).

On the other hand, management measures to reduce C&D waste at the project level have also attracted widespread attention (Bao et al., 2019). Previous studies have suggested some major variables affecting the overall effect of C&D waste reduction, including design change, investment of C&D WM, government regulations, site space for performing WM, low-waste construction technology, and WM culture within an organisation. Particularly, Yuan et al. (2012) described the design change occurring during construction is perceived as one of the most significant sources resulting in C&D waste because Osmani et al. (2008) estimated that around 33% of on-site waste is related to project design. Government regulations also play a critical role in C&D waste reduction by developing and fostering the regulatory environment for waste reduction (Karavezyris, 2007). Site space for performing WM activities is regarded as a significant variable by (Wang et al., 2010) as without a space layout pre-planned, the temporary placement of sorting facilities and implementation of WM activities might disarrange other construction activities.

2.3 ISSUES IN ACHIEVING SUSTAINABLE CONSTRUCTION AND DEMOLITION WASTE MANAGEMENT

Execution of WM in attaining sustainable construction still does not assist the stakeholder practices in the construction. It is also supported by Shafii et al. (2006) who stated that the lack of demonstration of tools and approaches made it difficult for stakeholders to deal with the waste created during construction. It might be caused by several complicated activities in construction associated with aspect planning, which probably reflect three main important elements in construction: which are time, money and material (Ismam & Ismail, 2014).

Regulatory practices related to issues in each area, lack of waste treatment methods, lack of coordination, poor performance of stakeholders, lack of eco-friendly awareness and information campaigns, and problems enforcing WM in C&D policies. Besides sound administrative management, progressive activities are also required (Crawford et al., 2017). In the absence of government policies, there are no incentives for support or local government interests where the old construction methods are being utilised (Liu et al., 2020). Actions of stakeholders, lack of actual financial subsidies, and lack of reward and penalty schemes can be destructive for WM in C&D operations (Chen et al., 2002). Improper C&D waste disposal has also been recognised as a factor. Due to these factors just stated, illegal dumping reached nearly 60% (Chen et al., 2021). Also, contributing to this there is a deficiency in research and development practices and a lack of extensive skills and special training among people who are working in this field. To see improvement in the area of WM in C&D, there is a need for effective professional practices from all C&D practitioners. Other issues that China is facing with regards to WM in C&D are incomplete policies and standards, lack of market acceptance and inadequate off-site construction development conditions (Yuan, 2013). As depicted in literature, previous researchers have classified waste management issues into several categories, which include managerial, financial, educational and environmental, socio-cultural, technical, government, economic, and market issues. The research findings section provides detailed information on the relevant waste management issues within each of these categories, taking into account the Sri Lankan context.

2.4 LIFE CYCLE OF A BUILDING PROJECT

The focus on a building's life cycle should guide decision-making in selecting the most appropriate technology and minimising the environmental impact of structures through thoughtful design or renovation. Buildings that appear to be cost-effective in the short term may have significant maintenance or waste management expenses, and elevated items may have extraordinarily high production costs never get recovered (Esa et al., 2017). Although different life cycle stages have been identified by many authors, this paper adopted five life cycle stages, Preconstruction; Construction and Building Renovation; Use and Operate; Demolitions and Repurpose; and Material Recovery and Production based on the categorisation done by Akanbi et al. in 2018, Esa et al. in 2017, and Yeheyis et al. in 2013.

3. METHODOLOGY

The Delphi technique is the well-received method of getting expert opinions on a certain knowledge area (Mansour et al., 2022). It aims to obtain a consensus among a panel of experts on real-world issues that are often intangible (Gad & Shane, 2012). The Delphi qualitative method was chosen as the research approach for this study. For this investigation, fifteen (15) interviews as Delphi round 1, ten (10) interviews as Delphi round 2 of expert interviews were conducted for about seventy to eighty minutes per each round with experts in the built environment and analysed them according to the experts' opinions through manual content analysis. These experts are selected based on the purposive sampling method.

According to Coy (2019), judgment sampling is used in the purposive sampling technique. It is commonly used in Delphi qualitative research to discover and pick the most information-rich examples in order to make the most use of available resources of C&D WM issues in Sri Lankan construction industry. The researcher determines what information is required and sets out to discover people who can and will offer it based on their knowledge or experience. Thus, the sample is purposefully determined and based on the researcher's judgment in relation to the research aim. Purposive sampling allows the selection of interviewees who are knowledgeable and interested in the selected area of study (Rai & Thapa, 2015). According to Grime and Wright (2016), a Delphi qualitative survey establishes the relevant diversity within that population. A review of the collected papers shown in Table 1 shows the existing issues in C&D WM.

Table 1: Expert profiles

Coding for Panel Experts	Designation	Delphi Rounds		Years of Experience	Criteria						Accessibility
					Compulsory Qualification		Additional qualifications (Satisfy at least three of the following criteria)				
		Round 1	Round 2		C1	C2	A1	A2	A3	A4	
I.01	Managing Director	✓	✓	25 years	✓	✓	✓	✓	✓	✓	✓
I.02	Senior Professor	✓	✓	20 years	✓	✓	✓	✓	✓	✓	✓
I.03	Senior Lecturer	✓	✓	19 years	✓	✓	✓	✓	✓	✓	✓
I.04	Contract Administrator	✓	✓	20 years	✓	✓	✓		✓	✓	✓
I.05	Environmentalist	✓	✓	10 years	✓	✓	✓		✓	✓	✓
I.06	Senior Quantity Surveyor	✓	✓	16 years	✓	✓	✓	✓	✓	✓	✓
I.07	Director	✓	✓	24 years	✓	✓	✓	✓	✓	✓	✓
I.08	Construction Engineer	✓	✓	22 years	✓	✓	✓	✓	✓	✓	✓
I.09	Project Manager	✓	✓	18 years	✓	✓	✓	✓	✓	✓	✓
I.10	Planning Engineer	✓	✓	12 years	✓	✓	✓	✓	✓	✓	✓
I.11	Senior Civil Engineer	✓		18 years	✓	✓	✓	✓	✓	✓	✓
I.12	Supervisor	✓		11 years	✓	✓	✓	✓	✓	✓	✓
I.13	Senior Architecture	✓		21 years	✓	✓	✓	✓	✓	✓	✓
I.14	Senior Facility Manager	✓		14 years	✓	✓	✓	✓	✓	✓	✓
I.15	Quality Controller	✓		17 years	✓	✓	✓		✓	✓	✓

C1: Knowledge and a better understanding of construction WM and CBE practices
C2: More than 10 years of experience in the C&D industry
A1: Graduate in a construction-related discipline
A2: A Postgraduate degree related to Construction Management or WM
A3: Corporate Member of a Professional Institution
A4: Practical Experience/ Research Experience in WM and CBE

As per the criteria given in Table 1, every expert had to fulfil the above compulsory qualifications, and at least three additional qualifications must be fulfilled. A wide range of information from different perspectives could only be achieved if the sample of building experts was selected from different professions. Furthermore, selecting professionals having more than 10 years of industrial experience in C&D industry specially in building projects.

4. RESEARCH FINDINGS

4.1 DELPHI ROUND 1 – CURRENT ISSUES OF CONSTRUCTION AND DEMOLITION WASTE MANAGEMENT IN SRI LANKA

During Delphi round 1, experts were asked to identify current applicable WM issues of C&D in Sri Lanka especially considering building projects. At the end of the Delphi round 1, six (6) managerial issues, five (5) educational and environmental issues, seven (7) financial issues, three (3) market issues, five (5) government issues, five (5) cultural issues, five (5) economic issues and three (3) technical issues were identified out of literature findings. In addition, four (4) managerial issues, three (3) educational and environmental issues, two (2) financial issues, two (2) market issues, two (2) government issues, one (1) socio-cultural issue and one (1) economic issue were suggested by the interviewees as WM issues and are indicated in bold letters. Hence, applicable WM issues in the Sri Lankan construction industry were listed and carried forward to the second round of the interview. Table 2 indicates the current C&D issues of WM in Sri Lanka.

Table 2: Construction and demolition issues of waste management in Sri Lanka

WM Issues Type	WM Issue
Managerial Issues	Weak waste characterisation
	Insufficient resources
	Inconsistency in making policies
	Lack of communication among participants
	Delay of material delivery
	Poor management of materials
	Unawareness of software usage
	Lack of supervision
	Incorrect decisions
	Improper energy management
Educational and Environmental Issues	Inadequate training for workers
	Attention on housing deficit than environmental impact
	Limited knowledge of designers
	Lack of healthcare waste handling training
	Lack of education in waste management
	Not producing waste management specialists
	Lake of environmental policies, acts, standards
	Lack of environmental impact assessment practices
Financial Issues	Cost of project
	Absence of economic penalisation
	Lack of recycling market
	Unsafe market and inflation of prices
	Finding financing in start-ups is difficult
	Need for investors
	Lack of financing from the government
	Financial market instability

WM Issues Type	WM Issue
	Insufficient financial resources
Market Issues	Rapid changes in markets, e.g., restrictions on exports or costs for recovering wood waste
	Business secrecy can hinder development projects
	Business competition in developing new waste-based products who gets the materials
	The biogas market's dependency on energy markets
	Unclear if waste materials will be available if legislation changes (e.g., division of responsibilities)
Government Issues	Negligence attitude of the government
	Inconsistent in making policies
	Public procurement lacks circular requirements
	Secondary material markets lack support from the government
	Lack of policy
	Political instability
Socio-cultural Issues	Lack of communication between designers and clients
	Insufficient gender equality in construction projects
	Perception that waste will never be eliminated
	In developing new products and services, forecasting consumer behaviour is difficult
	Remote locations prove challenging for networking
	Inadequate health on construction sites
Economic Issues	Economic savings and revenue models are difficult to assess because of the lack of data on access to and availability of waste
	Long distances and efficiency of logistics in waste collection
	Incineration is cheaper for companies than recycling
	Lack of processors/refiners of waste-based materials
	Schedules in business are tight, which hinders cooperation
	Virgin materials are cheap compared to recycled materials
Technical Issues	Lack of waste disposal charge
	Incomplete design
	Poor performance strategies

Some of the administrative issues impeding successful C&DW administration were weak waste characterisation, insufficient resources, and delayed material supply. According to **I.02** *"Waste characterisation information assists in planning how to decrease waste, set up recycling programmes, and preserve money and resources according to managerial decisions"*. Furthermore, **I.08** explained, *"Waste characterisation tools on this site may be used by local government planners, transporters, and recyclers to estimate the quantity of certain items in their waste stream"*. Although, the majority of the interviewees agreed for this software unawareness is considered as the main issue of WM. **I.07** mentioned, *"Lack of supervision can negatively impact construction waste management by leading to poor waste sorting, inadequate storage and disposal practices, and a lack of adherence to regulations"*. **I.03**, **I.06,** and **I.12** conferred, a corresponding idea of supervision, and it mitigates these effects, it is important to establish clear guidelines and procedures for WM, as well as regular monitoring and enforcement to ensure compliance. Additionally, providing education and training for construction workers on proper WM practices can help to promote responsible behaviour.

Furthermore, the rise in waste material prices as a result of unstable market conditions reduces workers' motivation to separate garbage for recycling and reuse. **I.02** deliberated, that the absence of economic penalisation in Sri Lanka for WM refers to the lack of financial penalties or disincentives for individuals or organisations that do not properly manage their waste. This means there is no cost for improper disposal of waste and as a result, WM practices may be neglectful or inadequate. **I.06**, **I.09, and I.14** proclaimed, in Sri Lanka for WM signifies the situation where the WM industry operates in an unregulated manner and the prices for WM services are artificially increased. According to the majority of interviewees' explanation, market issues in construction WM indicate challenges faced by the industry in properly managing and disposing of construction waste. These issues can result in environmental problems and inefficiencies, making it difficult for the construction WM industry to effectively serve its customers. **I.04**, **I.05**, **I.08**, and **I.09** established, changes can lead to changes in the demand for waste materials, which can affect the waste collection, processing, and disposal. These fluctuations in market conditions can challenge WM operations, making it difficult to maintain consistent and effective WM practices. According to **I.10** stated, *"the competition to obtain waste materials for these products can have an impact on construction waste management in Sri Lanka, as businesses may prioritise acquiring waste materials over disposing of them properly".* This can result in increased waste generation, illegal dumping, and other environmental issues if waste materials are not managed properly in the country.

In Sri Lanka, secondary material markets for construction WM are hindered by a lack of government support. This includes insufficient funding, regulations, and infrastructure, leading to challenges in managing and disposing of construction waste. As a result, these markets struggle to develop and contribute to sustainable WM practices. **I.06** stated, *"The government can address these challenges by providing support and resources to these markets, promoting sustainable Waste Management practices and a healthy environment".* Socio-cultural issues have a significant impact on WM and construction in Sri Lanka. **I.03**, **I.05,** and **I.09** emphasised, one major issue is the lack of proper waste disposal habits among the population, leading to littering and illegal dumping in urban and rural areas. This results in environmental degradation, and health hazards and it also affects tourism. Another issue is the inadequate infrastructure for WM, leading to the absence of organised collection, transportation and disposal of waste. There is also a lack of education and awareness among the public regarding the importance of WM and its impact on the environment. These socio-cultural issues, if not addressed, will continue to pose challenges in implementing effective WM and construction practices in Sri Lanka.

Furthermore, the absence of refiners and processors of construction waste also means that valuable resources are being wasted and not utilised to their full potential. According to **I.15** stated, *"Poor performance strategies in construction waste management can lead to negative outcomes for both the environment and the economy. One of the main issues is the lack of proper planning and coordination, resulting in ineffective waste management practices".* This leads to waste being generated unnecessarily, leading to increased costs for waste disposal and increased environmental degradation. Further, most of the interviewees argued, another issue is the lack of incentives for waste reduction, reuse, and recycling, resulting in waste being treated as a low priority by construction companies. Additionally, there is often a lack of investment in WM infrastructure and technology, resulting in a limited capacity for processing and recycling waste materials.

4.2 DELPHI ROUND 2 - CURRENT C&D WASTE MANAGEMENT ISSUES ACCORDING TO THE LIFE CYCLE OF BUILDING PROJECTS IN SRI LANKA

During Delphi round 2, experts were asked to classify current applicable important WM issues according to the life cycle of building projects. At the end of the Delphi round 2, eighteen (18) WM issues as Preconstruction, twenty (20) issues as Construction and Building Renovation, eight (8) issues as Use and Operate, nineteen (19) issues as Demolition and Repurpose and thirteen (13) issues as Material Recovery and Production stage were identified out of the applicable current C&D WM issues. Table 3 indicates the current C&D WM issues in building life cycle stages.

WM issues can arise due to a number of factors, including the generation of significant amounts of construction waste, the absence of proper sorting and disposal methods, a lack of recycling facilities and programs, non-compliance with WM regulations, improper storage and handling of hazardous waste, a lack of accountability among contractors and stakeholders, and limited awareness of sustainable WM practices. These issues can have negative impacts on the environment and public health, and it is important for all parties involved in a building project to work together to address and mitigate WM issues. By categorising the issues based on the different stages of the project life cycle, it becomes easier to identify where in the process the WM issues are most prevalent, and to develop targeted solutions to address them. This approach can also help stakeholders to better understand the interdependencies between different stages of the project, and to identify opportunities to optimise WM issues throughout the entire project life cycle.

WM issues at the Preconstruction stage of the building can have significant impacts on the environment and public health. One major issue is the lack of proper planning and implementation of WM strategies during the early stages of a building project. This can result in the generation of excessive waste and poor WM practices throughout the construction process. Another issue is the absence of waste segregation and sorting at the source, which makes it difficult to effectively manage and dispose of waste. There is also a need for greater awareness of the dangers of hazardous waste and proper handling and disposal methods. Additionally, limited regulations and enforcement of WM policies can result in inadequate WM practices and the risk of environmental degradation. Furthermore, limited public awareness and education on WM practices can also contribute to poor WM practices at the Preconstruction stage. Addressing these WM issues is crucial for promoting sustainability and safety in the building industry.

I.12 stated, *"Insufficient resources allocated to the construction industry in Sri Lanka can have a significant impact on waste management during the Construction and Building Renovation stage".* This can include a lack of access to proper waste disposal facilities and services, as well as limited investment in new technologies and methods for managing and disposing of waste. Additionally, **I.04**, **I.05,** and **I.14** asserted, insufficient resources can result in limited enforcement of regulations and standards, making it challenging to hold stakeholders accountable for their WM practices. This can also lead to inadequate WM practices, such as the improper handling and disposal of hazardous waste, limited waste segregation and sorting at the source, and increased waste generation. Further **I.01** stated, *"To address these issues, it is crucial for the Sri Lankan government to allocate sufficient resources to the construction industry to support effective and efficient waste management practices"*. By ensuring that WM is a priority and that adequate resources are available, the building industry can work towards reducing waste generation, promoting sustainability, and ensuring the safe disposal of waste.

Construction WM during the Use and Operate stage of a building refers to the challenges and problems faced in managing the waste generated after the building is completed and in use. This stage can produce waste from a variety of sources, including maintenance activities, renovations, and daily operations. **I.14** especially highlighted, *"The improper storage and disposal of waste during this stage can lead to environmental pollution, health hazards, and increased waste disposal costs. Additionally, the lack of designated waste storage areas and management systems can result in unsightly waste accumulation and potential health and safety risks".* To address these issues, it is important for buildings to implement proper WM practices and systems, including designating areas for waste storage and collection, establishing procedures for separating and disposing of waste, implementing recycling programs, and educating building occupants on the importance of WM and proper disposal methods. By doing so, buildings can reduce the amount of waste generated, promote environmental sustainability, and ensure the health and safety of building occupants.

I.01 thoroughly highlighted that, *"In Sri Lanka's construction industry, there is a lack of economic penalties for waste management issues during the Demolition and Repurpose stage. This means that companies and contractors are not incentivised to properly dispose of waste and can often leave it in an inappropriate manner, leading to environmental and health hazards".* The absence of economic penalties also allows for these practices to continue without consequences, contributing to the overall poor WM culture in the industry. Further, **I.12** and **I.14** articulated that, effective WM practices are crucial for the preservation of the environment and the safety of local communities. The implementation of economic penalties could help encourage better WM practices and improve overall sustainability in the construction industry in Sri Lanka. In the construction industry in Sri Lanka, there is a perception that waste will never be fully eliminated during the Demolition and Repurpose stage. This mindset results in a lack of effort to properly manage waste and can lead to environmental and health hazards. **I.05** highlighted that, *"The belief that waste will always be present contributes to the ongoing issue of poor WM practices and further perpetuates the problem".*

5. DISCUSSION

C&D WM is a critical issue in Sri Lanka as the country experiences a growing construction sector. In recent years, the amount of C&D waste generated in Sri Lanka has increased significantly, creating a strain on the country's WM system and its environment. The literature review found that there is a lack of proper WM policies and practices in the country, which has led to a high level of waste generation and limited recycling. Additionally, the study found that there is a lack of awareness among construction professionals and the general public about the importance of WM and limited financial incentives for sustainable practices (Begum et al., 2006). **I.08** highlighted that "*This growth has led to an increase in the amount of waste generated from construction and* *demolition activities, which often end up in open landfills, riverbeds, and other sensitive ecosystems".* To address this issue, this study aims to investigate the C&D WM issues in Sri Lanka according to the life cycle of building projects. Further, Hassan et al. (2012) confirmed that, less encouragement from related agencies is the only issue that has the mean response of importance. In addition, **I.12** confirmed that one of the main challenges in managing C&D waste in Sri Lanka is the lack of proper WM infrastructure. Many areas lack designated waste dispute sites, and there is a shortage of vehicles and equipment needed for the collection and transportation of waste.

During the preconstruction stage, decisions are made that can have a significant impact on the amount of waste generated during C&D. Further, **I.13** stated that *"This includes the choice of materials, design, and the construction method. It is important to consider the environmental impact of these decisions and to adopt waste reduction strategies from the outset".* Ismam and Ismail (2014) supported that design stage is crucial for the management of C&D waste, as decisions made at this stage can greatly impact the amount and type of waste generated. Architects and engineers should consider the life cycle of materials, the recyclability of products, and the feasibility of incorporating waste reduction and recycling into the design.

According to interviewees' arguments, at the demolition stage, a large amount of waste is generated. This waste includes concrete, wood, metal, and other materials that are often mixed together and difficult to recycle. Proper demolition and deconstruction practices, such as separating materials, can greatly improve the recyclability of the waste and reduce its impact on the environment (Hao et al., 2007). This finding supports the study done by Begum et al. (2006) that the average maximum willingness to pay to improve construction waste collection and disposal services is higher for large contractors as compared to the medium and small contractors. This finding is very critical because most contractors in Malaysia are medium and small-class ones. Contractors need to change their attitude in order to achieve our country's project goals and reduce construction site waste. In conclusion, managing C&D waste is a complex issue that needs to be addressed throughout the life cycle of a building. Effective WM practices, along with regulations and education, can help to reduce the environmental impact of C&D activities in Sri Lanka.

6. CONCLUSIONS AND RECOMMENDATIONS

The aim of the research was accomplished through a gradual method that included a review of the available literature and a two-stage Delphi survey. The research was carried out incrementally by first conducting a literature review, followed by Delphi Round 1, and finally Delphi Round 2, which involved interviews with experts. The conclusion of a study on C&D WM issues in Sri Lanka could summarise the key findings related to the management of waste during the different stages of the building project life cycle. Finally, eighteen (18) WM issues as Preconstruction, twenty (20) issues as Construction and Building Renovation, eight (8) issues as Use and Operate, nineteen (19) issues as Demolition and Repurpose and thirteen (13) issues as Material Recovery and Production stage were identified out of the applicable current C&D WM issues in Sri Lanka.

The study could suggest specific measures to improve C&D WM in Sri Lanka. These recommendations could be based on best practices from other countries, as well as on the results of the study. Some possible recommendations include:

1. Implementing a comprehensive WM plan for all C&D projects, which includes the segregation, collection, transportation, and disposal of waste,
2. Encouraging the use of recycled materials in construction projects, can reduce the amount of waste generated and promote sustainable development,
3. Promoting awareness and education about the proper disposal of C&D waste, as well as the benefits of recycling and reusing materials, and
4. Improving the infrastructure for WM, including the development of WM facilities and the upgrading of existing facilities.

These recommendations can be modified and refined based on the specific findings and context of the study, but they provide a general framework for improving C&D WM in Sri Lanka.

Table 3: Current Construction and Demolition Waste Management Issues during Life Cycle Stages of a Building Project in Sri Lanka

Preconstruction	Construction and Building Renovation	Use and Operate	Demolitions and Repurpose	Material Recovery and Production
Weak waste characterisation	Insufficient resources	Insufficient resources	Lack of supervision	Inconsistency in making policies
Unawareness of software usage	Poor management of materials	Inconsistency in making policies	Absence of economic penalisation	Lack of recycling market
Cost of project	Lack of communication among participants	Lack of communication among participants	Lack of recycling market	Unsafe market and inflation of prices
Absence of economic penalisation	Lack of supervision	Absence of environmental awareness	Lack of financing from the government	Lack of financing from the government
Unsafe market and inflation of prices	Incorrect decisions	Not producing waste management specialists	Inadequate training to workers	Absence of environment awareness
Clients' unawareness	Unsafe market and inflation of prices	Remote locations prove challenging for networking	Absence of environmental awareness	In developing new products and services, forecasting consumer behaviour is difficult
Absence of environment awareness	Absence of environmental awareness	Lack of waste disposal charge	Lack of education in waste management	Remote locations prove challenging for networking
Lack of environment policies acts, standards	Not producing waste management specialists	Unawareness of software usage	Perception that waste will never be eliminated	Public procurement lacks circular requirements
Lack of environment impact assessment practices	Lack of waste disposal charge		Lack of waste disposal charge	Secondary material markets lack support from government
Not producing waste management specialists	Incomplete design		Negligence attitude of the government	Economic savings and revenue models are difficult to assess because of the lack of data on access to and availability of waste
In developing new products and services, forecasting consumer behaviour is difficult	Poor performance strategies		Public procurement lacks circular requirements	Rapid changes in markets, e.g., restrictions on exports or costs for recovering wood waste
Incomplete design	Negligence attitude of the government		Secondary material markets lack support from the government	Business competition in developing new waste-based products who gets the materials
Poor performance strategies	Inconsistent in making policies		Long distances and efficiency of logistics in waste collection	The biogas market's dependency on energy markets
Lack of integrity	Economic savings and revenue models are difficult to assess because of the lack of data on access to and availability of waste		Lack of processors/refiners of waste-based materials	
Negligence attitude of the government	Virgin materials are cheap compared to recycled materials		Unawareness of advanced technology usage	
Inconsistent in making policies	The biogas market's dependency on energy markets			
Virgin materials are cheap compared to recycled materials				
Unawareness of technological software usage				

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CONSTRUCTION INNOVATION TOWARDS SUSTAINABLE CONSTRUCTION PROJECT SUCCESS IN SRI LANKA

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ABSTRACT

Sustainable construction is important for creating buildings and structures that have less impact on the environment. To make sustainable construction more effective, new and innovative techniques need to be used. The success of sustainable construction projects depends on how well these innovations are applied. A study was conducted in Sri Lanka to investigate the use of construction innovations in sustainable construction projects and to find ways to improve their success. The study used a qualitative approach, which involved collecting data through semi-structured interviews and use manual content analysis to analyse collected data. However, the study also revealed that the level of innovation application in sustainable construction was not satisfactory in Sri Lanka. Furthermore, this research discovered strategies that can be used to overcome the challenges of sustainable construction projects in Sri Lanka by adopting construction innovations. These strategies include mitigating challenges to innovation adoption and finding ways to increase the use of innovations. By implementing these strategies, sustainable construction projects can be more successful in Sri Lanka leading to less impact on the environment.

Keywords: *Challenges; Construction Innovation; Strategies; Sustainable Construction.*

1. INTRODUCTION

Considerable global attention has been given to “sustainable construction” when the construction industry shifted from the traditional paradigm towards sustainable development (Du Plessis, 2007). Traditional construction practices focus on cost minimisation, performance and quality objectives only but sustainable construction practices also focus on the minimisation of resource depletion, minimisation of environmental degradation and the creation of a healthy built environment (Bachayo et al., 2022). According to Athapaththu and Karunasena (2018), knowledge of construction innovations, technologies and processes is relatively high among higher-level of construction professionals. Nevertheless, sustainable construction evaluation criteria

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during tendering, searching for cost-effective methods and harmonisation of academic and technical institutions are not at a considerable level.

Furthermore, the authors stated that coordination and harmonisation with academic institutions and technical institutions are rare in the construction industry. In addition to that, the adaptation of construction innovations has become lower due to inadequate innovations to improve sustainable construction. Therefore, research and development play a vital role in sustainable development.

In Sri Lanka, the adoption of sustainable construction practices is still in its early stages (Thalpage & Karunasena, 2016), and construction innovations are not being fully utilised to achieve sustainability (Karunasena et al., 2016; Jayalath & Gunawardhana, 2017; Somachandra & Sylva, 2018). Addressing the existing research gap is of utmost importance, as it is vital to comprehend the obstacles involved in implementing construction innovations in sustainable construction projects for the advancement of Sri Lanka's future development. This research endeavour aims to bridge this gap by offering valuable insights into the challenges hindering the integration of construction innovations within sustainable construction. Furthermore, it seeks to identify and propose effective strategies to overcome these obstacles. The findings of this research will be highly relevant for policymakers, construction professionals, and other stakeholders involved in sustainable construction projects in Sri Lanka. By addressing the challenges in construction innovations to achieve construction goals, this research can help to improve the success of future construction innovations in Sri Lanka and contribute towards achieving global environmental targets.

2. LITERATURE REVIEW

2.1 APPLICATION OF CONSTRUCTION INNOVATIONS IN SUSTAINABLE CONSTRUCTION PROJECTS

With the growing economic, social and environmental issues, most of the organisations in the construction sector are focusing on sustainable construction practices (Hertwich & Peters, 2009). Furthermore, sustainable development goals can be achieved through the proper application of construction innovation in design, construction and facility operation (Bynum et al., 2013).

Elegbede and Lateef (2020) defined nanotechnology as the re-engineering of materials by controlling the shape and size at the nanometer scale. Nano cement, nano steel, nano glass, a nano-coat for concrete, nanoparticles for fire protection, nano sensors for concrete structures, and nanomaterials in concrete are examples of the application of nanotechnology on several building materials (Bhuvaneshwari et al., 2011). According to Kutschera et al. (2009), new technologies are adopted in sustainable construction projects to reduce CO_2 emissions during the construction process and energy consumption during the operation. Moreover, the authors suggested that the prevention of natural resources and energy reduction can be attained by producing new nanostructured materials.

Figure 1: 3D Concrete Printing Applications in Building

3D concrete printing, also referred to as additive manufacturing is playing a massive role in terms of dealing with the sustainability challenges in the construction industry (Bhattacherjee et al., 2021). Salet et al. (2018) stated that 3D concrete printing is more popular in sustainable construction projects and is used to produce structural concrete elements. Furthermore, the authors mentioned that the 3D-printed pedestrian bridge is one of the recent examples of the application of 3D printing in sustainable constructions in Figure 1. 3D concrete printing can produce complex shapes that are used in passive design (Mechtcherine et al., 2019). In addition to that, Harkouss et al. (2018) claimed that passive design enhances the energy efficiency of a building. Hence, 3D printing can be identified as a sustainable solution in the construction industry (Mechtcherine et al., 2019).

During the past few years, Building Information Modeling (BIM) has become a growing concept in the construction industry (Bynum et al., 2013). Total project quality increase, minimising total project cost and generating accurate quantity take-offs and time schedules are the main advantages of using BIM (Wang, 2012). Azhar (2011) stated that the use of BIM to evaluate various skin options, choose building orientation and conduct daylight studies during the design phase to position the building on the selected site, thus enhancing the sustainability of the construction project. Net-zero energy buildings and carbon emissions reduction have become more popular due to the trend in the construction industry towards sustainable development (Holness, 2008). Therefore, designers require to evaluate the building as a fully integrated dynamic design and construction process. Hence, BIM plays a significant role in sustainable construction projects (Bynum et al., 2013). Intelligence exhibited by software-driven systems and electronic devices to improve the quality and performance in the built environment is known as Artificial intelligence (AI) in buildings (Panchalingam & Chan, 2021). Gilner et al. (2019) stated that actions such as turning off light switches when no one is in the space, granting permission for visitors to enter into designated spaces and contacting authorities and commencing emergency procedures during an emergency such as a bomb blast can be achieved by using an AI. Building Energy Management System is one of the examples of an application of AI in sustainable construction.

3. METHODOLOGY

A qualitative approach is useful when exploring complex phenomena that are difficult to measure or quantify (Hammarberg et al., 2016). Construction innovation project success is a multifaceted and complex phenomenon that can be difficult to capture through quantitative methods due to diverse stakeholders, long-term perspective, complex systems, subjectivity, and data availability. A qualitative approach allows for an in-depth exploration of the experiences, perspectives, and attitudes of key stakeholders involved in sustainable construction projects in Sri Lanka. Semi-structured interviews are an appropriate method for collecting data from participants with different levels of knowledge and expertise. Semi-structured interviews allow for flexibility in questioning, which can be adapted to each participant's level of expertise and the knowledge in construction industry and sustainability (Creswell & Creswell, 2018). Using a qualitative approach and semi-structured interviews can provide rich and detailed data that can lead to a deeper understanding of application of innovation in sustainable construction projects in Sri Lanka.

According to Etikan et al. (2016), judgment sampling is used in the purposive sampling technique. It is also an intentional choice made to select a participant based on the traits they possess. Thus, the sample is purposefully determined and based on the researcher's judgment about the research aim. Purposive sampling allows the selection of interviewees who are knowledgeable and interested in the selected area of study (Etikan & Bala, 2017). A qualitative survey, according to Jansen (2010), establishes the relevant diversity within that population. Table 1 presents the criteria for defining experts for the research area which is the construction industry.

Table 1: Expert profiles

Coding	Designation	Client	Contractor	Consultant	Years of Experience	Criteria						Accessibility
						Compulsory Qualification		Additional qualifications (Satisfy at least three criteria)				
						C1	C2	A1	A2	A3	A4	
R1	Managing Director	✓			25 years	✓	✓	✓	✓	✓	✓	✓
R2	Construction Manager		✓		20 years	✓	✓	✓	✓	✓	✓	✓
R3	Senior Engineer		✓		15 years	✓	✓	✓	✓	✓	✓	✓
R4	Contract Administrator		✓		17 years	✓	✓	✓		✓	✓	✓
R5	Environmentalist			✓	11 years	✓	✓	✓		✓	✓	✓
R6	Senior Quantity Surveyor	✓			16 years	✓	✓	✓	✓	✓	✓	✓
R7	Director			✓	24 years	✓	✓	✓	✓	✓	✓	✓
R8	Electrical Engineer		✓		16 years	✓	✓	✓	✓	✓	✓	✓
R9	Service Engineer	✓			14 years	✓	✓	✓	✓	✓	✓	✓
R10	Planning Engineer	✓			12 years	✓	✓	✓	✓	✓	✓	✓
R11	Senior Electrical Engineer			✓	18 years	✓	✓	✓	✓	✓	✓	✓
R12	Maintenance Manager	✓			11 years	✓	✓	✓	✓	✓	✓	✓
R13	Senior Architecture			✓	21 years	✓	✓	✓	✓	✓	✓	✓
R14	Senior Facility Manager	✓			14 years	✓	✓	✓	✓	✓	✓	✓
R15	Quality Controller			✓	13 years	✓	✓	✓		✓	✓	✓

C1: Knowledge and a better understanding of sustainable construction and construction innovation
C2: More than 10 years of experience related sustainable construction
A1: Graduate in a construction-related discipline
A2: A Postgraduate degree related to construction management
A3: Corporate Member of a Professional Institution
A4: Practical Experience/Research Experience in sustainable or innovative construction

When selecting the purposive sample, as per the criteria given in Table 1, every expert must fulfil the above compulsory qualifications and at least two additional qualifications must be fulfilled. These criteria ensure that experts in sustainable construction possess a solid foundation of knowledge and experience, as well as specialised expertise in the field. Fifteen experts were interviewed between 45-60 minutes using prepared interview guideline and analysed them according to the experts' opinions through manual content analysis. Most of the interviews carried out through online platform, namely Zoom and rest of interviews were done physically.

4. RESEARCH FINDINGS

Research findings indicate that the application of innovations in construction projects in Sri Lanka faces significant challenges. These challenges include inadequate investment in research and development, a lack of skilled labour and training, limited access to modern construction equipment and technologies, and an absence of supportive policies and regulations. To overcome these challenges, suitable strategies include increasing investment in research and development, promoting skill development and training programs, adopting modern construction methods and technologies, promoting awareness and education on sustainable construction practices, and implementing supportive policies and regulations that encourage innovation and sustainable development. The successful implementation of these strategies can facilitate the adoption of innovative practices in construction projects, leading to more efficient, sustainable, and resilient construction practices in Sri Lanka.

4.1 CHALLENGES IN APPLICATION OF INNOVATIONS IN SUSTAINABLE CONSTRUCTION PROJECTS IN SRI LANKA

In Sri Lanka, the application of innovation in sustainable construction projects is currently at an unsatisfactory level, according to research. Sustainable construction projects can be influenced by innovations, but the implementation of such innovations has not been widespread in Sri Lanka. Innovation in sustainable construction can involve the use of new technologies, materials, and processes that lead to better environmental, social, and economic outcomes. By adopting such innovations, construction projects can improve their efficiency, reduce waste and carbon emissions, and provide better working conditions for workers.

Overall, increasing the application of innovation in sustainable construction projects in Sri Lanka has the potential to improve the success of such projects, and help the country achieve its sustainable development goals. By adopting innovative solutions, Sri Lanka can reduce its environmental footprint, improve the lives of its citizens, and support its economic development sustainably and equitably. According to the interviewees' suggestions here listed challenges in the application of innovations in sustainable construction projects in Sri Lanka. Figure 2 presents the findings of challenges in the application of innovations in sustainable construction projects in Sri Lanka.

CHALLENGES IN THE APPLICATION OF INNOVATIONS IN SUSTAINABLE CONSTRUCTION PROJECTS IN SRI LANKA

Nanotechnology

- High initial investment costs, which can be a significant barrier for small and medium-sized construction companies that may not have the financial resources to invest in nanotechnology
- Limited awareness and understanding of the benefits and potential of nanotechnology in the construction industry, which can result in scepticism and reluctance to adopt the technology
- Limited availability of nanomaterials in Sri Lanka, which can make it difficult to access and use these materials in construction projects
- Lack of specialised technical expertise and skilled workers to operate and maintain nanotechnology equipment and processes
- Limited research and development in the application of nanotechnology to sustainable construction in Sri Lanka, which can make it difficult to develop and implement innovative solutions
- Regulatory barriers and restrictions on the use of nanotechnology in Sri Lanka, including limitations on the use of certain nanomaterials and concerns about potential health and environmental risks associated with the technology
- Concerns about the long-term durability and performance of nanomaterials in construction applications, as well as the potential risks associated with their disposal at the end of their lifecycle

3D Concrete Printing

- Lack of awareness about the benefits
- High initial costs associated with acquiring 3D printing technology and equipment
- Limited availability of 3D printing infrastructure and support services
- Lack of regulatory framework in Sri Lanka for the use of 3D printing technology in construction
- Insufficient availability of suitable raw materials
- Technical challenges related to the durability and strength of 3D-printed concrete structures
- Limited research and development efforts
- Lack of skilled personnel trained and its use in construction
- Perceptions of 3D concrete printing as experimental or untested technology
- Reliance on traditional construction methods and a preference for familiar techniques among construction professionals in Sri Lanka

BIM

- Lack of standardisation and uniformity in the application of BIM technology in the construction industry in Sri Lanka, which can lead to confusion and difficulties in collaboration between different stakeholders
- Limited awareness and understanding of the benefits and potential of BIM technology in the construction industry, which can result in scepticism and reluctance to adopt the technology
- Limited access to BIM software and related technologies, which can make it difficult for construction companies in Sri Lanka to implement BIM effectively
- Lack of specialised technical expertise and skilled workers to operate and maintain BIM software
- Limited integration of BIM technology into existing construction processes and workflows, which can make it difficult to justify the investment in the technology
- Resistance to change from traditional construction practices, which can make it difficult to introduce and implement BIM technology effectively

AI

- Limited investment in research and development
- Limited availability of relevant data and information for AI analysis
- Fragmented nature of the construction industry
- Limited government support and policies to promote
- Shortage of skilled professionals with the necessary technical expertise
- High initial costs and capital expenditure for implementing AI
- Resistance to change and adoption of new technologies by industry professionals
- Limited awareness and education about the benefits and potential applications of
- Uncertainty about the reliability and accuracy of AI-generated data and analysis
- Limited availability of AI-related infrastructure and support services

Robotics

- Limited awareness and understanding of the benefits and potential of robotics
- High initial investment costs
- Lack of specialised technical expertise to operate and maintain
- Limited government support and incentives to encourage the adoption of robotics technology
- Cultural barriers and resistance to the adoption of robotics technology by construction workers
- Lack of suitable infrastructure and changes required to the existing infrastructure in Sri Lanka to accommodate the use of robotics technology

Drone Technology

- Concerns about data privacy and security, as well as safety issues related to the operation of drones in urban environments
- Limited integration of drone technology into existing construction processes and workflows, which can make it difficult to justify the investment in the technology
- Limited awareness and understanding of the benefits, which can result in scepticism and reluctance to adopt the technology
- High initial investment costs, which can be a significant barrier for small and medium-sized construction companies that may not have the financial resources to invest
- Lack of specialised technical expertise and skilled operators to operate and maintain drone technology, as well as a shortage of drone service providers in Sri Lanka.
- Regulatory barriers and restrictions on the use of drones in Sri Lanka, including limited drone flight areas and restrictions on the use of drones for commercial purposes
- Limited infrastructure for drone technology, including the need for suitable landing and take-off areas, and the availability of reliable and high-speed internet connectivity

3D Printed Houses

- Uncertainty about the reliability, durability, and quality of 3D printed structures for long-term use in Sri Lanka's climate and environment
- Limited availability of appropriate 3D printing materials and technology infrastructure
- Lack of government support and policies to promote the adoption
- Limited collaboration and partnerships between construction professionals, technology experts, and other stakeholders in the industry to drive innovation and adoption
- Limited investment in research and development of 3D printing technology
- Lack of awareness and education about the potential benefits
- High initial costs and capital expenditure for implementations
- Fragmented nature of the construction industry in Sri Lanka
- Resistance to change and adoption of new construction technologies by industry professionals
- Limited availability of skilled professionals with the necessary technical expertise to operate and maintain for construction purposes

Figure 2: Challenges in the application of innovations in sustainable construction projects in Sri Lanka

The majority of the respondents identified the unavailability of technology as the major barrier to the application of nanotechnology in Sri Lankan sustainable construction projects. **R3, R5** and **R12** explained that the unavailability of skilled workers is a reason for the lack of application of nanotechnology in Sri Lankan sustainable construction projects. Further, **R8** stated, *"Nano cement, nano concrete and other materials made using nanotechnology are popular and used in Germany, United Kingdom and South Korea. But in our country nanotechnology is not popular in the construction industry. Because we do not have the technology and skilled workers with good knowledge on nanotechnology".* R2 and R6 have identified that attitude of the client and the attitude of the consultant has prevented the application of nanotechnology in Sri Lankan sustainable construction projects. **R6** stated, *"Clients and consultants in Sri Lanka do not pay much attention to nanotechnology. According to my point of view that is the main reason".* Nevertheless, **R5** and **R11** declared that applications of nanotechnology are available in Sri Lanka. Furthermore, **R15** expressed, *"Nanotechnology is not widely used in Sri Lanka. But certain materials that are made using nanotechnology are used in some sustainable construction projects".*

R9 and **R10** highlighted that most of the time clients in Sri Lanka select traditional construction methods rather than using innovative methods such as 3D concrete printing due to a lack of technically capable professionals with sound knowledge of novel technologies. **R2** and **R7** emphasised that the usage of 3D concrete printing in sustainable construction projects is restricted by the complexity of the process. Further, **R15** stated, *"Process of constructing buildings using 3D concrete printing is complex. Because small concrete parts print separately and join together to build large components. So, most of the clients and contractors do not consider using 3D concrete printing for their constructions".*

In Sri Lanka, AI is being applied in several areas, including predictive maintenance, quality control, safety monitoring, and design optimisation. Predictive maintenance involves using AI to monitor and analyse data from construction equipment to detect potential maintenance issues, thereby reducing downtime and increasing productivity. Although the application of AI in the Sri Lankan construction industry is still in its early stages, its potential for improving efficiency, productivity, and safety is significant. Moreover, **R15** presented a moderately similar opinion to the literature findings as *"Automatic light control systems, motion sensors in bathrooms and Building Energy Management systems are used in sustainable buildings in Sri Lanka. According to my point of view, those applications are examples of application of AI in sustainable constructions".* In addition to that **R3** and **R4** emphasised application of AI in sustainable construction projects is lesser compared to other countries. Even though the majority of the respondents stated that AI is applied in sustainable construction projects, **R11** explained that AI is not used in Sri Lankan construction industry. Further, the respondent mentioned reasons such as the unavailability of experts, requirement of more investments, the high initial cost, and the unavailability of technology to justify the opinion of **R1**.

Only respondent **R10** has identified 3D-printed houses as an innovation that is used in sustainable construction projects in the world. Furthermore, the respondent explained that 3D-printed houses and 3D concrete printing are not similar. Moreover, **R1** stated, *"3D concrete printing is a part of 3D printed houses".* However, **R1** stated that 3D-printed houses are not used in Sri Lankan context. Further, the respondent explained that the lack of technology and lack of experience of the workers are the main reasons that avoid the application of 3D concrete printed houses in Sri Lanka. In addition, **R11** stated, *"The attitude of clients and professionals in the construction industry is also a reason for the lack of usage of 3D-printed houses".* Moreover, the respondent mentioned that clients in Sri Lanka tend to use traditional methods rather than using innovations. Reasons for the lack of usage of 3D Printed Houses in Sri Lankan sustainable constructions were identified through the semi-structured interview. Table 6 summarises the reasons given by the interviewees.

R2, R3, R5 and **R7** have accepted that construction robotics is an innovation that is used in sustainable constructions in the world. According to **R3**, the application of robotic technology in construction projects provide benefits such as reducing cost due to high productivity, reducing labour cost, reducing costs related to safety systems and reducing construction waste. **R2, R3** and **R7** agreed that robotic technology is applied to sustainable construction projects in Sri Lanka. Moreover, respondents stated that bricklaying robots, unmanned ground vehicles and heavy material handling robots are used in Sri Lanka.

Only **R8** accepted that drone technology is an innovation that is applied for sustainable construction projects in the world. Further, **R8** explained the importance of drone technology in construction industry *"Drone technology is very important to construction industry. Because if you want to inspect areas which are difficult to reach, you can use AR to inspect and capture photographs. It will help to minimise accidents in construction sites and provide safety for workers".* Drones can be used to conduct site surveys, allowing for a more accurate understanding of the site and any potential challenges before construction begins. They can also be used to monitor the progress of construction projects, providing construction teams with real-time updates on the status of the project and identifying any issues that need to be addressed. Drones can be used for the inspection of hard-to-reach or dangerous areas, such as bridges or tall buildings, allowing for detailed and precise inspections without putting workers in harm's way. Additionally, drones can be used for environmental monitoring, tracking the progress of reforestation or monitoring water quality.

R8 stated, "BIM is not used 100% for sustainable construction projects in Sri Lanka. But to a certain extent BIM is used in Sri Lanka. 5D BIM software is also used in some projects in our country". According to the majority of the respondents, BIM is not used for the entire construction project in Sri Lanka. Nevertheless, BIM is used in certain parts of the construction process or certain aspects of the construction project. According to **R3, R6** and **R8**, nowadays 2D and 3D BIM software are more popular in Sri Lanka and used for designing purposes of sustainable construction. **R2, R4** and **R8** stated that BIM-based software is used while preparing estimates for sustainable construction projects. Further, **R4, R7** and **R8** described that BIM technology can be applied for project planning and cost management purposes. BIM technology can be used to generate accurate quantity take-offs and cost estimates for the building materials and labour required to construct the building. In addition, **R8** mentioned that BIM technology is used in the construction phase of sustainable construction projects to check the progress of construction work and to provide tracking of better cost control. However, **R1** and **R5** stated that BIM is not used in Sri Lanka. Further, **R1** stated, "After construction is complete, BIM technology can be used to support ongoing facility management and maintenance, including the tracking of maintenance schedules, equipment, and asset management, and other key tasks". In addition to that, **R9** and **R12** highlighted the lack of knowledge and high initial cost as the main reasons for the lack of application of BIM technology in Sri Lanka.

4.2 SUITABLE STRATEGIES TO OVERCOME ABOVE IDENTIFIED CHALLENGES IN CONSTRUCTION INNOVATIONS PROJECTS IN SRI LANKA

According to respondents' arguments, to improve the success of sustainable construction projects in Sri Lanka, several strategies can be adopted through construction innovations. One of the key strategies is to focus on green building practices that prioritise energy efficiency, water conservation, and the use of sustainable materials. This can include incorporating renewable energy sources such as solar, wind, and hydropower to reduce reliance on non-renewable sources. Another important strategy is to adopt green transportation practices that encourage the use of public transport and reduce carbon emissions. Other construction innovations such as BIM, 3D printing, and offsite construction techniques can also improve the efficiency of the construction process and reduce waste. Additionally, strategies such as using biophilic design, improving indoor air quality, and utilising rainwater harvesting can improve the overall sustainability and durability of a building. By adopting these and other strategies, sustainable construction projects in Sri Lanka can achieve greater success in meeting the country's economic and environmental goals. Table 2 illustrates the strategies to improve the success of sustainable construction projects in Sri Lanka by adopting construction innovations.

Table 2: Suitable strategies to overcome challenges in construction innovations projects in Sri Lanka

No	Strategies to Improve the Success of Sustainable Construction Projects in Sri Lanka Through Adopting Construction Innovations
01	Conduct a thorough feasibility study before embarking on any construction project, taking into account the specific needs and resources of the local community.
02	Involve local communities in the planning process to ensure that their needs are being met.
03	Incorporate sustainable design principles into the project from the outset, such as using renewable energy sources and eco-friendly materials.
04	Implement a green building certification program, such as LEED or Green Star, to ensure that the project meets established sustainability standards.
05	Use energy-efficient building techniques, such as passive solar design, to reduce energy consumption.
06	Utilise renewable energy sources, such as solar or wind power, to reduce the reliance on fossil fuels.
07	Incorporate rainwater harvesting and greywater recycling systems into the design to conserve water.
08	Implement waste management systems that prioritise reducing, reusing, and recycling materials.
09	Use sustainable materials, such as bamboo, that are locally sourced and have a low environmental impact.
10	Adopt modular construction techniques to reduce waste and improve efficiency.
11	Implement BIM technology to improve project planning, design, and collaboration.
12	Utilise 3D printing technology to reduce construction waste and improve efficiency.
13	Implement drone technology for site inspections, project planning, and monitoring.
14	Use green roofs and walls to reduce the urban heat island effect and improve air quality.
15	Implement energy-efficient lighting systems, such as LED lights, to reduce energy consumption.
16	Use natural ventilation systems, such as passive cooling, to reduce the need for air conditioning.
17	Install smart building technology to optimise energy usage and improve the overall performance of the building.
18	Use recycled materials, such as reclaimed wood, to reduce the need for new resources.

No	Strategies to Improve the Success of Sustainable Construction Projects in Sri Lanka Through Adopting Construction Innovations
19	Incorporate biophilic design principles to connect people with nature and improve overall well-being.
20	Implement strategies to reduce embodied carbon, such as using low-carbon cement.
21	Adopt offsite construction techniques, such as prefabrication, to improve efficiency and reduce construction waste.
22	Use green building materials, such as low-VOC paints and adhesives, to improve indoor air quality.
23	Use thermal insulation materials, such as aerogel, to reduce energy consumption.
24	Implement natural ventilation and daylighting systems to reduce the need for artificial lighting and HVAC systems.
25	Use permeable paving and rain gardens to reduce stormwater runoff and improve water quality.
26	Implement energy recovery systems to capture and reuse waste heat.
27	Use shading devices, such as louvres and blinds, to reduce solar heat gain and improve comfort.
28	Implement a green transportation plan, such as providing bike storage and promoting public transit use, to reduce emissions.
29	Use a life cycle assessment (LCA) to evaluate the environmental impact of the building throughout its life cycle.
30	Establish a post-occupancy evaluation program to assess the performance of the building and identify areas for improvement.

Respondent **R1** stated that the drawbacks of the fragmented nature of the construction industry can be mitigated by introducing strict guidelines and frameworks to improve coordination and collaboration between parties. Further, **R2** expressed that the drawback of the fragmented nature of the construction industry can be mitigated through promoting innovation and modern technologies and increasing awareness of construction innovation among the parties involved in sustainable construction. Interviewees **R5** and **R7** also introduced a similar view to respondent **R2**. As stated by interviewee **R5** *"Institutions in Sri Lankan construction industry like CIDA and green building council need to take the leadership and responsibility to improve coordination and to increase the awareness of innovation among all the parties involved in the sustainable construction project"*. Furthermore, interviewee **R3** highlighted that lack of communication between project individuals and groups due to the fragmented nature of the construction industry can be minimised by adopting proper project management techniques. Hence, **R3** recognised adopting proper project management techniques as a strategy to mitigate drawbacks of the fragmented nature of the construction industry. Interviewee **R4** expressed that clashes due to the fragmented nature of the construction industry can be minimised by adopting novel technologies and techniques. Respondent **R8** also agreed to the view of **R4** and stated *"There may be clashes and coordination issues due to the fragmented nature of the construction industry. Due to those issues, implementation of innovation to sustainable construction projects may be difficult. So, newer technologies like BIM can be used to mitigate those issues. According to my point of view, using innovation against barriers to apply innovation in construction is the best strategy to mitigate those barriers"*. However, respondent **R6** claimed that the fragmented nature of construction industry is not a barrier to applying innovation to sustainable construction projects.

Implementing strategies that prioritise green transportation options, such as promoting public transit use and providing safe bike storage, can have a significant impact on reducing the carbon footprint of a building or development. Moreover, initiatives that focus on sustainable transportation also improve the overall durability and accessibility of the building. Several construction innovations can be adopted to improve the efficiency of the construction process and reduce waste. BIM technology, for instance, can help to improve project planning, design, and collaboration. 3D printing and offsite construction techniques can reduce the amount of waste generated during the construction process, while also improving efficiency and reducing costs. Other strategies, such as using biophilic design principles, improving indoor air quality, and utilising rainwater harvesting can also improve the overall sustainability and durability of a building. The biophilic design emphasises the connection between humans and nature and can be incorporated through the use of natural materials, green roofs, and other design features. Improving indoor air quality can be achieved by using low-VOC paints and adhesives, improving ventilation systems, and other strategies. Rainwater harvesting systems can also help reduce water consumption and promote a more sustainable approach to water management.

5. CONCLUSIONS AND RECOMMENDATIONS

Based on the global context of sustainable construction projects, applications of construction innovations such as nanotechnology, 3D concrete printing, BIM and AI were investigated through the literature review. In addition to the aforementioned innovations, respondents have mentioned several other innovations such as 3D printed houses, virtual reality, robotics and drone technology that are used in sustainable construction projects in the world. Application of innovations that are recognised under the literature and interviews in Sri Lankan sustainable construction projects were investigated by analysing the finding of the semi-structured interview. According to the outcomes of the analysis, the application of innovations in sustainable construction is at an unsatisfactory level in Sri Lanka. These innovations include but are not limited to robotics and drone technology, which can improve productivity, efficiency, safety, and quality in construction projects. To maximise the benefits of these innovations, it is important to implement strategies such as investing in training for workers, promoting collaboration between different stakeholders in the construction industry, and creating regulatory frameworks that support the adoption of these technologies. Furthermore, sustainable construction projects should be designed with a holistic approach that considers environmental, social, and economic factors. By implementing these strategies, Sri Lanka can create a more sustainable and prosperous future, benefiting both the construction industry and society at large.

Based on the investigation of construction innovation towards sustainable construction project success in Sri Lanka, the following recommendations can be made:

1. Encourage stakeholders in the construction industry to embrace innovation as a key driver of sustainable construction project success. This can be done by providing education and training on the benefits of construction innovation and its potential applications.
2. Foster collaboration between different stakeholders in the construction industry, such as architects, engineers, contractors, and building owners, to promote the exchange of ideas and the development of innovative solutions.
3. Create regulatory frameworks that support the adoption of construction innovation and sustainable practices. This can include incentives for sustainable construction, tax breaks, and building codes that require the use of sustainable materials and practices.
4. Support research and development in sustainable construction innovation to facilitate the development of new technologies and practices that can be applied to construction projects in Sri Lanka.

5. Provide training and education programs to workers in the construction industry, so that they can acquire the skills and knowledge necessary to implement sustainable construction practices and technologies.
6. Encourage the use of a holistic approach to sustainable construction, considering environmental, social, and economic factors in the design and execution of construction projects.

By implementing these recommendations, Sri Lanka can successfully adopt construction innovation to achieve sustainable construction project success, contributing to a more sustainable and prosperous future for the country.

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CONSTRUCTION WASTE ESTIMATION METHODS: A SYSTEMATIC LITERATURE REVIEW

Nguyet Tong[1], Niluka Domingo[2] and An Thi Hoai Le[3]

ABSTRACT

To date, researchers and governments have paid increasing attention to the zero-waste goal as an effective solution to alleviate the environmental impacts of construction projects towards sustainability. Accurate estimation of construction waste is a prerequisite for an effective waste management plan to achieve zero-waste construction sites. In literature, various methods have been adopted to estimate construction waste generation at the project level. However, there is a lack of an evaluation of existing construction waste estimation methods at the project level in terms of the information that the methods can provide to facilitate construction waste minimisation in a construction project. Hence, a systematic literature review was conducted in this study to bridge the research gap. Twenty-eight papers were selected based on the PRISMA approach and categorised into five estimation methods: area-based waste generation rate, variables modelling method, bill of quantity-based classification system accumulation method, BIM-based classification system accumulation method, and other particular methods. The applicability of those methods to aid practitioners towards construction waste minimisation was analysed based on four aspects: design information requirements, the ability to use in the early design stage, project characteristics, and the ability of waste tracking by material type and construction element.

Keywords: *Construction Waste; Estimation; Review.*

1. INTRODUCTION

Construction industry is one of the biggest waste contributors worldwide with 30-40% of the total solid waste (Islam et al., 2019), including waste generated in new construction, renovation, and demolition of buildings, roads, bridges and other infrastructures (Cheng & Ma, 2013). As a subset of waste generated in the construction industry, waste in the construction phase accounts for more than 10% of the total global waste (Bakshan et al., 2015). This results in adverse environmental impacts, natural resource exploitation, the depletion of landfill sites, increases in project cost and reductions in profits (Ajayi & Oyedele, 2018). Previously, waste generated during the construction stage was considered unavoidable (Tam & Tam, 2006); hence, construction waste estimation methods were established to support the waste treatment plan when construction waste was already generated, such as arranging on-site bins or planning transportation and

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disposal. However, the concept of “zero-waste construction site” has recently emerged in the global construction industry with an ambitious target of no waste produced at the construction sites. This requires a holistic and careful waste management plan from the early planning stage under the 3Rs principles: Reduce, Reuse, and Recycle (Lu et al., 2021). Accurate estimation of construction waste is the most important part of such an effective waste management plan to facilitate waste reduction, reuse and recycling in the construction project (Lee et al., 2016). During the design stage, waste prediction can assess the effectiveness of designing out waste solutions, identify and optimise measures to reduce waste. Contractors can adopt sustainable construction methods and technologies to prevent waste generation. Furthermore, accurate estimation of waste quantity can support the reuse and recycling plan within the project, between projects or across the industry. Therefore, this study conducts a systematic literature review to better understand extant construction waste estimation methods and how they can support waste management plan to achieve zero waste goal at the site level.

The remainder of this paper is structured as follows. Section 2 describes the research methodology for a systematic literature review. Section 3 presents the literature analysis results, including an overview of collected publications, construction waste estimation methods at the project level, and data collection to establish estimation methods. In Section 4, the applicability of existing estimation methods to aid construction waste minimisation is compared and analysed. Section 5 concludes the paper with a summary of the key findings.

2. RESEARCH METHODOLOGY

The study uses the systematic literature review method to systematically describe and analyse all estimation methods of construction waste at the project level since it can identify all research evidence that fits particular topics or research questions and provide reliable findings with minimum bias (Snyder, 2019). The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach was adopted with a 4-phase flow diagram and 27-item checklist to identify the most relevant sample (Page et al., 2021). Figure 1 illustrates the PRISMA flow diagram.

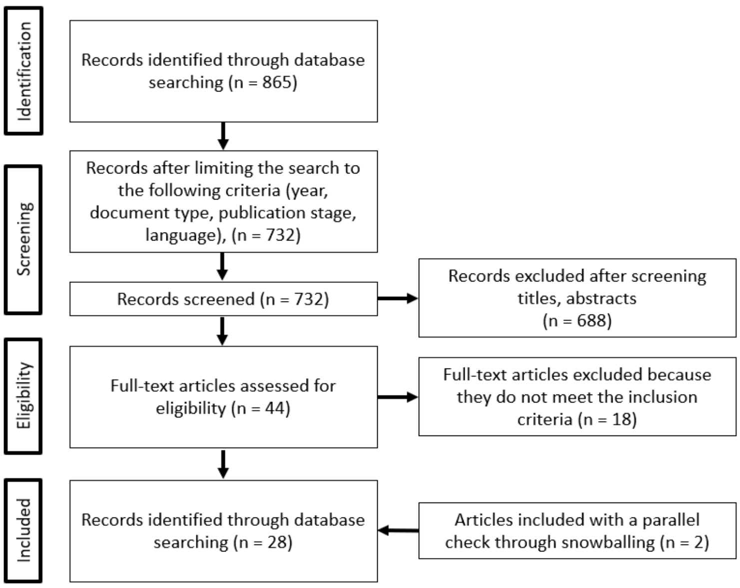

Figure 1: PRISMA flow diagram of the systematic literature review

The keywords used in the identification phase are (“C&D waste” OR “construction waste” OR “Construction and demolition waste”) AND (“estimat*” OR “predict” OR “quantification”) in the title, keywords, and abstract fields via Scopus database for searching the relevant literature within the scope of the study. Scopus was chosen because Scopus has accurate performance with wider coverage of peer-reviewed journal publications than other databases (Mongeon & Paul-Hus, 2016). The wildcard character * was used to capture relevant variations of the word “estimate*, such as estimation or estimate. Additional filters were used to restrict documents, including peer-reviewed articles and conference papers published in English, over the period from 2000 to February 2023. The papers were initially searched without a limited time span and only a few publications were found before 2000. Then the searching period was set from 2000 to 2023. After filtering, 732 papers were identified from SCOPUS database, and 688 papers were excluded after checking titles and abstracts. As a result, 44 full-text papers were retrieved and read carefully. Next, the journal articles and conference papers whose research objectives do not relate to the estimation method of construction waste at the project level were excluded. For example, research papers on the estimation of demolition waste or at the region level were excluded. Two additional papers were identified by using the snowballing technique. Finally, 28 journal articles were selected for a complete review. First, descriptive statistics were undertaken to provide information about the source of publication, geographical location, and publication year to identify the trends in research on construction waste estimation methods. Following the inductive content analysis approach, the data were coded according to the research focus. Then the emerging codes were grouped and reorganised into themes according to the similarity of their meanings and concepts. This study aims to understand better how extant construction waste estimation methods can support waste management plans towards waste minimisation; hence, the first purpose of data analysis is to analyse different methods used to estimate the amount of construction waste and the information that the methods can provide to support the waste management plan towards waste minimisation. Estimation methods were identified from selected papers and then grouped based on the basis used to estimate the amount of waste. As a result, estimation methods were categorised into five main groups: area-based generation rate (AWGR) method calculated on the construction area, variables modelling (VM) method considering different factors of waste generation, bill of quantity-based classification system accumulation (BoQS) method based on accumulating the waste of all items in the BoQ, BIM-based classification system accumulation (BIMS) method built on BIM model, and other particular methods. In addition, waste tracking themes were identified to indicate the information that the estimation methods can provide to support waste management. Following this stage, five estimation methods are further analysed based on the applicability of those methods to support practitioners to implement waste minimisation from the early design stage, as the zero-waste target requires a management plan from the early plan stage under the 3Rs principles – Reduce, Reuse, and Recycle (Lu et al., 2021). The qualitative analysis software NVivo 12 was used to aid the process of data coding and theme identification.

3. FINDINGS

3.1 OVERVIEW OF PUBLICATION COLLECTION

Overall, the search identified 28 articles distributed over 9 journals. The highest number of publications come from Waste Management journal, accounting for 7 articles. In terms of publishing countries, 28 selected papers were distributed across 10 countries, of which China and Spain are the main contributors with 9 and 7 publications respectively, as shown in Figure 2. Figure 3 indicates the number of publications over the period from 2000 to 2022. The interest in construction waste estimation at the project level started from 2009 and witnessed an overall upwards. This trend can be explained by the fact that according to EU Directive 2008/98/EC in 2008, all EU member states by 2020, have to take necessary actions to reduce 70% of construction and demolition waste by prevention, reuse, recycling and recovery (EC, 2008).

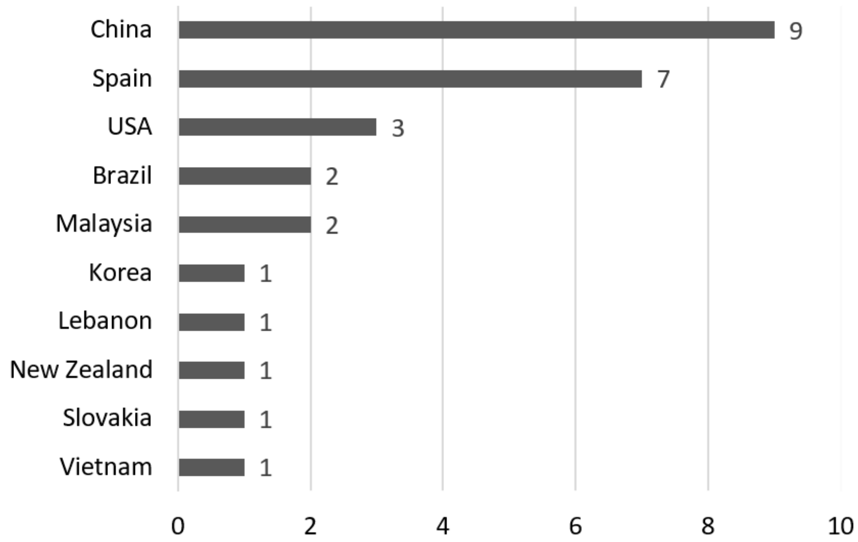

Figure 2: Publishing countries

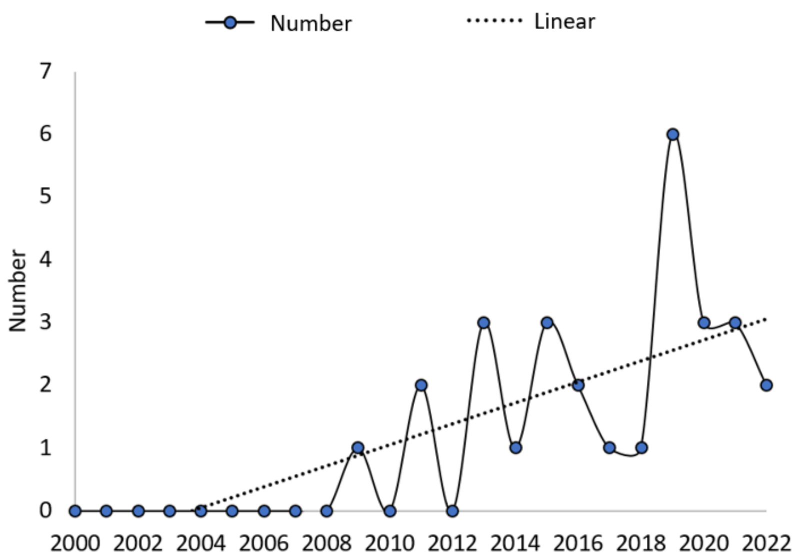

Figure 3: Research trend on construction waste estimation at the project level

3.2 CONSTRUCTION WASTE ESTIMATION METHODS

Selected articles are retrieved and classified into five groups based on the estimation methods (see Table 1). These five waste estimation methods are area-based waste generation rate (AWGR) method, variables modelling (VM) method, bill of quantity-based classification system accumulation (BoQS) method, BIM-based classification system accumulation (BIMS) method, and other particular methods. The ability of waste tracking in each method is analysed since an in-depth knowledge of the type and source of construction waste will enable project managers to select optimal solutions for waste minimisation and to build sustainable waste streams. For example, understanding waste generation in different construction stages (CS) aids project managers in planning for on-site waste management, such as sorting spaces, sorting labour, and waste transportation. The ability to track the waste source based on construction activities or elements (CA/E) will help designers understand the origin of waste; therefore, they can choose optimal design solutions for waste minimisation. Estimating waste by material type (MT) will help project managers develop waste diversion strategies based on the 3Rs principles. Detailed descriptions are given in the following sub-sections.

3.2.1 Area-Based Waste Generation Rate (WGR) Method

The principle of area-based WGR method is based on waste generation rate (WGR) per construction area. The total construction waste can be easily calculated by multiplying WGR by the total area (Sáez et al., 2011). WGR can be classified by individual waste streams according to their recyclability. For example, Wang et al. (2020) calculated WGR per floor area for five waste categories, including inorganic nonmetal waste, organic waste, metallic waste, composite waste, and hazardous waste. Furthermore, WGR by material type is employed by many researchers to disaggregate waste composition, such as concrete, steel, wood, masonry, and tiles (Bakshan et al., 2015; Li et al., 2013). In order to support the waste management plan through the construction phase, WGR for different construction stages is used to support on-site waste management (Bakchan et al., 2019). However, area-based WGR methods do not enable users to track the origin of waste from which construction activities and elements; hence, they hinder waste reduction at source.

3.2.2 Variables Modelling (VM) Method

Construction waste generation is directly impacted by numerous variables, such as total areas, structural types, economic indicators, etc., which are considered in variables modelling methods to provide more accurate waste estimation. These methods are classified into function-driven methods and data-driven methods. Function-driven methods refer to linear regression models and fuzzy set theory. Multiple linear regression analysis is often used to explain the relationship between predictor variables and waste generation (Domingo & Batty, 2021; Islam et al., 2019; Kern et al., 2015; Sáez et al., 2015). Meanwhile, Maués et al. (2020) established a fuzzy logic model with an accuracy of 66.67%. On the other hand, thanks to the development of artificial intelligence, data-driven methods are developed to learn the complex non-linear relationships between factors and the quantity of waste from historical data in order to predict the quantity of waste (Hu et al., 2021; Lee et al., 2016; Liu et al., 2018). Overall, existing VM methods tend to determine the quantity of waste in total without reference to the type and source of waste. Except for the study by Islam et al. (2019), linear regression analysis was adopted to estimate waste by material type; however, this method does not refer to the waste source.

Table 1: Previous studies on construction waste estimation methods at the project level

	Reviewed paper	Estimation method	Data collection	Waste tracking			
				TT	CS	CA/E	MT
1	Sáez et al. (2011)	AWGR	SD	✓			
2	Li et al. (2013)	AWGR	IM				✓
3	Bakshan et al. (2015)	AWGR	IM				✓
4	Noor et al. (2017)	AWGR	DM	✓			✓
5	Bakchan et al. (2019)	AWGR	IM	✓	✓		✓
6	Hoang et al. (2020)	AWGR	DM	✓			✓
7	Wang et al. (2020)	AWGR	DM	✓	✓		✓
8	Kern et al. (2015)	VM	IM	✓			
9	Sáez et al. (2015)	VM	SD	✓			
10	Lee et al. (2016)	VM	IM	✓			
11	Liu et al. (2018)	VM	IM	✓			
12	Islam et al. (2019)	VM	DM	✓			✓
13	Maués et al. (2020)	VM	IM	✓			
14	Domingo and Batty (2021)	VM	DM	✓			
15	Hu et al. (2021)	VM	DM	✓			
16	Solís-Guzmán et al. (2009)	BoQS	DM	✓		✓	
17	Llatas (2011)	BoQS	DM	✓		✓	✓
18	Li and Zhang (2013)	BoQS	UI	✓		✓	✓
19	Liu et al. (2014)	BoQS	SD	✓		✓	
20	Li et al. (2016)	BoQS	IM	✓		✓	✓
21	Lam et al. (2019)	BoQS	IM	✓		✓	
22	Liu et al. (2019)	BoQS	SD	✓		✓	✓
23	Spišáková et al. (2022)	BoQS	IM			✓	
24	Quiñones et al. (2021)	BIMS	SD			✓	✓
25	Quiñones et al. (2022)	BIMS	SD			✓	✓
26	Mercader-Moyano and Ramírez-de-Arellano-Agudo (2013)	Other	SD				✓
27	Bakchan and Faust (2019)	Other	IM			✓	✓
28	Guerra et al. (2019)	Other	IM			✓	✓

Note: AWGR – Area-Based Waste Generation Rate; VM – Variables Modelling; BoQS – Bills of Quantities-Based Classification System Accumulation; BIMS – BIM-Based Classification System Accumulation; DM – Direct Measurement; IM – Indirect Measurement; SD – Secondary Data; UI – User Input; TT – Total Waste; CS – Construction Stage; CA/E – Construction Activity/Element; MT – Material Type.

3.2.3 BoQ-Based Classification System Accumulation (BoQS) Method

In BoQS method, the bill of quantities (BoQ) is used as a classification system, the total waste is determined by accumulating the waste of all items in the BoQ. Solís-Guzmán et al. (2009) adopted the method to estimate the construction waste in Spain projects. Transformation coefficients are used to estimate demolitions, wreckage, and packaging waste of each item. Similar methods were also adopted in China (Liu et al., 2014) and

Slovakia (Spišáková et al., 2022). In these models, the source of waste can be easily tracked based on the BOQ; however, the waste quantity is not disaggregated by material type to assess the potential for reuse and recycling of waste, as each kind of material has different properties and requires different treatment methods. This limitation is addressed in another model developed by Llatas (2011) where the total amount of waste is accumulated from all elements and classified by material type. Later, Liu et al. (2019) used this methodology to estimate construction waste in China. In addition, Li and Zhang (2013) developed an online platform for construction waste estimation which enables users to track the origin of waste; however, material quantity take-off and waste level are entered by users. BoQS method estimates the quantity of waste based on project design, considers the categorisation of waste by material type, and enables users to track the source of waste. However, the method can only be used when the bill of quantities is available; therefore, this does not support waste assessment from the early design stage.

3.2.4 BIM-Based Classification System Accumulation (BIMS) Method

BIMS method is developed based on BoQS method; therefore, the method can also separate waste streams by material type and track the source of waste. The primary improvement is that the estimation model is integrated into BIM, which automatically estimates the quantity of waste and updates any changes during the design stage. Quiñones et al. (2021) developed a BIM-based model to estimate the construction waste from the structural system of a Spanish residential building. The model, later, was used to compare the waste amount generated from a reinforced concrete structure and a steel structure (Quiñones et al., 2022).

3.2.5 Other Methods

Apart from the above estimation methods, another method was established based on the difference between the amount of purchased materials and needed materials (Bakchan et al., 2019; Guerra et al., 2019). The method can only be applied when the purchasing records are available and can estimate the waste due to material losses; however, packaging waste and extracted waste are not quantified. Earlier, Mercader-Moyano and Ramírez-de-Arellano-Agudo (2013) determined the quantity of waste by multiplying the total quantity of consumed material by coefficient of transformation. This method depends on material quantity take-off and the availability of corresponding coefficient of transformation.

3.3 DATA COLLECTION METHODS FOR WASTE ESTIMATION

Database of waste generation is a fundamental part of a waste estimation model and significantly impacts the accurate results. Data collection methods are classified into three types: direct measurement, indirect measurement, and secondary data. Table 1 illustrates the data collection methods chosen in each waste estimation model.

3.3.1 Direct Measurement

Direct measurement refers to the method of quantifying actual on-site waste by sorting and weighting (Hu et al., 2021; Wang et al., 2020) or by heap-survey (Noor et al., 2017). Direct measurement provides the most realistic data to establish an accurate estimation method. However, the method also causes interruptions in site operations, additional health and safety concerns, as well as cost, labour and time intensive (Hoang et al., 2020), especially, when it comes to data collection to calculate waste generation by material type for particular building elements. This explains why researchers tend not to choose direct measurement to collect data in BoQS and BIMS methods.

3.3.2 Indirect Measurement

Compared to direct measurement, indirect measurement provides a quicker way to collect waste data. Project data is used to collect waste data, such as hauling tickets (Bakchan et al., 2019) or purchasing records (Guerra et al., 2019). The estimation model significantly depends on the availability and quality of project data. Furthermore, the material waste rate can be determined by personnel's perception, such as project managers' experience (Li et al., 2013), or contractors' judgment to define the waste percentage allowances (Lam et al., 2019; Li et al., 2016). Compared to direct measurement, indirect measurement may provide less reliable data; however, this method is still employed in many estimation models in order to save resources.

3.3.3 Secondary Data

Secondary data comes from region waste-related statistics or literature sources. Sáez et al. (2011) used national statistical publications to calculate the waste generation waste per built surface of Spanish dwellings. Spanish statistical publications were also used in another study to establish a linear regression model for waste estimation of residential buildings (Sáez et al., 2015). Furthermore, recent BoQS and BIMS models use the waste data in Spain by Solís-Guzmán et al. (2009) and Llatas (2011). The data is out of date and inapplicable in other regions due to different construction characteristics. For example, concrete is the top waste contributor in Hong Kong and Malaysia, whereas timber is commonly used in the New Zealand construction industry (Domingo & Batty, 2021). As a result, using secondary data from literature will impact the accuracy of waste quantity.

4. DISCUSSION

In this section, the applicability of each estimation method to facilitate construction waste minimisation is analysed based on four aspects: (1) design information requirements, (2) the ability to use in the early design stage, (3) project characteristics, and (4) the ability of waste tracking by material type and construction element. Table 2 summarises the comparison of the existing construction waste estimation methods at the project level.

Firstly, design information requirements define when the method can be used to estimate the waste of a construction project. Area-based WGR method only requires the information of construction area; hence, developers and managers can roughly estimate the quantity of waste from the early stage of the project. Apart from area information, VM methods need further information about predict variables to provide more accurate estimation. The variables depend on different models. For instance, Sáez et al. (2015) only considered the number of dwellings and total floor area. More predictor variables were employed in Domingo and Batty (2021) study, such as floor area, number of stories, materials for external and internal walls. BIMS method can apply from the schematic design stage as this method requires a BIM model with the level of development for elements at least equivalent to LOD 200 standard (Quiñones et al., 2021). Therefore, area-based WGR, VM and BIMS methods enable users to estimate the amount of waste in the early design stage. This ability is fundamental to an effective waste management plan from the early design stage (Lu et al., 2021). However, the remaining methods cannot be used until the bill of quantity is available.

Table 2: Comparison of the existing construction waste estimation methods at the project level

Estimation method	Design information requirements	Use in the early design stage	Project characteristics	Material type/ Construction element
Area-based WGR	Construction area	✓		MT
Variables modelling	Construction area and variables	✓	✓	MT
BoQS	BoQ		✓	MT, CE
BIMS	LOD200	✓	✓	MT, CE
Others	Purchasing records & BoQ		✓	MT, CE

Regarding the project characteristics, an individual project has its own features which directly impact the construction waste generation. However, area-based WGR method does not consider project characteristics; therefore, the method is unable to provide the actual amount of construction waste generated in an individual project. Meanwhile, VM method considers design and project parameters to predict total waste generation in a construction project. BoQS and BIMS methods estimate waste generation based on the detailed design of an individual project; therefore, project managers can estimate the waste quantity of the project and assess the efficiency of designing out waste alternatives for further needed improvements. Nevertheless, in BoQS method, the transformation coefficient needs to be aligned with the measurement and item descriptions in BoQ, which depends on the standard method of measurement chosen for the project. This may hinder the widespread use of the model. In addition, only design parameters are considered in BoQs and BIMS methods; meanwhile, qualitative measures such as site management and practices also have a direct impact on waste quantity (Domingo & Batty, 2021).

Considering another aspect, the ability of waste tracking by material type and construction element will provide detailed information for more effective waste management. First, by understanding the composition of the waste stream, project managers can optimise the waste treatment plan under the 3Rs principles and select sustainable materials to replace conventional ones. Although all methods can estimate the amount of waste by material type, VM models tend to limit to waste estimation in total without disaggregating waste by type. Due to the requirement of realistic data for construction waste estimation, gathering realistic waste data by material type is significantly costly and time consuming. BoQS and BIMS methods allow users to estimate construction waste by material type. However, there is a lack of an up-to-date waste database to implement the method. Another advantage of BoQS and BIMS methods is understanding the waste source at the element level; hence, designers can find which elements generate a significant amount of waste to decide whether design alternatives are needed for improvements.

5. CONCLUSIONS

Reliable construction waste estimation is fundamental to an effective waste management plan for the zero-waste construction site. Through a systematic review of twenty-eight papers, existing construction waste estimation methods at the project level are analysed based on how they can facilitate effective waste management in construction projects.

The ability to estimate waste in the early design stage will support waste management from the early planning phase. Considering project characteristics in estimation methods will improve the accuracy of waste quantity since design and project parameters directly impact waste generation. The information on the waste stream composition aids project managers in waste management plans under the 3Rs principles. Furthermore, understanding the waste generation at the building element level helps designers select optimal design solutions for waste minimisation. However, each estimation method has advantages and limitations in supporting effective waste management in construction projects; the selection of an appropriate estimation method depends on the objectives of waste estimation, waste database, and realistic conditions. A reliable and sufficient waste database directly impacts the accuracy of waste estimation. The data collection method should be selected according to the availability of resources and data quality.

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CRITICAL ASSESSMENT OF THE EXISTING DISASTER RESILIENCE FRAMEWORKS AND THEIR APPLICABILITY TO IMPROVE COMMUNITY RESILIENCE

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ABSTRACT

Disasters are inevitable and unique; however, their impact on livelihood can be minimised. Improving disaster resilience is used as one of the key approaches to minimise the impact of disasters. Several disaster resilience models were presented during the last 20 years. However, these disaster resilience models have a vast diversity and research has not been conducted to assess the connectivity of the available models and frameworks. Therefore, this study critically reviews the disaster resilience models and frameworks to identify their positive and negative aspects that support the development of community resilience. The research is following a narrative literature review methodology while using selected journal and conference papers from the last 20 years. The models and frameworks were critically reviewed using the characteristics and availability of different concepts concerning disaster resilience context. the study summarises 10 disaster resilience models and frameworks utilised in different contexts. The outcome illustrates that DROP and Regional Resilience of Process and Outcome frameworks are comprehensive based on the availability of concepts. Moreover, the Regional Resilience of Process and Outcome framework signifies the suitability of the particular framework for disaster resilience based on concepts and characteristics. This study enhances the existing level of knowledge on disaster resilience and its understanding based on diversified discussion.

Keywords: *Community; Disaster; Frameworks; Models; Resilience.*

1. INTRODUCTION

Disasters are complex global issues which are inevitable in the community (Makwana, 2019). Raju et al. (2022) have commented that hazards turn into disasters when society is not equipped to handle the severity of the hazard and is unable to absorb their intensity. In 2021, 367 major disasters occurred affecting 127 countries around the world. According to statistics presented in 2021, floods were indicating the highest frequency

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among other types of disasters. Similarly, its impact in terms of deaths and impact on the population was recorded at 41.87% and 28.03% respectively (United Nations Disaster Risk Reduction [UNDRR], 2022). In 2021, 432 catastrophic events were recorded, which is higher than the average of 357 events that occurred in the last 20 years (Center for Research on Epidemiology of Disasters [CRED], 2022). Kahn (2021) emphasized 2021 was called the era of Anthropocene due to the increased number of disasters.

Disaster resilience is a vital concern in the modern world to minimise the impact of disasters on livelihood (Walker, 2020). In the global context, Takeda, Jones, and Helms (2017) have elaborated on the importance of the community to develop disaster resilience practices. Furthermore, several studies have demonstrated that disaster resilience is an important aspect to uplift the livelihood of the community, irrespective of the different disciplines (Asadzadeh et al., 2017). Moreover, several studies conducted to enhance disaster resilience or recovery with the development of models addressing diversified disciplines (Bruneau et al., 2003; Cutter et al., 2008; Palekiene et al., 2015; Renschler et al., 2010). Tariq et al. (2021) researched community disaster resilience frameworks identifying their characteristics from a stakeholder perspective. However, the available models/ frameworks and previous studies do not provide a common outline for the development of a disaster resilience model. Therefore, this paper aims to critically assess the available disaster resilience frameworks and models and identify their positive and negative aspects that support the development of community resilience.

2. LITERATURE REVIEW

2.1 MODEL OF RESILIENCE

The model of resilience shows the impact of disruptive events and the process of obtaining a new level of functionality. Lester and Smith (2018) presented that resilience taxonomy identifies four principles namely, capacity flexibility, tolerance and cohesion. The presence of extreme events, artificial or natural creates a shock. When the shock exceeds the design capabilities, it creates failure. Figure 1 shows the disaster readiness of the built environment.

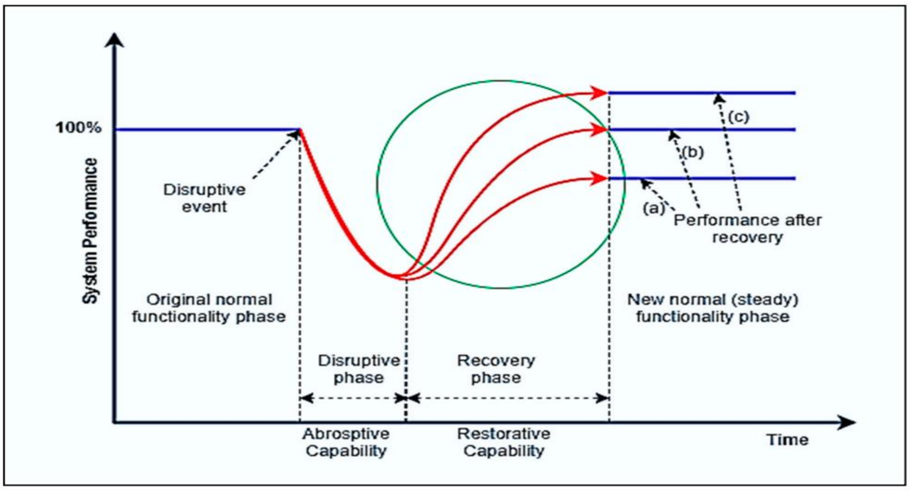

Figure 1: Model of resilience

Source: (Lester & Smith, 2018)

Curve C shows the higher readiness of the community which exhibits exponential recovery while curve A shows the sinusoidal recovery with lower community recovery. Finally, curve B demonstrates the linear recovery with the average level of readiness of the community. Figure 1 shows the model of resilience presenting the four phases of the disaster and the mechanism followed by the community to recover. Nevertheless, the main emphasis has been given to the disruptive and recovery phases, which allows the users of the model to decide the expected resilience at the end of the cycle.

2.2 PANARCHY FRAMEWORK

This framework is a hierarchical structure which connects natural and human systems and involves growth, accumulation, restructuring, and renewal (Cutter, et al., 2008). The particular framework occupies discrete niches in space and time. Moreover, the combination of resilience and sustainability is developed using the adoptive cycles in the use of the human environment mental system. According to Allen et al. (2014), the panarchy framework is used in ecological and social sciences. The panarchy implications are linked with resilience and assess the resilience of complex systems. Accordingly, the panarchy framework allows simplifying complicated systems. From a broader perspective panarchy framework demonstrates the relationship between social and ecological systems with the understanding of enhancing resilience (Brunckhorst, 2002).

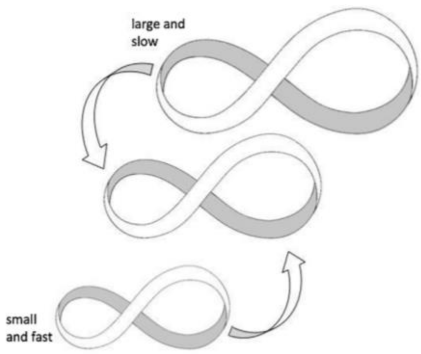

Figure 2: Panarchy consisting of a nested set of adaptive cycles

Source: (Berkes & Ross, 2013)

Figure 2 shows the adaptive cycle with a wider range of systems to accommodate the nested systems. Gunderson and Holling (2002) used the name panarchy concerning the Greek god of nature instead of hierarchy since this Figure 2 is not showing rigid top-down implications.

2.3 DISASTER RESILIENCE OF PLACE MODEL

The DROP model is another reliable technique that supports the development of disaster resilience and comparative assessment along with the support of local and community practices (Béné, 2020; Cutter et al., 2008). Figure 3 demonstrates the DROP model that supports applying resilience for real places based on the applications (Cutter et al., 2008). The DROP model is presenting the relationship between mitigation, preparedness, event, and adaptive resilience. Moreover, the model is consisting of the illustration of the risk formula and the actions that need to be taken when the absorptive capacity of the resilience is exceeded.

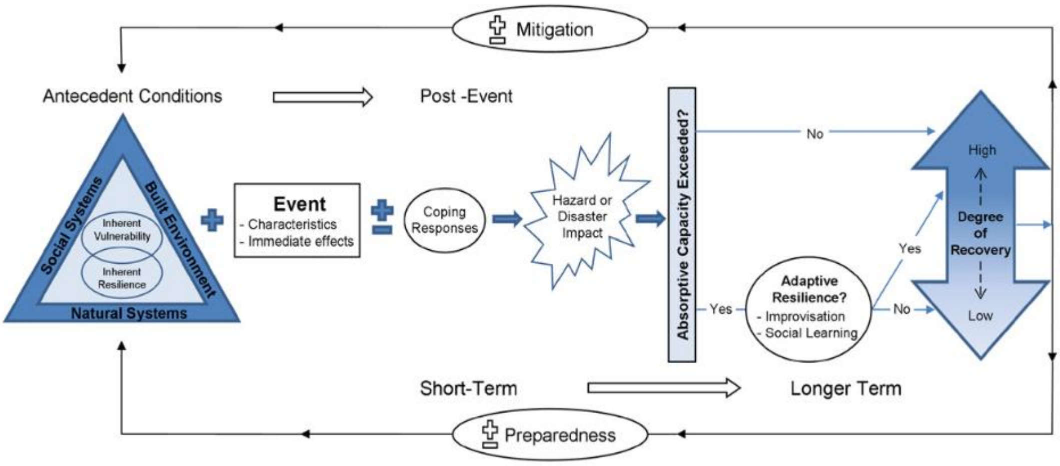

Figure 3: DROP model

Source: (Cutter et al., 2008)

Figure 3 presents the DROP model, which is showing the connectivity of risk and resilience.

2.4 CONCEPTUAL MODEL OF RECOVERY

Miles and Chang (2006) developed the comprehensive Conceptual Model of Recovery is developing the relationship between households, neighbours, businesses, and infrastructure systems. The particular model is focused on the investigation of community recovery and operational levels including household income, businesses, building construction and building retrofit.

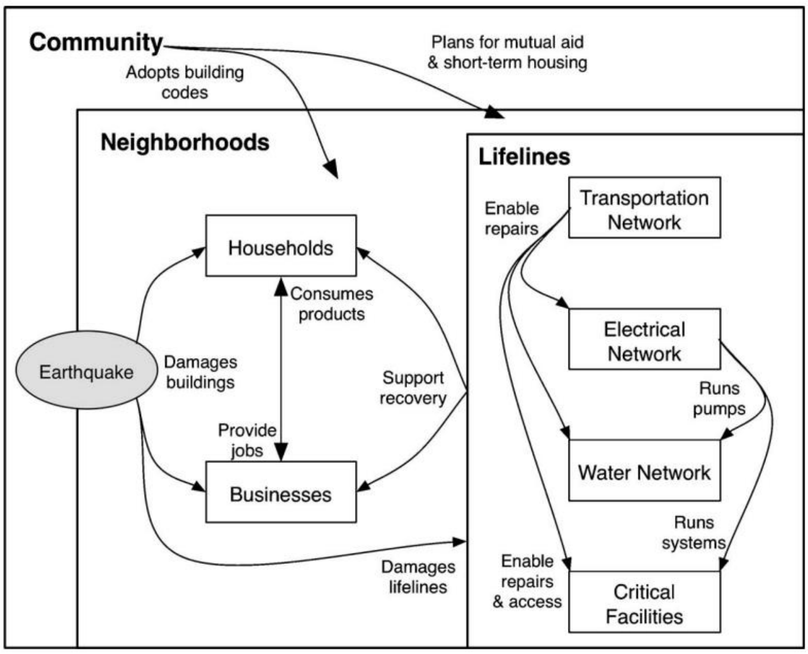

Figure 4: Conceptual Model of Recovery

Source: (Miles & Chang, 2006)

2.5 GENERAL FRAMEWORK

The General Framework was introduced by Bruneau et al. (2003) to quantify seismic hazard identifying the resilience of the community based on 'reduced failure probabilities' reduced consequences from failures' and 'reduced time to recovery'. Bruneau et al. (2003) further elaborated that the framework applies to individual systems and a combination of systems. Figure 5 demonstrates the applicability of different systems for the resilient community system. Accordingly, the framework shows the feedforward and feedback loops. Furthermore, it is demonstrated as an open loop and closed loop system. Since the General Framework has been defined for the seismic retrofit it shows the specification for the earthquakes. Figure 5 is showing that the General Framework systems diagram is consisting of 3 layers. The bottom layer is illustrating the situation where it has no intervention for the existing systems. The middle layer is showing the first level of actions and decisions taken based on simple triggers. The top level of the diagrams demonstrates the multi-attribute information which is gathered and used for decision-making. The decision system is consisting of advanced technical-organisational-socioeconomic information.

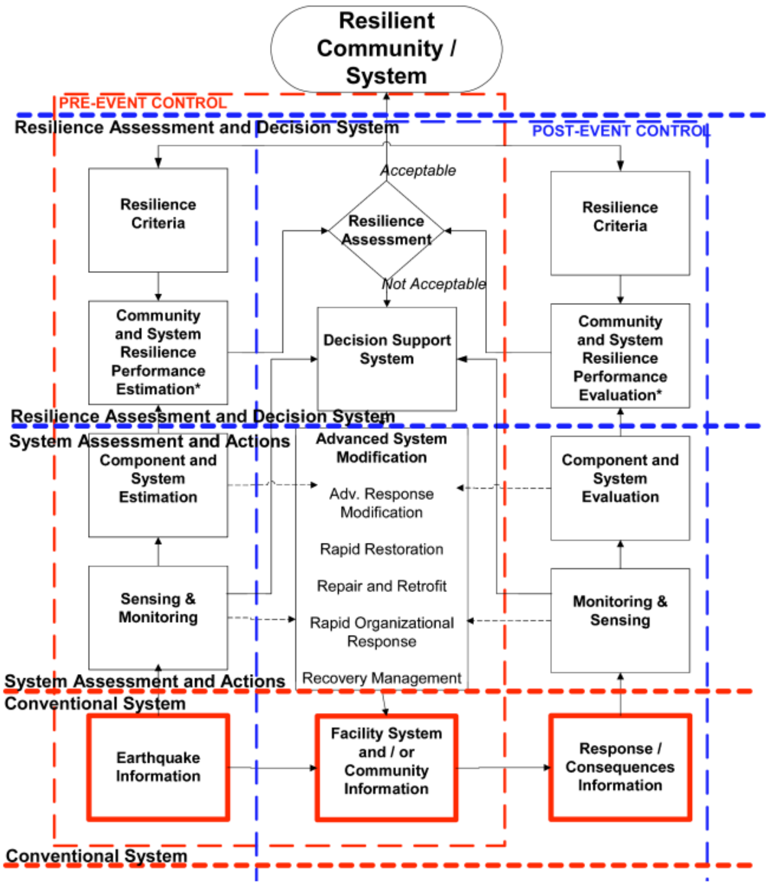

Figure 5: General framework systems diagram

Source: (Bruneau et al., 2003)

2.6 PEOPLES RESILIENCE FRAMEWORK

Renschler et al. (2010) introduced a resilience framework consisting of seven dimensions to assess community resilience namely, population and demographics, environment or ecosystem, organized governmental services, physical infrastructure, lifestyle and community competence, economic development, and social-cultural capital, which was highlighted as PEOPLES Resilience Framework.

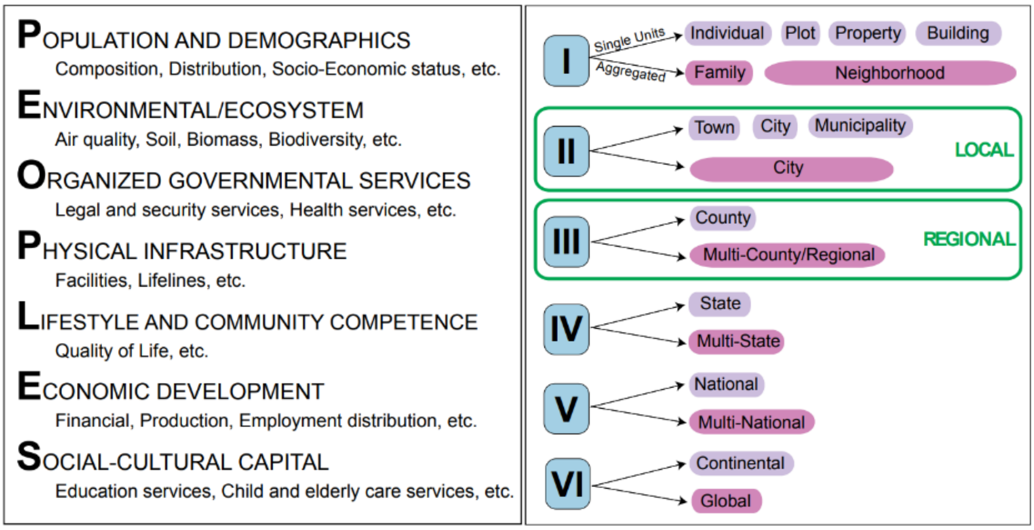

Figure 6: Association of the geographic scales among the PEOPLES Resilience Framework

Source: (Renschler et al., 2010)

2.7 THE REGIONAL RESILIENCE PROCESS AND OUTCOME FRAMEWORK

The Regional Resilience Process and Outcome Framework explained by (Palekiene et al., 2015) is evaluating the resilience notion based on the different regional development contexts and regional resilience capacity-building factors.

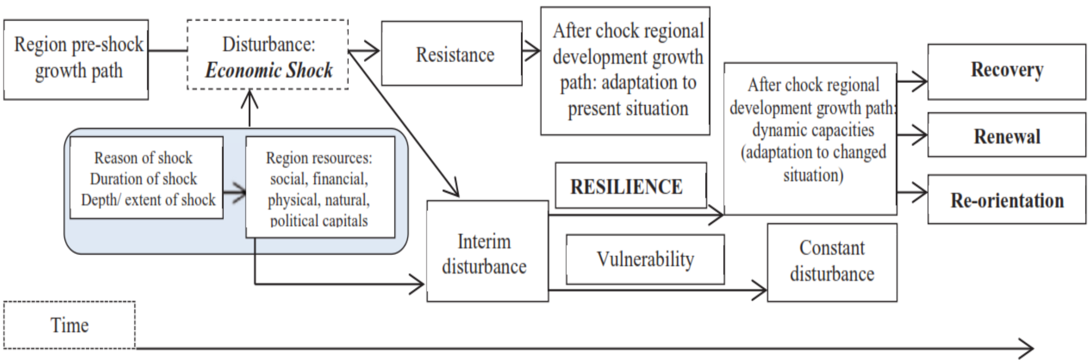

Figure 7: Regional resilience process and outcome framework

Source: (Palekiene et al., 2015)

Resilience is having different perspectives. Tierney and Bruneau (2007) developed resilience as an outcome. Another review has illustrated resilience as a process. However, Cutter et al. (2008) represented resilience as a combination of process and outcome. Similarly, regional resilience is addressed as a combination of process and outcome (Palekiene et al., 2015). This framework shows the significance of the interim disturbances on resilience and the four types of economic resilience's response to shock. Furthermore, the amount of time taken for the resilience and economic declines in the region is demonstrated with the particular model.

2.8 FLOODING DISASTER RESILIENCE INFORMATION FRAMEWORK

Then, Kumar et al. (2019) introduced Flooding Disaster Resilience Information Framework, which collects data from flooding situations and provides a personalised response to the human actuators. The model ensures the minimisation of injuries and infrastructural damage with early warning and a personalised response process.

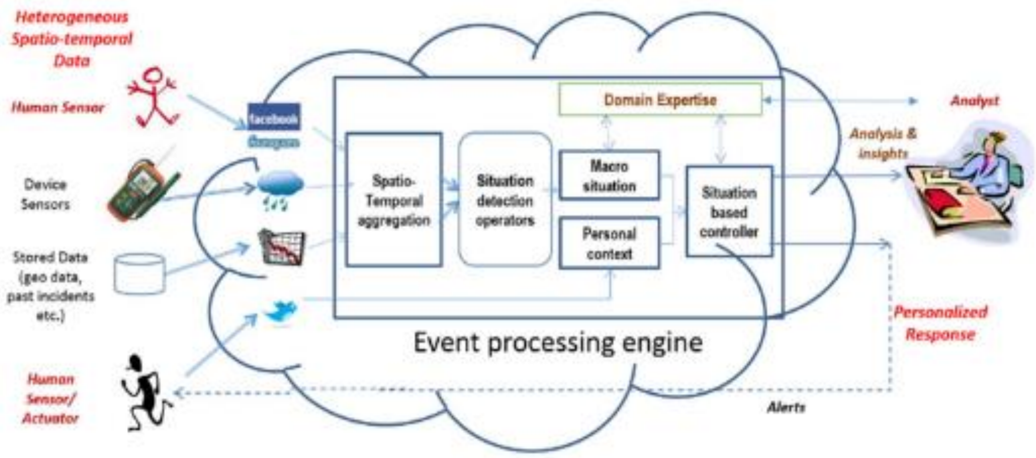

Figure 8: Flooding Resilience Information Framework

Source: (Kumar et al., 2019)

The framework is consisting of the inputs generated via human sensors, stored data and an actuator. Then the output is generated via a human actuator. However, the working condition for the particular model is consisting of several challenges such as data uncertainty, modelling with domain experts, and collaboration of data into a physical prediction model. Despite the challenges the Flooding Disaster Resilience Information Framework has been validated for Hurricane Irma that occurred in the United States of America (USA).

2.9 HOSPITAL DISASTER RESILIENCE MODEL

Fallah-Aliabadi et al. (2020) developed the Hospital Disaster Resilience (HDR) model showing the method of engaging with hazards occurring in hospitals. Hence, it indicates that resilience and disaster concepts are not limited to a particular discipline.

The review of resilience and its subsequent implications are vital to demonstrate the theory of complexity (Turner & Baker, 2019). Arias-Pineda and Ramirez-Martinez (2019) elaborated that the theory of complexity is applied to manage complex organizations to establish preliminary warning systems and obtain lessons from previous incidents. Hence, disaster resilience and related frameworks are demonstrating the application and suitability of disaster resilience concepts in different disciplines to minimise the impact of disasters.

2.10 THE DISASTER RESILIENCE INTEGRATED FRAMEWORK FOR TRANSFORMATION

The Disaster Resilience Integrated Framework for Transformation (DRIFT) conceptualises and operationalises the relationship between resilience and capacity (Manyena et al., 2019). Figure 9 shows the key features of the DRIFT model with a critical review. The model is connected with risk drivers while understanding the capacities of the system to absorb disasters. This model presents the bounce forward terminology in addition to bounce back. It highlights improved disaster resilience. Furthermore, according to Figure 9, disasters and disaster resilience are interrelated with prevention, anticipation, absorption, adaption, and transformation. The DRIFT model is focusing creating a resilience index of countries based on hazard, vulnerability, and resilient capacities. Furthermore, the application of the DRIFT model is diversified in temporal, spatial, and institutional scales (Manyena et al., 2019).

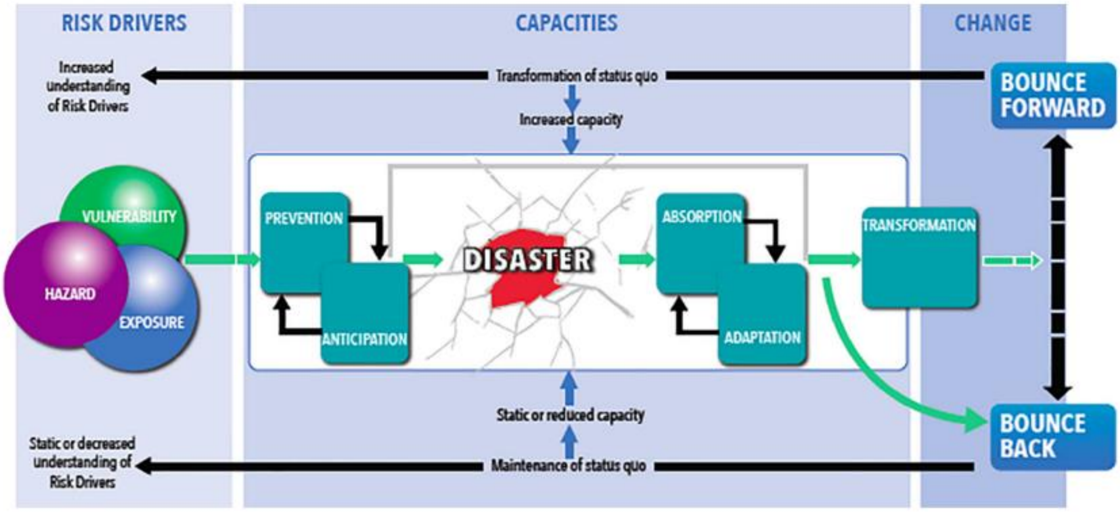

Figure 9: DRIFT model

Source: (Manyena et al., 2019)

3. METHODOLOGY

The research has been conducted using narrative literature review using, journal articles and conference papers. The selection of the articles is expanded to the last 20 years and connects the old and new knowledge for the identification of the strong existing model or framework related to disaster resilience. Clarke and Oxman (2000) confirmed narrative literature review articles are publications that describe and discuss the state of the science of a specific topic or theme from a theoretical and contextual point of view. These types of review articles do not list the types of databases and methodological approaches used to conduct the review nor the evaluation criteria for inclusion of retrieved articles during databases search. The narrative review consists of a critical analysis of the literature published in books and electronic or paper-based journal articles (Khan et al., 2000).

4. FINDINGS AND DISCUSSION

Some researchers also criticized resilience for promoting conservatism and the status quo, which contrasts with the point of view that adaptation is a fundamental characteristic of resilience (Bankoff, 2019). The most common misinterpretation of resilience is gaining the previous level of resilience. Resilience is the ability to adapt and change, to reorganize, while coping with disturbance. A resilient system responds to a disturbance by changing the relative amounts of its various parts and how they interact, thereby changing the way it functions (Walker, 2020). Resilience is having different overviews and based on these varieties; resilience is utilized in organizations (Somers, 2009), networks, and communities. Another review has maintained that resilience is applied to crisis management at organizational, inter-organizational, and local community levels (Normandin & Therrien, 2016).

The implementation of resilience in the global context has been able to reduce the impact of disasters over time from a financial perspective and impact lives. Wildavsky (1988) explained that the development of resilience is demonstrating the ability to address risk and prevention in particular situations. Therefore, resilience is identified as the method of implementing stability in any situation (bounce back, persistence, same relationships) and the level of adaptability (learning, absorbing change). According to Olsson et al. (2015), resilience has been divided into five perspectives in social science namely, ecological approach (Holling, 1973) organization and management sciences (Wildavsky, 1988), safety sciences (Bergström, 2019), crisis management and sociology of disasters and the study of socio-technical systems (Emery, 2016). The concept of community resilience is consisting of planning for, resisting, absorbing, and rapidly recovering from disruptive events (Koliou et al., 2020). Hence, community resilience comprises factors related to emergency response, preparedness and security, mitigation, risk communication, and recovery of communities from physical, economic and social disruptions. Table 1 is connecting the characteristics of different models/ frameworks with the light of community resilience.

The discussion on the identified models and frameworks demonstrates the similarities and contracting points. Table 1 summarises the critical aspects of the disaster resilience models and frameworks. Accordingly, it identifies the suitability and the application of different characteristics of the aforementioned models. The application of different characteristics was identified through the comparative evaluation of the models and frameworks.

Table 1: Discussion on the disaster resilience models/ frameworks

Application of Different Characteristics	**Model/ Framework**									
	[1]	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**	**[7]**	**[8]**	**[9]**	**[10]**
Pre-disaster events	✓			✓		✓	✓	✓	✓	✓
Post-disaster events	✓		✓	✓	✓	✓	✓	✓	✓	
Presence of hazard	✓		✓				✓	✓	✓	✓
Presence of disaster	✓		✓				✓	✓	✓	✓
Presence of resilience	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Presence of the time factor	✓	✓	✓				✓	✓		
Presence of community				✓	✓			✓	✓	✓
Presence of risk			✓				✓	✓	✓	
Use of technology				✓	✓	✓		✓		
Use of human resources			✓	✓				✓		
Theoretical perspective	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Practical perspective			✓	✓	✓		✓	✓		

[1] Model of Resilience **[2]** Panarchy Framework **[3]** DROP **[4]** General Framework **[5]** Conceptual Model of Recovery **[6]** PEOPLES Resilience Framework **[7]** The Regional Resilience Process and Outcome **[8]** Flooding Disaster Resilience Information Framework **[9]** DRIFT **[10]** HDR

According to the findings of Table 1, resilience is a common factor, which was presented in all the disaster resilience models/ frameworks. Additionally, all the models and frameworks were developed from a theoretical perspective and only DROP, General Framework, Conceptual Model of Recovery, the Regional Resilience Process and Outcome and Flooding Disaster Resilience Information Framework have presented the practical perspective of the models. Furthermore, except Panarchy Framework and HDR, all the other models and frameworks are elaborating on the post-disaster events.

Additionally, Panarchy Framework, DROP, and PEOPLES Resilience Framework are not discussed in the pre-disaster events. According to the discussion, Panarchy Framework has been highlighted as the theoretical model which is only consisting of resilience and time factor. Hence, further evaluation is required on the particular framework when assessing the suitability of the Panarchy Framework as a disaster resilience framework. Time is another unique factor which is only present in the Model of Resilience, Panarchy Framework, DROP, The Regional Resilience Process and Outcome, and Flooding Disaster Resilience Information Framework. The concept of community is only addressed in the General Framework, Conceptual Model of Recovery, DRIFT, HDR, and Flooding Disaster Resilience Information Framework.

Table 2 critically discusses the unique characteristics of the different disaster resilience models. Accordingly, except for the Model of Resilience, PEOPLES Resilience Framework, and The Regional Resilience Process and Outcome all the other models are illustrating the circular information flow for disaster resilience. Conceptual Model of Resilience, Flooding Disaster Resilience, and Hospital Disaster Resilience have been developed for specific disasters. Meanwhile, all the other models have the potential to apply to any type of disaster.

Hence, the Model of Resilience, General Framework, Conceptual Model of Recovery, Flooding Disaster Resilience Information Framework, The Regional Resilience Process and Outcome, DRIFT, and PEOPLES Resilience Framework are identified as the applicable disaster resilience models and frameworks for community resilience.

Table 2: Application of Models and Frameworks

Model/ Framework	**Year**	**Unique Characteristics**	**Applicable Situations**
Model of Resilience	2018	Level of resilience among the community during the pre-disaster and post-disaster event The impact of time on the disaster event and the relationship between time and the disruptive phase Relationship of the recovery phase Performance of the system/ community	Any disaster events
Panarchy Framework	2002	Behaviours of the Social and ecological systems Nested relationship of the resilience system Impact of the lower level on community resilience (organisational level) Impact of change on the higher level of the system (national and global aspects) Presents socio-ecological resilience and circular flow of the system	Focused on socio-ecological system
DROP	2008	Discusses the existing resilience and vulnerability in social, built, and natural systems including recovery Hazard or disaster occurs with the combination of vulnerability, resilience, event and coping responses Presents the concept of adaptive resilience The feedback mechanism is demonstrated with mitigation and preparedness concepts Illustrates the impact of time short and long categories Related to the pre and post-event the disasters and circular flow of information	Not specified to specific disaster type
General Framework	2003	Discusses the pre and post-event control for the resilient system Demonstrates 3 different systems under the resilient community system (resilience assessment and decision system, system assessment and actions, conventional system) Use of technology for sensing and monitoring Resilience criteria introduced Resilience and performance evaluation and estimation processes discussed Advanced system motivation demonstrates the combination of response, restoration, repair, retrofit, and recovery. Disaster information, community information systems and response information systems are used as the bottom level Information flow and interconnectivity presented	Applied for earthquakes Has the potential to apply to other disasters
Conceptual Model of Recovery	2006	The project consists of 3 boundaries as community, neighbourhood and lifelines Community boundary focused on building development Neighbourhood boundary discusses the impact on households and businesses only Lifeline boundaries are demonstrating the factors affecting the livelihood of the people (transportation, electrical network, water network, critical facilities)	Defined for earthquakes

PEOPLES Resilience Framework	2010	Lifeline boundaries are supporting the neighbourhood development Interconnected circular approach Discusses the community resilience Focusing the national perspective with large-scale resilience Connected with the geographical aspects/ locations using GIS Diversified in local, regional, global, continental, organisational, family and national Pre-disaster event is presented	All types of disasters
The Regional Resilience Process and Outcome	2015	Availability of resources discusses The disturbance occurred with the economic shock Resilience is presented in 4 categories (resistance, recovery, renewal, re-orientation) Constant disturbances affect the system to become resilient Post-disaster event is presented Following the linear approach Presents the impact of time	For any type of disaster
Flooding Disaster Resilience Information Framework	2019	Feeding data to the system using human sensors, devise sensors, past data from databases, and actuator Use the event processing engine consisting of situation decision operators, macro situations, personal context, and situation-based controller Use the knowledge of expertise Human analyser used for the process Personalised response system Circular information system	Flooding disasters only
DRIFT	2019	Demonstrates 3 steps (risk drivers, capacities/ Change) The basics for the disaster are hazard, vulnerability, and exposure Prevention and anticipation are 2 aspects that decide the occurrence of disasters Absorption and adaptation are key aspects of the transformation Resilience is presented with 2 levels (bounce forward and bounce back) Increased capacity and reduced capacity have 2 different impacts on disasters Circular information system	Not specified applicable for any disaster
HDR	2020	Method of engaging with disasters at hospitals Connected with the theory of complexity Supports the installation of a preliminary warning system	Hospital-related disasters only

5. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, all the disaster resilience models and frameworks discuss the different aspects of disaster resilience. Accordingly, critical discussion on the applicable concepts of the frameworks and models shows that DROP and The Regional Resilience Process and Outcome models are more comprehensive. Furthermore, the combination of characteristics of the models and frameworks signifies that the Regional Resilience Process and Outcome is the ideal disaster resilience framework for improving community resilience in a disaster resilience context. The study concludes that the presence of hazard, disaster, time factor, community, and risk improve community resilience. Additionally, the use of human resources and technologies supports community resilience. Hence, the development of a common model/ framework for the improvement of community resilience needs to combine the aforementioned factors. Application of all these factors in a single model helps to implement a platform for improved community resilience.

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DATA SCIENCE APPLICATIONS FOR CARBON FOOTPRINT MANAGEMENT IN BUILDINGS: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Buildings have a significant impact on climate change. The building industry is the world's biggest energy consumer and the building's operation accounts for 80–90% of its total energy consumption over its lifetime. Data-driven solutions for the management of carbon footprint in buildings have great potential due to the data science field's rapid growth and the expansion of operational building data availability. Therefore, this study's aim is set as to investigate the potential applications of data science for the management of carbon footprint in buildings. The study adopted a systematic literature review as a research methodology. Accordingly, 31 publications were reviewed using the content analysis technique. The study revealed that facilitating pre-process of the operational data of buildings, fault detection and diagnosis, implementing waste management in buildings, conducting the building energy performance modelling, conducting the parametric analysis at the design phase, evaluating the energy efficiency of building designs, benchmarking evaluation, control optimisation and retrofitting analysis are the major applications of data science to the management of carbon footprint in buildings. Moreover, the study suggested carrying more studies should be done on automating and building operational data pre-processing tasks, gathering sufficient labelled data for all possible faulty operations and applying modern big data management tools and advanced analytics techniques lead to improve the applications of data science in the built environment. The results from this study provide better guidance to building sector stakeholders, information technology sector stakeholders, academic persons, non-governmental organisations (NGOs) and other relevant authorities to address the carbon footprint in buildings using data science applications.

Keywords: *Building; Carbon footprint; Data Science; Energy; Management.*

1. INTRODUCTION

All facets of human life are disrupted by the worldwide phenomenon due to climate change (Evans, 2019). These include things like warming climates, increasing sea levels, and an increase in the frequency of extreme weather events. These modifications have an

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impact on all facets of the world (Lu, 2021). Increased amounts of greenhouse gases (GHG) in the atmosphere are the primary reason why the climate is changing more dramatically than it does naturally (Radlbeck et al., 2004). The building industry has overtaken transportation as the world's biggest energy consumer, accounting for more than a third of global energy consumption (Fan et al., 2019). Since a building's operation accounts for 80–90% of its total energy consumption over its lifetime and the majority of defects manifest themselves during this phase, there are significant possible benefits from improving a building's energy efficiency (Fan et al., 2019). Environmental impact of buildings occurs at different stages of their life cycle: planning, construction, operation, renovation and demolition, with operation stage accounting for largest percentage, with approximately 85% of GHG emissions (Akbarnezhad & Xiao, 2017). In addition to that, Akbarnezhad and Xiao (2017) stated that embodied carbon also emitted considerable amount of GHG emissions. Therefore, buildings have a significant impact on global sustainability and climate change (Fan et al., 2021). Hence, the adaption of necessary actions to reduce carbon footprint (CFP) in the construction industry fundamentals (Sander et al., 2022). According to Akbarnezhad and Xiao (2017), low-carbon materials; material minimisation and material reduction strategies; material reuse and recycling strategies; local sourcing and transport minimisation; and construction optimisation strategies can be applied to reduce the embodied carbon of buildings.

In addition, the adaption of energy efficiency systems, the use low carbon construction materials, buildings retrofitting, the use of clean fuel and energy for buildings operation, the proposal of energy efficient alternative designs, the adaption of green building techniques mentioned in the green rating tools around the globe, implement proper waste management techniques, use of more energy efficient machinery and equipment and control the energy management of buildings are main strategies that can be implemented to reduce both embodied and operational carbon in buildings (Chen et al., 2022; Fu et al., 2023; Robati et al., 2021). However, previous studies showed the lack of an internationally comparable and agreed data inventory and assessment methodology which hinders the application of life cycle assessment (LCA) from the perspective of environmental concerns within the building industry (Khasreen et al., 2009). Yeheyis et al. (2013) stated that it is difficult to apply proper waste management process to the construction industry due to lack of construction data. Moreover, Hong et al. (2015) revealed that the lack of detail on and off-site process data is the main barrier to calculating embodied carbon (EC) in China. In addition to that Moncastera and Songb (2012) showed the lack of existing buildings data to conduct a comparative review of new designs CFP another challenge to managing CFP in buildings.

Technology has improved in many different fields throughout the years, and wide range of applications of the new technologies in the built environment increased (Fan, Liu, et al., 2021). It has been significantly impacted by advancements in a variety of ICT fields, including Control and Automation, Smart Metering, Real-time Monitoring, and Data Science (Fan, Yan, et al., 2021). As it is generally known, data scientists use algorithms and systems to extract information from massive amounts of data, identify patterns, and produce insightful conclusions and forecasts. It includes every stage of the data analysis process, from data cleaning and extraction through data analysis, description, and summary (Inibhunu & Carolyn McGregor, 2020). The prediction of new values and their visualisation are the outcomes. Thus, data science uses information technology techniques along with mathematical and statistical analysis (Fan et al., 2021). In order to extract knowledge, identify patterns, and produce insightful conclusions and predictions from massive amounts of data, data scientists create systems and algorithms (Zhou et al., 2013). It includes every stage of the data analysis process, from data cleaning and extraction to data analysis, description, and summary. The prediction of new numbers and their visualisation are the outcomes (Silva et al., 2017). Data science, therefore, combines information technology tools with mathematical and statistical research (Nguyen & Aiello, 2013). Accordingly, massive on-site measurements can now be easily accessed, stored, and analysed using recent developments in information technology and data science. This has led to the emergence of a new big-data-driven research model (Fan et al., 2021). In addition to that Fan et al., (2021) revealed there are now many chances to create data-driven solutions for intelligent building energy management using data science field's rapid development and the expansion of building operational data availability (Fan et al., 2021). Moreover, exploring the potential for energy savings through data-driven approaches has become simpler due to advancements in data mining technology and the broad availability of operational data on buildings (Fan et al., 2021). Ramesh et al. (2010) showed predictive modelling, fault detection and diagnosis, and control optimisation are just a few examples of how tasks connected to building energy management can benefit greatly from the knowledge found in massive building operational data. Therefore, this paper aims to explore data science applications for building carbon footprint management in the global context using a systematic literature review approach. The paper is structured as follows. First, it provides the steps of the methodology approach. Next, research findings are revealed based on a systematic literature review. Furthermore, it is followed by the conclusions and way forward.

2. METHODOLOGY

In order to develop a thorough understanding of studies by analysing themes, highlighting trends, finding gaps, and ultimately offering directions for future research, the systematic review method was considered to be appropriate (Mishra et al., 2021; Paul & Feliciano-Cestero, 2021; Paul & Singh, 2017; Rosado-Serrano et al., 2018). As a result, this research adopted a systematic review methodology to explore data science for building CFP management in the global context. Accordingly, the systematic literature review was conducted based on the methodology proposed by Denyer & Tranfield (2009). It consisted of two steps: (1) identification; and (2) screening and eligibility, as illustrated in Figure 1.

2.1 IDENTIFICATION

The identification process consists of two main phases such as choosing the database and choosing the most pertinent keywords. Accordingly, the Web of Science and Scopus were the sources of the data used in this research. One of the biggest databases of peer-reviewed literature on the globe is the Web of Science. Authoritative, multidisciplinary coverage from more than 12,000 high impact research journals globally is offered by the world's top citation databases (Sweileh et al., 2014). Additionally, with more than 49 million registered individuals, Scopus is the most peer-reviewed database worldwide (Dangelico, 2016). After the selection of databases, a list of keywords is chosen based on the review of the initial literature search. As the final step in developing keywords for the search, search-field descriptors and wildcard characters and Boolean operators were applied to the identified keywords and index terms in the logic grid shown below.

("building*" OR "construction" OR "built environment") AND ("data science") AND ("carbon management" OR "carbon reduc*" OR "carbon minimis?ation" OR "carbon management strateg" OR "net-zero carbon" OR "GHG*" OR "carbon emission" OR "net-zero emission" OR "net-zero energy" OR "smart building" OR "smart construction" OR "smart building management" OR "smart built environment")

By using the keywords mentioned above, 28 documents from Web of Science and 24 documents from Scopus appeared in the result. Then the study limited the search to document type (journal articles, review articles and conference papers) and the language was limited to English only to minimise publication bias (Mahood et al., 2014; Paez, 2007). Similarly, subsequent stages of data collection were performed to exclude duplication, filtering to the publication period from January 2015 to March 2023. After all exclusions, 47 documents were selected for the screening and eligibility phase.

2.2 SCREENING AND ELIGIBILITY

Some publications that are not very informative for this study analysis are unavoidably included in the search results due to the similarity of the keywords and the wide scope of the search. Two rounds of screening and eligibility were conducted in this respect: Titles and abstracts were checked as part of the initial filtering process. The full-text content was examined for the final round of screening, with an emphasis on the uses of data science for managing buildings CFP in a global context. After this stage, 31 publications were selected as the sample of this study. Accordingly, 31 publications were selected as the final sample of this study. The manual content analysis was adapted as an analysis technique for this study.

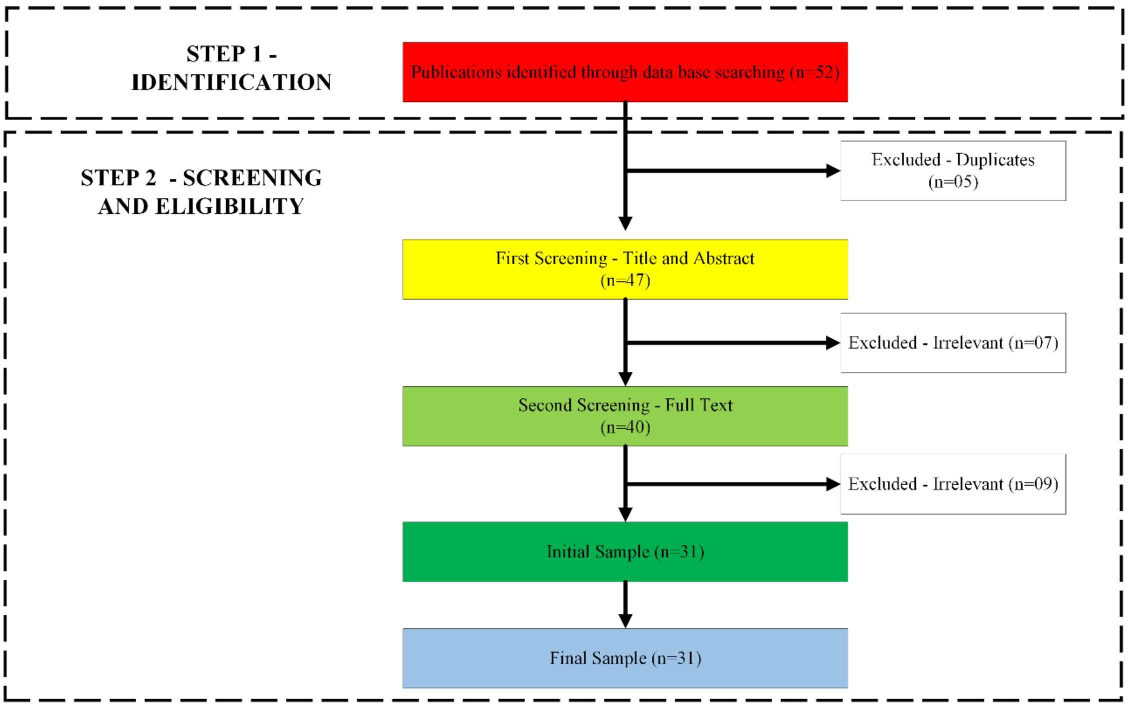

Figure 1: Process of the systematic literature review

3. FINDINGS AND DISCUSSION

This part presents and evaluates the studies' findings. The articles chosen for the current systematic review are examined in terms of their nature and changes over time. As a result, the first stage of this research identified potential data science applications for managing CFP in the building sector. The possible challenges and solutions in implementing data science for the building industry were then outlined.

3.1 GENERAL OBSERVATION OF REVIEWED ARTICLES

According to the selected 31 publications, 18 papers were journal articles and 13 papers were conference proceedings. In addition to that, when considering the chronological distribution of reviewed articles, 2015 (n=01), 2016 (n=04), 2017 (n=04), 2018 (n=04), 2019 (n=04), 2020 (n=02), 2021 (n=07) and 2022 (n=05) were published. Therefore, it is evident that the research interest was increased during last five years since 22 publications out of 31 were published in the last five years.

3.2 APPLICATIONS OF DATA SCIENCE FOR THE MANAGEMENT OF CFP IN BUILDINGS

Through the systematic literature review, it was identified that facilitating to pre-process of buildings' operational data required for GHG emission analysis, identifying the fault detection and diagnosis (FDD) of energy systems of buildings, improving the process of waste management in buildings, improving the building energy performance modelling (BPS), to conduct the parametric analysis at the design phase, to propose the more energy efficient designs, to conduct benchmark evaluation, to implement the energy efficient operational strategies to the buildings and to conduct the retrofitting analysis of buildings are the major applications of data science for the management of CFP in buildings.

3.2.1 Facilitate Pre-process of the Operational Data of Buildings

Buildings' operational carbon directly link to the energy consumption of the buildings (Wang et al., 2022). As revealed in previous studies, the management of energy consumption led to managing the CFP of buildings (Chen et al., 2022; Fu et al., 2023; Robati et al., 2021). Ramesh et al. (2010) showed operational data of buildings is essential to the management of buildings' energy consumption. Moreover, Fan et al. (2021) revealed that maintaining the buildings' operational data manually is time, labour and cost consuming. Therefore, Fan et al. (2021) revealed that data-driven solutions for intelligent building energy management have a lot of potential using the data science and the expansion of operational building data availability. Pre-processing of data lays the groundwork for reliable data analytics (Fan et al., 2021). Because operational building data are frequently of poor quality, data pre-processing is frequently required to guarantee the accuracy of data analysis using various methods. It may take up 80% of all data mining efforts and is generally acknowledged as a non-trivial task in data analysis (Cui et al., 2018). Given the generally poor data quality and the inherent complexity of building processes, data pre-processing can be very difficult in the building context. To guarantee the validity and dependability of the outcomes of data analysis, data pre-processing is frequently required. For instance, due to flaws in data gathering, transmission, and storage, building operational data usually have a lot of missing values and outliers (Cui et al., 2018; Xiao & Fan, 2014). To eliminate outliers and fill in missing values for a more trustworthy data analysis, a pre-processing phase can be applied to the data. Most data mining programs also have certain specifications for the data they can accept as input. For instance, numerical data about electricity, temperature, humidity, flow rates, and pressures make up the majority of building operational data (Fan et al., 2015).

Moreover, Fan et al. (2021) study also outlines three sophisticated data pre-processing methods for creating operational data analysis, namely data augmentation, transfer learning, and semi-supervised learning. The potential data shortage issue in specific buildings can be addressed using data augmentation and transfer learning techniques. These techniques can significantly improve the generalisation and dependability of data-driven models. Meanwhile, massive amounts of unlabelled data can be completely utilised using semi-supervised learning to fully unlock their value. As determining labels for building operational data, such as whether a data sample corresponds to normal or defective operations, can be very expensive and labour-intensive, it is particularly helpful when developing classification models for building systems (Fan et al., 2021).

3.2.2 Fault Detection and Diagnosis

To guarantee the best performance of systems and maximise energy efficiency, fault detection and diagnosis (FDD) schemes that are automatic, fast to react, accurate, and reliable are highly desirable (Khan et al., 2013). Andriamamonjy et al. (2018) stated FDD is crucial for managing the building's energy system in real-time in the construction industry and is closely linked to big data collected from the system's sensors, such as the chiller, pumps, fans, AHUs, and indoor environmental parameters (Andriamamonjy et al., 2018). Moreover, FDD plays a crucial role in ensuring building sustainability (Gholamzadehmir et al., 2020; Sha et al., 2019). Accordingly, Gholamzadehmir et al. (2020) revealed as equipment, actuator, and sensor faults in AHU operations can result in 15–30% energy savings, and it is essential to use FDD. Moreover, Fan et al. (2021) investigates the value of semi-supervised learning in detecting unseen faults during AHU operations and the study revealed that AHUs' FDD must be precise and reliable because they have a significant impact on a building's ability to regulate its indoor environment and energy efficiency.

3.2.3 Improve the Waste Management in Buildings

In the built environment, recycling, landfilling, and incineration are the three main waste control methods (Kucukvar et al., 2014). However, Kucukvar et al. (2014) revealed that the only method of reducing the carbon, energy, and water footprints of building materials was recycling. For the categories of water and energy footprint, incineration is a better option after recycling, whereas landfilling is found to be a marginally better strategy when carbon footprint is the primary emphasis of comparison. Therefore, the proper waste management implementation leads to reduce the CFP in buildings (Aadal et al., 2013). As mentioned by Yeheyis et al. (2013), lack of the construction data is main barrier to implement suitable waste management techniques in built environment. However, Andriamamonjy et al. (2018) revealed, the real time data of buildings can be extracted using data science and such data can be used to implement proper waste management techniques (Silva et al., 2017). Accordingly, Silva et al. (2017) revealed that Big Data analytics lead to improve waste management in buildings as well as in smart cities.

3.2.4 Improve the Building Energy Performance Modelling

Building energy performance modelling (BPS) has established itself as a vital method for assessing and improving building operations, which enhances building energy system management (Harish & Kumar, 2016). The assessment and optimisation of building energy system design (Attia et al., 2012), the development and assessment of operational control and optimisation strategies of building systems (Coakley et al., 2014; Li & Wen, 2014), and policy making on building regulations and power grid (Chung, 2011) have all benefited from the long-standing research and development of traditional physics-based BPS over the past 40 years (Foucquier et al., 2013). BPS typically builds on physical principles, thermodynamics, as well as heat and mass transfer, and heavily relies on meteorological data and detailed building information, such as the building's configuration and properties, its air conditioning system's design and operational parameters, and its occupants' energy-related behaviours (Tian et al., 2021). Amasyali and El-Gohary (2018) emphasised large high-rise buildings with complex structures and numerous uses have recently become more common due to urbanisation's growth and advancements in building technology. The job of preparing the inputs for the BPS of such buildings has grown cumbersome and time-consuming (Amasyali & El-Gohary, 2018). Large buildings, meanwhile, are supported by intricate energy systems that create the ideal indoor environment (Zhao & Magoulès, 2012). Building energy modelling has become increasingly difficult due to the coupled impacts of the building envelope, energy systems, automated management systems, and climate conditions (Xiao & Fan, 2014). In these circumstances, a data-driven approach is particularly interesting because it can rapidly learn the building energy behaviour from the building operation data and needs little prior knowledge of building and energy system configurations and integrations (Amasyali & El-Gohary, 2018; Bourdeau et al., 2019).

3.2.5 Conduct the Parametric Analysis at the Design Phase

Elbeltagi et al. (2017) mentioned due to the worry over CFP in buildings, there has been a significant increase in demand for sustainable building design and construction. Rising energy prices and growing environmental worries, especially GHG emissions, are the driving forces behind this demand. As a result, it is crucial to assess building energy usage, which is the main obstacle to reducing building energy use (Hollberg et al., 2018). When addressing the building envelope and orientation in the early design stage, the designers are hampered by the constraints of energy simulation tools (Elbeltagi et al., 2017). Accordingly, the parametric analysis provides the greatest potential for optimising the energy efficiency of buildings in the early design stages (Hollberg et al., 2018).

Accordingly, the typical patterns of energy use in residential and non-residential structures have been extensively researched (Escobar et al., 2020). It is now feasible to collect hourly or sub-hourly data from a huge number of households using the promotion of smart meters in homes (Zhou, Yang, & Shen, 2017). This data is used to support pattern analysis. Numerous methodologies, including clustering-based algorithms (Zhou, Yang, & Shao, 2017) and big data algorithms (Satre-Meloy et al., 2020), were used to obtain such data. Such studies typically result in typical energy use profiles, which are a collection of average energy use curves that help people better understand how much energy is consumed by different types of buildings. These profiles are then used as input schedules for building energy models used in simulations during the design phase as parametric analysis (Fan et al., 2021).

3.2.6 Evaluate the Energy Efficiency of Building Designs

To calculate the energy balance, various energy simulation programmes are adopted, which may result in higher measurement accuracy for building energy efficient buildings

(Ustinovichius et al., 2018). Therefore, some researchers have substituted data-driven models for physics-based models during the design process due to the shortcomings of physics-based building simulation models (Sha et al., 2019). In addition to that, Sha et al. (2019) mentioned researchers perform correlation analysis or sensitivity analysis to identify the most pertinent factors that influence the building energy consumption for a particular instance, which helps to simplify the model. After that, trained and verified data-driven models based on machine learning algorithms are used to regress the energy usage with chosen features (Sha et al., 2019). Building management system (BMS) data from actual buildings is used in the model's training (Zhan et al., 2020). The suggested model will then be applied to support the design phase evaluation of energy efficiency (Tian et al., 2021).

3.2.7 Benchmarking Evaluation

In comparison to other structures of the same type, benchmarking refers to the assessment and rating of a building's energy use efficiency (Pérez-Lombard et al., 2009). To effectively apply benchmark analytics, it is necessary to comprehend the current state of the building's energy distribution (Yang et al., 2018). These applications typically involve commercial or public buildings. Big data analysis sheds light on this viewpoint. The trained model can be used to predict the expected value or range of building energy use indicators (EUIs), based on which the energy efficiency of the building is rated (Papadopoulos & Kontokosta, 2019).

3.2.8 Control Optimisation

Control minimisation has always been a major problem in managing building energy systems. The building energy systems' big data analytics are heavily reliant on the control strategy, especially a real-time control strategy. After that, control techniques are used to attain environmental comfort and energy efficiency (Fan et al., 2021). Accordingly, the study identified that a data-driven model can be used for thermal-comfort-based environment control and energy-efficient-oriented system control optimisation.

- Thermal-comfort-based environment control

Real-time equipment management is one of the fundamental uses of building system control, used to improve indoor environment regulation and user comfort. The physics-based thermal balance model may not attain considerable accuracy in thermal comfort prediction due to the diversity and complexity of occupants' thermal comfort preferences (Giama & Papadopoulos, 2020). However, data-driven models are capable of learning and correcting the models under various application contexts because they are based on real monitoring data and environmental parameters (Amasyali & El-Gohary, 2018). In addition to that, Dinarvand et al. (2018) developed an automated approach based on probabilistic machine learning to model and predict energy consumption using occupancy data for energy efficiency management in non-domestic buildings to manage the indoor environmental quality of the buildings in the UK.

- Energy-efficient-oriented system control optimisation

Before using strategic optimisation, which has been a hot subject in recent studies, building energy prediction is required. Many energy prediction models are data-driven (Tang et al., 2020), combining data with building physics knowledge to increase prediction accuracy and provide trustworthy information for the following stage of control optimisation (Zakula et al., 2014). Moreover, Dinarvand et al. (2018) developed an automated approach based on probabilistic machine learning to model and predict energy consumption using occupancy data for energy efficiency management in non-domestic buildings to manage the energy consumption of the buildings in the UK.

3.2.9 Retrofitting Analysis

Older building renovations will significantly affect the commitment made by construction industry stakeholders to lower CO_2 emissions (Nowak & Skłodkowski, 2016). In addition, urban planning has always viewed retrofitting analysis of existing structures from a district or city scale as being essential. Cross-comparing various building properties is necessary for the evaluation of various retrofitting methods (Moazami et al., 2016). In order to discover their correlations, researchers taught data-driven models using building EUIs and building properties from large samples (Sanhudo et al., 2018). Re Cecconi et al. (2019) presented various data-driven methods to support regional energy retrofit policy when applied to school buildings as part of a regional-scale retrofit analysis. In order to assess the energy-saving potential of retrofitting steps for numerous buildings at a regional level, a data-driven approach is very cost-effective. Big data analytics' benefit is that the model is trained using actual energy consumption data from existing buildings, preventing a discrepancy between the outcomes of simulations and actual consumption (Fan et al., 2021).

3.3 CHALLENGES AND SOLUTIONS TO ADAPT DATA SCIENCE APPLICATIONS FOR BUILDINGS

As discussed above the second phase of the analysis was focused on identifying the challenges and solutions to adapt data science for buildings.

3.3.1 Complexity and Various Natures of the Buildings

Due to the wide variations in building operating characteristics and data quality, Fan, Chen, et al. (2021) stated that the data pre-processing for operational building data cannot be completely automated. Currently, it is more of a trial-and-error procedure that heavily relies on the practical tasks at hand and domain expertise. To increase the effectiveness of data analysis, more studies should be done on automating and building operational data pre-processing tasks.

3.3.2 Lack of Sufficient Labelled Data

One essential challenge in creating accurate and reliable FDD classification models is the lack of adequate labelled data. In reality, it can be highly time-consuming, labour-intensive and sometimes even infeasible to gather sufficient labelled data for all possible faulty operations (Fan et al., 2021).

3.3.3 Storage and Analysis of a Large Amount of High-Speed Real-Time Buildings Data

Bashir and Gill (2016) identified that storage and analysis of a large amount of high-speed real-time buildings data is a challenging task for big data analytics. Several modern Big Data management tools and advanced analytics techniques can be used to address this issue (Bashir & Gill, 2016).

Based on the above findings, a conceptual framework to improve the data science applications for management of carbon footprint in buildings was developed and shown in Figure 2.

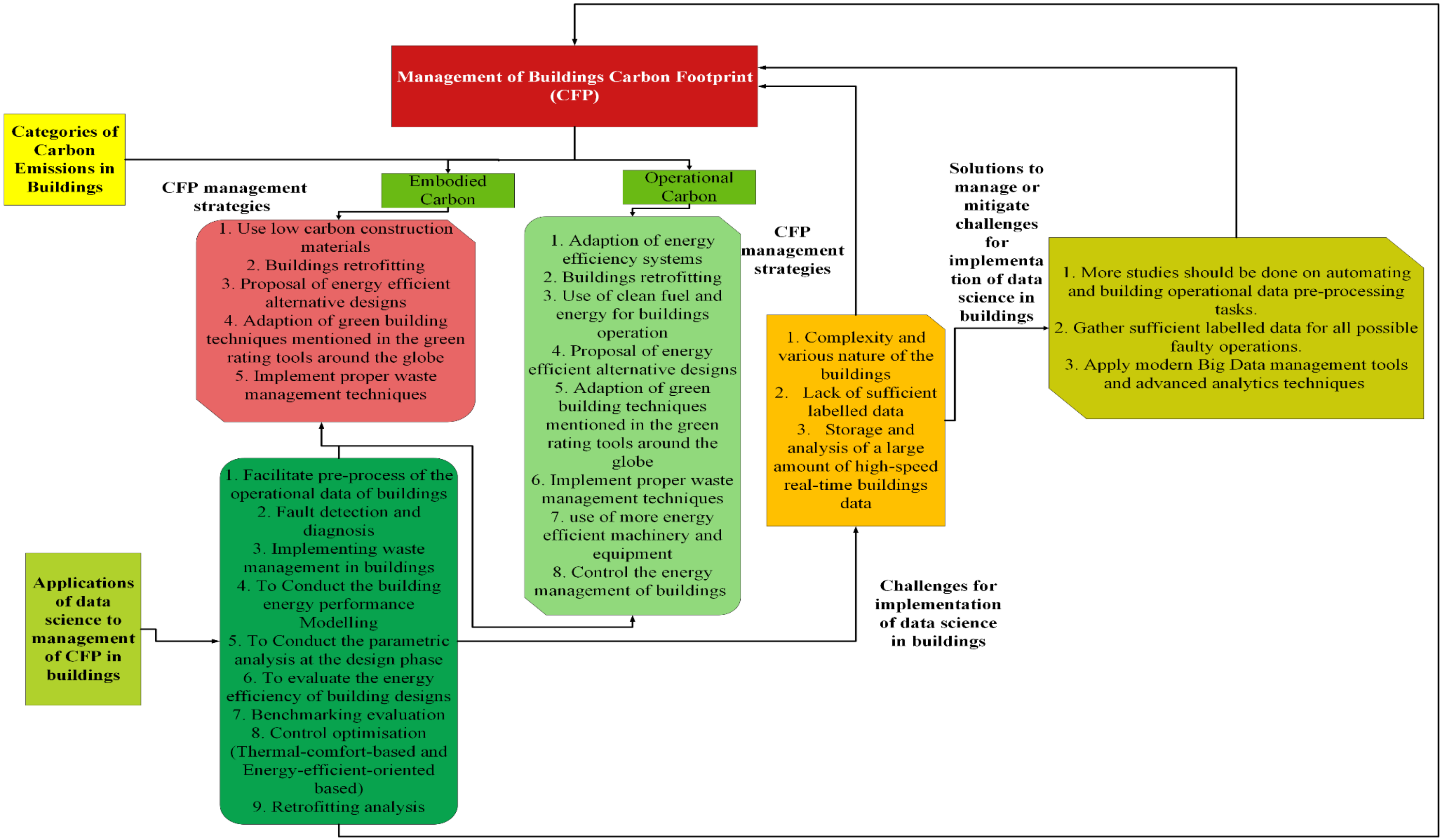

Figure 2 – A proposed conceptual framework for improve the Data science applications to management of building' carbon footprint

4. CONCLUSIONS

The main aim of this study is to investigate the data science applications for the management of CFP in buildings. Accordingly, the study concluded that facilitating pre-process of the operational data of buildings, fault detection and diagnosis, implementing waste management in buildings, conducting the building energy performance modelling, conducting the parametric analysis at the design phase, evaluating the energy efficiency of building designs, benchmarking evaluation, control optimisation and retrofitting analysis are the major applications of data science to the management of CFP in buildings. In addition, the study concluded that complexity and varied nature of the buildings, lack of sufficient labelled data and storage, and analysis of a large amount of high-speed real-time buildings data are the main challenges to implementing data science in the building sector. However, above challenges can be managed by carrying out more studies on automating and building operational data pre-processing tasks, gathering sufficient labelled data for all possible faulty operations and applying modern Big Data management tools and advanced analytics techniques.

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DIGITAL TECHNOLOGY ENABLED CIRCULARITY IN THE CONSTRUCTION INDUSTRY: A BIBLIOMETRIC STUDY

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ABSTRACT

The construction industry has a crucial role in a country's development process, nevertheless, it has a significant impact as it contributes to the emission of harmful gases, waste generation, and energy and resource consumption, making it one of the major contributors to environmental issues. By adopting Circular Economy (CE) principles, the construction industry can reduce costs, mitigate negative environmental impacts, address inherent complexities, and increase the resilience of urban areas to create more liveable, productive, and convenient cities. Utilising Digital Technologies (DT) is crucial in achieving circularity in construction. By identifying a knowledge gap in DT-enabled circularity, this research is aimed at exploring current research on DT-enabled circularity in the construction industry. A bibliometric analysis was conducted to address this aim and identify prominent authors, countries, and key research studies (co-occurrences of keywords). Around 66 documents published in Scopus were collected and analysed using "VOSviewer" software. The analysis revealed that a limited number of studies have been carried out in the selected research area. The results reported in the paper not only serve as a useful reference for both researchers and practitioners, but also signpost further works to be undertaken.

Keywords: *Bibliometric; Circular Economy; Construction Industry; Technology, VOSviewer.*

1. INTRODUCTION

The construction industry plays a crucial role in realising people's aspirations and needs through the physical execution of various construction projects (Razak Bin Ibrahim et al., 2010). However, the construction sector has a significant impact as it contributes to the emission of harmful gases, waste generation, and resource consumption, making it one of the major contributors to environmental issues (Esa et al., 2017). The environmental impact of the construction sector primarily stems from the consumption of non-renewable resources and the generation of pollutant residues, both of which are experiencing a rapid

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increase (Núñez-Cacho et al., 2018). Construction activities have multiple impacts, including the generation of waste, consumption of resources, noise and air pollution, ecosystem degradation, and the emission of greenhouse gases due to vehicle and machinery operations (Oke et al., 2019). The World Business Council for Sustainable Development (2021) states that the construction industry is responsible for consuming approximately half of the world's virgin resources and generating close to 40% of global CO_2 emissions.

Traditionally, the construction industry has followed a Linear Economic (LE) model, which involves extracting virgin materials, processing them into new products that often cannot be disassembled, assembling them on-site, generating waste, and eventually discarding them before the end of their useful life (Cheshire 2017; Ellen MacArthur Foundation 2015). However, the limitations of the LE model have led to the emergence of the Circular Economy (CE) concept as a solution for balancing environmental protection and economic growth (Lieder & Rashid, 2016). The concept of CE has been discussed by various researchers and theorists. Boulding, identified as one of the first economists to present the CE paradigm, described it as an economic system that pursues long-term growth, zero waste creation, and sustainability (Pasqualotto, 2015). In 1988, O'Rorke has described the CE by formulating the term 'pre-cycling' which defines all actions that should be implemented at the initial stage of the product life to avoid waste generation rather than waste management (Pasqualotto, 2015). In 1989, Pearce and Turner introduced CE itself, although the concept has been date-back to the 1960s and it has been committed by several theorists, researchers, and vocational parties (Sariatli, 2017). Further, author has explained that in 2006, Anderson has presented a simplified model for CE which still appears as the idea of CE. CE is a regeneration system that minimises energy leakages, emission, and resource input, and waste by slowing, closing, and narrowing energy and material loops (Geissdoerfer et al., 2017).

The shift towards a CE paradigm in the construction industry would have great impacts in terms of reduction of pressure on non-renewable resources and of residues generated. Other claimed benefits would be the reduction of energy consumption or increase in the control on scarce materials dependency, creating more resilience to face environmental and economic crisis (HuertaCarrascosa et al., 2018 as cited in Gonz´alez et al., 2021). According to Charef et al. (2021), there are six categories of barriers in implementing CE in the construction industry as economic, sociological, political, organisational, technological, and environmental. Regarding technological barriers, most of them are related to the lack of appropriate tools and procedures. Emerging technologies play a vital role in achieving the desired level of the circular supply chain, which is fundamental to moving toward an integrated circular construction economy (Elghaish, et al., 2022). Industrial revolution has considered a most important part of the development of the world which emerged from the 18th century (Vinitha et al., 2020). The phenomenon of Industry 4.0 was first mentioned in 2011 in Germany as a proposal for the development of a new concept of German economic policy based on high-tech strategies (Mosconi, 2015). Industry 4.0 is based on the concept of a smart factory, where the machines are integrated with men through cyber-physical systems (Petrillo et al., 2018). Industry 4.0 encompass artifacts such as Artificial Intelligence (AI), robotics, big data, additive manufacturing, Internet of Things (IoT), synthetic biology, and physical cyber systems (Gavrila & Ancillo, 2021). The concept of Construction 4.0 focuses on the digitalisation of construction processes, enabling more effective coordination, design, and execution of infrastructure projects (Dallasega et al., 2018). According to Jemal et al. (2023), advanced technologies are crucial in leveraging new value from the CE and making strategies more cost-effective, as the scope of the Industry 4.0 concept continues to expand. Further authors have explained the integration of digitalisation within the Industry 4.0 framework can promote the broader implementation of the CE concept in the construction industry by enabling the interaction between products, processes, and individuals throughout the lifecycle via cyber-physical technologies. The emerging industrial revolution will enhance the symbiotic pursuit of new technologies and CE to transform extant production systems and business models for sustainability (Ramakrishna et al., 2020).

Although existing reviews studies on CE are contributing, they often have a narrow focus on linkages between CE and digitalisation. In particular, how different DTs can enhance diverse CE strategies in the construction sector is still not fully discovered. Research focusing on the practices of Industry 4.0 applications and CE is scant. More research is needed to explore the potential of integrating various Industry 4.0 technologies (i.e., IoT, blockchain, etc.) to foster CE adoption in construction. For example, (Gupta et al., 2021) identified the practices of Industry 4.0, cleaner production and CE, but this review was limited to manufacturing organisations in an emerging economy context. It is clear that, there is a research gap in the application of DT to achieve CE in construction industry. To contribute to enhanced understanding, a quantitative study using the bibliometric analysis technique was conducted on DT-enabled circularity in construction industry by reviewing the articles to identify the keywords and prominent authors, countries in the field. The following sections of this paper first describe the methods and process utilised in the study. The results in terms of the performance of publications and science maps are next presented and discussed. Further works to be undertaken to complement the results of this study are highlighted in the conclusion section.

2. METHODOLOGY

A systematic literature review is a rigorous and structured approach to identify, evaluate, and synthesise all available evidence on a specific research question, using a transparent and reproducible methodology (Peters et al., 2018). This type of review aims to minimise bias and provide a comprehensive overview of the current state of knowledge on a particular topic, and is commonly used in healthcare, social sciences, and other fields. A systematic literature review, using a bibliometric analysis, as conducted by Cobo et al. (2011), provides a comprehensive and quantitative analysis of the research output on a particular topic, highlighting the most influential authors, journals, and research trends in the field. This methodological approach allows for the identification of gaps in knowledge and research opportunities and can inform future research directions. Understanding the factors that influence the citation impact of articles is crucial for research evaluation (Sjögårde & Didegah, 2022). This study focuses on publications, and Scopus was chosen as the database to retrieve articles due to its extensive coverage of peer-reviewed journals and reliable academic information (Klapka & Slaby, 2018). The selection of search terms for the database search is an important consideration, as highlighted by Norouzi et al. (2021), as it greatly affects the study results. Therefore, the keywords used in this study were carefully chosen after reviewing an initial set of relevant research publications. The research process is depicted in Figure 1. To conduct the initial screening, a specific time period from January 2011 to January 2023 was chosen as the eligibility criteria. This selection was based on the emergence of the concept of Industry 4.0 in 2011.

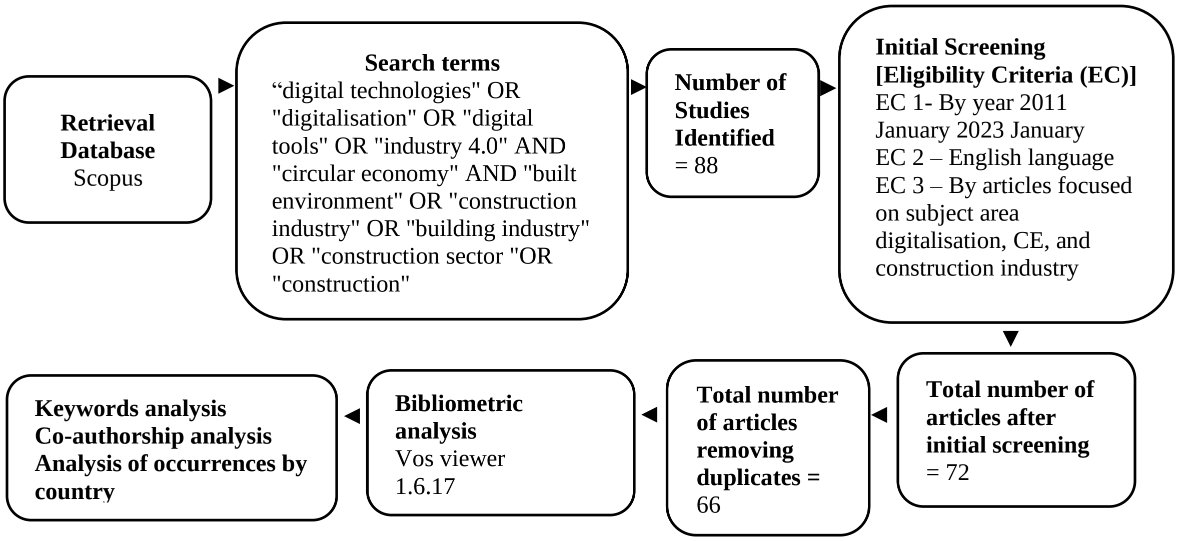

Figure 1: Research process

To conduct a comprehensive review, bibliometric analysis was employed to identify and examine relevant papers (Bellis, 2009). Bibliometric analysis is a computer-assisted methodology that enables the exploration of core research, authors, and their relationships by analysing publications related to a specific field or topic (Bellis, 2009). Co-authorship can be determined using bibliometric analysis, as noted by Castriotta et al. (2019). It was noted that extensive sources were accessed, including electronic databases, utilising keywords and the names of researchers who had published studies related to specifics or niche areas within the field of psychosocial studies (McCusker & Gunaydin, 2915). In this study, the literature was analysed using three bibliometric indicators: keyword co-occurrence, author co-authorship, and country affiliation. The collected data was then imported into bibliometric analysis and visualisation software for further examination. The software used for visualising and analysing trends in bibliometric maps was VOSviewer (van Eck & Waltman, 2010). VOSviewer allows the creation of publication maps, country maps, journal maps, and keyword maps based on networks and shared relationships (Hudha et al., 2020). The findings obtained from the bibliometric analysis and visualisations are discussed in the subsequent sections.

3. ANALYSIS AND DISCUSSION

3.1 KEYWORD ANALYSIS

Keywords are nouns or phrases that reflected the core content of a publication. The network of co-occurrence keywords illustrates the connections between research subjects and connection frames. In VOSviewer, the minimum number of occurrences of a keyword was set to 2, and out of 503 keywords, 60 met the threshold with 8 clusters, 1184 links, and total link strength of 1908. Figure 2 illustrates the clusters of keywords. The strength of the link connecting two keywords indicates the number of articles in which the keywords appear together, showing the connection of their corresponding research focuses. The main occurring keywords identified from the network are "circular economy, industry 4.0, construction sector, built environment, sustainable development, architecture design, Building Information Modelling (BIM), and digital technologies". The generated network is presented in Figure 2.

It was identified that blockchain, modular construction, BIM, digital storage, Radio Frequency Identification (RFID), machine learning, automation, 3d printers, 3d modelling, Internet of Things (IoT), additive manufacturing, robotics, artificial intelligence, and digital twin are the visualised DT, which have links with the construction sector, Industry 4.0 and CE. Charaf and Emmit (2020) have identified seven new BIM uses in CE as digital model for sustainable end of life, material passport development, project database, data checking, circularity assessment, materials' recovery processes and materials' bank. Gordan et al. (2023) conducted a case study that explores the adaptation of Scan-to-BIM processes to develop digital models of demolition sites.

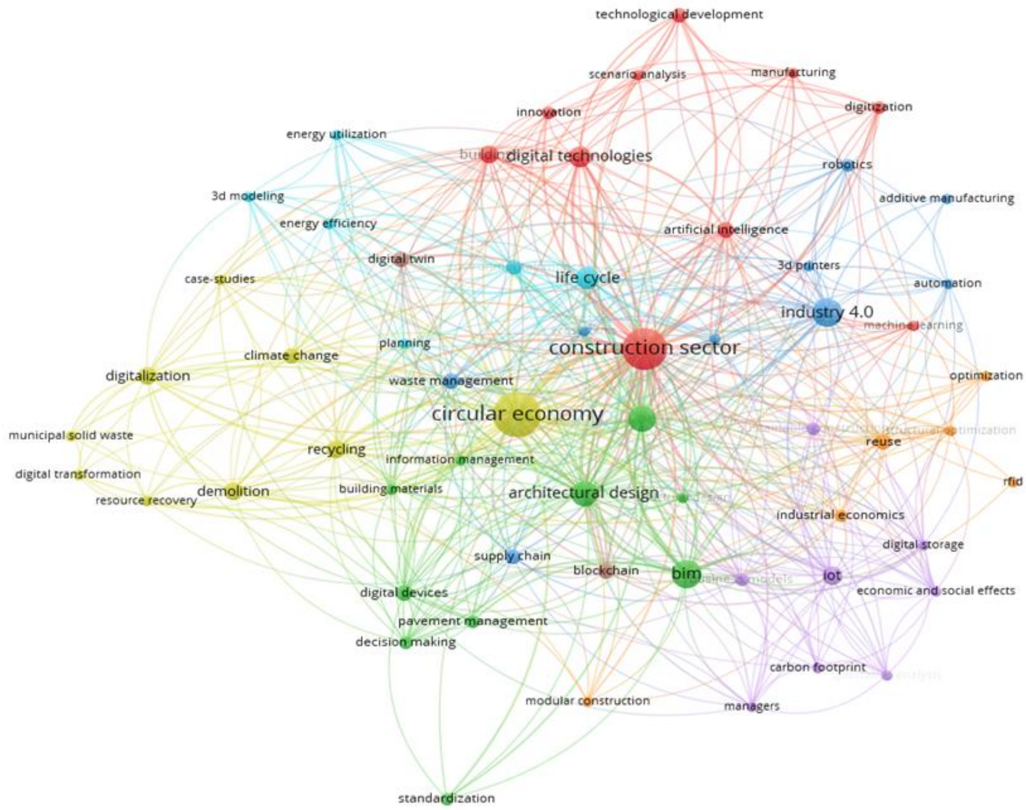

Figure 2: Co-occurrence of keywords (network visualisation)

The objective was to enhance the planning of deconstruction activities and maximise the utilisation of recovered materials. Similarly, Oreto et al. (2022) proposed a BIM-LCA (Life Cycle Assessment) study with the goal of integrating environmental considerations into road pavement design. The study aimed to promote the use of digital tools in the road industry and facilitate decision-making processes related to pavement maintenance, aligning with the principles of the CE. Table 1 depicts the application of disruptive technologies for a circular building industry in terms of different CE principles.

Table 1: Application of disruptive technologies for a circular building industry

	Design to disassembly, reuse, or recycling	Optimal material use	Re-covering by-products & waste
IOT	Insight into local conditions and sourcing options		
BIM	Calculating the percentage of circularity of a building during the design phase		Maintain material via registration of location and digitalisation: Material Passport
Robotics		Re-use of nonstandard materials (formerly discarded, non-industrially processed etc)	Enable re-use of materials due to dry assembly.
AI	Generative design methods that automate the use of nonstandard materials (former discarded, non-industrially processed etc)		
(Robotic) 3D printing		Zero waste production - Local resourcing - On-site construction and reduced logistics	Repeatedly recyclable building components
Blockchain	Enables transparency and secured privacy to make valid claims about sustainability		
Drone		Use of local materials	Enables the reuse of materials due to dry assembly.
AI		- remote construction in optimal workflow and high accuracy - efficiency & speed during construction phase	

Source: (Setaki & van Timmeren, 2022)

Ghaffar et al. (2020) suggested that mobile robotic sorting and reprocessing machines with innovative technologies such as AI and IoT could contribute to realising circular construction. The potential use of blockchain in waste trading processes for sharing, reporting, and auditing waste materials eliminating trusted intermediaries is to create wider circular business networks (Steenmans et al., 2021). Blockchain has the ability to create the platform to connect all construction project stakeholders to achieve circular buildings by closing the loop (Senaratne et al., 2021). The design and construction of circular modular construction projects promote sustainable material usage, maximise material recovery, and avoid unnecessary waste generation disposed to landfills (Wuni & Shen, 2020). According to the study of Copeland and Bilec (2020) which focused on provide solution to apply current technology to Building As Material Banks (BAMB) project, blockchain can be used to manage and create reliable transaction records between the supply and demand projects. Further to authors, the RFID data tag’s information can be stored within a blockchain to track the material’s location throughout its life cycle. Thus, it is clear that the identified digital tools have potentiality to implement CE in the construction sector. However, it is clear that still there is a gap in research on DT-enabled circularity in the construction industry, as the network map shows some limited enabling DTs than the potential DT tools.

3.2 CO-AUTHORSHIP ANALYSIS

The analysis of co-authorship networks has become a prevalent approach in understanding the intricate patterns of scientific collaborations, uncovering hidden or overlooked structural and dynamic aspects (Carchiolo et al., 2022). Various bibliometric methods are used to quantify the scientific collaboration among researchers and scientific communities (Ullah et al., 2022).

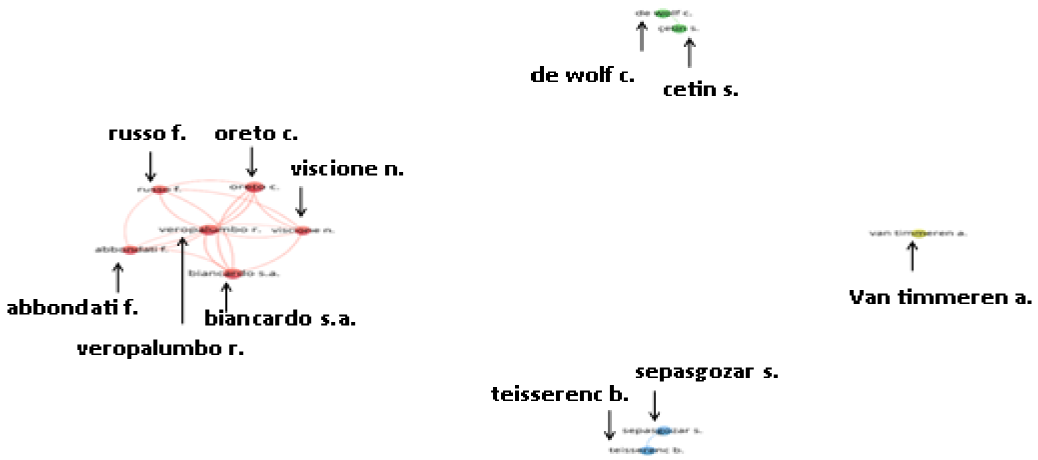

Figure 1: Co-authorship analysis (network visualisation based on links)

When conducting bibliometric analysis using VOSviewer, specific parameters must be set to align with the study's objectives. These parameters involve determining the thresholds for the minimum number of documents and citations for the subjects being analysed. In the case of authors, the minimum document threshold was set at '2', and the minimum citation threshold was set at '1'. Out of the 248 authors, only nine (3.6%) met these thresholds, as depicted in Figure 2.

Figure 2 illustrates the co-authorship network, where the size of a node indicates the number of connections an author has with other authors, and the colours of the nodes represent collaboration clusters. Among the four collaboration clusters, the only cluster with more than two authors consists of 'F. Russo', 'C. Oreto', 'R. Veropalumbo', 'N. Viscione', 'F. Abbondati', and 'S.A. Biancardo'. These authors form a strong network, accounting for eight out of 14 total connections (57%). The proximity and connectivity of researchers reflect their influence on each other. Given the dispersed nature of the clusters and the limited number of connections, fostering more collaboration among researchers is recommended for research on DT-enabled circularity in the construction industry.

Table 1, generated using the 'save as' function in VOSviewer, provides a summary of the analysis findings, ranking authors based on average citations. It reveals that although some authors have a relatively low number of connections, their publications have received frequent citations. This may be attributed to the novelty and comprehensiveness of their work. For instance, the highly cited paper titled "Circular Digital Built Environment: An Emerging Framework," co-authored by 'S. Cetin,' 'C. De Wolf,' and 'N.

De Bocken', presents a framework for implementing CE in the construction industry by identifying potential technologies. This framework serves as a promising starting point for further research at the intersection of CE and the construction sector.

Table 2: Co-authorship analysis of authors

Rank	Authors	Documents	Links	Total Link strength	Average citations	Average Publication year
1	abbondati f.	2	5	2	1	2022
2	biancardo s.a.	2	5	3	3.333	2022
3	de wolf c.	2	1	1	19	2022
4	oreto c.	2	5	3	3.3333	2022
5	russo f.	2	5	2	5	2021
6	sepasgozar s.	2	1	2	17	2021
7	teisserenc b.	2	1	2	17	2021
8	van timmeren a.	2	0	0	13.5	2020
9	veropalumbo r.	2	5	3	3.3333	2022
10	viscione n.	2	5	2	5	2021
11	çetin s.	2	1	1	21.5	2021

3.3 ANALYSIS OF PUBLICATIONS (BY COUNTRY)

The minimum threshold for the number of documents and citations required for a country was set at '2' and '1' respectively. Out of the 38 countries, only 19 (50%) met these criteria. Among these 19 countries, only 13 were found to be connected, as depicted in Figure 3 and Figure 4. In Figure 3, the size of the nodes corresponds to the number of publications, with larger nodes indicating a greater contribution from that country. Five distinct scientific clusters are identified and represented by different colours. Countries such as the Netherlands, Austria, the United Kingdom (UK), and Italy have shown a relatively higher number of publications (more than 5). Regarding co-authorship, the UK, Netherlands, Singapore, South Africa, and Spain exhibit some level of collaboration. Overall, the Netherlands and the UK emerge as the most active countries in terms of publication output and collaboration

Figure 2: Network Visualisation (by country)

4. CONCLUSIONS

In order to explore the current development of DT-enabled circularity in the construction industry, a bibliometric analysis was conducted. The analysis covered 66 articles published between 2011 and 2023. VOSviewer was utilised to perform a co-occurrence analysis to identify keywords, as well as a co-authorship analysis to identify authors and countries relevant to DT-enabled circularity in the construction industry. The findings revealed that modular construction, BIM, digital storage, RFID, machine learning, automation, 3D printers, 3D modeling, IoT, additive manufacturing, robotics, artificial intelligence, and digital twin are the prominent DT concepts within Industry 4.0 that are currently being adopted for implementing CE in the construction sector.

Among the authors, 'F. Russo', 'C. Oreto', 'R. Veropalumbo', 'N. Viscione', 'F. Abbondati', and 'S.A. Biancardo' were found to have the strongest network, but the author clusters showed significant distance and disconnection. Thus, it is recommended to foster more collaboration among researchers to enhance knowledge in this research domain. The most productive countries in terms of publications and collaboration related to DT-enabled circularity in the construction sector are the UK and the Netherlands, while China, Switzerland, and Italy are emerging countries that have published a significant number of papers in this field. It is further advised to share and synergise knowledge from various domains, with a focus on conferences and knowledge-sharing sessions to encourage researchers to exchange ideas and findings, thereby facilitating collaborative research.

Although the study successfully achieved its objectives, there are some limitations. The search terms used as keywords were carefully selected based on previous studies, but due to the emergence of industry 4.0 in 2011, publications in this area were limited. Despite these limitations, as the first bibliometric analysis in DT-enabled circularity in the construction industry, the study provides valuable patterns for future researchers to consider. It offers insight into key enabling dt that have the potential to implement ce in the construction industry, identifies active authors and leading countries in this field, and serves as a directory for literature search. The study's findings are also beneficial for industry practitioners seeking to understand the key DTs that can be implemented for ce in construction sectors across different countries. Future studies can focus on qualitative analysis of key potential DTs to implement CE in the construction industry, building upon the findings of this study.

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ECONOMIC MODELS OF CLIMATE CHANGE: SYSTEMATIC REVIEW OF BENEFITS, LIMITATIONS, AND FUTURE DIRECTIONS

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ABSTRACT

Climate change substantially impacts the community's livelihood, affecting their socioeconomic status. Considering the severity of impacts in the developing country context, economic models have been identified as a feasible application to determine the socioeconomic impacts of climate change. Consequently, this study provides benefits, limitations and future directions of economic models, which can be used as guidance to apply the economic models to determine the community impacts of climate change and thereby contribute to sustainable development. A systematic literature review has been adapted as a methodology to identify 18 benefits and 14 limitations of economic models of climate change. In addition, 18 future directions for applying and improving economic models of climate change have been derived. Benefits are mainly associated with the financial and decision-making aspects, while the limitations highly encounter due to possibility of producing misleading results and uncertainty. Future directions of economic modelling of climate change mainly concentrate on modelling for uncertainty and integrating multiple climatic conditions, livelihood status, models, technologies, and stakeholders in economic modelling. The findings are helpful for policymakers to successfully apply the economic models to address the climate change issues in the community. Further, the community will ultimately benefit from the set of policies and management strategies that occurred with the guidance of these findings. Further research can be conducted on addressing the identified limitations of the economic models and developing them.

Keywords: *Change; Climate; Economic-Modelling; Livelihood; Socioeconomic; Systematic Literature Review (SLR).*

1. INTRODUCTION

Climate change and the persistence of the community are two related activities which have mutual impacts on each (Matsumoto, 2019). Climate change is a critical global issue that significantly and uniquely impacts different regions (Hashida & Lewis, 2022). According to Evans (2019), climate change refers to “a dynamic, multidimensional system of changes in environmental conditions that will likely influence human

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behaviour" (p.2). Global climate change is characterised by average temperature and rainfall changes simultaneously with the associated physical impacts of it (Ogada et al., 2020; Sánchez, 2018). Climate change negatively impacts people; however, the magnitude and direction of impacts display some variations at the national and regional levels (Wang et al., 2021). Further, as stated by Hossain et al. (2019), the effects of climate change illustrate differences based on location. Henceforth, it can be argued that climate change creates broad socioeconomic impacts like increase poverty, be a cause of conflicts, and reduce resource availability for consumption (Rising et al., 2022) on different communities worldwide.

Climate change impacts primary production, causing reductions in harvest revenue and affecting the downstream industries, thereby negatively impacting the net welfare of people (Hashida & Lewis, 2022; Wang et al., 2021). Specifically, it threatens people's livelihoods and affects their socioeconomic status (Adego & Woldie, 2022). Similarly, climate change impacts different parameters of the community, including their demography, social status, and economy and constitutes challenges to the community's existence (Navarro & Tapiador, 2019). Consequently, there is a dire necessity for actions to cope with climate change to ensure the socioeconomic status of the community.

Mitigation and adaptation are two important focuses of climate change to diagnose and reduce the risks and costs associated with climate change (Rising et al., 2022). Further, Antle et al. (2018) highlight that integrating mitigation and adaptation practices helps to manipulate the climatic impacts and will ensure the resilience of the communities to survive amidst climate change. Moreover, there is a requirement to determine the welfare impacts of climate change and introduce adaptation strategies to manage the socioeconomic impacts (Adego & Woldie, 2022; Gurgel et al., 2021). Since adaptation refers to responses given by nature and humans to an actual or predicted climatic condition, use of adaptation actions manipulate the impacts of climate change (Adego & Woldie, 2022). Using a systematic method assists in deriving planning, adaptation, and mitigation actions to be resilient to climate change (Meijl et al., 2018).

Economic modelling is a practical approach to assessing the costs and benefits of climate change on people's livelihoods, which helps to generate optimal actions to manage the impacts of climate change and achieve climate goals (Rising et al., 2022). A similar view has been expressed by Khabbazan (2022); there is an urgency to address climate change which can get significant findings using rigorous economic models and analytical frameworks to inform climate change decisions. Economic models of climate change are theoretical frameworks used to predict the economic impact of climate change, including costs associated with physical, environmental and social effects (Nikas et al., 2018). Further to Rising et al. (2022), economic models combine the opposite views of multiple disciplines, including climatic variations and their non-linear impacts, to detect the risks and benefits of climate change on livelihood.

The economic impacts of climate change on livelihoods are expected to be more severe in developing countries (Aryal et al., 2020), and there is a deficiency of adaptation measures taken to resist climate change (Wang et al., 2021). Hence, economic models of climate change can be applied to address the socioeconomic impacts of climate change. Henceforth, this article focuses on articulating the benefits, limitations, and future trends of economic models of climate change, which could be used to determine the impacts of climate change on the community.

2. RESEARCH METHODOLOGY

2.1 SYSTEMATIC LITERATURE REVIEW

This study used a systematic literature review (SLR) to identify the benefits, limitations and future trends in climate economic modelling. It provides the basis for researchers to identify patterns, trends, and inconsistencies in the available evidence adhering to a structured methodology. Accordingly, Preferred Reporting Items for Systematic Literature Reviews and Meta-Analyses (PRISMA) were used as the research method.

Among the variety of SLR search tools, this study considers PICO as the most appropriate tool considering the coherence and cohesion of its element to appropriate into the context of climate economic modelling. PICO stands for the four elements of the population (P), intervention (I), control (C), and outcome (O). Considering the expectations of the SLR and PICO elements, the research question was formulated as "What are the characteristics, benefits and limitations of the economic models which are to manage the socioeconomic impacts of climate change". This research question was based on a manual initial keyword search. The researcher identifies that the articles to extract findings about the future trends of climate economic modelling link their future directions with the characteristics, benefits, and limitations. The research question was located with the PICO elements and identified global context as the population since the researcher focuses on the entire community to identify future directions. In addition, climate change and economic models were respectively identified as intervention and control, while the characteristics, benefits, and limitations were identified as the outcomes. Subsequently, a logic grid was developed, including the alternative terms to finalise a comprehensive search string with all possible keywords. Table 1 depicts the keywords used under each PICO element.

Table 1: The logic grid of Systematic Literature Review

Population	Intervention	Control	Outcome
Global context	Climate change	Economic models	Characteristics Benefits Limitations
	Climat*	Econom* W/0 model*	Econom* W/0 value* Character* Feature Benefi* Barrier* Advantage* Disadvantage* Limitation Challenge

As shown in Table 1, since the global context has been identified as the population, the term was not included in the search string. Database selection is vital to ensure the success of SLR. This study used three databases, namely Scopus, Web of Science, and Science Direct, which are related to the context of the study and have been identified as top databases for academic research. Moreover, the "title-abstract-keyword" search was used to have a precise and comprehensive result. However, climate change, which is the intervention of this study, has undertaken a “title only” search, as there are plenty of articles that use the term “climate” in their abstracts that are irrelevant to climate change. In addition, instead of the phrase climate change, variations of the word “climate” were used for the search as it covered the phrase “climate change” as well.

Moreover, wildcards (*, W/n) and Boolean operators (AND, OR) were used to increase the findings' versatility. The search criteria were set for the last five years (since 2018) to eliminate outdated results and increase accuracy. Since the paper focuses to capture benefits, limitations and future directions, which are three of frequently updating areas, this time frame of five years were continued to maintain. Further, publications in the language of English were only considered. Overall, the below-mentioned search string was used to identify the records.

(TITLE-ABS-KEY
((econom* W/0 value*) OR character* OR feature OR benefit* OR barrier* OR a dvantag* OR disadvantag* OR limitation OR challenge* AND (econom* W/0 m odel*)) AND TITLE (climat*))

2.2 Systematic Literature Review Record Results

As stated in *Systematic Review: PRISMA* (2022) guidelines, the flow diagram for “systematic reviews which included searches of databases and registers only” was applied for this study, and Figure 1 shows the summary of the process followed in this study for the three main stages of SLR.

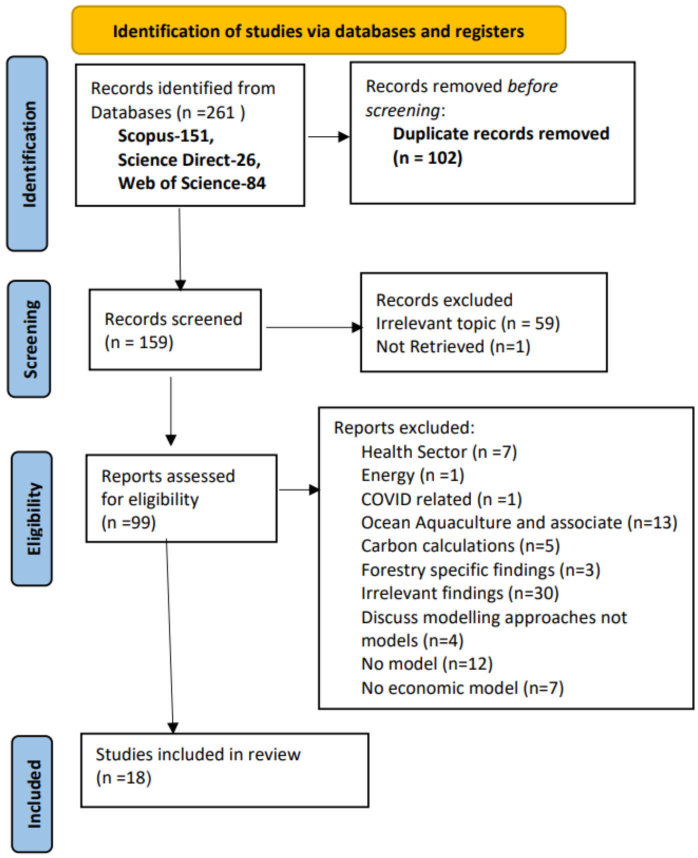

Figure 1: Identification of studies in the Systematic Literature Review

As per Figure 1, since the study focuses on identifying the future of climate economic modelling relevant to livelihoods, areas which do not discuss livelihoods (health, COVID, forestry, ocean, aquaculture, carbon calculations) were removed. Further, the articles with no model or no economic model were eliminated from the study. Moreover, irrelevant findings like managing food demand in the phase of climate, fertiliser, transport, and fossil fuel depreciation were disregarded. Finally, 18 records were selected for the detail processing, and the chart in Figure 2 summarises the type and number of articles accepted for the study.

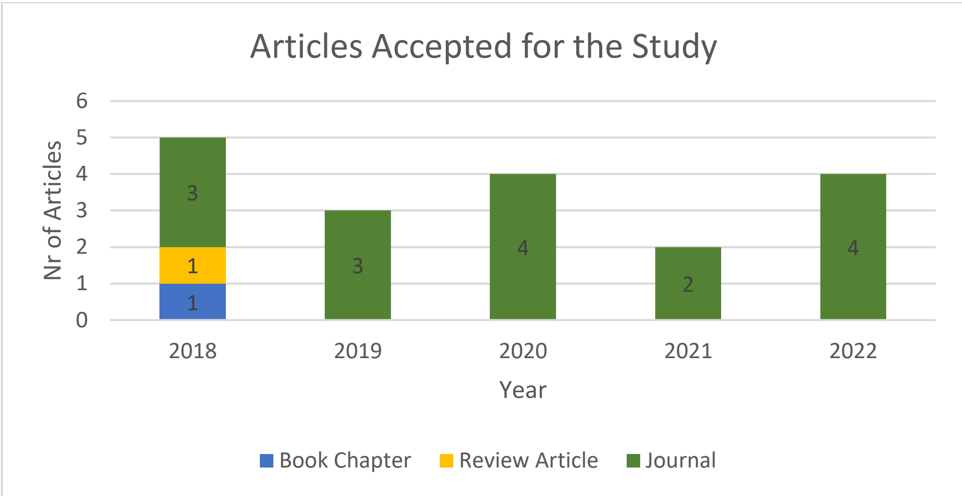

Figure 2: Summary of accepted articles

3. RESULTS AND DISCUSSION

As the next step, 18 articles screened out from SLR were subjected to a detailed analysis to identify the (i). benefits, (ii). limitations, and (iii). future directions of economic models of climate change in the context of socioeconomic development. The following section presents the outcomes of the analysis.

3.1 RESULTS- BENEFITS AND LIMITATIONS OF ECONOMIC MODELS OF CLIMATE CHANGE

Following the findings of SLR, 19 benefits and 14 limitations of using economic models of climate change to determine the socioeconomic impacts on the community have been recognised which are presented in Figure 3.

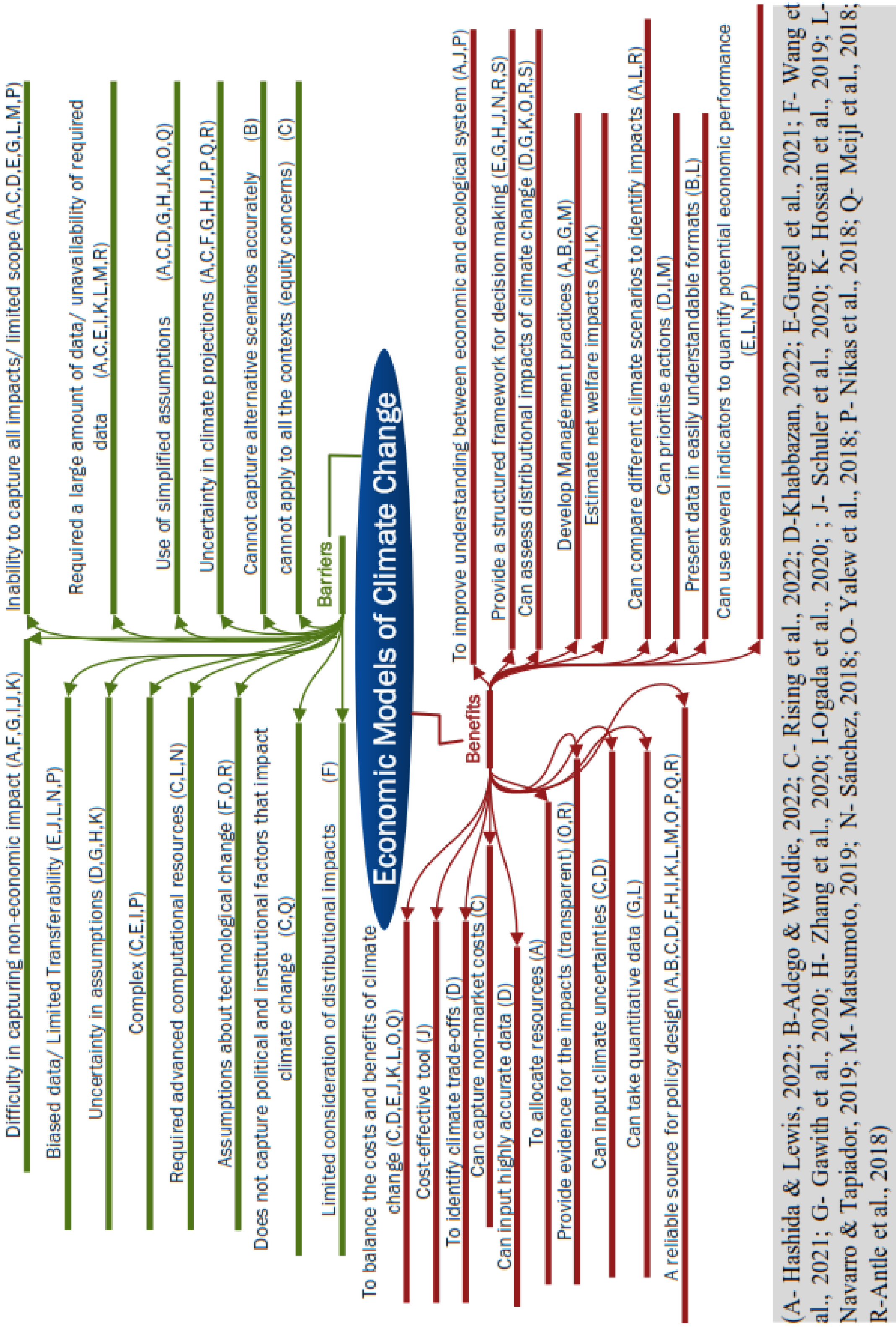

Figure 3: Benefits and limitations of economic models for determining socioeconomic impacts of climate change

The findings expressed in Figure 3 identify the benefits of climate change which can be discussed through the two main aspects of benefits in decision-making and the financial aspects which will ultimately benefit the community. Moreover, the limitations recognised from the SLR can be discussed under the two main areas of uncertainty and less accuracy. Accordingly, the knowledge of the benefits and limitations of economic models of climate change expressed in Figure 3 can be used to determine the impacts of climate change on the community.

3.2 BENEFITS OF ECONOMIC MODELS OF CLIMATE CHANGE

The benefits of using economic models of climate change for determining the socioeconomic impacts of climate change can be broadly discussed under two main areas of assistance in decision-making and financial aspects.

3.2.1 Benefits in Decision-Making

According to the findings of SLR, most articles have emphasised the guidance of economic models in policy-making as an advantage. Policies play an essential role in adapting to climate change, specifically in the context of developing countries (Adego & Woldie, 2022; Wang et al., 2021). Further, climate change is a significant and urgent global challenge that requires effective policies to mitigate its impacts (Khabbazan, 2022; Rising et al., 2022). These policy decisions will support the sustainable and resilience of the community under changing climatic conditions (Hashida & Lewis, 2022). Moreover, Adego and Woldie (2022) revealed that policies enlighten the agricultural community's socioeconomic status by regulating farmers' adoption decisions to withstand climate change.

In addition to the benefits in policy-making, economic models possess a variety of matrices to smooth the decision-making process and help to determine the potential economic importance to derive practical management actions (Gurgel et al., 2021). Specifically, economic models derive the net welfare impacts with numerical shreds of evidence identifying income losses (Hashida & Lewis, 2022) and changes in domestic assets (Ogada et al., 2020). Moreover, actions to mitigate or adapt to climate change can be managed and prioritised based on the findings of economic models, which will ultimately benefit decision-making. For example, according to the findings of Gurgel et al. (2021), through the use of computable general equilibrium (CGE) models, efforts to study the impact of climate change on crops can be prioritised. Overall, it can be highlighted that economic models of climate change assist in the decision-making process by making it convenient and comprehensive.

3.2.2 Financial Aspects

Performing a cost-benefit analysis of climate change impacts using economic models has become a popular approach for accounting financial values of climate change (Hossain et al., 2019). Specifically, Rising et al. (2022) have identified economic modelling as an aspect which allows capturing non-market costs, risks to non-market goods and non-market damages, including loss of biodiversity, costs of injuries and deaths. However, the authors further stated that it is an undeveloped area which should be further developed to make it beneficial. Furthermore, the ability to use several indicators to quantify economic performance is also identified as a benefit of climate change, which in return is beneficial to engage in a comprehensive assessment by identifying interconnections among different indicators. This view has been adduced by several authors (Gurgel et al., 2021; Navarro & Tapiador, 2019; Nikas et al., 2018).

Moreover, the benefits address the concept of trade-off, which refers to a situation or action when something is given up in favour of something else that is viewed as having higher worth. Accordingly, economic models help capture and implement climate trade-offs by including trade-off parameters to detect welfare losses and mitigation actions (Khabbazan, 2022). Overall, economic models provide an opportunity to account for the impacts of climate change using various cost indicators.

Awareness of the limitations of the economic models of climate change is essential to determine the socioeconomic impacts of climate change on the community, as it provides impressions about the required areas of development and the degree of reliability of the determined impacts.

3.3 LIMITATIONS OF ECONOMIC MODELS OF CLIMATE CHANGE

3.3.1 Uncertainty

10 out of 18 papers have identified uncertainty of climate projections as a limitation to using economic models to identify the impacts of climate change on the community's livelihood. Several reasons lead to uncertainties in economic models of climate change. Moreover, Khabbazan (2022) and Yalew et al. (2018) highlighted that economic models tend to use simplified assumptions, which allow no space to incorporate uncertainties. Further, an economic model of climate change can capture data from limited scope (Gawith et al., 2020; Matsumoto, 2019) and, therefore, is uncertain about accounting for variations. In addition, economic models are complex and require advanced computational skills, leading to uncertainty (Rising et al., 2022). Similarly, economic models tend to make wrong assumptions about the technology, which provides uncertain feedback in return (Meijl et al., 2018; Wang et al., 2021). Overall, consequent to the abovementioned reasons, economic models of climate change have become a limitation to determining the socioeconomic impacts on the community's livelihood.

Possibility of producing misleading results because policy decisions are frequently reliant on the forecasts produced by economic models of climate change, the accuracy of economic models is vital when anticipating the socioeconomic implications of climate change. Inaccurate forecasts can result in ineffective or unproductive policies, negatively impacting the economy and society. Zhang et al. (2020) state that the limited incorporation of all related data will capture the intensity and nature of the actual scenario emphasising Ethiopia, a developing country. This limitation with data application causes a reduction in the accuracy of the output of economic models. Moreover, most economic models cannot accurately capture alternative climatic and economic scenarios (Adego & Woldie, 2022), as they have been designed to examine the relationship between and among a particular set of variables and cannot predict the changes in variables. Further, economic models of climate change are developed concerning a particular context (eg: climatic condition, region, livelihood sector, etc.) and therefore have low equity concerns (Rising et al., 2022). In addition, economic models incorporate political and institutional factors into their models, which limits the practical implementation of findings (Antle et al., 2018).

Contradictory views of the benefits and limitations of economic models of climate change have emerged through the SLR. Accordingly, Rising et al. (2022) state that economic models can capture the non-market costs of climate change, while 1/3rd of the articles subjected to SLR argue that it is difficult to capture. The non-market costs identified by the authors include value reduction in forests and crops (Hashida & Lewis, 2022), conflicts, and migration (Rising et al., 2022) as aspects which are easily observable as non-market impacts. Therefore, it is argued that the non-market costs are challenging to quantify in economic models, and consequently, it is a limitation.

Moreover, several authors developed their argument by mentioning that the economic models can capture the distributional impacts of climate change (Antle et al., 2018; Rising et al., 2022; Schuler et al., 2020; Wang et al., 2021) while there are opposing views by a few authors (Hashida & Lewis, 2022; Nikas et al., 2018; Rising et al., 2022). Since the articles encountered in SLR represent a combination of studies conducted focusing on a particular region/livelihood sector and articles with a macro focus on climatic impacts, it can be argued that distributional impacts of climate change can be quantified through economic models. However, they are less applied and less investigated.

3.4 FUTURE DIRECTIONS OF CLIMATE ECONOMIC MODELLING

The findings of the SLR disclose 18 future directions of climate economic modelling. Accordingly, integrating different climatic impacts and multiple livelihood scenarios generates more impactful results (Hossain et al., 2019; Nikas et al., 2018; Sánchez, 2018; Meijl et al., 2018). Further, instead of isolating economic models to determine the climate change impacts on livelihood, integrating them with other models will increase the accuracy of the socioeconomic impacts determined in the models (Gawith et al., 2020; Khabbazan, 2022). A few authors have already initiated this approach. However, further developments and effective integration are still below the requirement. For example, Rising et al. (2022) and Zhang et al. (2020) identified a vital view: increasing stakeholder collaboration from different perspectives in a single model could generate versatile results.

Embedding technology to economic modelling also has been identified as another valuable direction for improving climate economic models. For example, spatial technology has been identified as a potential future application for climate economic modelling (Navarro & Tapiador, 2019; Meijl et al., 2018), which will be helpful in scenario analysis and climate information mapping. Similarly, Table 2 demonstrates the findings of SLR regarding the future directions of climate economic modelling.

Table 2: Future directions of climate economic modelling

Future Direction	Citation
Consideration of multiple scenarios and pathways (multiple sectors and impacts)	(B, E, F, G, I, K, N, P, Q)
Integration with different models	(B, C, F, K, L, M, N, O)
Improve representation of uncertainty	(A, B, D, F, G, P, R)
Improving the modelling of adaptation	(F, G, I, J, L, Q)
Study the extreme conditions where land use is difficult to manage under climatic changes	(A, G, I, R)
Improve modelling techniques	(C, F, L, O)
Study non-market values of different goods and services impacted by climate change	(A, F, J)

Investigation regarding substitution possibilities	(E, M, Q)
Integrate technology	(I, L, N)
Incorporate feedback loops into economic models	(B, Q)
Enhance stakeholder engagement from different perspectives	(C, H)
Use of in-depth data	(G, Q)
Increasing spatial resolution	(L, R)
development of comprehensive models that can capture heterogeneity	(C)
Increase the use of open information	(C)
Study on delayed action scenario	(D)
Integrate trade-off	(J)
Integrate holistic approach	(K)

(A- Hashida & Lewis, 2022; B-Adego & Woldie, 2022; C- Rising et al., 2022; D-Khabbazan, 2022; E-Gurgel et al., 2021; F- Wang et al., 2021; G- Gawith et al., 2020; H- Zhang et al., 2020; I-Ogada et al., 2020; ; J- Schuler et al., 2020; K- Hossain et al., 2019; L- Navarro & Tapiador, 2019; M- Matsumoto, 2019; N- Sánchez, 2018; O- Yalew et al., 2018; P- Nikas et al., 2018; Q- Meijl et al., 2018; R-Antle et al., 2018)

According to Table 2, it is clear that the future trends of economic models of climate change are more towards integration as it considers the integration of different technologies, stakeholder perspectives, models, climate scenarios, and modelling techniques to generate informed and accurate results. Simultaneously studies on alternative actions to be resilient in climate change and accounting for uncertainty should approach in the future.

4. CONCLUSIONS

This paper presented the findings of the systematic literature review (SLR) regarding the benefits, limitations, and future directions of economic models to determine the socioeconomic impacts of climate change on the community. SLR findings portrayed 19 benefits of economic models, mainly associated with decision-making and financing. Thus, economic models have been identified as a reliable source for policy design, developing management practices, prioritising actions, and allocating resources. Furthermore, the 14 limitations identified regarding applying economic models to determine people's socioeconomic status were directed towards the two main complications of uncertainty and low accuracy. The complexity followed this low accuracy, use of simplified assumptions, and use of few data than the requirement. Uncertainty has occurred consequent to the difficulty of capturing changes in climatic conditions. Therefore, the future direction of economic models of climate change prefers an integration approach merging multiple climatic conditions, livelihood status, models, use of more detailed information, and encountering uncertainties. Overall, the findings are assisting the government, climate authorities, researchers and economists to apply the economic models of climate change to their country context to derive actions and policies which will results the increasing of the community resilience to climate change by smoothing their livelihoods and mitigating socioeconomic impacts. Moreover, further researches can be conducted to develop economic models, by addressing the identified limitations.

5. ACKNOWLEDGEMENTS

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EXPLORING STATE-OF-THE-ART RESEARCH ON BLOCKCHAIN ADOPTION IN THE CONSTRUCTION INDUSTRY: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Blockchain is often considered a potential disrupter in how industries operate, due to its decentralised nature and several other salient features like enhanced security, transparency, traceability, immutability etc. The Construction Industry, though regarded as a late adopter of technologies, is striving to harness blockchain to improve its processes. The subsequent research initiatives, however, are scattered around several application areas, with different levels of maturity. This would prove troublesome for a potential researcher to identify a suitable research gap and carry out impactful research. Addressing this, the study attempts to identify the evolution of blockchain research in the construction industry and its current and future trends through a systematic literature review. The review identified that blockchain research is gaining popularity in construction sector exponentially and is expected to continue that pace. The developed countries are dominating these application oriented researches while developing economies are lacking behind. Research on adopting blockchain in procurement and design and construction processes has been done substantially while newer topics are evolving since the beginning of this decade, focusing on the sustainability initiatives of the sector and fusing other digital technologies with blockchain. It is believed that while procurement and design related researches iterate their findings, these new topics would define the blockchain researches in the years to come. Also, attention should be paid on holistically evaluating the blockchain solutions considering not only the technological aspect but also the sustainability, resilience and the productivity of the industry, which is yet to be observed in the studies.

Keywords: *Blockchain; Built Environment; Construction Industry; Distributed Ledger; Technologies.*

1. INTRODUCTION

Construction industry is often considered as a key driver of economic development and activities, contributing an equivalent to 6% of global gross domestic product (Kang et al., 2022). Nevertheless, it has been widely accepted that it is described as a “complex product systems industry” and its projects are characterised by their complexity in design as well as delivery (Erri Pradeep et al., 2021). This has resulted in construction projects facing

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challenges due to poor alignment between stakeholders, compliance issues, inefficiencies in finance and payments and project delays, among others (Ameyaw et al., 2023; Lu et al., 2021a; Nanayakkara et al., 2021). However it has been argued that the advent of Industry 4.0 technologies such as Artificial Intelligence, Internet of Things and Blockchain have the potential to eliminate several of these barriers (Ameyaw et al., 2023; Kiu et al., 2022). Among them, blockchain has garnered specific interest of researchers worldwide, owing to several of its key characteristics such as decentralisation, transparency, immutability and improved security (Msawil et al., 2022; Rodrigo et al., 2020).

Blockchain could simply be referred as a disruptive technology, with a decentralised database that chronologically and securely records transactions (Sheng et al., 2020). It has been reported that blockchains could reform financial markets, supply chains, consumer and business-to-business services, and publicly-held registers (Akinradewo et al., 2022). Further, previous studies confirm that it has the potential to be applied in several industries such as finance, identity protection, transportation, healthcare and logistics management (Perera et al., 2020). In addition, Scott et al. (2021) in their exploratory review, established that blockchain could be used throughout a construction project, in multiple phases ranging from procurement and supply, to energy and carbon footprint, throughout design and construction as well. Regardless of this, blockchain adoption has not received significant interest yet, as a potential disrupter in the construction industry. This could be attributed to the negative shade around cryptocurrency owing to its market instability and alleged role in money laundering (De Filippi et al., 2022). However, it is worth noting that blockchain is not merely a cryptocurrency or its financial applications (Akinradewo et al., 2022), instead it is the underlying technology behind cryptocurrencies, and blockchain as a technology, has immense potential of applications in construction and other industries.

Partly due to this perception, the studies conducted on the domain of blockchain applications in construction industry are majorly ad-hoc and spread over multiple areas with asymmetric levels of research in which some have matured to the development of prototypes while some are still in conceptual or exploratory levels. This could be detrimental to a potential researcher to identify the possible gaps in the completed studies so far and to get an idea of the current level of blockchain adoption in the construction industry. While some of the previous studies have attempted to do this, the global research on blockchain has evolved since they were published. Accordingly, this study intends to analyse the available literature that explicitly discuss the application of blockchain in the construction industry and present the evolution, current trends and the state of their research to assist organisations and personnel to understand the applicability of blockchain in the construction industry.

2. BLOCKCHAIN

Blockchain is a decentralised transaction ledger that acts as part of a large computing architecture, including many other functions related to storage, communication, file serving and archives (Rodrigo et al., 2020). It can secure the information while inducing trust in the system through several of its key characteristics like immutability, integrity, transparency and auditability among others (Msawil et al., 2022; Yang et al., 2022). In blockchain, merkle trees, consensus algorithms and other technologies pave way for multiple nodes to maintain a shareable and immutable ledger and induce collaboration within a decentralised system (Sheng et al., 2020). Data can be bundled into blocks and each block is a package data structure containing an encrypted hash of the previous block, a timestamp and exchange information (Shu et al., 2022). The header in the block contains metadata such as previous block hash, nonce, timestamp and merkle root (Li et al., 2021).

Hash value is a unique identifier of the block generated by a hash function, characterizing the contents of the block and usually 64 characters long while nonce are random values which make the first digits of corresponding hash values equals to zero (Kim et al., 2020). The data structure of a blockchian is show in Figure 1.

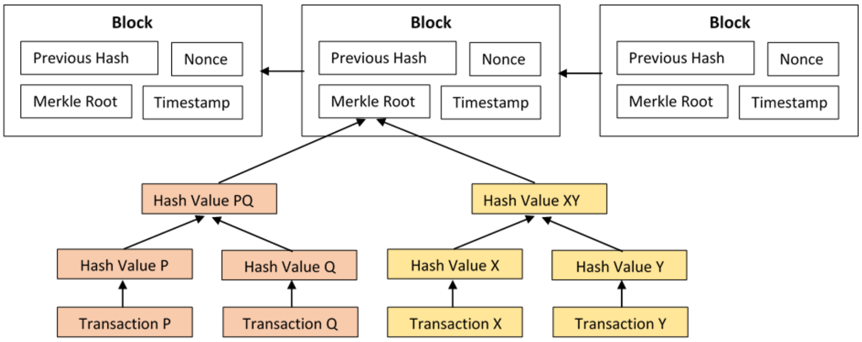

Figure 1: Data structure of a Blockchain

3. METHODOLOGY

The key intentions of literature review papers can be binary: summarising available literature in a topic by identifying key themes and issues while suggesting grounds for future research, and enfolding any scientific literature against existing knowledge and theories (Maditati et al., 2018). Among the several literature review techniques available, systematic literature review (SLR) employs a structured protocol to identify, interpret, appraise and summarise key research findings from literature that are most relevant to the chosen topic (Chen et al., 2022). Typically, SLR consists of four key steps: 1) Identification of articles; 2) Screening of articles; 3) Checking the eligibility of articles and 4) Inclusion of selected articles and synthesis (Chen et al., 2022), which have been demonstrated over the course of this section.

3.1 REVIEW PROTOCOL

Initially, the selection of the databases to be used for the study was done to ensure a sound and holistic literature could be retrieved. Accordingly, SCOPUS and Web of Science databases were selected for the purpose of this study as they contain relatively more published articles and they have deemed to possess a better comprehensive coverage of most of the prominent publishers related to this study such as Elsevier, Taylor and Francis, Emerald etc.

Consequently, taking account of the original objective of this paper, i.e. identifying the current state and focus of blockchain related research in construction industry, the research question was developed as "What are the application and focus areas of construction industry related blockchain research globally?" Emphasising it, taking account of the keywords and titles of the articles gathered during the preliminary literature review, the key search string was formulated as **(("Blockchain" OR "Distributed Ledger Technology") AND ("Construction Industry" OR "Construction Sector"**

OR “Built Environment” OR “Built Sector” OR “Building Sector” OR “Building Industry”)). Also, the search was limited to journal articles omitting grey literature including conference proceedings to ensure authenticity and credibility while also considering the probability of more application oriented, impactful articles being sent to journals than conferences. Also, the language was limited to English. Time of publication however, was not limited as the first publication related to the topic appeared in 2017, from which the articles published up to the period of search were included. Following the search in the article title or abstract or keywords fields, 102 and 94 records were yielded from the SCOPUS Index and Web of Science, respectively. After removing the duplicates, a total of 127 articles were screened for review.

The title and abstract of the yielded articles were screened to assess the relevance to the research question, followed by which 60 articles were excluded while 67 were shortlisted for further scrutiny. The shortlisted articles were further assessed for eligibility. Among which, only the articles that discuss about the specific application of blockchain in construction industry were included while articles that provide an overview, barriers and influencing factors of blockchain adoption in construction industry, and those discuss about more broader topics such as sustainability and resilience of the industry were omitted. Finally, 51 articles were shortlisted for the study. Figure 2 presents the framework of the SLR methodology used in the study.

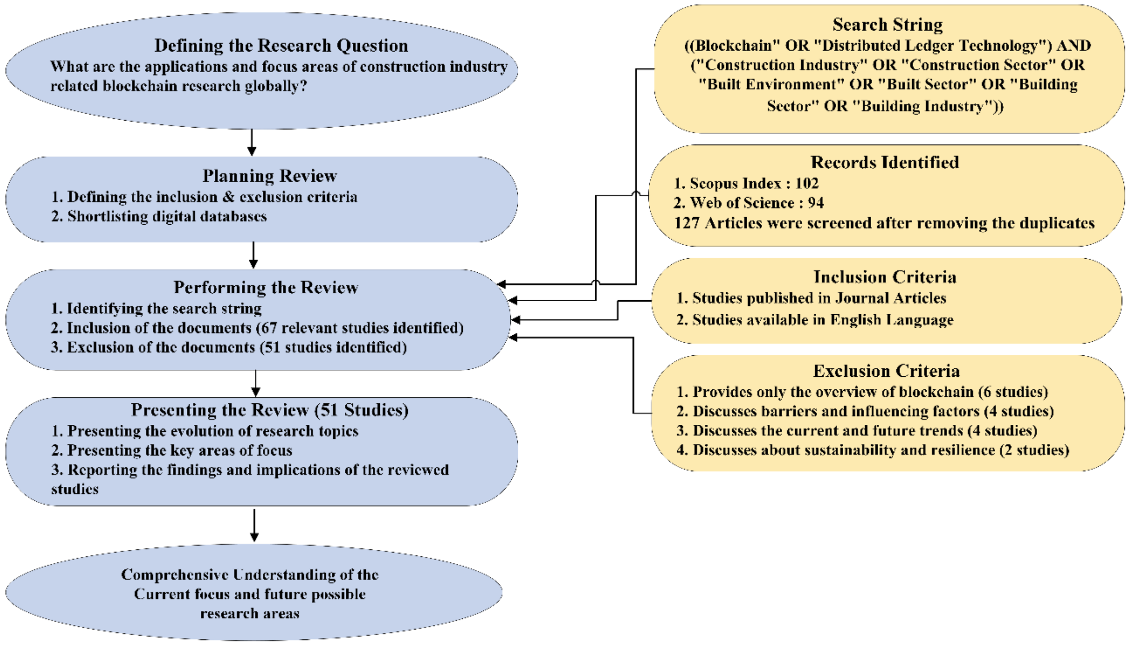

Figure 2: Systematic literature review framework

4. RESULTS

The shortlisted articles were reviewed to gather their metadata and the areas of key focus from which the following figures and sub-sections were derived. Figure 3 and figure 4 depict the number of publications in each year, till the time of writing this paper and the key methodologies used in them respectively. Figure 5 illustrates the heat map of the countries from which these papers were emerged, moving from low intensity greener colours to a higher intensity yellow colours as the number of papers from the countries increases.

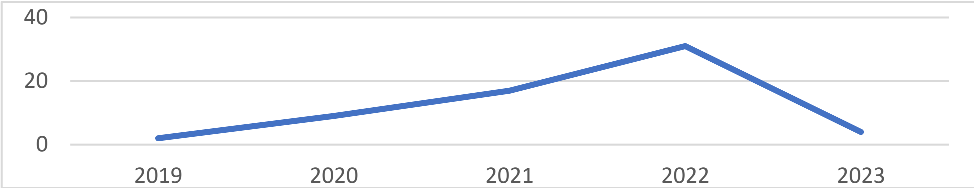

Figure 3: Number of publications in each year

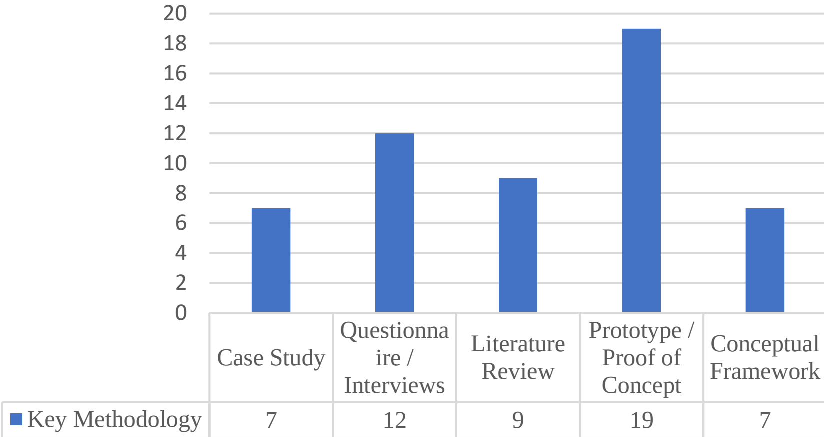

Figure 4: Key methodology used in the studies

Figure 5: Density of studies published by countries

Table1 categorises and tabulates the key areas of focus in each of the studies and the number of studies that discussed them while figure 6 depicts a tree map derived from table1.

The analysis and findings from these figures and tables have been elaborated in the ensuing discussion section while the subsections to follow, discuss the state of research in each of the categories from Table1.

Table 1: The key areas of focus and the number of studies that discuss them

Procurement	Design & Construction	Operations & Maintenance	Construction Intelligent Systems	Sustainability
Payment & Cash flow (6)	Building Information Modelling (4)	Property Transactions (1)	Artificial Intelligence (1)	Circular Economy (1)
Smart Contracts (8)	Digital Twins (3)	Asset tracking (1)	Chatbots (1)	Environmental Monitoring(1)
Supply Chain (8)	Off-site construction (3)	Facilities Management (1)		Carbon Trading (1)
Contract Administration (5)	Quality Compliance (2)	Waste Management (1)		Carbon Estimation (1)
	Stakeholder Management (2)	Safety & Health (2)		
	Integrated Project Management (6)			

4.1 PROCUREMENT (DISCUSSED IN 27 PAPERS)

Out of the 6 papers that discussed payment & cash flow in the procurement category, Ahmadisheykhsarmast and Sonmez (2020) developed a novel smart contract payment security system named SMTSEC, to reduce payment issues. Similar attempts were made

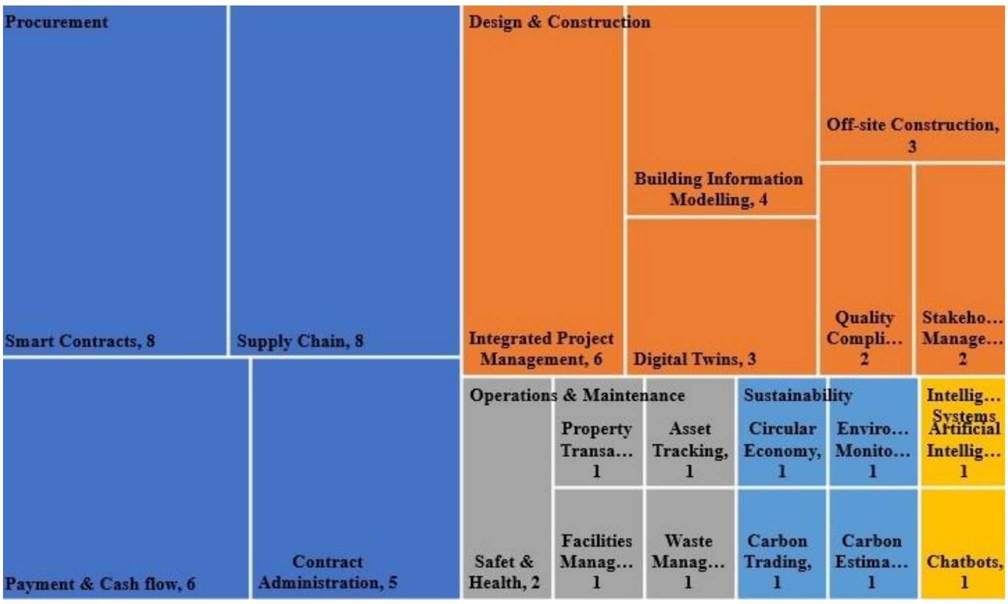

Figure 6: Tree map on the key areas of focus

by Ameyaw et al. (2023) and Nanayakkara et al. (2021), while they were limited to questionnaires/interviews to get expert opinion. Blockchain was also found to be effective in automating progress payments (Hamledari and Fischer, 2020; Sonmez et al., 2022), though the attempts are restricted to interviews and conceptual frameworks. In most cases, smart contract applications are discussed concurrently with payment & cash flow, though Chung et al. (2022) explored the fusion of smart contract with BIM through literature reviews. It was perceived that, major influencing factors of the adoption of blockchain in payment management is the increased trust and transparency.

Supply chain related research however, seems to be relatively matured as Hijazi et al. (2022; 2023), Wang et al. (2021), Lu et al. (2021b) have done proof of concept and case studies, providing application oriented papers while Singh and Kumar (2022) and Tezel et al. (2021) adopted literature review and interviews, respectively. Wang et al. (2021) specifically, reports a two-year design science research study of enabling blockchain to the supply chain of a consortium in the UK's construction sector. Also, Hijazi et al. (2022; 2023) integrate BIM and blockchain for supply chain data delivery through proof of concept. The outputs of these studies suggest that blockchain has a viable potential to be applied in supply chain of construction projects.

Ibrahim et al. (2022) introduced an ecosystem prototype using a smart contract within a novel cryptocurrency blockchain for construction while Sigalov et al. (2021) describes a framework called BIMcontracts, integrating BIM with blockchain for data exchange and digital contract management workflow. These two articles discuss about the adoption of blockchain in the domain of contract management. Further, Kiu et al. (2022) identifies the possibility of using blockchain in the electronic document management while Msawil et al. (2022) conducted a literature review on the applicability of blockchain in construction contract administration. It is understood that the major influencing factor is the high security and easy dispute resolution on blockchain (Ibrahim et al., 2022; Msawil et al., 2022).

4.2 DESIGN & CONSTRUCTION (DISCUSSED IN 20 PAPERS)

As for the design & construction, the possibility of integrated project management is the most discussed topic. Yang et al. (2022) demonstrate the applicability of blockchain to grant reliability and efficiency of information management, pertaining to scaffolding work, including the several parties involved, through a case study. It was also deemed through proof of concept that blockchain-aided processes address the issues of design liability and improved security (Erri Pradeep et al., 2021). Other than these, Teisserenc and Sepasgozar (2021a; 2022) and Ni et al. (2021) discuss the possibility of integrating BIM and digital twins, respectively with blockchain conceptually. Altogether, these studies prove that blockchain adoption in project management would induce inclusion among the several stakeholders involved.

BIM and Digital Twins are another set of frequently mentioned domains on the application of blockchain in built environment. BIM has been considered a viable option to integrate with blockchain to address the issues in supply chain (Hijazi et al., 2023), contract administration (Sigalov et al., 2021) and project management (Ni et al., 2021). Similar trend could be seen in digital twins as well (Hunhevicz et al., 2022; Teisserenc and Sepasgozar, 2021b).

Another key area is off-site construction, which was discussed in 3 papers. Li et al. (2021) developed an innovative Two-Layer Adaptive Blockchain-based Supervision (TABS) for off-site modular housing production. The key benefit in this is the lack of tampering and privacy leaks. Jiang et al. (2021) too, proposes a blockchain-enabled cyber-physical smart modular integration construction platform to facilitate cross-enterprise information sharing among multiple stakeholders, reinforcing inclusion and privacy. Meanwhile, Bakhtiarizadeh et al. (2022) explored the applicability blockchain in the off-site construction sector of New Zealand through questionnaire surveys.

In addition to these, quality compliance has also garnered the attention of the researchers. Sheng et al. (2020) developed a blockchain based framework for managing quality information, referred as “Product Organisation Process qualityChain”, establishing through case study that blockchain can decentralise the management of quality information, achieving consistent and security. Wu et al. (2021) came up with an on-site construction quality inspection exploiting blockchain and smart contracts. Meanwhile, Kang et al., (2022) and Lu et al. (2021b) presented a blockchain-based model to rebuilt trust and uplift construction efficiency, i.e. stakeholder management.

4.3 OPERATIONS & MAINTENANCE (DISCUSSED IN 6 PAPERS)

When considering the operations & maintenance, Perera et al. (2021) did a commendable attempt in developing blockchain-based trusted property transactions in the built environment, eliminating the middlemen involved in property transactions, hence reducing cost. Van Groesen and Pauwels (2022) demonstrated a plug-and-play framework of interacting applications and a workflow to operate it for asset tracking. Further, Xu et al. (2022) developed a blockchain-enabled occupational safety and health deployment framework to create privacy and occupational safety, while Liu et al. (2022) and Gunasekara et al. (2022) explored the possibility of using blockchain in waste management and facilities management, respectively. While the earlier two articles demonstrate prototypes, these studies are limited to conceptual framework and interviews.

4.4 CONSTRUCTION INTELLIGENT SYSTEMS (DISCUSSED IN 2 PAPERS)

As for the construction intelligent systems, both the papers retrieved are authored by Adel et al. in 2022. The first paper introduces a tailorable decentralised AI system which utilises blockchain. The proposed system validates and audits the decision-making processes. The second paper proposes a novel information exchange and management system for construction firms, integrating blockchain and chatbots, to track work progress. Both these studies present a prototype to be assessed for its suitability in the construction industry.

4.5 SUSTAINABILITY (DISCUSSED IN 4 PAPERS)

The application of blockchain in the sustainability domain of the construction industry is largely centered on carbon estimation and trading. Shu et al. (2022) presented an emissions-trading system which could also handle carbon emissions within the materialisation phase of a project while Rodrigo et al. (2020) conducted a literature review followed by a questionnaire survey for the potential application of blockchain for accurate estimation of embodied carbon in construction supply chain. In addition, Zhong et al. (2022) proposed a blockchain-enabled framework for on-site environmental monitoring by proof of concept and Shojaei et al. (2021) investigated blockchain to facilitate circular economy. A blockchain model was presented and tested through a synthetic case study.

5. DISCUSSION

While the first publication on blockchain in the construction industry dates back to 2017, the earliest article used in this study is from 2019, since most of the early publications were either grey literature or those that provide an overview or discuss the challenges of blockchain adoption. More application based studies started to appear on 2019, growing exponentially till 2022 at an annual average of 174%, as it could be seen from figure 3. It was identified during the preliminary review that the number of review papers and the blockchain use-cases in construction industry, they discuss have also gradually increased, suggesting that a similar growth in use-case studies could be observed for 2023 and the years to come. In addition, the outlook appears to be more positive given the fact within the first quarter of 2023 itself, 4 articles have already been published.

As for the key methodology used in the studies, it could be seen that 19 articles used prototype/proof of concept (Erri Pradeep et al., 2021; Hijazi et al., 2023; Wang et al., 2021) which is the highest while the lowest of the pack, case study and conceptual framework each were used in 7 studies (Hamledari and Fischer, 2021; Liu et al., 2022; Sonmez et al., 2022), as shown in figure 4. An interesting trend observed is that majority of the studies strive to provide more demonstrable output through case studies and prototypes as opposed to the findings of earlier similar studies (Scott et al., 2021), in which theoretical and exploratory studies dominated numerically, as discovered in the preliminary review. However, it should be noted that the review protocol of SLR in the study shortlists only the use-case based studies and hence this trend might change when exploratory and grey literature are included as well. Nevertheless, it should be acknowledged that demonstrable output are starting to emerge in the recent years, which is a positive sign for blockchain adoption in the construction industry.

In addition, another notable finding was most of these application based studies are from developed countries such as Australia, Hong Kong, China, USA and UK (Ameyaw et al., 2023; Chung et al., 2022; Rodrigo et al., 2020), as it could be seen from figure 5 in which they are denoted with higher density. This reinforces a popular notion that economic development and rigorously embracing new, disruptive technologies go hand-in-hand, especially when considering the likes of construction industry, which is often characterised by its immense contribution to Gross Domestic Product.

When pondering on key areas of focus, it should be noted that applications of blockchain in procurement related areas are the most present among the articles retrieved for the study (Ibrahim et al., 2022; Nanayakkara et al., 2021; Tezel et al., 2021), taking a larger area of figure 6, suggesting that the potential of blockchain is the most in procurement phase of a construction project when compared to others, while closely followed by design & construction (Ni et al., 2021; Sigalov et al., 2021; Yang et al., 2022). However, when considering the operations & maintenance, though this category has not gained the depth in research like the earlier two based on the number of articles, studies have touched several areas of application such as waste management (Gunasekara et al., 2022), property transactions (Perera et al., 2021), and asset tracking (van Groesen & Pauwels, 2022). Similarly, sustainability related research are also yet to gain popularity, judging from the number of articles. Nevertheless, it is safe to acknowledge that though the sufficient depth has not been attained yet in these two categories, the research has been matured to an extent in the existing topics owing to the several proof of concept studies evolving, moving forward from the exploratory reviews and expert opinions.

Another key observation is that, procurement and design related applications somewhat attribute to the inherent scope of applications of blockchain that could have been diffused from the financial industry as similar payment and logistics related solutions are already being practiced in other industries. However, more advanced topics such as artificial intelligence (Adel et al., 2022) and sustainability related topics like carbon estimation and trading (Rodrigo et al., 2020) have started to appear only from this decade, suggesting that these could be the key areas of focus for the years to come as construction industry itself is gearing towards digitalisation and sustainable processes.

6. CONCLUSIONS

Summing up, it could be seen that the interest and popularity of blockchain based research in the construction industry is gaining momentum exponentially over the years. The transition from exploratory reviews and surveys towards prototypes and proof of concept has been witnessed rapidly within the span of a half a decade. The developed countries as usual, dominate these application oriented studies numerically, urging the developing economies as well, to reflect on the outcome of these studies and strategically orient their research on blockchain adoption in their construction sector.

As for the research trends, the research on using blockchain in the procurement and design and construction processes are reaching maturity, as relatively higher number of studies with diverse methodologies have already appeared. While there is scope for more research and iteration in these areas, a more recent trend is, fusing intelligent systems like artificial intelligence with blockchain and harnessing blockchain for sustainability related initiatives of the built environment. It could be argued that this would define the blockchain research for the latter half of this decade. In addition, while blockchain solutions are being presented by researchers, negligence could be sensed with respect to their impact on the sustainability, productivity and resilience of the construction industry. As these topics are gaining attention, owing to the increased impact on climate change, increase in population and resource constraints, focusing only on the technological aspect would prove the efforts fruitless. Hence, during the years to come, due diligence should be given to the holistic evaluation of these emerging blockchain solutions as well, on the sustainability, productivity and resilience, which would pave way for an effective adoption of blockchain in the construction sector.

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EXPLORING SUSTAINABLE PROJECT MANAGEMENT PRACTICES: A PERSPECTIVE OF MEP CONTRACTORS IN SRI LANKA

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ABSTRACT

The construction industry can contribute to social inequality and environmental degradation. In order to address these concerns, effective management throughout their lifecycle is crucial. Sustainable Project Management (SPM) is a managerial concept that sustainability of a project from inception to completion. Although SPM has received less attention compared to other concepts, it assists project managers in achieving sustainability across all three bottom lines. This study examines the SPM methods employed by mechanical, electrical, and plumbing (MEP) contractors in Sri Lanka. MEP sector is selected to narrow down the scope of the study. Subsequently, a qualitative research approach was adopted to collect data with semi-structured interviews involving ten MEP contractors who have experience and exposure in the industry. The sample was selected using snowballing sampling to ensure the diverse representation of MEP contractors of different scales throughout the study. The research findings highlight that the adoption of SPM practices in Sri Lanka is relatively low compared to international standards, primarily due to a lack of awareness among project managers. Furthermore, MEP managers face challenges in exerting control over their environments, emphasizing the need for a change in attitudes. The results of this study will contribute to efforts aimed at reducing the environmental impact of construction activities, promoting social equity, and enhancing long-term economic viability. Moreover, these findings will serve as a catalyst for further research exploring potential improvements in the implementation of SPM practices.

Keywords: *MEP; Project Management; Sustainable Communication; Sustainable Project Management; Sustainable Project Planning.*

1. INTRODUCTION

Sustainable construction involves achieving social, economic, and environmental sustainability by using sustainable construction methodologies while delivering the best value for money for the client (Bandara et al., 2019; Silvius & Schipper, 2014). Its main expected outcomes are to maximise the occupants' comfort flexibility and save time through operational efficiency (Janjua et al., 2021). Further, there are other outcomes such as economic gains, including energy savings, reduced time usage, reduced design

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cost and minimum life cycle costs, and environmental gains inclusive of the adaptation to climatic changes, energy efficiency, and expert systems (Bandara et al., 2019).

However, the construction sector is recognised as a significant source of environmental contamination (Porras, Walter, Soriano, & Ramirez, 2023). The reason for this is the large amounts of energy consumption for the processes of building material production and operations, including the function of mechanical, electrical, plumbing, and other building services (Xie, et al., 2022). This high responsibility placed on the construction industry for environmental pollution and the lack of growth in sustainable construction in developing countries designates the necessity for an ideal framework to satisfy all the needs expected to be accomplished by a construction project regarding sustainability (Benachio et al., 2020). When it is investigated the possibilities to motivate sustainable construction, Mechanical, Electrical (Porras, Walter, Soriano, & Ramirez, 2023), and Plumbing (MEP) contractors' role becomes crucial in terms of reducing the operational and maintenance costs of a given project and reducing the environmental impact at greater levels (Ahmad, 2023; Olanrewaju, et al., 2021). According to Rodriguez et al., (2020), MEP can effectively achieve the reduction of operational carbon (OC) and embodied carbon (EC) to reduce the whole life carbon (WLC) of a building.

Even though MEP contributes largely to pollution and lack of sustainability, little attention has been paid to MEP practices toward sustainability. Therefore, this paper is aimed to assess sustainable project management (SPM) practices from the perspective of MEP contractors by investigating the challenges faced by them during the implementation of sustainable project management practices and providing solutions for those under the Sri Lankan context.

2. LITERATURE REVIEW

Sustainability of projects is becoming increasingly important due to the limited resources, the growing number of stakeholders, and the need to balance environmental, economic, and social objectives (Yu et al., 2018). When implementing sustainability in the projects, 'sustainable project management', which is the practice of controlling projects to ensure their sustainability goals are met is essential (Sabini et al., 2019). As Chawla et al. (2018) demonstrate, the project manager always has a significant role in implementing sustainability. However, there is a discrepancy between the standards for project management competencies and the competencies which are required for sustainable project management (Silvius & Schipper, 2014). Therefore, the project managers are unable to deliver the expected outcomes from their roles as sustainable project managers (Azzam, Zayat, & Marzouk, 2022). The reason for this is the lack of competencies of the professionals regarding the SPM. Therefore, it is important to align the competencies of project managers with the principles of sustainable project management. Figure 1 shows the expansion of the traditional project management role to the sustainable project management role including the discrete requirements which both have concerns.

According to the figure 1, traditional project management primarily focuses on the organisation and project level, whereas the sustainable project management broadens the scope to the next generation, then local, and global levels. It emphasises assessing the

global environmental impact, social and community factors and implementing strategies considering the globe rather than depending on a single project or organisation.

Figure 1: Expansion of sustainable project management

Source: (Silvius & Schipper, 2014)

According to Goedknegt and Silvius, (2012), the below mentioned SPM principles were identified initially through the literature review.

- Balancing or harmonising social, environmental and economic interests
- Both short-term and long-term orientation
- Both local and global orientation
- Values and ethics
- Transparency and accountability
- Consuming income, not capital

Issues related to sustainability often involve high levels of complexity and uncertainty. Therefore, it requires effective communication to deliver information and understanding among stakeholders (Porras, Walter, Soriano, & Ramirez, 2023). Amongst several factors influencing sustainable project management implementation are discussed in the following subsections.

2.1 SUSTAINABLE PROJECT PLANNING

Sustainable project planning is vital for achieving socially, ecologically, and financially successful project outcomes (Yu et al., 2018). As per the same author, incorporating sustainable principles into project planning ensures that MEP systems are designed, installed, and operated in a way that optimises energy performance, minimises environmental impacts, and meets the specific needs of the project and its stakeholders. However, there is a lack of understanding and measurement regarding sustainable project planning in construction engineering projects. Therefore, by considering factors like energy planning for the construction period and continuous monitoring of energy consumption, it is required to explore the role of sustainable project planning and its impact in the MEP sector to maintain high-performance standards throughout a project lifecycle.

2.2 SUSTAINABLE STAKEHOLDER MANAGEMENT

Sustainable stakeholder management recognises the importance of considering the needs and interests of all stakeholders, aligning with the triple bottom line concept (Silvius & Schipper, 2014). Involving stakeholders throughout the project's lifecycle and evaluating the project's effects are crucial for sustainable project success (Porras, Walter, Soriano, & Ramirez, 2023). Involving stakeholders early in the decision-making processes related to MEP systems allows for better integration of sustainable technologies and strategies, as well as addressing their concerns and preferences. Hence, a critical examination of stakeholder engagement and management practices is necessary to implementation of sustainable MEP solutions which align with the project's objectives and contribute to long-term sustainability.

2.3 SHIFTS ASSOCIATED WITH SUSTAINABLE PROJECT MANAGEMENT

Figure 2 describes that there are three main shifts associated with the implementation of SPM practices which are namely the mind shift, paradigm shift and scope shift.

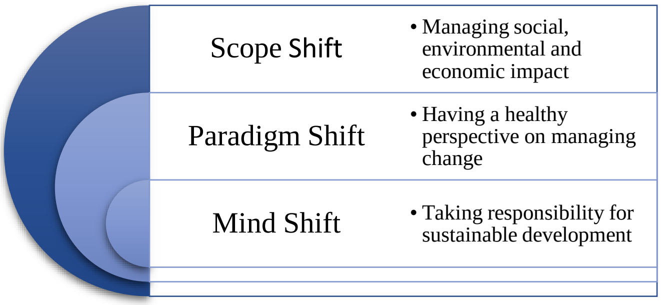

Figure 2: The three shifts of sustainable project management

Source: (Goedknegt & Silvius, 2012)

In the early stages of a project, the project manager can prioritise sustainability with a scope shift in his project managerial scope. This includes incorporating sustainable practices into the project's objectives, strategies, and decision-making processes. Once the project manager has adjusted their scope to include sustainability, then a paradigm shift is necessary for the entire project team. A paradigm shift refers to a fundamental change in the team's mindset and approach toward managing the project. In this case, it involves adopting a positive outlook on managing change and embracing sustainability as a core value. However, the successful implementation of SPM depends on the project team's willingness to take responsibility for sustainable development. Therefore, a mind shift is essential to ensure the project team's accountability.

Nevertheless, whether these shifts in project management practices towards sustainability are essential for achieving sustainable outcomes in the industry, the limited research conducted in these areas leaves a significant knowledge gap. Further, whether there have been studies related to SPM, no research has identified how to effectively apply SPM practices within the MEP sector. Therefore, there is a critical need to explore sustainable project management practices, specifically within the MEP sector, to promote sustainable practices, enhance energy efficiency, and reduce environmental impacts in MEP systems, thereby advancing sustainability in the construction industry as a whole.

3. RESEARCH METHODOLOGY

In order to identify the available SPM practices in the construction industry, an initial literature synthesis was conducted. The review of the literature revealed a research gap, specifically the lack of studies examining SPM practices within the Sri Lankan context. Therefore, a qualitative approach was employed to investigate SPM practices in the MEP sector. This approach allows for a comprehensive understanding of the actual situation and provides valuable insights into people's perspectives.

Due to the limited number of recognised MEP contractors and a scarcity of experienced MEP project managers in Sri Lanka, the sample size for the study was limited to ten experts who are actively involved in MEP building service management. Semi-structured interviews were chosen as the primary method for data collection, as they allow for in-depth questioning guided by a comprehensive interview guide. The snowball sampling method was used to ensure the appropriate selection of interviewees, with the aim of identifying challenges and exploring potential solutions to promote sustainable construction practices within the MEP sector in the Sri Lankan context. The profiles of the interviewees are presented in table 1.

Table 1: Profiles of the interviewees

Code	Designation	Work Experience	Scope of Work	Professional Qualifications	Awareness on SPM
R-01	Project Manager	13 years	MEP Building Services Project Management	B.Sc. (Hons) in Quantity Surveying, M.Sc. in Project Management	Well aware
R-02	MEP Project Manager	10 years	MEP Building Services Project Management	Project Management Professional (PMP), MBA	Well aware
R-03	Project Manager	11 years	MEP Building Services Project Management	B.Sc. in Chemical Engineering	Not Aware
R-04	MEP Project manager	22 years	MEP Building Services Project Management	B.Sc. in Chemical Engineering	Not Aware
R-05	Project Manager	11 years	MEP Building Services Project Management	B.Sc. in Electrical Engineering, Project Management Professional (PMP)	Well aware
R-06	Project Planning Engineer	12 years	MEP Building Services Project Management	B.Sc. in Chemical Engineering	Aware
R-07	Project Manager	21 years	MEP Building Services Project Management	Project Management Professional (PMP)	Well aware
R-08	MEP Project manager	10 years	MEP Building Services Project Management	B.Sc. in Electrical Engineering, MBA	Aware

R-09	MEP Project manager	13 years	MEP Building Services Project Management	Project Management Professional (PMP)	Well aware
R-10	MEP Project manager	14 years	MEP Building Services Project Management	B.Sc. (Hons) in Quantity Surveying, Project Management Professional (PMP)	Well aware

As table 1 explains, a total of ten industry professionals with over ten years of experience as project managers in the MEP sector were interviewed to gather data. It revealed that the majority of the participants were either well aware or at least familiar with the concept of sustainable project management practices. However, it is noteworthy that two experienced professionals were unaware of the sustainable project management (SPM) concept despite their extensive industry experience.

4. ANALYSIS AND FINDINGS

This section presents key findings of the study broadly on three major headings such as current MEP practices, level of knowledge on SPM practices among MEP contractors, and solutions to the challenges faced by MEP contractors in implementing SPM in Sri Lanka.

4.1 THE CURRENT SPM PRACTICES IN SRI LANKA

In Sri Lanka, the awareness of the concept of SPM can be categorised into three levels. The first level comprises those who are well-informed about SPM practices. The second level has some understanding of the concept but questions whether it is part of sustainable development or just a new trend in project management. The third level has little to no clarity on SPM. One of the main reasons for this can be attributed to the fact that some current project managers lack formal qualifications in project management. As pointed out by R-02, many project managers in the industry come from non-project management backgrounds, which results in limited familiarity with project management concepts. The interviews revealed that project managers from other backgrounds generally have less awareness of SPM.

R-01, R-06, and R-07 emphasised that, particularly in the mechanical, electrical, and plumbing (MEP) sector, the incorporation of inverter technologies, solar energy, and green-rated products can significantly contribute to sustainable building practices. These practices can lead to reduced operational costs and lower emissions in the long run, benefiting both the environment and building occupants. However, according to the experts, although there is potential for companies in Sri Lanka to adopt these practices, none of them are currently at a level where they can invest in international projects.

The SPM principles which were identified initially through the literature review were used during the interviews to identify the SPM practices in the Sri Lankan context.

4.1.1 Balancing or harmonising social, environmental, and economic interests

To ensure effective project execution, the experts emphasised the significance of adhering to sustainable principles throughout all project phases, including the crucial Project Charter stage. R-04, R-06, and R-08 highlighted the importance of engaging with all relevant stakeholders, including those not directly involved in the project, to understand their expectations and gain their support. The implementation of sustainable practices should consider the outcomes and interests of all stakeholders. As an example, R-01 mentioned, "The Kandalama hotel serves as an illustration of sustainable development methods by avoiding ecological disruption, benefiting the local community, and maximising social and ecological advantages." Conversely, R-02 raised concerns about the Lotus Tower project due to worries about its societal impact and the disregard for stakeholder benefits. According to R-02, the Mahaweli development project demonstrated how to strike a balance between the interests of various stakeholders while achieving lasting results that benefited many individuals. However, it may be challenging to identify and involve all indirect stakeholders in large-scale projects.

4.1.2 Both short-term and long-term orientation

An experienced MEP project manager (R-07) stated, "The decision was made to switch from using traditional hard copies to implementing a soft copy method due to the skyrocketing cost of paper, which is a result of inflation in the country". With this change, the Gmail address of their company's project was utilised, and Google Drive was designated as the main database. They have divided their teams into ELE, PLMB, QA/QC, CAD, QS, and other relevant teams and established a workflow that suited everyone, granting access only to the relevant teams. For instance, the QS team was given view access to CAD files, IRs, MIRs, NCRs, VOs and CVIs without the ability to edit or delete those files. Similarly, other teams had restricted access based on their needs. Each team was responsible for updating the registers in Google Drive, utilising Google Sheets for this purpose. They scanned and uploaded all soft copies using smartphones, making our workflow smooth and efficient. R-07 explained, "This approach allowed to access documents quickly using the smartphones, even at the site, eliminating the need to carry hard copies everywhere. It provided greater mobility, flexibility, and ease of access whenever a document was required."

This demonstrates how project managers can integrate sustainable communication practices into their project management processes, even if the project's main focus is not sustainability. Practices such as transitioning to a soft copy method, utilising digital tools, implementing workflow and access control, and applying access restrictions based on needs can be employed. Through the implementation of these SPM practices, project managers effectively reduce paper consumption, improve accessibility, enhance collaboration, and streamline information management. This exemplifies that sustainable communication can be incorporated as a project management process, irrespective of whether the project's primary objective is sustainability. It showcases how project managers can consciously make choices to integrate sustainable practices into their projects, thereby contributing to environmental responsibility in the short and long term.

During the interviews, it was observed that projects in Sri Lanka often commence with short-term objectives but may eventually transition to long-term goals. As explained by R-08, "Project managers in Sri Lanka face challenges in implementing sustainable practices due to the country's tendency towards a short-term orientation." R-01 stated that the effectiveness of sustainable project management is influenced by various factors, including the project manager's characteristics and personality traits. According to R-06, "Long-term planning and orientation are considered crucial for sustainable projects, taking into account the project's duration and its impact on the environment and legal system." However, the constraints within the project manager's working environment and the prevailing short-term orientation in Sri Lanka make it difficult to consistently implement sustainable techniques. Furthermore, the application of sustainable principles varies based on the project managers' personalities and their priorities for different project phases. Hence, the management of sustainable projects is subjective and dependent on multiple variables.

4.1.3 Both local and global orientation

The majority of experts agreed that the application of this principle is contingent upon the type of project. R-02 emphasised the need for a global perspective during the initiation and planning stages, while a local approach is crucial during the execution, monitoring, and control phases. As an illustration, R-01 provided an example of how this concept could be applied in the context of the Northern Province airport project, where local considerations were necessary to enhance connectivity and expand its scope. R-06 expressed, "By adhering to the first principle and incorporating locally produced items during construction, stakeholders can foster collaboration." However, it was observed during the interview that MEP construction service organisations in Sri Lanka primarily rely on imported goods due to limited local manufacturing, making it challenging to depend on locally sourced materials. While using locally made materials may be feasible for civil construction, it is less practical for MEP building services.

4.1.4 Values and ethics

All the experts unanimously agreed on the significance of the values and ethics principle in sustainable project management. To ensure responsible and ethical execution throughout the entire project life cycle and to consider the interests of all stakeholders, R-06 emphasised the importance of establishing the right values and ethics from the project's initiation. The efficient implementation also requires proper reporting and cost capturing. R-03 stressed the need to initiate these processes early on in the project and maintain adherence to them. It should be noted that, according to the experts, the second principle of accountability and transparency aligns with these procedures.

4.1.5 Consuming income, not Capital

Regarding the application of the financial sustainability principle, the experts expressed differing opinions. R-02, R-03, and R-10 emphasised the importance of effective cost management and cash flow planning to ensure project success. However, R-01 emphasised that the type of development and potential income sources determine its viability. R-04 and R-06 agreed with R-01's assessment and added that income utilisation without solely relying on capital varies depending on the project. Additionally, R-09 stated, "While it is crucial to implement financially sustainable principles, the management of the company ultimately bears the responsibility of guiding employees to adhere to them."

4.2 THE LEVEL OF KNOWLEDGE ON SPM PRACTICES AMONG MEP CONTRACTORS IN SRI LANKA

Based on the data, it can be concluded that project managers in Sri Lanka's building services industry possess varying levels of awareness regarding Sustainable Project Management (SPM) methods. While some project managers demonstrate a strong understanding of the concept and its methods, others have a vague comprehension, and some possess minimal knowledge. The lack of awareness can be attributed to the fact that many project managers in Sri Lanka come from engineering backgrounds rather than project management backgrounds.

Furthermore, the data indicates that professionals with more expertise in project management exhibit a deeper awareness of SPM procedures. However, due to specific constraints, some experts have been unable to implement SPM practices. For instance, R-03 provided a clear example of utilising a sustainable approach by adopting soft copies instead of traditional hard copies. Unfortunately, some project managers face challenges in incorporating new techniques into their projects due to resistance to change.

The overall conclusion drawn from the analysis is that project managers in Sri Lanka would greatly benefit from increased awareness regarding the significance and advantages of implementing SPM principles. Additionally, providing project management training and education to individuals with engineering backgrounds is essential to enhance their understanding of project management practices and principles.

4.3 SOLUTIONS TO THE CHALLENGES FACED BY MEP CONTRACTORS IN IMPLEMENTING SPM PRACTICES IN SRI LANKA

The interviewees were requested to provide solutions to the challenges encountered by MEP contractors when implementing sustainable project management practices in Sri Lanka. These solutions will be discussed in the following subsections.

4.3.1 Challenges faced when implementing Scope Shift

Resistance to change emerges as a significant challenge in the sector. Multiple interviewees have noted that the Sri Lankan industry hesitates to embrace change, resulting in missed opportunities. R-05 highlights, "We observe resistance to change and the adoption of new ideas in various industries. Perhaps this stems from Sri Lankans' rigid mindset or their skepticism towards technology." However, it would have been unconventional if we had incorporated these elements into our daily routines and activities. Following R-05's statement, R-03 reveals the effort required to persuade team members to adopt new approaches. Yet, resistance to change, particularly among experienced professionals, remains a major obstacle that hinders their full potential.

Another challenge arises from project managers' limited ability to alter the project scope. Experts assert that once the scope has been established, project managers have minimal influence over it. As mentioned by R-02, "If we neglect the social aspects during the project design, there is a high probability of sustainability failure. Expanding the scope to include social factors may lead to conflicts in the Sri Lankan context. Hence, it is challenging and difficult to address them."

4.3.2 Challenges faced when implementing Paradigm Shift

Project managers often face challenges when it comes to delegating duties and responsibilities. According to R-05, the failure to assign appropriate responsibilities, even for minor tasks, can lead to significant issues later in the project. As highlighted by R-07, "it is essential for all stakeholders to contribute to the project, as the responsibility cannot be solely shouldered by one person."

4.3.3 Challenges faced when implementing Mind Shift

Another major issue in Sri Lanka is the absence of international norms and practices. The project management sector in the country is currently undergoing a transitional period.

As stated in R-01, this change has already begun, and the sector is expected to adopt more international standards in the near future. However, experts have emphasised that in order to achieve advanced sustainability practices, the sector must embrace additional international norms and standards. Table 2 provides an overview of the three shifts of Sustainable Project Management (SPM), along with the associated challenges and proposed practices to overcome them.

Table 2: Shifts followed to implement SPM practices and their challenges

Shift Type	Challenges	Practices followed/ Practices to be followed
Scope Shift	Less power for Project Managers The high cost can occur due to scope shifts. Higher authoritarian decisions are taken by the higher management of the companies. Less interest in going for internationally standardised sustainable development projects in Sri Lankan context.	Have meetings with the management. Have meetings with the clients. Pitching the idea of SPM to the management and clients Highlight examples and benefits from international projects
Paradigm Shift	Resistance to change. The fixed mindset of experienced professionals Lack of extrinsic motivation due to less number of international projects carried out in Sri Lanka	Conduct pocket meetings regularly (daily, weekly, or monthly) Highlight and promote the benefits for the project team members. Show examples from other projects or other countries. Approach the youngsters first and then gradually go to senior levels.
Mind Shift	Attitudinal issues Not following orders Lack of Communication skills	Conduct pocket meetings regularly (daily, weekly, or monthly) Assign Project team leaders. Assign tasks. Establish sustainable communication platforms. Distinguish Hierarchical levels among project team members.

Table 2 illustrates that each shift type presents unique challenges and requires specific practices to be followed for effective management. For example, one challenge related to scope shifts in project management is the reduced decision-making authority for project managers. To tackle these challenges, it is crucial to conduct meetings with both management and clients. These meetings serve as a platform for open dialogue and negotiation, ensuring that everyone involved shares a common understanding of project requirements and objectives. Additionally, such meetings allow project managers to advocate for Sustainable Project Management (SPM), highlighting its benefits and emphasising the importance of incorporating sustainable practices.

By implementing these practices, project managers can address the challenges associated with each shift type and drive successful sustainable project management within the MEP sector. However, there are challenges to implementing SPM practices in the MEP sector in Sri Lanka, as described in Table 3.

Table 3: Solutions suggested by the interviewees for respective challenges

Challenge	Expert Opinion
Unstable economy	This is a significant obstacle that is currently being faced. Limited options are available, primarily those that are financially feasible. In many cases, the only option is to negotiate.
Lack of investment in sustainability	Integrate proper sustainable practices into Project Management focusing on less material wastage, proper material handling, accurate documentation and carry out sustainable construction methods.
Obstructive Policies	This varies between companies. In my company, there is not a bureaucratic structure instead there is an autocratic one. In a bureaucratic approach, professionals have more power and there is a more organized method of decision-making, but in an autocratic approach, the senior management has more authority and can make decisions without input from others.
The absence of a methodical approach to implementing plans to achieve sustainability	The task at hand presents a challenge, and a systematic approach can be implemented during the development of a team. Utilizing a Quality Management System (QMS) can aid in monitoring and maintaining this systematic approach.
lack of comprehension regarding the potential advantages of being proactive and the economic risks associated with the outcomes of unsustainability	There is also an issue in that a post-project analysis, or "lesson learned" document, is not typically created. In international projects, it is common practice to create such a document to allow both the company and its employees to learn from the project's successes and failures.
Environmental or social sustainability improvements are not prioritised in internal capital allocation decisions.	The challenge exists and it is related to an attitude issue., carry out pocket meetings, awareness sessions among project staff and labours
The challenge of interacting with governmental organisations	It is a common occurrence and cannot be overcome without a fundamental change in society.
shortage of well-trained staff and labour with proper knowledge and expertise in sustainable practices	It is also difficult to train individuals for repetitive tasks, resulting in a lack of development of specific skills over time. Recruit or train staff with required competency levels.
Project managers do not possess the required KSAs (knowledge, skill, ability)	One of the significant issues is that many project managers come from engineering backgrounds and lack the necessary project management mindset. Project Managers should only be appointed with proper project managerial educational qualities.
Insufficient attention given to researching the involvement of promoting successful adoption of green procurement practices at the local level.	As project managers, we can only do implementing a systematic approach and so we can't force beyond that. Prioritise sustainable bottom lines as a way of promoting sustainability for project planning and management sessions.
ISO 14000 certification issues	Conduct negotiations with relevant authorities, maintain proper QMS documentation, Adopt to soft copy methods from hardcopy methods.
HSE issues	Though these issues exist, there is a slight trend of progress. Carry out proper health & safety awareness sessions.

As presented in Table, the unstable economy was identified as a significant challenge that limited available options and necessitated negotiations. The absence of a systematic approach to implementing sustainability plans and a lack of understanding regarding the benefits of proactive measures also contribute to these challenges. Furthermore, environmental and social sustainability improvements are often not given priority in internal capital allocation decisions. Additionally, project managers' lack of essential knowledge, skills, and abilities, combined with insufficient attention given to promoting green procurement practices at the local level, further impede progress. As a result, it has been determined that overcoming these obstacles may require significant societal changes, negotiations with relevant authorities, and the adoption of a systematic project management approach. Further the findings seem applicable not only to the MEP sector but also to the Civil construction sector as well. However, the impact would be different due to the high number of clearances carried out within MEP sector when compared to Civil sector.

5. CONCLUSIONS

Sustainable project management (SPM) is a crucial concept in project management across various industries. Specifically, in the construction sector, SPM plays a vital role in promoting sustainability, reducing environmental impact during construction activities, and ensuring long-term economic viability. However, there is a lack of literature addressing the application of SPM in the Sri Lankan environment, especially from the perspective of MEP contractors. Therefore, the objective of this study was to explore the feasibility of implementing SPM practices among Project Managers in Sri Lanka's MEP contractor industry.

To achieve this goal, the study conducted a literature review and semi-structured interviews with industry experts. The purpose was to identify SPM practices, assess the level of awareness and understanding among MEP contractors, and uncover potential challenges. The findings revealed that MEP project managers should incorporate sustainable practices into their projects, including stakeholder management, project planning, and sustainable communication. However, the study also identified obstacles to implementing SPM practices, such as stakeholder attitudes, resistance to change, and limited awareness among higher management.

Based on these findings, the study recommends several actions to promote SPM practices among project management professionals. These include raising awareness through continuing professional development programs and knowledge exchange, conducting industry-specific studies to understand how SPM practices can be incorporated, and establishing a separate body to advocate for SPM practices. Additionally, the study proposes investigating the impact of SPM practices on civil engineering construction in the Sri Lankan infrastructure industry, developing a framework for Sri Lankan project managers to adopt SPM practices, and researching the distinctions between lean construction techniques, SPM practices, and sustainable construction techniques to identify the most effective practices.

It is important to note that the study focused specifically on MEP/building services, as this sector significantly impacts building operations costs and emissions compared to civil/infrastructure development. Therefore, the study provides valuable insights and recommendations for promoting sustainable practices among MEP contractors in the construction industry. It emphasises the potential for significant environmental, economic, and social improvements within the sector through the adoption of sustainable practices. Furthermore, the study contributes to actionable steps for promoting and integrating SPM practices, ultimately paving the way for a more sustainable and responsible construction industry in Sri Lanka.

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EXPLORING THE FACILITIES MANAGEMENT EDUCATION NEEDS IN SRI LANKA

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ABSTRACT

Facilities Management (FM) is a multidisciplinary profession at the core of building operations management. As such, it requires a wide range of skills that differ significantly from region to region due to variable industry sizes, maturity levels, characteristics of building stocks and services, and occupant cultures. Consequently, it is essential to cultivate the necessary knowledge and skills to produce competent FM professionals to cater to the demand of the FM industry. Worldwide, various professional bodies have specified essential competencies for the FM profession. This study aims to reveal the current state of such competencies in the FM industry in Sri Lanka. Accordingly, a scrupulous literature review was conducted to identify the FM competencies. Twelve competency attributes germane to the Sri Lankan context were identified, and subsequently, a web-based questionnaire survey was conducted to analyse their importance and competence levels. The mean ratings were calculated using the received responses and were used to develop an Importance-Competence Analysis (ICA) matrix. The results indicated that 'operations and maintenance', 'leadership' and 'technology' are the prioritised competencies that need improvements through appropriate education and training.

Keywords: *Competencies; Education; Facilities Management; Profession; Sri Lanka.*

1. INTRODUCTION

Since its inception, Facilities Management (FM) as a dynamic profession continues to mature and evolve. From the late 1980s, FM has gradually gained a position as a discipline and a profession within the property and construction industry. Professional bodies offer vital platforms for the exchange of experience and information among their

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members (Green, 2015). International Facility Management Association (IFMA) in the United States (US), the Japan Facility Management Association (JFMA) in Japan, the British Institute of Facilities Management (BIFM) in the United Kingdom (UK) - currently known as the Institute of Workplace and Facilities Management (IWFM), and the Facility Management Association (FMA) in Australia are different FM professional institutes around the world who contributed towards the evolving journey of FM. In 1992, IFMA created an educational program for FM professionals, and there are now over 80 FM-related degree programs offered by 65 different universities around the world (Anna-Lissa, 2005, as cited in Mohamat-Nor, 2014). Given the rapid development in building management technology, cultivating an accurate understanding of FM is important to ensure that the demands of this dynamic industry are met.

While studies on FM education have emerged (Lai et al., 2019), research on FM education in Sri Lanka is limited. After an extensive search using the keywords “research”, “Facility Management education”, and “Sri Lanka” on renowned literature databases including Scopus and Emerald, no results were obtained. However, the establishment of the FM degree program and professional body are important milestones of the FM industry evolution in Sri Lanka. The Honours Degree of Bachelor of Science in FM degree programme, started in 2006 by the University of Moratuwa, covers a wide arena of subjects to equip the graduates with knowledge and skills in FM, including ‘services technology’, ‘property management’, ‘project studies’, ‘construction technology’, ‘management’ and ‘IT studies’ (University of Moratuwa, 2023). This 4-year degree program has been accredited by the Royal Institution of Chartered Surveyors (RICS) since 2006 and by IFMA since 2020. The Institute of Facilities Management Sri Lanka (IFMSL), which is the sole professional body for FM in Sri Lanka, was founded in March 2013. After completing the 4-year degree programme, graduates can apply for the Associate Membership of IFMSL and invest in their knowledge growth through different Continuing Professional Development (CPD) programs and pieces of training organised by IFMSL (IFMSL, 2023). However, considering the multi-disciplinary nature of the profession, fresh graduates need time to adapt to the needs of the dynamic industry.

The capability of an FM graduate to match the industry needs can be demonstrated in terms of FM competencies established by leading FM professional bodies around the world. However, refinement of those competencies is needed to customise them to the local context. Assessing the current competence levels of professionals against the importance levels of the competencies for the local industry would facilitate the identification of the needs for improvement in the current education program curriculum (Lai, 2010). By identifying areas for improvement, educational institutions and industry stakeholders can work together to enhance the skills and knowledge of FM professionals and support the sustainable development of infrastructure and facilities in Sri Lanka. Hence, the research question of the present study is: “What are the FM competencies that require special attention in FM education and training in Sri Lanka?”. Accordingly, the following three (03) research objectives were formulated to answer the research question:

- Objective 1: Identify the competencies required of an FM professional.
- Objective 2: Solicit the importance level of the FM competencies in the Sri Lankan context and their current competence levels; and
- Objective 3: Recommend the need for education and training to enhance the identified FM competencies.

Section 2 of this paper reports the literature review conducted to identify the FM competencies. Section 3 explains the research methods adopted in this study and Section 4 presents the findings of the study along with the discussion of the findings. The concluding remarks are presented in Section 5.

2. FACILITIES MANAGEMENT COMPETENCIES

A comprehensive literature review was conducted on FM competencies. Competencies are the capacity or ability required in an individual to perform a job effectively. According to Mace (2005), competencies are acquired personal skills that reflect the potential ability to provide a consistently adequate or high level of performance in a specific job function. Competency is used to ensure that all demands in the workplace are met, and it includes job-relevant behaviour, motivation, and technical knowledge (Kamaruzzaman et al., 2018). FM competencies have evolved over time. Several professional organisations and individual researchers have identified different attributes of competencies in which a facility manager should excel. RICS has defined six (06) hard FM competencies, which are essential technical skills for FM operations, and eight (08) soft FM competencies, which are required for collaborative organisational operations. IWFM has defined 10 competencies. Furthermore, FM professional bodies in various regions have customised those competencies to cater to local requirements (table 1). Those competencies defined by professional bodies have been reviewed and amended by various researchers for different and specific needs. Among those proposed competencies, property management, operations management, maintenance management, sustainability, technology, and leadership are commonly required in all the above contexts.

Table 1: Summary of FM competencies specified by professional bodies

FM competency	**IFMA**	**IWFM**	**RICS**	**IFMSL**
Property Portfolio Management				
Develop/implement the real estate master plan		√		√
Property and asset management	√	√	√	
Space design, planning and management		√		√
Management of fitting out projects				√
Project Execution and Management				
Project (including minor renovations, repair/refurbishment, etc.) planning	√	√	√	√
Technology				
Building Information Modelling (BIM) management			√	√
Procurement and Contract Management				
Service innovation			√	
Procurement and tendering	√	√	√	√
Contract administration	√	√	√	√
Supplier management			√	√
Outsourcing			√	√
Inventory management	√	√	√	
Organisational Resource Management				
Information management	√	√	√	
Knowledge management	√			
Operation and Maintenance Management				
Improve facility performance	√			

Manage/oversee facility operations and maintenance activities				√
Manage/oversee occupant services (parking, landscaping, janitorial services, food services, concierge, facility helpdesk, security, and safety)	√	√	√	√
Manage building service systems (e.g., drainage, piping, sanitary, safety, electrical systems, etc.)	√	√	√	√
Maintenance of building elements		√	√	√
Compliance Management				
Energy management	√	√		
Building hygiene management		√		√
Health and safety management	√			√
Risk management techniques and practices		√		
Occupational safety and health management in construction	√			√
Sustainability	√	√		√
Waste management	√			
Leadership				
Manage/oversee the development/use of the facility communications plan	√			
Prepare and deliver messages that achieve the intended result		√		
Plan strategically	√	√		
Sector knowledge		√		
Organisational performance				√
Corporate social responsibility	√			
Workplace/facilities management policy	√			
Project management	√			√
People management	√		√	√
Culture and values	√	√		
Healthy and productive workplace	√	√		√
Problem-solving and decision making				√
Analysis of client requirements				√
Negotiation				√
Conduct rules, ethics, and professional practice			√	
Team working			√	
Cooperation with suppliers and specialists for matters/work processes related to facility management	√		√	
Understand organisational aim and strategy	√		√	
Understand organisation structure and organisation administration	√			
Develop/implement practices that support the performance and goals of the entire organisation	√	√	√	
Develop/implement practices that support the performance of the facility organisation	√			
Emergency Preparedness				
Plan/manage/oversee/support the organisation's emergency preparedness plan	√			
Plan/manage/oversee/support the organisation's business continuity plan	√			
Risk management	√			
Logistics management				
Legal				
Resilience	√			
Local legal system			√	
Dispute resolution				√
Data management				√
Financial Management				
Manage/oversee the finances associated with contracts	√	√	√	
Administer procurement and chargeback procedures	√			
Budgeting	√			
Insurance on property and liability	√			
Auditing	√			

Financial reporting	√

Based on the findings presented in Table 1, it is evident that the recognition of BIM management as a competency is lacking in IFMA and IWFM, which is a noteworthy factor. Additionally, within the field of FM, despite the significance of legal considerations, competencies such as dispute resolution and data management are not acknowledged by IFMA, IWFM, and RICS. Knowledge of the local legal system is also not regarded as a competency by IFMA, IWFM, and IFMSL. Furthermore, it can be observed that a significant number of competencies related to financial management and emergency preparedness are not recognised by RICS and IWFM as well. Surprisingly, IFMSL does not recognise any competencies in financial management, emergency preparedness, and organisational resource management as requirements for the FM profession. A main reason for these deficiencies could be the lack of FM education and training-related research.

3. RESEARCH METHOD

The list of FM competencies identified in Table 1 is identified using a comprehensive literature search, screening, and selecting studies, and extracting and analysing the findings. The findings listed in Table 1 were consolidated and summarised into 12 Competency Attributes (CA)s, based on a manual content analysis. The list of CAs was validated by the council members of the IFMSL, thereby attaining objective 1. This study defines competency attributes as overarching qualities or characteristics that encompass and relate to multiple individual competencies. These attributes are conceptualised as higher-level themes that provide a comprehensive perspective on the underlying factors contributing to the effective performance of FM.

The validated 12 CAs are:

- Competency Attribute 1 (CA1): Property portfolio management (e.g., asset management, space planning)
- Competency Attribute 2 (CA2): Project execution and management (e.g., manage/oversee renovation projects)
- Competency Attribute 3 (CA3): Technology (e.g., use of IT on building operations and maintenance)
- Competency Attribute 4 (CA4): Procurement and contracts management (e.g., supplier/inventory management, outsourcing)
- Competency Attribute 5 (CA5): Organisational resources management (e.g., information/knowledge management, labour management)
- Competency Attribute 6 (CA6): Operations and maintenance (e.g., oversee and improve facility operations/maintenance)
- Competency Attribute 7 (CA7): Compliance management (e.g., conform to quality standards, good practices)
- Competency Attribute 8 (CA8): Leadership (e.g., strategic planning, decision-making)
- Competency Attribute 9 (CA9): Emergency preparedness (e.g., business continuity planning, crisis/recovery management)
- Competency Attribute 10 (CA10): Legal (e.g., laws and regulations, dispute resolution)

- Competency Attribute 11 (CA11): Financial management (e.g., budgeting, financial reporting, insurance)
- Competency Attribute 12 (CA12): Documentation management (e.g., record keeping, word processing)

Based on the literature findings, this study adopted a survey approach. A questionnaire survey was conducted and the questionnaire design for the survey facilitates the revelation of the perceived importance of the 12 CAs and the perceived competence levels of FM practitioners in Sri Lanka. The importance and competency levels were collected using a 5-point Likert scale (ranging from 1: very low to 5: very high). Purposive sampling was used in this study, and a web-based questionnaire survey form was developed and distributed via emails to 189 IFMSL members who have registered under the associate, member, and fellow categories. Furthermore, the questionnaire was disseminated to 35 non-FM graduates employed as FM practitioners in leading FM organisations in Sri Lanka. Purposive sampling techniques were used in the study to target individuals who possess specific experiences related to FM. The data collected through the questionnaire survey were analysed using their mean ratings. To further analyse the relationship between the perceived importance and competence levels indicated by the respondents, the Importance-Performance Analysis (IPA) matrix was utilised. IPA is a “simple and useful technique for identifying those attributes of a service that are most in need of improvement” (Abalo et al., 2007, p. 115). While reference is made to the IPA method, this study investigated “competence level” rather than “performance level”. Hence, the term is modified to Importance-Competence Analysis (ICA). The calculated mean importance and competence ratings were analysed using the ICA matrix. Among the different matrix variants available, the flexible diagonal line approach (Lai & Hitchcock, 2015), in combination with the data-centered quadrants approach (due to its ability to demonstrate the utilisation of resources), was adopted to develop the ICA matrix for the present study. The steps taken are as follows:

- **Step 1:** Initially the data centered traditional matrix with four quadrants was constructed. The location (axis value) of the horisontal demarcation line was determined using the mean rating of the importance levels of all the 12 CAs and the location (axis value) of the vertical demarcation line was determined using the mean rating of the competence levels of all the 12 CAs. The y-axis of the matrix indicates the importance level, whereas the x-axis indicates the competence level.
- **Step 2:** A 45° diagonal line across the demarcation lines is used to re-partition the matrix for further, detailed analysis of the importance-competence ratings. The region above the diagonal line represents a high priority for improvement and the region below represents a low priority; also, the distance to the diagonal line is considered as an indicator for prioritising the improvement (Bacon, 2003).

Accordingly, the findings of the ICA matrix were used to identify educational and training needs for FM students and practitioners in the Sri Lankan FM industry.

4. FINDINGS AND DISCUSSION

4.1 DEMOGRAPHIC DETAILS OF RESPONDENTS

The number of total responses received was 126, of which the majority came from the sectors of commercial buildings, construction sites, residential buildings, and industrial buildings (Figure 1). Among them, the commercial building sector had the highest proportion (46%) of participants who took part in the survey. The distribution of the respondents illustrated in Figure 2 shows that the FM industry of Sri Lanka is in its adolescence, as the majority (61%) of the respondents are with 0-5 years of experience.

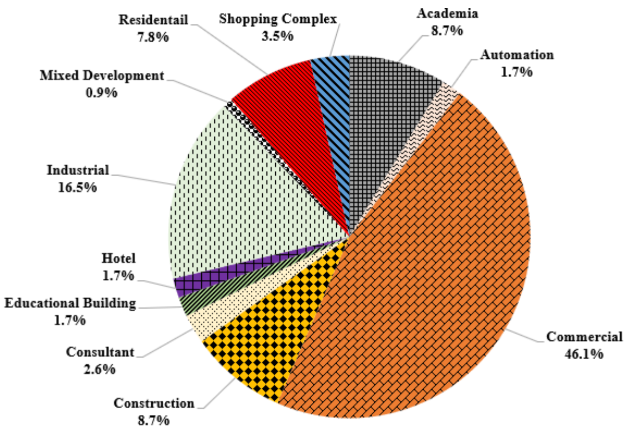

Figure 1: Demographic details of the respondents

[Industry sectors]

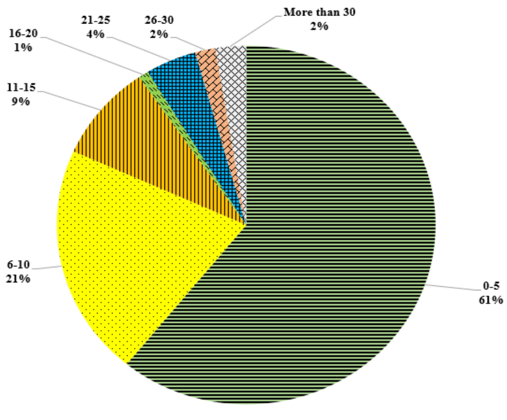

Figure 2: Demographic details of the respondents

[Years of Experience]

4.2 IMPORTANCE AND COMPETENCE LEVELS

Figure 3 shows the ICA results on the traditional data-centered matrix, while figure 4 shows the ICA results on the modified matrix (with a diagonal line).

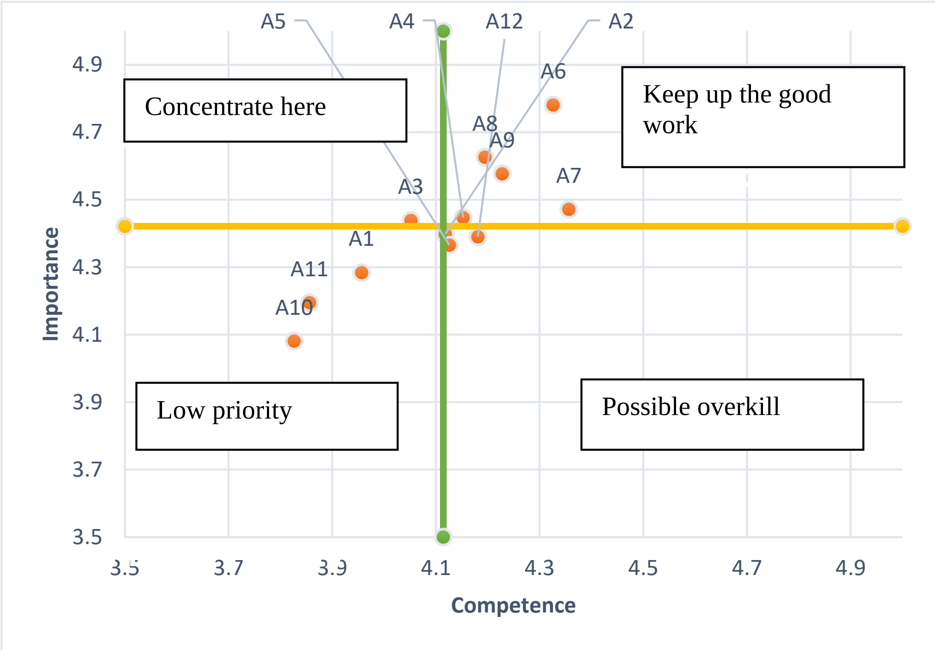

Figure 1: Results on the traditional data-centered ICA matrix

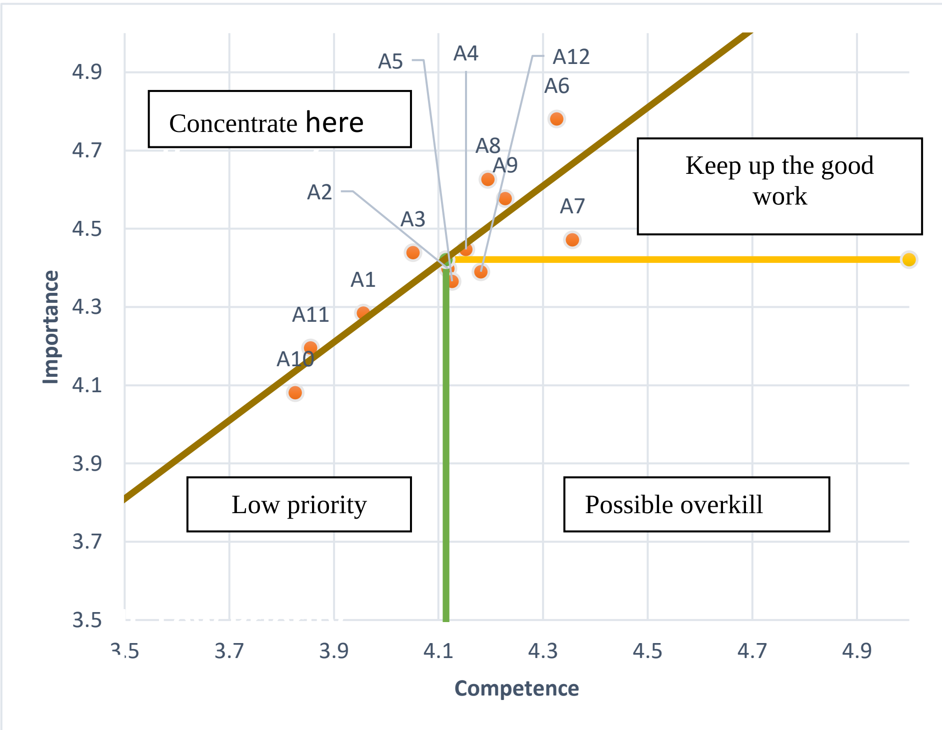

Figure 2: Results on the modified ICA matrix

The vertical and horisontal demarcation lines of the IPA models were determined based on the mean value of the collected responses under 12 competencies. By observing the spread of the competencies on the two ICA matrices, the flexible diagonal line approach offers in-depth insights into the competencies requiring improvement.

4.2.1 FM Competencies with an Immediate Need for Improvement

By analysing the results in Figure 4, the need for improvement is mostly required for CA6 - *operations and maintenance***.** It is still contending to gain recognition from building owners and users, as the key driver for organisational improvement. Common shortfalls with operations and maintenance include inadequate knowledge and experience, slow or lack of technology adoption, and lack of involvement at the strategic level (Adewunmi et al., 2009; Naidoo & Bayat, 2020). CA8 - *Leadership* is identified as the second most critical attribute that needs immediate attention. As Gunnoe et al. (2018) mentioned, FM Professionals should shift their focus away from technical skills and instead focus on leadership. Thus, they should not only maintain a building but also be the driving force behind maintaining and advancing a company's physical assets. Since most FM professionals have less than five years of experience and have yet to reach top management, there is a vacuum for strategic-level leaders.

CA3 - *Technology* has been ranked as the third highest priority. Since the FM industry in Sri Lanka is fragmented, and the sub-contractor market is unsophisticated, FM services have not kept pace with the technological advancement of Information Technology (IT), Internet of Things (IoT) and BIM-enabled FM applications, due to inadequate resources and a reluctance to bear high initial costs for technology. Furthermore, a typically low level of expertise and the non-existence of standards to measure the quality of performance are seen as key hindrances for blending technology into the FM industry, as is similarly seen in other developing regions (Adewunmi et al., 2009; Amos et al., 2019).

CA9 - *Emergency preparedness*, which has shown the need for improvement, is one of the 11 core competencies in FM as stipulated by IFMA. In the recent past, events such as Tsunami, the Covid-19 pandemic, import restrictions, increased taxes, frequent power outages, and increased material costs due to the severe economic crisis in the country are major situations that re-emphasise the importance of strategic emergency preparedness planning. The study conducted by Chandrasekera and Hebert (2019) for the tourism sector in the country found that preparedness plans have not covered tsunami-related flooding, frequent power outages and other unexpected situations, other than flooding, fire, and terrorist attacks. The same study found that the lack of financial support for preparing such plans was stated as one of the main barriers to increasing companies' overall state of preparedness. CA11 - *Financial management* has also fallen into the high-priority zone in the ICA matrix. This demonstrates the significance of prudent financial management in these times of rising operational costs and budgetary constraints in Sri Lanka. According to Amos et al. (2019), the timely release of funds for FM tasks, proportion of the FM budget, and cost-effectiveness in delivery are the key indicators of financial management competency. Among the under-capacity attributes, CA1 - *Property portfolio management* has been ranked as the least priority attribute for performance improvement in Sri Lanka. The involvement of FM in Sri Lanka is not largely expanded to property portfolio management yet, as the profession is still in its adolescence. Thus, the insufficient knowledge and inexperience of the respondents could be a plausible reason for the low priority of the attribute.

4.2.2 The Need for Education and Training to Enhance the Identified FM Competencies

While CAs such as operations and maintenance, leadership, technology, emergency preparedness, financial management, and property portfolio management calls for extensive improvement in education and training needs, it should be acknowledged that the competence levels of FM practitioners in attributes such as legal, project execution and management, organisational resources management, procurements and contracts management, documentation management, and compliance management were perceived by the respondents to be up to the industry needs. The findings give an important message to the educational sector including higher education institutions, professional institutions, and training divisions in FM organisations that more attention to developing essential courses is required. With the current advancement in building technology, the requirements and demands of the occupants are ever-increasing. To cater to their requirements, it is essential that the knowledge and skills of practising facility managers evolve with education as well as hands-on experience. Hence, more in-depth studies are required to identify the root causes of the low competency levels. For example, whether the causes are about the curriculum of FM education or the CPD programs organised by professional institutions would need to be investigated. In parallel, efforts should be made to implement measures for raising competency levels. For instance, FM employers should provide opportunities for FM graduates and practitioners in the early stages of their careers to attend on-the-job training sessions sponsored by the organisation. A close relationship between the practitioners and the academia should also be established. The Quality Assurance unit of the University Grants Commission of Sri Lanka is currently in the process of developing subject benchmarks for each higher educational programme. With the establishment of the new Department of Facilities Management at the University of Moratuwa, the academic staff, together with the support of the University's alumni from the FM industry, will be committed to addressing the education and training needs to enlighten the future of the Sri Lankan FM industry.

5. CONCLUSIONS

The objectives of the study were to identify the competencies required of an FM professional, solicit the importance level of the FM competencies in the Sri Lankan context and their current competence levels, and finally recommend the need for education and training to enhance the identified FM competencies. A scrupulous literature review was conducted to synthesise the key FM competencies stipulated by reputable FM institutions. A web-based questionnaire survey, designed on 12 FM Cas1 identified from the literature review, was then conducted to seek practitioner opinions about the importance and current competence levels of each attribute. The collected data were analysed using a modified ICA matrix.

Findings reveal that 60.9% of respondents had only 0-5 years of FM experience, implying that the FM industry is still in the adolescence stage in Sri Lanka. Given this situation, competency attributes such as 'operations and maintenance', 'leadership' and 'technology' were identified as competencies in the high-priority zone of the ICA matrix. Hence, these competencies warrant immediate attention from FM educators and trainers. Priority should be given to these competency areas when developing FM degree program curriculums, CPDs and other training awareness sessions to improve the knowledge levels of professionals. Specifically, arranging discussion forums between academia and the industry to enable closer collaborations between the sides is worth considering.

While this study has unveiled insightful findings, it is not without limitations. Even though the study examines the relationship between the importance and competence levels of FM competency attributes, it does not reflect the actual competency gaps prevalent in the industry. Hence, it is recommended that further studies should be pursued in the future to identify the competency gap of each attribute to facilitate the development of more in-depth and focused solutions for meeting the education and training needs of the FM industry in Sri Lanka.

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FROM GRAVE-TO-CRADLE: QUALITY ASSURANCE SYSTEM FOR THE DEMOLITION WASTE MANAGEMENT

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ABSTRACT

The recent decade has witnessed significant demolition waste (DW) due to rapid urbanisation in many economies. Transforming from the traditional linear supply chains into a circular arrangement while thinking from 'grave-to-cradle' is a value-adding approach to managing DW effectively. Consequently, the concept of 'reverse logistics supply chains (RLSC)' has captured the attention of the construction industry. However, the poor quality of re-processed products has hindered the successful adoption of RLSC in the construction industry. Therefore, this study examines aspects of the quality assurance system needed for RLSC to manage DW effectively and efficiently. The study used a qualitative approach, including 20 semi-structured interviews with internal stakeholders of the RLSC of DW. The study empirically confirmed that the RLSC of DW should embrace an integrated system for QA, including four aspects: process, people, policy, and technology. Under process for QA, standard practices are to be undertaken separately during building dismantling and off-site waste processing stages. While people in RLSC are skilful, competent, licensed, supervised and monitored, internal and external organisational policies should also be available for QA. Besides, espousing traditional practices with innovative technologies is also imperative for QA in RLSC of DW. The study makes a significant contribution by empirically proving that an integrated system of process, people, policy and technology is needed for QA in RLSC of DW. The developed quality assurance system provides useful insights for industry practitioners about the aspects that they should embrace in enforcing QA throughout the transformation from 'grave-to-cradle' in the construction industry.

Keywords: *Construction Industry; Demolition Waste (DW); Grave-to-Cradle; Quality Assurance System; Reverse Logistics Supply Chains (RLSC).*

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1. INTRODUCTION

The construction industry contributes to 40% of the aggregate waste produced globally, mainly due to construction and demolition activities (Jin et al., 2017). The volume of demolition waste (DW) produced on average is more than 70% of the total construction and demolition waste (CDW) (Ding et al., 2016). The DW encompasses a highly heterogeneous composition of inert and non-inert materials; thus, it exerts unfavourable environmental effects on the environment than the other types of waste if not otherwise properly managed (Hossain et al., 2017). Closing the loop of the construction supply chain by embracing well-planned and well-executed reverse logistics supply chains (RLSCs) would reduce the detrimental effects that have been caused due to the improper management of demolition waste (Brandão et al., 2021). In this study, the RLSC of DW is a process that moves materials and associated information from the dismantling of buildings to the new constructions to recapture the value of waste, which, if not disposed of at landfills (Hosseini et al., 2015). Given this, the organisations in the RLSC aim to divert waste from landfills to the forward supply chain by re-processing them into usable products which have demand from the secondary market (Shooshtarian et al., 2020). Therefore, producing quality re-processed products is a make-or-break factor that determines the successful adoption of RLSC in the construction industry.

However, the construction stakeholders had encountered quality issues in re-processed products, so they were reluctant to choose re-processed products over virgin products (Chileshe et al., 2016; Pushpamali et al., 2021). Previous studies indicated that the lack of technologies, physical resources, information, skills and competent workforce, rules and regulations, systematic procedures and benchmarking tools are the key reasons for the reduced quality of the re-processed products (Chileshe et al., 2019; Wijewickrama et al., 2021b). Product quality does not happen by chance; instead, it depends upon how well the quality is assured with the production process (Nikolaidis, 2012). In this regard, quality assurance (QA), a process-centred systematic approach to determining whether the final product meets the established requirements, plays an important role in the RLSC of DW.

According to Da Cruz et al. (2006), QA is crucial to prevent quality issues in products by assuring quality throughout the process rather than controlling it at the end. In light of this, QA is evolving with the notion of 'getting everything right first time every time' (p.23). Wijewickrama et al. (2021b) established through their systematic literature review (SLR) that an integrated system of people, process, policy, and technology is needed for QA in RLSC DW. However, this study demanded future research to validate the findings of their review by examining the empirical insights to develop a quality assurance system for RLSC of DW. Given this, the aim of this paper is thus to examine aspects of the quality assurance system needed for RLSC to manage DW effectively and efficiently through an empirical study.

The original contribution of the study is that it empirically proved that an integrated system of process, people, policy and technology is needed for QA in RLSC of DW. The developed quality assurance system provides useful insight for industry practitioners about the aspects that they should embrace in enforcing QA throughout the transformation from ‘grave-to-cradle’ in the construction industry. The remainder of the paper is organised as follows. The subsequent section is the literature review which is followed by the research methodology and results and discussion. The final section concludes by outlining the conclusions of the study.

2. LITERATURE REVIEW

The studies around RLSC in the construction industry were pioneered by Hosseini et al. (2013) and later extended by Hosseini et al. (2015). After these initial works, many empirical studies have been done in this area, especially focusing on identifying the advantages, barriers and challenges of adopting reverse logistics (e.g., Chileshe et al., 2016; Pushpamali et al., 2021). Throughout these studies, it is a recurrent fact that the poor quality of re-processed products is a significant impediment to the successful adoption of RLSC in the construction industry. For instance, Pushpamali et al. (2021) criticised a stigma attached to using re-processed products due to the perception of poor quality even if they are up to the expected standard requirements. Moving beyond this perception, Chileshe et al. (2016) pointed out that the practitioners in the construction industry have experienced quality issues in re-processed products in the real context due to poor quality control and compliance. Even though these studies have highlighted the issues related to the quality of re-processed products, none of these empirical studies has attempted to investigate how to improve their quality.

There is no solitary definition for 'quality'. Deming (1986) defined quality as producing a product or service to ensure customers' expectations. Later, Arditi and Gunaydin (1997) explained two distinct classifications of quality: product quality and process quality. The authors further described that product quality is the 'quality of elements directly related to the physical product itself' (p. 236), whilst process quality means the 'quality of the process that causes the product to be either acceptable or not' (p.236). Given this, Arditi and Gunaydin (1997) revealed that the product's quality depends upon the quality of the process used to produce it. Therefore, this concludes that ensuring process quality is paramount to producing quality output.

According to Keffane et al. (2021), QA is a process-centred approach that includes all the planned and systematic activities to fulfil the quality requirements of a product or service. It helps to achieve customer satisfaction via a continuous effort in improving product quality while identifying and eliminating the causes of quality issues during the production process. In this regard, QA is a proactive way of assuring quality throughout the process rather than controlling it at the end. Fox (2011) asserted that each task in the manufacturing process includes four elements: documentation required, the item being worked upon, the equipment being used to perform the task, and the person carrying out the work. The author further posited that all these four elements should be thoroughly considered for QA. Based on this proclamation, in the context of the RLSC of DW, Wijewickrama et al. (2021b) established that QA is a system integrated with four elements: process, people, policy, and technology. The authors highlighted that this quality assurance system includes practices and approaches that should be conducted by competent people using high-tech machines and equipment, complying with current legislation, regulations, standards, and guidelines. In this study, Wijewickrama et al. (2021b) developed a conceptual framework by reviewing the literature to build a foundation for QA in the RLSC of DW. However, there is still a lack of empirical research based on the investigations of the opinions of RLSC stakeholders, revealing the aspects of the quality assurance system needed for RLSC to manage DW effectively and efficiently. Consequently, the present study is a progression in fulfilling this gap in the literature.

3. RESEARCH METHODOLOGY

Busetto et al. (2020) stated that the qualitative approach advocates understanding and exposing the holistic view, including experiences and proclamations over a phenomenon under study. Therefore, this study aims to examine aspects of the quality assurance system needed for RLSC to manage DW effectively and efficiently through an empirical study. With the exploratory nature of this inquiry, which demands a holistic understanding of QA in RLSC of DW, a qualitative interview-based approach was considered appropriate for data collection in the current study. A total of 20 semi-structured interviews were conducted with practitioners involved in building dismantling and off-site waste processing sectors in South Australia. The reason for conducting this study in South Australia is its leadership in waste management (Green Industries South Australia, 2020), with the highest contribution of 67% of CDW recycling in Australia (Zhao et al., 2022). Therefore, conducting this study in a context like South Australia advocates providing a valuable stream of knowledge regarding how QA is assured effectively and efficiently in RLSC to yield a higher percentage of waste recovery. Both purposive and snowball sampling techniques were used to recruit interviewees for the study. Due to the limited and unsupportive nature of the study's population, six participants were initially interviewed, and then they suggested the remaining 14 interviewees for the study. Table 1 outlines the profile of the interviewees.

Table 1: Profile of interviewees

Building dismantling and on-site processing			**Off-site waste processing**		
Interviewee (code)	**Designation**	**Experience (years)**	**Interviewee (code)**	**Designation**	**Experience (years)**
BD1	Managing Director	19	WP1	Business Development Manager	11
BD2	Managing Director	28	WP2	Accounts Manager	16
BD3	Managing Director	21	WP3	Occupational Health and Safety Manager	10
BD4	Quality Control and Sales Manager	18	WP4	Accounts Manager	8
BD5	Sales and Marketing Manager	18	WP5	Regional Manager	8
BD6	Director	14	WP6	Sales and Marketing Manager	15
BD7	Director	16	WP7	General Manager	11
BD8	Contracts Manager	19	WP8	Sales and Marketing Manager	10

Building dismantling and on-site processing			Off-site waste processing		
Interviewee (code)	**Designation**	**Experience (years)**	**Interviewee (code)**	**Designation**	**Experience (years)**
BD9	Managing Director	30	WP9	Sustainability Advisor	13
BD10	Operations Manager	10			
BD11	Managing Director	22			

The interviews were conducted from September 2020 to May 2021. The average duration of an interview was nearly 45-60 minutes, and the interviews were recorded with the interviewees' consent. The qualitative data collected from semi-structured interviews were analysed using the directed content analysis, which describes the themes of the study with support from the previous research that is incomplete and thus, demands further research (Hsieh & Shannon, 2005). This analysis consisted of three phases. First, the data was transcribed and scrutinised to identify preliminary themes known as open codes. Second, the developed open codes were combined, refined and categorised to form the axial codes, which were further refined in the third step to form the final themes of the study, which are known as selective codes.

4. RESULTS AND DISCUSSION

A summary of the findings of semi-structured interviews is presented in Figure 1. Accordingly, Figure 1 explains how process, people, policy and technology contribute to the QA in RLSC of DW. Each aspect of the quality assurance system is expansively discussed in the following sections.

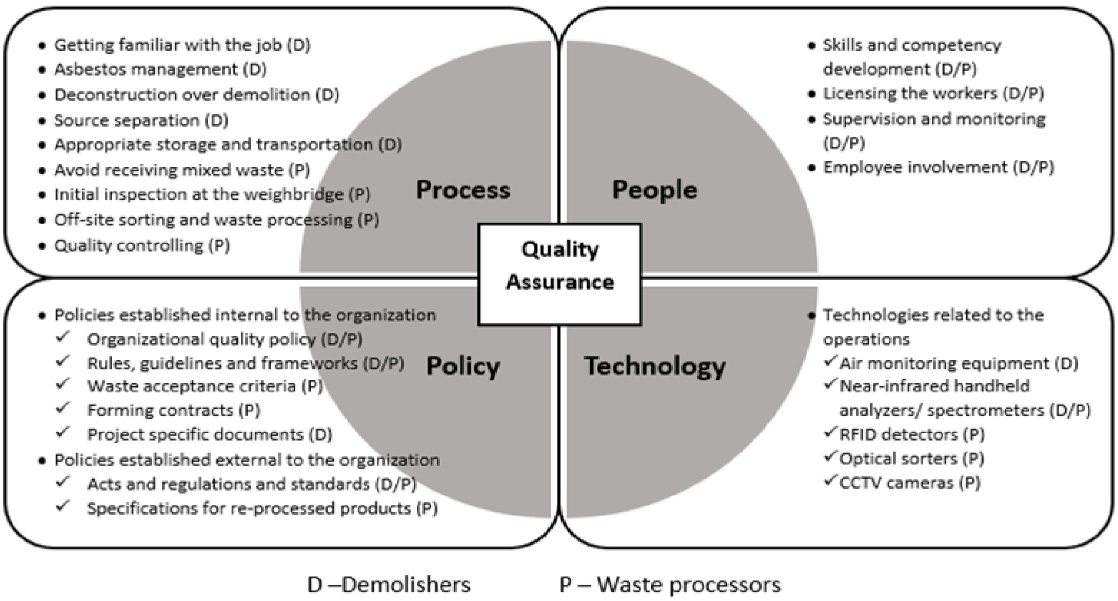

Figure 1: Quality assurance system for RLSCs of DW

4.1 PROCESS FOR QUALITY ASSURANCE

Corresponding with Wijewickrama et al. (2021b), the process for QA starts by getting familiar with the job before commencing dismantling. For this, demolishers visit the site and thoroughly investigate the status quo of the building to be demolished and get an in-depth understanding of the job scope. Similarly, collecting drawings and asbestos registers is also imperative to be familiar with the job. Asbestos management is a crucial QA practice undertaken during building dismantling and on-site processing (Zoraja et al., 2021). According to Interviewee BD3, the demolishers get samples and test them to confirm the presence of asbestos in the building. When carrying out the asbestos removal work, the licensed asbestos removalist should label the asbestos-contained waste appropriately and dispose of it as soon as practicable at a site authorised to accept it. The deconstruction of the building is also an important QA practice. Interviewee BD5 mentioned that instead of demolishing everything at once, considering deconstructing the building in sections helps prevent destroying components and materials that would otherwise be wasted in the end. The interviewees identified that source separation is an effective practice that reduces waste contamination, thence improving the quality of re-processed products. Interviewee BD1 highlighted that demolition sites have multiple bins or defined areas to separate each material on-site such as concrete, bricks, metal and timber.

> We always separate the concrete, bricks, timber, green waste, trees and rubbish. All the elements, stainless steel and all that separate. The ordinary sheet iron goes in with the iron waste, but stainless steel is separated, copper is separated, brass is separated, and lead is separated. We have separate piles, so we load up [all] piles separately and don't mix them (Interviewee BD1).

Most interviewees asserted that the appropriate storage and transportation of extracted materials to an off-site waste processing facility after demolition is a significant practice for QA in RLSC. Interviewee BD2 underlined that the most important concern here is to store and remove asbestos waste appropriately without allowing them to contaminate with other recovered waste. Interviewee BD10 stated that salvaged waste also should be uniformly stockpiled on the site to avoid contamination with each other. It is also important to take appropriate measures to minimise contamination or damage to salvaged materials during transportation.

The process quality of the waste processor primarily depends on the quality of waste that enters the material recovery facility (Chileshe et al., 2019). Conforming, Interviewee WP3 stated that as a large-scale waste processing company, they have a separate designation known as "Accounts Manager" who actively engages and ensure that the material recovery facility receives the sorted and uncontaminated waste, which complies with the waste acceptance criteria of the waste processor. The waste acceptance criteria are qualitative and quantitative criteria developed by waste processing companies and approved by the Environment Protection Authority to accept waste streams from demolishers (Wijewickrama et al., 2021a). After complying with the waste acceptance criteria, the demolisher needs to pay the gate fee (or tipping fee), which is the charge levied upon the waste accepted by the material recovery facility. Besides, Interviewee WP2 asserted that their company is forming contracts with some large-scale demolishers in SA. The interviewees revealed that when the waste loads are transferred to the weighbridge of the material recovery facility, the waste processor conducts an exhaustive examination to ensure that it is not contaminated. Interviewee WP1 pointed out that there are two full-time assigned roles as "customer service representative" and "spotter" to inspect the waste loads at the weighbridge. Interviewee WP2 mentioned that a few CCTV cameras are also fixed to inspect each load at the weighbridge. Interviewee WP1 divulged that if the waste load contains more than 5% of non-compliant materials, the waste load will not accept. Interviewee WP3 stated that even if the demolishers do source separation, the waste processor does off-site sorting again before introducing waste to the processing plant. After an exhaustive mechanical separation process, Interviewee WP3 revealed that his organisation ships all the ferrous metals to external specialists for further processing. The sorted inert fractions are recycled into rubbles, road-based materials, and clean, wet and mixed fill. The trommel fines, which arise as a by-product of trommel screening, are used as alternative daily cover material at landfills. The waste processors test re-processed products before dispatching them to the secondary market. Interviewee WP5 underpinned that their plant has an insitu-lab that advocates testing the re-processed products efficiently. Interviewee WP1 elucidated that in their organisation, they test the re-processed products against Department of Planning, Transport and Infrastructure (DIT) sampling specifications, and if products do not meet the standard requirements, they are not going to sell them.

> We have an Environ team who do some testing on products. And we also have a company called … who come in and test the stockpiles, which is independent. So that's a third party. So that no one can say that we rig the testing or whatever, we get a third party to come in twice a week. And then, those results get sent to the Environ team. And they're tested against DIT standards for the product (Interviewee WP1).

Interviewee WP3 stated that a group of specialists is assigned to do these tests in a waste processing organisation.

4.2 PEOPLE FOR QUALITY ASSURANCE

Even if the demolition is not a complicated operation, it demands workers with skills and expertise (Rameezdeen et al., 2015). Most interviewees mentioned that years of practical experience in the field are more important than the theoretical and explicit knowledge of workers engaged in demolition. Interviewee BD1 further highlighted that even after recruiting well-experienced workers for the company, the demolition companies conduct extensive training programs periodically for their workers as per the requirements in AS 4801:2001 (Occupational health and safety management systems). According to Work Health and Safety Regulations 2012, any worker assigned to remove asbestos should have either a Class A license (i.e., to remove all asbestos-containing materials, including friable asbestos materials) or a Class B license (i.e., to remove any amount of non-friable asbestos.). By getting Asbestos Removal License, the person conducting a business or undertaking (i.e., the employer of the business), on the one hand, is getting the assurance about his workers' safety as they are well informed to get protected from being exposed to the asbestos. On the other hand, the entire licensing process improves the knowledge of workers on managing asbestos safely, which is a significant practice in QA of demolisher's work (Wijewickrama et al., 2021a). Many interviewees raised the need for overseeing the execution of operations during the building dismantling and on-site processing. For instance, Interviewee BD1 stated that, as the company manager, he is on-site nearly every day instructing and directing his subordinates even if they are experienced and well-trained.

> We’re a QA company; we’ve got procedures to abide by. When I go on the site, I fill out JHA (job hazard analysis) paperwork. I have the paperwork in place with their names on it, who’s on site, who’s doing what, and they all know what they’ve got to do by filling out paperwork, having the safety here, and generally making sure everything runs smoothly. (Interviewee BD1)

Despite advanced plant and machinery usage, human involvement plays a significant role in waste processing (Botello-Alvarez et al., 2018). Therefore, employing experienced labour and developing their skills and competencies throughout their job is vital for QA. For instance, Interviewee WP1 pointed out that most workers started with their company as waste pickers; thus, they possess expertise in the field due to long-term engagement in the same company. Also, waste processing companies always encourage workers to get relevant licenses for their jobs from authorised third-party organisations. In addition, in-house training programs are periodically scheduled to enhance the knowledge and skills of workers around contemporary techniques and technologies related to their work. Employee involvement and top management commitment are paramount toward QA during the off-site waste processing phase. Herein, Interviewee WP6 divulged that their company has a decentralised culture where the activities, particularly those regarding planning and decision-making, are delegated among many teams rather than a single one. Consequently, each employee in the organisation is responsible for their work; thus, it advocates for improving the quality of the job. Interviewee WP3 mentioned that his organisation has daily tool-box meetings, weekly QA meetings and monthly top management meetings. All these meetings promoted knowledge sharing among employees and a strong awareness of the issues and status-quo of the organisation. Given this, Interviewee WP3 revealed that top managers' influence and involvement in organisational performance are the key driving forces for his company to become competitive in the industry.

4.3 POLICY FOR QUALITY ASSURANCE

Demolishers and waste processors always work to deliver a quality service for clients through the highest performance standards, professionalism and customer service (Chileshe et al., 2019). To achieve this, most companies have obtained different third-party accreditations for quality management systems. For instance, Interviewee BD4 mentioned that his company's third-party accreditation to AS/NZS ISO 9001:2008 Quality Management Systems underlines its commitment to providing quality service while engaging with clients to understand their specific needs. The Interviewee BD4 further stated that a company-wide quality policy and, thereby, some supplementary documents (e.g., rules, guidelines and frameworks) had been established as part of this quality management system, considering it as a guide to continually improving the quality of their work.

> We’ve got ISO 9001:2008. Based on this, the company has a quality policy. To achieve this quality policy, the company has also developed a business management system manual, clear procedures outlining quality approach and operations, detailed quality work instructions, and customer satisfaction surveys. (Interviewee BD4)

From the waste processor's perspective, in addition to quality policy, they have developed waste acceptance criteria and formed contracts to minimise the risk of receiving mixed waste from demolishers. On the other hand, from the demolishers' perspective, project-specific documents are developed for the QA. For instance, Interviewee BD1 stated that they prepare a demolition management plan, asbestos removal control plan, safe work method statement, and sub-contracts for each project. Noteworthily, some of these documents are prepared due to stringent regulatory requirements (e.g., asbestos removal control plan), while the others are developed as per the organisational requirement to plan for the successful completion of the project.

In addition to the policies established within the organisations, there are externally developed policies that affect demolition and waste processing (Brandão et al., 2021). The Environment Protection Authority and SafeWork SA (i.e., state government agencies in South Australia) have developed acts, regulations and codes of practices that influence the QA in RLSC. For instance, Interviewee BD3 pointed out that the landfill levy, which is the most crucial influencer for QA of demolition (Wijewickrama et al., 2021a), is regulated through the Environmental Protection Regulation 2009. Furthermore, both Environment Protection Authority and SafeWork SA regulate asbestos management. Interviewee BD2 highlighted that SafeWork SA is responsible for administering asbestos removal as per the Work Health and Safety Act 2012 and the Work Health and Safety Regulations 2012 and provides important information for demolishers regarding managing and removing asbestos. Similarly, waste processors are also getting influenced by different acts, regulations and standards of regulatory bodies. For instance, Interviewee WP1 highlighted that the Environment Protection Act 1993 mandates that waste processing companies that receive more than 100 tons of waste during a year must have a license with Environment Protection Authority. Also, there are different specifications that DIT used to acknowledge waste processors of the quality requirements they expect from the re-processed products, such as national specifications, Austroads specifications and specifications used in other states. In addition, DIT has developed a master specification that communicates standard quality and/or performance requirements that the industry needs to achieve when supplying materials for infrastructure projects in South Australia.

4.4 TECHNOLOGY FOR QUALITY ASSURANCE

According to the interviewees, very few new technologies are used for QA during the dismantling and on-site processing stage, especially for asbestos management in a demolition project. Interviewee BD3 highlighted that since there are stringent regulatory requirements around asbestos management, they are setting up air monitoring over the demolition site at all times of asbestos removal operations. For this, they are using advanced static and positional air sampling instruments to take samples at fixed locations over an area during work on asbestos removal is taking place. Then the collected air monitoring samples are analysed by a NATA-accredited laboratory. Interviewee BD5 divulged that as a large-scale demolition company in SA, his company uses near-infrared handheld analysers to identify asbestos-containing materials in a building.

> Generally, a lab-based analysis would cost us more and be time-consuming. Therefore, to make our job easy and ensure the health and safety of the working environment, we are using a near-infrared analyser to identify asbestos rapidly

The Interviewee BD5 further mentioned that they plan to use a site proximity warning system in their future demolition projects. According to Interviewee BD5, this system uses radio frequency identification detectors to enhance site safety by avoiding accidents during the demolition process. It is a kind of early warning system for workers making them aware of risks at the site.

Waste processors also use different technologies for QA (Thatcher & Oliver, 2015). The authors further mentioned that waste processing is in-deed machine-oriented; thus, they always look for sophisticated technologies to improve the performance and quality of their work. Conforming, Interviewee WP1 stated that their waste processing plant uses optical sorters to sort commingled materials during the last stage of waste processing. These optical sorters help the material recovery facilities reduce their reliance on the workforce to sort various materials while making the entire process more efficient and effective. Furthermore, Interviewee WP1 mentioned that his company uses near-infrared spectrometers to detect asbestos in the waste loads before accepting them to the material recovery facility. Also, Interviewee WP4 divulged that his company uses CCTV cameras to observe waste loads more clearly at the weighbridge.

5. CONCLUSIONS

Quality assurance acts as a system in RLSC, which plays a significant role in producing quality output. The current study aims to examine aspects of the quality assurance system needed for RLSC to manage DW effectively and efficiently through an empirical study. The study used the qualitative approach, conducting 20 semi-structured interviews with internal stakeholders from building dismantling and on-site processing and off-site waste processing stages. The study confirmed that process, people, policy, and technology are the four aspects integrated to form the quality assurance system in the RLSC of DW. Herein, as the process, there should be well-compiled activities and practises for QA. In addition, an experienced, knowledgeable and competent workforce should be present to conduct these activities and practices by getting technical support from advanced and innovative technologies. Simultaneously, all these activities and practices should be undertaken within a guided framework complying with the extant laws, regulations, standards and internal organisational policies. With this, the study makes a significant contribution by empirically proving that an integrated system of process, people, policy and technology is needed for QA in RLSC of DW

The following significant implications are suggested. The developed quality assurance system would provide useful insights for industry practitioners in the RLSC about the aspects they should embrace in enforcing QA throughout the transformation from ‘grave-to-cradle’ in the construction industry. On the other hand, for the government and policymakers, identifying aspects of the quality assurance system would provide an opportunity to develop appropriate legislative strategies and coping mechanisms to promote QA in the RLSC. The study also encompasses a limitation which is acknowledged as follows. Given the study's exploratory nature, the results are not statistically generalisable. Therefore, this warrants a future research agenda where a more widespread investigation across the geographic regions.

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HIGHLY EFFECTIVE CIRCULAR ECONOMIC PRACTICES FOR THE LIFE CYCLE OF A CONSTRUCTION PROJECT

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ABSTRACT

The circular economy (CE) concept has emerged as an important aspect of sustainable development in the construction industry. Inadequate knowledge and understanding on properly integrating CE practices into the construction life cycle is a significant obstacle. Thus, this research aimed to investigate the most effective CE practices at each stage of a construction project's life cycle. A literature review was conducted to comprehend the theoretical framework of the CE concept and its application in the construction industry. Adhering to a quantitative approach, a google questionnaire was distributed among experts in the field to identify the most effective CE practices for the Sri Lankan construction industry. The study's population included 70 industry experts, and a mandatory 50% response rate was achieved. In the group of construction industry experts, subgroup of experts with knowledge of sustainable construction practices was chosen using the cluster sampling method to achieve reliability of the data. According to the study's findings, the most effective CE practices for the various stages of a construction project's life cycle included minimising waste generation, promoting the use of sustainable materials, implementing prefabrication techniques, and developing a circular supply chain. The findings of the study offer insights into CE practices that can be implemented in the Sri Lankan construction industry to improve sustainability and reduce environmental impacts throughout the life cycle of a construction project. The study adds to the body of knowledge on CE practices in the construction industry and serves as a foundation for future research on the subject.

Keywords: *Circular Economy (CE) Practices; Construction Industry; Construction Life Cycle; Sustainability.*

1. INTRODUCTION

The construction industry is diverse and essential to all national economies, accounting for 7% to 10% of Gross Domestic Product (GDP) in many countries (Greenhalgh et al., 2021). Construction waste generation in 40 nations exceeded 3.0 billion tons per year in 2012, and this trend has been steadily expanding since then (Akhtar & Sarmah, 2018). When environmentally friendly concepts are considered, Circular Economy (CE) concept plays an important role. This concept is intended to ensure that materials and

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products are used continuously, and hence, reducing waste and pollution (Ghosh & Ghosh, 2021).

CE can be defined as an economic system that aims to eliminate waste and pollution by designing products and processes in such a way that resources are used efficiently and continuously cycled within the system (Ellen Macarthur Foundation, 2023). Cooperation among construction life cycle stakeholders, CE criteria for all project stages, a guide for the planning and implementation of demolition work, and voluntary targets for the recycling of construction and demolition wastes are important steering approaches for CE in the construction sector. (Husgafvel & Sakaguchi, 2021).

One of today's most considered social issues is establishing a CE in the built environment (Andriulaitytė & Valentukeviciene, 2020). There are several challenges and risks raised during the implementation of CE in a built environment. In organisations and management, a lack of information can result in suboptimal resource consumption, inefficient waste management, and ineffective process optimisation (Geng & Doberstein, 2008). Because of the industry's negative environmental impacts, there is a growing need in the Sri Lankan construction industry to promote sustainable practices in construction projects (Samaraweera & Gunawardhana, 2020). Thus, this study focused to improve the understanding of how CE ideas can be applied to the construction industry to promote sustainability and reduce environmental consequences along with a lifecycle perspective.

Accordingly, aim of this research is to identify most significant CE practices for each stage of the lifecycle of a construction project. The study provides insights for stakeholders in the construction industry on how to promote sustainable practices in their operations by identifying the most impactful CE practices for each stage of a construction project's lifecycle and examining the challenges and risks associated with their implementation.

2. LITERATURE REVIEW

2.1 IMPORTANCE OF CIRCULAR ECONOMY TO THE CONSTRUCTION INDUSTRY

Natural resource shortages, including those of crucial materials, are caused by construction-related activities and the built environment under a linear economy. (Ghisellini et al., 2018). The use of practises at all stages of a building's life cycle to keep materials in a closed loop for as long as possible to reduce the use of new natural resources in a construction project (Benachio et al., 2020). The CE offers a sustainable approach to the construction industry by emphasising material reduction, reuse, and recycling. Designing solutions to implement component reuse can help to reduce environmental and economic impacts (Buyle et al., 2019). The CE seeks to reduce resource input while also avoiding or reducing waste (Liu et al., 2021). This method reduces waste generation, conserves natural resources, and lowers greenhouse gas emissions.

Since waste management and waste reduction are not considered in the planning and design stages of a project, waste generated by construction and demolition (C&D) occurs throughout the life cycle of buildings (Esa et al., 2016). The negative consequences of the dominant economic development model jeopardise economic stability and the health of natural ecosystems critical to human survival (Adi & Wibowo, 2020). Implementing a CE model in the construction sector can successfully address the negative environmental impacts caused by resource consumption, waste generation, and pollution throughout a building's existence (Samaraweera & Gunawardhana, 2020).

Circular approaches to construction can result in more efficient construction practices, lowering labour and transportation costs. Furthermore, by implementing circular business models, companies can generate new revenue streams while improving their bottom line. CE can address environmental challenges while also fostering economic resilience and long-term sustainability by shifting to circular approaches. Companies that follow circular principles can reduce waste, save money, and improve social and environmental outcomes. Reusing materials, recycling post-consumer materials, and focused on leaving the environment (and society) in a better shape than before, for as by enhancing biodiversity, is known as renewing the cycle of material use (Çetin et al., 2021). As the construction industry expands, it is critical that it embraces the CE to ensure a sustainable and prosperous future for all.

2.2 CIRCULAR ECONOMIC PRACTICES IN DIFFERENT STAGES OF A CONSTRUCTION PROJECT'S LIFE CYCLE

CE strategies have grown in importance in the construction industry as a means of addressing environmental concerns and promoting sustainability. The building life cycle contains five stages: project design, manufacture, construction, operations, and end of life (Benachio et al., 2020). The design stage of a project is crucial for incorporating CE principles. Çimen, (2021) suggests that early-stage activities of the inception of a construction project such as investments, technical or financial viability, and planning activities, are made during the feasibility, and planning stage. Waste in construction can be reduced by defining waste reduction goals, using environmentally labelled items, selecting resources carefully, standardising procedures, and employing modular construction approaches (Adi & Wibowo, 2020). As a result, incorporating CE techniques into the design stage is critical to constructing a sustainable future.

Adopting CE methods at the material manufacturing stage can aid in the reduction of, waste, resource consumption, and environmental effects. Manufacturers can use recycled materials, repurposed waste products, and novel sustainable manufacturing techniques to create environmentally friendly and cost-effective building materials. Utilising recycled mass during the manufacturing process has been discovered to be a key element in boosting material sustainability (Giama & Papadopoulos, 2020). To recover material value at the end of the building's useful life, suppliers are encouraged to keep ownership of their materials whenever possible (Leising et al., 2018). Manufacturers can encourage a more sustainable and responsible construction industry that helps both the environment and the economy by embracing CE principles.

CE methods can have a substantial impact on a project's construction stage. Materials can be easily disassembled and reused at the end of a building's lifecycle by using modular and prefabricated construction techniques. This not only minimises wastage but also improves construction efficiency. Utilising new ownership models where materials are only temporarily held in the building that serves as a material bank, a life cycle strategy that maximises the functional lifetime of the building and integrates the end-of-life phase into the design (Benachio et al., 2020). Considering the significance of using waste materials in the construction industry, it is especially vital to reuse parts that are still structurally sound (reusing) or to employ raw materials as components in the creation of new structural elements (Lucena et al., 2014).

Closed-loop technologies, such as on-site waste management and water recycling, can help to minimise waste and resource consumption even further (Zulkifli & Khor, 2021). The construction sector may reduce its environmental impact while also enhancing cost-effectiveness and long-term sustainability by embracing CE strategies (Norouzi et al., 2021). CE approaches can also be used to reduce waste and resource consumption during the operating stage of a construction project. This entails implementing sustainable construction management methods such as lowering energy and water use, increasing indoor air quality, and promoting environmentally friendly mobility options (Ghufran et al., 2022).

CE principles can be utilised to extend the useful life of a structure and reduce the need for resource-intensive maintenance and repair activities by improving its efficiency. The maintenance of a closed material loop, one of CE's core concepts, has caused the end of the building stage to now interphase with manufacturing and use in the larger lifetime. (Sanchez & Haas, 2018). The desire for a CE and the highest suitable material reuse necessitates the improvement of methods for evaluating a construction project's performance throughout its entire life (Akanbia et al., 2018). CE strategies can aid in the reuse and recycling of materials and equipment during the operating stage, hence minimising waste, and the demand for new materials. Overall, introducing CE techniques into the operation stage can assist improve the construction project's environmental and economic sustainability across its full existence.

The End-of-Life stage of a construction project is critical for CE processes since it specifies how materials and products will be disposed of or repurposed. Construction waste might end up in landfills if CE concepts are not followed, contributing to environmental deterioration and natural resource depletion. Analysis of a building's disassembly performance at the end of its life can now give useful information during the early design stage because of improvements in design software. (Akanbi et al., 2019). Due to the End-of-Life (EoL) buildings' bulk/value ratio, repair and remanufacturing of their products would be done locally, stored locally, and then incorporated into new constructions locally as well to reduce costs (Hopkinson et al., 2019). Materials and products can be developed with end-of-life concerns such as ease of disassembly, reuse, and recycling by using CE processes. This can result in the recovery of valuable materials, waste reduction, and the development of new goods, lowering the need for virgin resources and reducing the environmental effect of the construction sector.

The construction sector may contribute to a more sustainable future and promote the well-being of people and the environment by implementing CE principles at all phases of a construction project's life cycle. Table 1 contains a compilation of CE practices identified according to the stages of a construction project’s life cycle through the literature review.

Table 1: Circular economic practices for each stage of the construction project's life cycle

Stages of a construction project's life cycle	Circular economic practices	References
Design stage	Design and use of modular buildings	[1]
	Design for adaptability of existing buildings	[2],[14],[16],[17],
	Design for disassembly of building structures	[2],[3],[16],[18], [19], [14], [20]
	Design for adaptability and flexibility	[4]
	Design out the waste/set target for allowable wastage	[4]
	Increase the lifespan	[4]
	Specify recycled/eco-label materials procurement	[4]
	Use secondary materials	[4]
	Take-back schemes/reverse logistics construction	[4]
	Use of life-cycle analysis to find the benefits of reusing different types of materials	[18],[27]
Material manufacture	Change of use of materials, by giving it ownership to the manufacturers to reuse	[3], [21]
	Development of material passports	[3],[22],[23],[24]
	Reuse of secondary materials in the production of building materials	[5]
	Developing a schedule of recyclable resources	[4]
	Follow environmental accreditation standards and sustainable construction guidelines	[6]
	Take-back schemes	[4]
Construction stage	Reuse of building materials in a new construction	[7],[16],[19],[14]
	Waste reduction	[8], [25]
	Off-site construction	[8],[16], [26]
	Use of recycle materials	[4]
	Use of material stock data to help reuse of materials	[9]
	Double checking of material quantities before ordering	[6]
	Procuring material from green certified suppliers	[6]
Operation stage	Use of a tool to evaluate the state of materials during the lifespan and end of life of a building	[10]
	Use of water management practices	[11]
	Minimise recuperative maintenance	[8]
	Proper scheduling to keep track of material usage	[6]
	Life-cycle information management	[12]
	Environmental impact assessment of CDW	[12]
	The material spaces must be constantly updated	[13]
	Ensure easy repair and upgrade	[8]
End of Life	Analyse the potential for reuse or recycling of existing materials	[14]
	Management of demolition waste	[15], [2]
	CDW management performance evaluation	[12]
	Closed-loop recycling	[8]

Sources: [1] Kyrö et al. (2019); [2] Maerckx et al. (2019); [3] Leising et al. (2018); [4] Adi & Wibowo (2020); [5] Nußholz et al. (2019); [6] Wijewansha et al. (2021); [7] Smol et al. (2015); [8] Adams et al. (2017); [9] Oezdemir et al. (2017); [10] Akanbi et al. (2019); [11] Pimentel-Rodrigues & Siva-Afonso (2019); [12] Yu et al. (2022); [13] Drangevåg (2022); [14] Sanchez & Haas (2018); [15] Ghisellini et al. (2018); [16] Mangialardo & Micelli (2018); [17] Geldermans (2016); [18] Eberhardt et al. (2018); [19] Rasmussen et al. (2019); [20] Manelius et al. (2019); [21] Swift et al. (2017); [22] Sauter, et al. (2018); [23] Honic et al. (2019); [24] Munaro et al. (2019); [25] Esa et al. (2016); [26] Minunno et al. (2018); [27] Hossain & Ng (2018)

2.3 CHALLENGES IN IMPLEMENTING CE IN THE SRI LANKAN CONSTRUCTION INDUSTRY

CE transition is a multifaceted task that involves factors from the environment, the economy, technology, society, government, and behaviour (Pomponi & Moncaster, 2017). High levels of waste generation, energy consumption, and greenhouse gas emissions are some of the global challenges associated with the construction industry. The lack of understanding of CE principles was identified as a barrier to its implementation, emphasising the importance of raising awareness among both professionals and clients in the Sri Lankan construction sector (Wijewansha et al., 2021). Implementing CE methods in the built environment is difficult since it necessitates waste prevention through maintenance, reuse, and remanufacture. One of the largest societal difficulties of the modern era is creating CE in the built environment, as the basic pillar of CE is to prevent waste by making the best use possible of internal processes like "maintenance," "reuse," and "remanufacture." (Andriulaitytė & Valentukeviciene, 2020).

The traditional linear construction model, which is strongly embedded in the industry, presents a considerable barrier to the move to circularity. To address these issues, it is critical to educate and increase awareness among stakeholders, implement suitable policies and regulations, invest in technical breakthroughs, and encourage stakeholder collaboration and partnerships. The absence of defined standards for monitoring CE success, as well as supporting legislation and regulations, can stymie the adoption of circular practices. Risks associated with the application of CE solutions in manufacturing contexts include a mismatch between changing demand, supply, and used component values, which makes it difficult to predict costs and return on investment (Jabbour et al., 2018). One of the most significant challenges confronting the Sri Lankan construction industry is a lack of awareness about potential CE practices that can be implemented at each stage of a construction project. This emphasises the importance of research to identify the most impactful CE practices for each stage of the project lifecycle and to provide guidance to industry stakeholders on how to promote sustainable practices in their operations.

3. RESEARCH METHODOLOGY

A quantitative research design has always been concerned with defining an epistemological methodology for judging the veracity of propositions. It offers a structured and systematic approach to data collection and analysis and allows flexibility in how data are treated in terms of comparisons, statistical analysis, and repeatability of data collection to ensure reliability (Amaratunga et al., 2002). The rationale for using a quantitative technique for the research is that a larger sample size with a greater number of respondents can improve the accuracy and reliability of the research findings.

Questionnaire survey was the adopted technique for data collection and an online questionnaire form was prepared and circulated among the specific experts in the construction industry to determine the most impactful CE practices throughout the life cycle of a construction project. Participants were asked to assign a number weight ranging from 1 to 5 to each of the practices under consideration throughout the questionnaire survey. Cluster sampling is a technique in which researchers divide a population into smaller groups (Thomas, 2020). Therefore, cluster sampling method was used as the sampling method within the population of construction industry experts who have the academic qualification and experience in construction industry and a subgroup of experts who have knowledge on sustainable construction was selected as the cluster. Content analysis is a research technique for describing the manifest content of communication in an objective, systematic, and quantitative manner (Harvey, 2022).

The correct data analysis approach must be chosen to analyse the collected data and come to an accurate conclusion. Content analysis, statistical analysis, hypothesis analysis, and discourse analysis can all be categorised as the most often utilised data analysis techniques in research (Maryville, 2021). As the nature of quantitative data is numerical, quantitative data analysis entails working with numerical variables such as statistics, percentages, calculations, measurements, and other data (Maryville, 2021). The relative importance index (RII) method was employed in this study to identify the most significant CE practices in the built environment. The use of the relative importance index method was justified due to its fairness through the incorporation of diverse opinions from a group of individuals, and ability to effectively rank a wide range of items, thereby improving the validity and comprehensiveness of the research findings. The research would identify the elements as highly influential CE practices when they had a RII score of greater than 80% (Munshi & Chaudhuri, 2011).

4. DATA ANALYSIS, FINDINGS AND DISCUSSION

The responses to the questionnaire survey were analysed, and the CE practices were ranked according to their effectiveness according to the RII value. It entails interpreting and synthesising data to reach meaningful conclusions and insights.

4.1 RESPONDENTS' PROFILES

A total of 70 construction industry experts were invited to participate in the questionnaire, and 35 completed it, that produced a 50% response rate. The sample size ensures that the target population is adequately represented, allowing for reliable data analysis and meaningful insights into the construction industry. Figure 1 shows the breakdown of the 35 respondents by their professional expertise. Out of the 35 respondents, 19 individuals are Quantity Surveyors, which indicates that most of the respondents have expertise in cost management and estimating in the construction industry. X axis shows the expertise and Y axis demonstrate the number of experts.

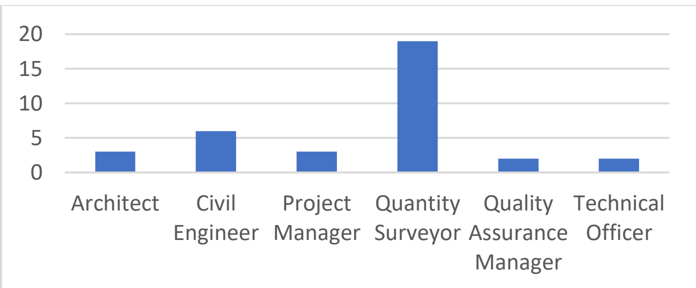

Figure 1: Responses according to their profession

The distribution of the 35 respondents by construction industry experience reveals that most respondents have a considerable level of experience in the field, with 20 individuals having 1-5 years of experience. Most respondents demonstrated a high level of knowledge and awareness of CE principles.

4.2 HIGHLY IMPACTFUL CIRCULAR ECONOMY PRACTICES AT EACH STAGE

A comprehensive literature review was used to identify 53 CE practices for all stages of the construction project lifecycle. These practices were then distributed to field experts via a Google questionnaire, which asked respondents to rate each practice on a scale of 1 to 5, with 1 representing a very low-impactful practice and 5 representing a very high-impactful practice. The highly impactful practices were identified using the RII analysis method, with a RII value of more than 80%. This process ensured that only the most effective CE practices were chosen for each stage of the construction project lifecycle, providing valuable insights for construction industry stakeholders on how to promote sustainable practices in their operations.

The RII analysis has been presented in tables (Refer to Tables 2 to 6) for each stage in construction project life cycle, indicating the highly influential CE practices identified through the questionnaire survey.

Table 2: RII and rank for CE practices at design stage

Design Stage	RII	Rank
Design and use of modular buildings	93.714	1
Design for disassembly of building structures	90.857	2
Use of life-cycle analysis to find the benefits of reusing materials	84.000	3
Use secondary materials	71.429	4
Design for adaptability of existing buildings	64.000	5
Use of a scale to analyse the level of implementation of CE practices in the company	63.429	6
Increase the lifespan	61.714	7
Design strategically to minimise waste	57.714	8
Focus on disassembly during building design	57.143	9

Table 2 shows the respondents' opinion on the impact of different CE practices in the design stage of a construction project. The top three practices are the design and use of modular buildings, building structure design for disassembly, and the use of life-cycle analysis to determine the benefits of reusing different types of materials. "Design and use of modular buildings" is the most impactful CE practice in the design stage, accounting for 93.7% of RII value. Many authors and industry experts promote that the use of Design for Disassembly in building structures, as well as the use of Life-cycle analysis to identify the benefits of reusing various materials.

Table 3: RII and rank for CE practices at Material manufacture stage

Material manufacture stage	RII	Rank
Change of use of materials, by giving it ownership to the manufacturers to reuse	91.429	1
Development of material passports	86.286	2
Reuse of secondary materials in the production of building materials	82.286	3
Take-back schemes	56.571	4
Follow environmental accreditation standards and sustainable construction guidelines	55.429	5
Developing a schedule of recyclable resources	54.857	6

Material manufacture stage	RII	Rank
Avoid toxic and/or hazardous materials	54.857	6
Supply chain environmental impact assessment	52.571	8
The material spaces must be constantly updated	52	9
Real-time supply chain tracking & monitoring	50.286	10

The RII analysis and ranking of CE practices in the material manufacturing stage are shown in Table 3. The most significant practice is changing the use of materials, allowing manufacturers to reuse them after the first building's life. The second most influential practice is material passports, which track the life cycle of building materials. The third most influential practice is the use of secondary materials in the manufacture of building materials. Prominent authors and construction industry experts support the promotion of manufacturers taking ownership of materials for reuse to facilitate material change and the establishment of material passports.

Table 4: RII and rank for CE practices at construction stage

Construction stage	RII	Rank
Off-site construction	86.286	1
Reuse of building materials in a new construction	85.714	2
Waste reduction	85.143	3
Use reversible mechanical fastening methods instead of chemical ones	53.143	4
Procuring material from green certified suppliers	52.571	5
Use of material stock data to help reuse of materials of a new building	52.000	6
On-site material, labour & equipment control	52.000	6
Double checking of material quantities before ordering	50.857	8

Three CE practices were found to be highly impactful in construction stage, with a RII value greater than 80%, according to the RII analysis. The most impactful practice was identified as off-site construction, followed by the reuse of building materials in new construction and waste reduction. These practices have the potential to significantly reduce waste and the construction industry's overall environmental impact, making them promising avenues for future exploration and implementation. Various construction industry authors and experts support the advancement of off-site construction, the use of recycled building materials in new construction projects, and the implementation of waste reduction measures.

Table 5: RII and rank for CE practices at operation stage

Operation stage	RII	Rank
Use of water management practices	87.429	1
Use of a tool to evaluate the state of materials during the lifespan and end of life of a building	80.000	2
Life-cycle information management	78.857	3
Environmental impact assessment of CDW	62.286	4
Minimise recuperative maintenance	57.714	5
The material spaces must be constantly updated	56.000	6
Ensure easy repair and upgrade	54.857	7

According to the RII analysis, two CE practices were discovered to be highly impactful in the construction industry's operation stage. With a RII value of 87.429%, the use of water management practices was identified as the most impactful practice, followed using a tool to evaluate the state of materials during the lifespan and end-of-life of a building with a RII value of 80.00%. These practices have the potential to significantly reduce water consumption and waste while also improving construction project’s sustainability, making them promising areas for further investigation and implementation.

Table 6: RII and rank for CE practices at end of life

End of life	RII	Rank
Management of demolition waste	89.143	1
Analyse the potential for reuse or recycling of existing materials	84.571	2
CDW management performance evaluation	56.571	3
Closed-loop recycling	54.286	4

According to the RII analysis, the construction industry's end-of-life stage has two highly impactful CE practices. The management of demolition waste was found to be the most impactful practice, with a RII value of 89.14%, followed by the analysis of the potential for reuse or recycling of existing materials, with a RII value of 84.57%. This emphasises the potential importance of these practices in the long-term management of construction waste and resources.

Based on the questionnaire responses, the Relative Importance Index (RII) analysis revealed 13 CE practices with more than 80% RII value. A significant finding among these practices is that most of them were suggested by more than one author, indicating expert consensus on their effectiveness. This convergence of recommendations from multiple authors strengthens the credibility and dependability of these practices in promoting sustainable and resource-efficient approaches in the construction industry.

5. CONCLUSIONS

The study successfully uncovered extremely effective CE concepts for each stage of a building project's lifecycle using a quantitative approach and a google questionnaire. In design stage the most effective CE practices found to be as design and use of modular buildings and the design for disassembly of building structures. The most effective CE practices discovered during the material manufacturing stage is the development of material passports. In construction stage the most effective CE practices found to be as off-site construction and the reuse of building materials in new construction. The most effective CE practices discovered during the operation stage were waste reduction and the use of water management practices. In end-of-life stage the most effective CE practices found to be as the management of demolition waste. Implementing these practices has the potential to significantly reduce waste, increase efficiency, and improve sustainability in the construction industry. This study provides valuable insights into the application of CE principles in the sector by investigating CE concepts relevant to the Sri Lankan construction industry and identifying highly impactful CE activities. The findings can be used as a guide for industry experts and policymakers interested in implementing CE strategies that will result in more efficient and sustainable construction processes. This research benefits construction stakeholders significantly by identifying the most effective CE practices for each stage of construction. However, further research and effort are required to fully realise the potential of CE principles in the construction industry and ensure a sustainable future for both the industry and the environment. One significant limitation of this research is its exclusive focus on the Sri Lankan construction industry.

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HONOUR CODES AND THEIR INFLUENCE ON ACADEMIC INTEGRITY IN ENGINEERING EDUCATION

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ABSTRACT

The subject of academic dishonesty at colleges and universities is an old one. However, it is now increasingly believed to be an area of discussion and concern world-wide. Academic dishonesty takes many forms. These include plagiarism, cheating in examinations, contract cheating, etc. The causes of academic dishonesty include lack of awareness particularly in relation to plagiarism, student perceptions of peer behaviour, failure to integrity students into the academic community and financial, time or academic pressures, etc. Honour codes have for long been developed and implemented at colleges and universities in the USA. Honour codes include traditional or modified honour codes. Honour codes underline the core values of an institution and enable students to play a much bigger role to influence peer behaviour and to police academic misconduct. Honour codes promote holistic growth and development of students rather than focussing on the punitive nature of academic integrity policies per se. The work reported in this paper is based on a literature review and concludes that tackling academic dishonesty effectively at colleges and universities require a multi-pronged approach including implementation of the academic integrity policies, the honour code, creative pedagogical practices and a supportive approach to learning and development of students' skills.

Keywords: *Academic Integrity; Cheating; Engineering Education; Ethics; Honour Codes.*

1. INTRODUCTION

Academic integrity continues to be a subject of increasing concern in higher education institutions world-wide. This was the case even before the move to online delivery of programs since March 2020 due to the COVID-19 pandemic. Many colleges and universities have over the years developed academic integrity policies to address the problem. Academic integrity concerns include plagiarism, cheating in examinations, falsification of data or research findings, etc. Penalties for academic dishonesty range from warnings or admonition or failure in a course to expulsion from the institution in the extreme. Intellectual honesty is the only currency in higher education. Failure to uphold academic integrity devalues academic qualifications. Academic integrity is at the heart of trust for individuals and institutions in higher education. Intellectual honesty is a prerequisite for the moral and proper functioning of individuals and society that higher education institutions seek to serve.

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Some colleges and universities particularly in the United States of America have developed academic honour codes to improve academic honesty. The concept of honour codes is not new. One of the earliest honour codes was developed at the University of Virginia in 1840 following the horrible incident of the shooting of an academic member of staff by a student. In the honour code, all students of the university undertook not to cheat, lie or steal whilst studying at the university. This code was policed by students and the single sanction for breach of the code was expulsion from the university (Carter, 2008).

This paper provides an evaluation of the influence of honour codes on academic integrity. The research method adopted in the collation of published information is given in the next section. This is followed by a review of the major causes of academic dishonesty in colleges and universities. Finally, detailed qualitative analysis of the impact of honour codes on academic integrity is provided.

2. RESEARCH METHODOLOGY

There has been very limited research into the impact of honour codes on academic integrity at colleges and universities outside the United States of America. The overall aims of this study within the context of the Sultanate of Oman are to:

1. Ascertain the extent to which honour codes have been adopted at colleges and universities,
2. Explore the perceptions of university students and academic staff to academic integrity and the honour code system,
3. Assess the feasibility of implementing the honour code system at colleges and universities,
4. Analyse the impact of honour codes on faculty actions and opinions regarding academic integrity on university campuses, and
5. Evaluate honour codes and their influence on the culture of academic integrity at higher education institutions.

This study seeks to answer several research questions in the context of the Sultanate of Oman namely:

1. What are the perceptions of college and university academic staff towards plagiarism and other forms of academic dishonesty at higher education institutions?
2. What are the perceptions of students towards plagiarism and other forms of academic dishonesty at higher education institutions?
3. Does the presence of an honour code reduce the level of academic dishonesty at a university?
4. Does the influence of the honour code vary between students on different majors, colleges and freshmen versus graduating students?
5. To what extent do academic staff communicate the provisions of the honour code?
6. To what extent do academic staff enforce penalties associated with violation of the honour code?
7. Does the presence of the honour code impact on the culture of academic integrity at a university?

A literature review was undertaken and the work started by identifying academic work published in peer-reviewed journal and conference papers, books, theses, dissertations, and academic reports. The literature was identified by searching published sources through electronic search engines including Masader, Google Scholar, Science Direct, and ProQuest. Masader is the Oman virtual science library and provides single point online access to a wide range of research publications provided by international publishers and online libraries.

The search terms used to identify the relevant literature were: honour codes, academic integrity, academic dishonesty, cheating and ethics. The objective of the search was to narrow down and identify those research publications relevant to honour codes. Non-academic literature such as university policy documents, social media reports, newspaper articles, unpublished reports were excluded from the study. Publications on other areas of academic integrity were also excluded from the study. Most of the research on the subject of honour codes for example the work of McCabe et al. (1999), McCabe et al. (2002), and McCabe et al. (2003) was USA-based. The search overall revealed that there is a dearth of academic literature on the subject of honour codes although there is plenty of published work on academic integrity in general. The work of Richards et al. (2016) was conducted in the Australian context well as the work of Yakovchuk et al. (2011) was undertaken in the United Kingdom.

This research work is still in its early stages and what is reported below are preliminary findings from the literature review. The next stage of the study will utilise both qualitative and quantitative research methods. Primary data will be collected using structured telephone interviews, online questionnaires and focus groups. Focus groups offer a powerful qualitative data collection approach in which six to eight respondents are interviewed as a group. It is anticipated that the study will be extended to cover two other countries to enable comparisons to be made. Comparative analysis methods will be used to assess this qualitative data. Data collected will also be subjected to exploratory factor analysis tests. For example, the Kaiser-Meyer-Olkin measure will be used to examine the strength of partial correlation between factors before a factor analysis is undertaken. Bartlett's test of sphericity will be undertaken to ascertain that the data collected is suitable for factor analysis. Qualitative and quantitative relationships will be explored using standard descriptive and inferential statistical tests such as the Chi-squared and F-tests. Quantitative techniques will be used to analyse quantitative data using standard computer packages such as MINITAB and SPSS.

3. CAUSES OF ACADEMIC DISHONESTY

Academic dishonesty includes cheating, fabrication of data and research outcomes, plagiarism and collusion. Cheating includes use of unauthorised material in examinations or copying of answers from other students in examinations. Falsification may occur and include fabrication of data or laboratory reports. Plagiarism is defined as use of material, text, or computer code and passing it off as one's own. Assisting other students or copying reports and assignment constitutes a breach of academic honesty. Other examples of academic dishonesty include the "dead grandmother problem" which is an excuse often given by students prior to taking of final semester examinations. These students normally wish to delay or postpone the dates for taking of their own examinations.

Plagiarism is a very common form of academic dishonesty. It is essential that academic staff provide detailed guidance to students on academic integrity policy and their own university expectations. Students should be given guidance on how to source information, how to paraphrase work and how to provide citations. Where students are allowed to work in groups, the extent of collaboration permitted should be clarified. Specific detailed instructions should be given to students on the first day of classes, and throughout the teaching semester. Students should be given small assignments that are not graded to provide them with opportunities to practice paraphrasing and essay writing before they tackle lengthy graded assignments.

Assuming that students are rational and risk-neutral, they will commit academic offences if the expected benefits in terms of grades improvement is higher than the perceived cost (Awad et al., 2016). Their study finds that complete deterrence in terms of punishment is achieved when the expected penalty is higher than the maximum possible gain. Furthermore, they also conclude that increasing penalties is not always optimal to punish repeat offenders when learning by both the offenders and academic staff is considered. In the paragraphs, that follow, the reasons why students often commit acts of plagiarism and academic dishonesty are discussed.

3.1 STUDENT PERCEPTIONS OF PEER BEHAVIOUR

The single biggest predictor of cheating at university is the perception by students of what their peers are doing. Peer behaviour influences the attitudes of others. Based on social learning theory, students learn behaviour from others. If students see their peers cheating and academic staff do nothing about it or get away with it, then they are more likely to cheat. If there is a group of students who are cheating, they can make it appear as if it is the norm. Students can also justify their own behaviour by believing that if others are cheating, they might as well cheat.

Academic staff must define what constitutes cheating behaviour and explain university policy and consequences should a student be caught cheating or attempting to cheat. Academic staff must address cheating where it occurs in a fair and consistent manner. Students ought to always be reminded that cheating has no place in academic life in a university and that dishonest behaviour of any form will be detected and punished. If academic staff address all instances of cheating fairly and consistently, this is likely to reduce dishonest behaviour.

3.2 LACK OF PLAGIARISM AWARENESS

Many students in colleges and universities particularly in their early years on their majors are unaware of what plagiarism is. If they do, their knowledge is rudimentary. Thus, many students may commit plagiarism acts inadvertently or even when they had no intent to cheat. Where students do not have the full knowledge and understanding of the issues, they are likely to ignore and not pursue the matters. Some students feel that fabricating references or submitting work where a few lines of text have been taken from submissions of other students does not constitute academic misconduct. Indeed, others feel that working in groups and submitting the same piece of work even where individual submissions are required is not unacceptable academic conduct.

Lack of plagiarism awareness by students can easily be addressed by academic staff. They can modify assessment practices. For example, assignments which require students to write extensive reports can be replaced by class tests or short quizzes. However, such changes can lead to other forms of academic misconduct including cheating.

3.3 FAILURE TO INTEGRATE STUDENTS IN THE ACADEMIC COMMUNITY

Failure to integrate students into the academic community can lead to increased incidents of academic dishonesty. Integration of students into a program or college or academic community will influence their attitudes to the community. Students with a positive attitude to their learning are likely to be motivated to do the right thing so as not to be caught in unethical behaviour. Excessive use of group work, large class sizes and lack of regular contact with academic staff are all factors that can lead to student alienation. Other activities which can assist in student integration into the academic community include extra-curricular activities, summer schools and sports.

3.4 SURFACE LEARNING APPROACH TO STUDIES

Students who adopt a surface learning approach in their studies are much more likely to plagiarise (Guo, 2011). A deep learning approach assists students to develop moral reasoning capabilities when faced with complex ethical situations.

3.5 EASE OF ACCESS TO INFORMATION

Students now have access to vast sources of information available via the internet. This ease of access to information makes it easier for students to plagiarise. Through the internet, students also have access to services of ghost writers which has increased the incidence of contract cheating. Plagiarism detection is now possible through use of text matching software but work procured through contract cheating can be difficult to detect.

3.6 FAILURE TO ADHERE TO INSTITUTIONAL POLICIES

It is extremely important that institutions take plagiarism detection seriously. Where it is detected, university policies must be followed to ensure a fair resolution. Unfortunately, academic staff occasionally perceive this as an extra burden. If students perceive that academic staff do not take plagiarism seriously, they are unlikely to do so themselves. Where the perception by students is that they are unlikely to be caught, the chances of engaging in plagiaristic behaviour will be higher.

3.7 ACADEMIC AND TIME PRESSURES

A university academic qualification is a very desirable achievement and therefore students come under pressure from family and peers to succeed. Such students may resort to plagiarism and other acts of academic dishonesty. Students under financial pressures may need to take up part-time employment. Faced with limited time, such students may resort to plagiarism. Students with an active social life or poor time management skills may find that they do not have adequate time to devote to their studies which also increases the temptation to plagiarise. Academic staff must always give students reasonable deadlines which provide them with ample time to complete assignments. Extremely tight deadlines to complete written assignments may compel students to take short cuts due to time pressures.

3.8 INTERNATIONAL STUDENTS

Some international students for example may find themselves plagiarising because of language difficulties. Academic staff can support such students by replacing extended essays and written assignments with short class tests. In some cultures, copying a piece of work verbatim may be accepted as a sign of showing respect to the author of the work when indeed it is unacceptable in western education.

3.9 STUDENT ACADEMIC SUPPORT

Students must be trained and supported in their studies to get them to develop their abilities to take good decisions when faced with ethical dilemmas. Courses in development of academic writing skills will help students to understand and avoid plagiarism. Students must be informed in the early stages of their studies about course and program expectations and must also be given adequate time to complete assignments. Extra support in development of their writing skills can be provided through academic writing centres, foundation programs, language and skills training. Other support mechanisms such as access to funding sources and hardship funds, spiritual needs and legal advice where necessary all help students to feel valued and integrated into the university community.

It should be emphasised that the solution to academic dishonesty does not lie in detecting and punishing students; even if punishments are as severe as expulsion from a university. Expulsion from a university is not a sufficient deterrent to plagiarism. The solution is an overarching one where responsibility to promote academic integrity is shared by all stakeholders including students, staff and the institution. Colleges and universities should focus on inculcating a culture of academic integrity and providing support for students to develop their academic skills.

Some authors have asserted that male students are more likely to cheat than female students, and that younger students are more likely to cheat than their mature older counterparts. Furthermore, other researchers go further to state that students demonstrating lower academic performance are more likely to cheat than those demonstrating superior academic performance. However, research into these demographic variables and their impact on cheating or plagiaristic behaviour remains inconclusive (McCabe, et al 2002).

4. HONOUR CODES

Honour codes have been widely adopted across many colleges and universities in the USA. However, they are not common in universities throughout the commonwealth. These tend to focus on academic integrity policies and student training rather than honour codes. The honour code system enables a university to inculcate its value system in its culture and fabric. It serves as a moral compass to empower students to take responsibility for upholding academic standards. Honour codes also help to shift the focus of responsibility from academic staff to students. Provided that they are well-designed and clearly communicated, honour codes are likely to have mitigating effects on academic dishonesty (Carpenter et al., 2005). Tatum and Schwartz (2017) assert that honour codes reduce both the perception and prevalence of cheating and yet academic staff rarely discuss academic integrity expectations or policies with their students.

Traditional honour codes generally include the following elements:

- A written pledge signed by all students in which they undertake not to cheat or lie in their assignments and examinations,

- Students play a key role in policing and enforcement of the code, for example, all panel members of the disciplinary body may be students and the panel may be chaired by a student,
- Students are expected to report their peers who may be in violation of the code, and
- Students may benefit from taking unsupervised or unproctored examinations.

In the modified honour code, academic staff take on more extra responsibilities for enforcement of the honour code as it is recognised that such a role should not be left to students alone.

Institutions with modified honour codes have less cheating behaviour than those without honour codes. However, they have more cheating behaviour than those with traditional honour codes (McCabe et al., 2002). Their work further confirms that the factors that have the largest influence on student cheating behaviour are as follows:

1. Perception by students of the behaviour of their peers,
2. Existence of the honour code,
3. Perceptions about the chance of being caught,
4. Perceptions about the severity of penalties that are likely to follow when the academic integrity policy is breached,
5. Perceptions about the chance of being reported by other students and staff, and
6. Understanding and acceptance of the institution's academic integrity policy.

Tatum et al. (2018) report that students from modified honour code institutions perceive more severe punishments for cheating and understood the process of reporting academic misconduct better than students from non-code institutions. In order to successfully implement the honour code in a university, an understanding of how and why it affects students' behaviour is essential. The sections that follow provide an evaluation of the processes by which the honour code makes a contribution to reducing academic dishonesty.

4.1 FOSTERING STUDENT COMMITMENT TO THE HONOUR CODE

If students are committed to the university's values, they are less likely to cheat. It is essential that faculty work to foster students' convictions and satisfaction with the honour code. Increasing student commitment to the honour code requires that universities ensure that students invest effort into the honour code. Investments in the honour code can take several forms including fostering relationships with academic staff, voting during approval of the honour code, maintaining an atmosphere of trust, concern and respect for others in the university environment. Cultivating a sense of commitment to university values is more effective than focussing on detection and punishment of students (Dix et al., 2014). Thus, universities should focus on building a culture of academic integrity in which students and staff are committed to the honour code and upholding of its principles.

An active participatory approach for students in academic integrity matters and framing academic integrity as being central to the mission, vision and values of the college or university should be encouraged. Active participation by students through an academic integrity society at university level to play roles such as adjudication, leadership, dissemination of information, promotion of academic integrity, peer motivation and engagement, counselling support for other students, and other preventive strategies all contribute to reducing academic dishonesty (Richards et al., 2016).

4.2 INFLUENCE ON PEER BEHAVIOUR

The honour code in a university can reduce the incidence of plagiarism in several respects. Firstly, it lowers the perceptions of students that their peers are not engaging in academically dishonest behaviour. Secondly, it promotes better student understanding of what academic cheating means. Thirdly, it makes it difficult for students to rationalise cheating. Fourthly, students and academic staff are more likely to report academic transgressions. Finally, students who understand the honour code are less likely to cheat than those in a university without the honour code. Universities with honour codes are also perceived to have more severe sanctions than those without.

Honour codes help to focus minds of students on academic integrity. Cheating will reduce if in addition to the honour code, universities focus on increasing students' commitment to academic integrity, trust and educational objectives. Honour codes promote the relationship of trust between students and academic staff. Honour codes alone are not the silver bullet to academic integrity problems. Indeed, they cannot be effective without a culture of academic integrity being promoted and inculcated within the university setting. Ideally, the honour code should be introduced at university level and be applied throughout the institution. However, there is nothing to stop the honour code from being introduced at college, departmental or even program level.

Honour codes promote and help to build strong and trusting relationships between students and academic staff. If a member of academic staff is perceived as being fair, students are unlikely to cheat. Where academic staff are perceived as being unfair, students are likely to cheat. Good moral conduct serves as a very powerful example for the development of student attitudes and behaviour.

The honour code impacts on students' social behaviour. It helps in getting students to understand that academic dishonesty is socially unacceptable. The honour code therefore assists in providing students with suitable peer role models. If students see their colleagues cheating, they are much more likely to cheat too. Honour codes enable students to participate in socially acceptable behaviours such designing and enforcing academic integrity policies, making personal pledges to behave with integrity, not to cheat, behaving honestly and educating others not to cheat. Students play a very proactive role in an honour code institution as role models in the development of the university's values and academic integrity culture. The honour code nurtures a culture of academic integrity and makes students accountable for their actions to their peers.

Students in honour code institutions are hesitant or disinclined to be dishonest for fear of being caught. The presence of an honour code assists students in understanding and accepting the university's academic integrity policies. Perceived severity of penalties for academic misconduct also serves as a deterrent and reduces incidents of academic dishonesty.

The honour code encourages professionalism and ethical behaviour. It promotes a positive attitude on the issue of academic integrity; and its fundamental values of honesty, trust, fairness, respect for others and responsibility. Honour codes also promote holistic growth of the individual student rather than focussing on the punitive nature of academic integrity policies and rules.

Graduates of honour-code institutions have been found to be less unethical than those from non-code institutions demonstrating the long-term impact of the honour code on the ethical behaviour of students (McCabe et al, 2003). This is explained by the fact that socialising effects of the experience of academic staff whilst in the early formative years has long-term effects.

4.3 ROLE OF ACADEMIC STAFF

Academic staff play a key role in shaping students' academic behaviour. They can take steps to motivate students to engage in honest academic behaviour. Academic staff can do so by giving students clear instructions on expectations when giving out individual and group assignments. They must confront and challenge academic dishonesty when it occurs. They can foster a culture of trust and honesty in the learning environment. Academic staff must invigilate effectively in classroom tests and examinations and design seating arrangements that make unauthorised collaboration between students impossible. They must also design good assessments and give students ample time within which to return assignments.

Academic staff must integrate academic integrity into the curriculum The honour code should be implemented within the context of a supportive and creative pedagogical approach (Raman & Ramlogan, 2020). Training of students should be interactive and promote self-evaluation and assessment by students and staff. It can be included in orientation programs for new students and university wide programs and courses such professional ethics, critical thinking, leadership, technical writing, and small group discussions, and interviews, etc.

Some academic staff take the view that cheating is best addressed between the lecturer and the student (Carter, 2008). Indeed, some academic staff suggest that they would not report a student to their Dean of College or university administrator. Such academic staff may address these issues by warning the student or reducing the student's grade. Of course, the academic staff member may opt to do nothing.

Academic staff who offer to deal with students directly rather than reporting them through official channels cite the time-consuming nature, time and effort required to gather evidence and the punishments meted out to be harsh or lenient. Academic staff who deal with academic integrity issues on a direct individual basis with students are more likely to be lenient and no evidence of academic dishonesty is left on the students record. Failure to adhere to the academic integrity policy of a university by academic staff may in fact lead to more cheating cases.

Academic staff in honour code colleges and universities are more likely to report cheating cases than in non-honour environments. This is a reflection of their support for the university academic integrity policies in honour code environments. Academic staff at honour code institutions have been found to have positive attitudes about their higher education institution's academic integrity policies. They are therefore committed and more positive about these policies.

Some academic staff view policing of student academic misconduct as being an additional burden which takes them away from their central role of teaching, student assessment, and research.

4.4 POLICING STUDENTS' ACADEMIC MISBEHAVIOUR

Honour codes require students to monitor each other's behaviour and report cheating to university authorities. This helps to nurture a strong academic integrity culture. Students take their responsibilities seriously because of the trust placed upon them by the institution. With this freedom comes responsibilities and students are accorded certain freedoms and privileges. For example, students may take examinations that are unsupervised. Students may also be allowed to self-schedule examinations. Thus, student roles and responsibilities for policing breaches of academic integrity are clear. This makes it more likely that students at institutions with honour codes are more likely to report cheats than those without honour codes.

Honour codes therefore empower students to take responsibility for holding each other accountable for academic transgressions. Enforcement of the honour code is the responsibility of students who form part of academic integrity committees or panels that decide on sanctions for the academic misbehaviour of others.

At many universities world-wide, there is a growing belief in shared governance where students are represented on most university committees. Where academic integrity committees are chaired by a student and where most members are students, this means that faculty take a smaller share of responsibility in judicial matters. Where students play a bigger role in judging the guilt or innocence of other students, there is a greater sense of procedural fairness and justice (Carter, 2008). Since academic staff are spared somewhat from having to address some aspects of academic integrity, this should increase the satisfaction of academic staff, commitment to their institution and reduced staff turnover.

4.5 HONOUR CODES VIS-À-VIS ACADEMIC INTEGRITY POLICIES

Honour codes have an explicit moral element. They may read along the lines of: "As a student of the University, I shall not lie, cheat or plagiarise". Student perceptions of the honour code may vary. In addition, signing an honour code does not necessarily mean that students agree with it. Thus, the consistency with which the honour code is likely to be upheld will vary from student to student or indeed from society to society. However, university policies, regulations and rules provided they are understood by everyone are likely to be more effective as the consequences for breach will be the same for all students.

As the concept of plagiarism is not well understood by all students alike, a signed declaration that the work submitted is that of the student is likely to be more effective as it leaves students in no doubt about the consequences of breaching the academic integrity policy.

Honour codes require students to report their peers who are in breach of the code. Most students find it difficult to support this notion as it undermines the trust and comradeship that students have with their peers. Unsupervised examinations are also highlighted as one of the potential benefits of applying the honour code. This is equally opposed by students and staff as unworkable. Staff are generally very supportive of student involvement in promoting academic integrity through peer education and membership of academic integrity panels. However, giving panels whose composition is only students the responsibility to hear breaches and to decide on academic integrity matters are not supported particularly in the United Kingdom context (Yakovchuk et al., 2011).

5. CONCLUSIONS

One aspect of academic dishonesty which has received considerable attention in the academic literature is plagiarism. Many universities worldwide have invested in text-matching software such as Turnitin, Crosscheck or Unicheck which are used by academic staff to screen assignment submissions for plagiarised material from the internet. Turnitin for example is used by well over 10,000 universities worldwide. Students plagiarise for a whole host of reasons. These include availability of materials on the internet, work pressures, pressures to score excellent grades, lack of skills to paraphrase and to acknowledge sources of information. Use of text-matching software now makes it possible to identify cases of plagiarism which would have gone unnoticed in the past. In many colleges and universities, text-matching software are now integrated with learning management systems thus allowing assignment submissions to be checked automatically for plagiarism.

Factors which influence students' academic dishonesty include the probability of detection, penalties for violation of academic integrity rules, improvements in grades that are likely to be gained, and the cheating record of the students. When the expected penalty is greater than the maximum possible gains, complete deterrence can be achieved assuming that students are rational decision-makers and risk neutral. This is consistent with deterrence theory. However, increasing the penalties is not always the optimal thing to do for repeat offenders. The sensible thing here is training for both students and academic staff.

Honour codes underline the basic core values of an institution. Honour codes are of two types: traditional and modified. Traditional honour codes are those where students pledge not to cheat, lie or deceive and to maintain academic integrity. In return students are given roles and responsibilities including taking unsupervised examinations and to report any cheating among students. Students are also given the duty to administer the code. A student may chair the committee responsible to enforcement of the code and students decide on the penalties to be meted out to other students for its breach. The modified code was developed in response to the view that staff also need to be involved in the administration of the code rather than leaving all responsibility for the code to students. Colleges and universities with traditional honour codes have fewer cheating cases than those with modified codes. Those institutions with modified honour codes in return report fewer cheating cases than those without honour codes. This is because in honour code institutions, academic integrity permeates the culture of the institution and students conceptualise academic integrity differently. Honour codes contribute to a students' moral development. Universities with honour codes tend to have a culture where there is a strong peer disapproval of cheating behaviour.

The honour code coupled with creative pedagogical practices can assist an institution to reduce academic dishonesty. The process requires a multi-pronged approach involving policies, the honour code, proper student support in subjects such as academic writing, ethics, and professionalism to promote academic integrity throughout an institution. All stakeholders including students, staff, alumni and the institution need to be brought on board to promote discussions and guidance on the subject of academic integrity.

The findings reported in this paper are preliminary and based on the literature review. Research is in progress to collect empirical data using both qualitative and quantitative techniques. The study will be extended to a selection of universities in Africa, the Gulf Cooperation Council and Australia to facilitate a comparative analysis.

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IMPACT OF ECONOMIC CRISIS ON EMPLOYEES OF CONTRACTORS' ORGANISATIONS IN THE SRI LANKAN CONSTRUCTION INDUSTRY

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ABSTRACT

The construction industry contributes more than 6% of the GDP of the Sri Lankan economy, employing workers at different levels of the value chain. The economic crisis in the country from 2019-2022 has had a significant impact on contractors' organisations in the Sri Lankan construction industry, resulting in job losses, pay cuts, and reduced working hours. Hence this study aims to investigate the impact of the economic crisis on the employees of contractors' organisations in the Sri Lankan construction industry, the most affected level of employees, and propose strategies to minimise the impact on the most affected level of employees. This study has been done using the mixed-method approach. Thirty-three (33) employees participated in a questionnaire survey and seven (7) managerial-level professionals were interviewed who are currently engaged in construction projects. This study has explored the levels of employees including technical, supervisory, and similar levels, professional level, administration, and managerial level. Further, this study provides the strategies adopted by the employees and the contractors to overcome the impact of the crisis, including measures to enhance productivity, cost reduction strategies, and access to financial support. The findings of the study will provide insights into the impact of the economic crisis on the construction industry in Sri Lanka and inform policy recommendations to support affected workers and ensure the long-term sustainability of the industry in a resilient way.

Keywords: *Construction Contactors; Construction Industry; Developing Countries; Economic Crisis; Employees.*

1. INTRODUCTION

The construction industry holds significant importance within the Sri Lankan economy, making substantial contributions to the country's Gross Domestic Product (GDP) and offering considerable employment opportunities. Over the years, the construction industry's contribution to Sri Lanka's GDP has shown consistent growth, with a recorded contribution of 6.1% in 2016, followed by subsequent increases of 7.2% in 2017, 6.8% in 2018, 6.9% in 2019, and 6.2% in 2020 (Central Bank of Sri Lanka, 2021; Central Bank

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of Sri Lanka, 2020). This industry employs a diverse workforce, ranging from unskilled labourers, semi-skilled labourers, skilled labourers, managers, and supervisors. According to the Department of Census and Statistics (2021), the construction industry employed approximately 1.03 million individuals in 2020, representing around 7.5% of the total employment in Sri Lanka. However, the construction sector, like many others, has been significantly impacted by the economic crisis that has plagued Sri Lanka since 2018. This crisis encompasses various challenges, including rising public debt, diminishing foreign exchange reserves, trade imbalances, and the additional burden imposed by the COVID-19 pandemic in 2020 (De Silva et al., 2008). The industry has faced adverse consequences such as reduced investment, a scarcity of skilled labour, declining demand for construction services, and a decline in its contribution to the GDP. As stated in Inflation, Consumer Prices (Annual %) - Sri Lanka (2022), Sri Lankan real GDP is expected to fall by 9.2% in 2022 and fall by 4.2% in 2023. Further, the inflation rate grew up to 73.7 % by August 2022 when it was 17.5% in February 2022.

The construction industry is highly vulnerable to economic crises, as evidenced by the research conducted by (Eicher et al., 2018). During periods of economic downturns, construction projects are often postponed or abandoned, leading to job losses and decreased investment. According to Perera (2010), the 2008 economic crisis, triggered by the global financial crisis, had a significant impact on the construction industry of Sri Lanka resulting in employment losses and a decline in project quality due to inadequate investment and the construction sector experienced negative consequences for workers and project outcomes. Fadhil et al. (2021) found that the economic crisis led to a decrease in construction projects, causing job losses, especially among contractor businesses. Many workers were laid off, and others faced reduced working hours. Sriyani (2022) focused on small and medium-sized contractor groups and discovered that financial difficulties due to the crisis directly affected their workforce. Employees experienced reduced wages and irregular payments. Similarly, Edmund et al. (2018) observed a decline in the demand for construction services, resulting in job losses among contractor firm staff members.

Despite the significant impact on contractor organisations' employees in Sri Lanka, there is a research gap in understanding this specific aspect, with limited attention given to their unique challenges compared to the broader impact of the pandemic on the country's economy. Therefore, the objective of this research is to investigate the impact of the economic crisis on employees of construction industry contractors' organisations. Additionally, the study will propose strategies to mitigate the negative effects on the most affected level of employees. The findings of this research will have significant implications for policymakers, employers, and employees in the construction industry, offering valuable insights into the economic and social ramifications of the 2019- 2022 economic crisis in Sri Lanka.

2. LITERATURE REVIEW

2.1 IMPACT OF THE ECONOMIC CRISIS ON THE CONSTRUCTION INDUSTRY OF SRI LANKA

The term "economic crisis" encompasses various situations where financial institutions or assets experience an unexpected and significant loss in value (Gaziet al., 2022). A crisis, as defined by Angelita and Saksono (2023), refers to an unforeseen event that poses a substantial threat to an organisation's core values, necessitating a swift response. Predicting financial crises is a challenging task due to the complexity of the factors involved (Berg & Catherine, 2000). The economic crisis in Sri Lanka has presented a significant obstacle to the nation's economy, with profound effects on the construction sector. The crisis has been characterised by a decline in economic growth, an increasing trade deficit, a reduction in foreign exchange reserves, and a substantial rise in public debt. These challenges have had far-reaching implications for various economic sectors, including the construction industry. The Annual Report 2019 of the Central Bank of Sri Lanka highlighted several economic challenges faced by the country during that year, such as a widening trade deficit, a decline in foreign exchange reserves, and a significant increase in public debt. Pathirana (2021) noted that the construction industry in Sri Lanka has experienced a decline in investment, a shortage of skilled labour, and a reduced demand for construction services. Moreover, they pointed out that the industry has encountered additional obstacles, including labour shortages, disruptions in the supply chain, and financial constraints. These challenges have resulted in a decrease in the number of construction projects and employment opportunities within the sector.

2.2 IMPACT OF THE ECONOMIC CRISIS ON EMPLOYEES OF CONTRACTORS' ORGANISATIONS

The Global Financial Crisis, as argued by Fratzscher (2012), significantly impacted the economy of the countries globally. This economic downturn had far-reaching consequences, including in the construction industry (Alshanbri et al., 2015), where employee turnover and knowledge retention were affected. According to Ramachandra (2006), the construction industry heavily relies on labour-intensive processes, making labour costs a significant component. In this context, the labour force in the construction industry refers specifically to the workforce involved in on-site construction activities.

However, the employment dynamics in construction have become increasingly temporary and insecure due to the practice of outsourcing labour through subcontractors (Wells and International Labour Organisation, 2001). In the overall European Union (EU), the number of employees in 2008 was estimated to be approximately 15 million, experiencing a 1% reduction compared to 2007. This decline worsened to 51% by 2009 due to the Global Economic Crisis (Central Bank of Sri Lanka, 2008)

Crises in the construction industry are inevitable due to human involvement, and they do not discriminate based on company size or specialisation. Both small and large companies, as well as specialised and general companies, can face potential demise at some point.

To further explore the impact of the economic crisis on employees of contractor organisations in the construction industry, it is essential to consider the specific level of employees within these organisations. Gunawardena and Jayawardena (2001) have proposed an occupational structure categorisation that can be applied in this research context. Their categorisation encompasses administration and managerial, professionals and technical, supervisory, and similar grades. For this research, these categories will be interpreted as shown in Table 1.

Table 1: Occupational structure categorisation of employees
(Source: Gunawardena and Jayawardena, 2001)

Level of Employment	Professions
L1 - Administration and Managerial - Top Management Level	Administrators Project Managers
L2 - Professionals - Middle Management Level	Engineers Architect Quantity Surveyors Accountants
L3 - Technical, Supervisory, and similar grades - Lower Management Level	Technical Officers Draftsman Site Supervisors

Zuo et al. (2015 conducted a study on the impact of the economic crisis on contractor organisations in Australian construction industry. They identified the impacts during the Global Financial Crisis in 2008 as listed below:

- Lay off employees,
- Reducing the number of graduate positions, and
- Freezing salaries/bonuses/overtime for employees.

These findings provide insights into the specific consequences faced by employees in the construction industry during economic crises. Understanding these impacts is crucial for formulating effective strategies to mitigate the negative effects on employees of contractor organisations. However, it is important to note that this literature review focuses on the broader context of the impact of economic crises on employees of contractor organisations, rather than specific studies related to the Sri Lankan construction industry.

2.3 STRATEGIES TO OVERCOME THE IMPACT OF THE ECONOMIC CRISIS ON EMPLOYEES OF CONTRACTOR ORGANISATIONS

Several strategies can be implemented to overcome the impact of the economic crisis on employees of contractor organisations in the construction industry. Firstly, providing financial support to businesses and employees can help alleviate the immediate financial burdens caused by the crisis. This can include government stimulus packages, tax relief measures, and loan assistance programs to help businesses retain their workforce and maintain operations. Secondly, promoting training and upskilling programs is essential to address labour shortages and skill gaps resulting from the crisis. Investing in employee development and providing opportunities for reskilling and retraining can enhance their employability and adaptability in a changing industry landscape (Sri Lanka: World Bank Open Data, n.d.-a). Training programs can focus on emerging technologies, sustainable practices, and project management to equip employees with the necessary skills to thrive in the post-crisis construction industry. Thirdly, implementing policies to promote investment and economic growth can stimulate the construction sector and create employment opportunities. Governments can incentivise infrastructure projects, provide subsidies for construction activities, and streamline regulatory processes to attract private investment in the sector (Sri Lanka: World Bank Open Data, n.d.-a). These measures can lead to increased project demand, which in turn generates employment and supports the recovery of contractor organisations.

3. RESEARCH METHODOLOGY

This research seeks to investigate the impact of the 2019-2022 economic crisis on employees of contractor organisations in the Sri Lankan construction industry and identify the most affected level of employees. To achieve this, a mixed research design approach will be employed. Initially, a literature review was conducted to explore the existing knowledge on the impact of economic crises on employees in the construction industry. This literature review serves as a foundation for the research study and provides insights into previous findings and gaps in the current understanding of the subject. Subsequently, a questionnaire survey was administered to 33 employees currently working in CS2, CS1, and C1 grade contractor organisations in Sri Lanka since the study only forces on the larger scale contractor organisations. These employees were actively involved in ongoing construction projects. To select the survey participants, a non-random convenient sampling method was employed, considering the accessibility and availability of individuals within the targeted organisations. In the second stage of data collection, seven managerial-level professionals were selected for interviews using a convenient sampling method currently working in CS2, CS1, and C1 grade contractor organisations in Sri Lanka. These professionals possess first-hand experience of the impact of the economic crisis on their respective organisations. The interviews were conducted to gather in-depth insights and perceptions regarding the specific effects of the crisis on employees. Phenomenology was chosen as the inquiry strategy for analysing the data collected from the interviews.

3.1 QUESTIONNAIRE SURVEY

The main objective of the questionnaire survey was to identify gaps in the interview guideline that had been developed through a literature review. It should be noted that the majority of the data found in the literature review pertained to developed countries. Thus, the survey aimed to assess the applicability of the literature review data to a developing country context such as Sri Lanka. By addressing this research objective, the survey aimed to bridge the gap between existing literature and the specific conditions in Sri Lanka's construction industry during the economic crisis. As the analysis method of this research "probability" was used as stated by Gelman et al. (2014). According to the authors, probability is a central concept in modern statistics, and it plays a crucial role in data analysis. Berzofsky, et al. (2018) stated that probability-based sampling methods, such as simple random sampling and stratified sampling, have long been recognised as effective techniques for ensuring representative data from questionnaire surveys. Furthermore, to their study, probability theory and statistical inference are essential tools in analysing questionnaire data, as they enable researchers to estimate population parameters and draw meaningful conclusions.

Table 2: Respondent's profiles for questionnaire survey

Profession	No. of participants	Type of Project Involved during the Crisis
Project Managers	4	Commercial Building/Residential Building/Road Project/ Water Supply Project
Engineers	8	Commercial Building/Residential Building/Road Project/ Water Supply Project

Profession	No. of participants	Type of Project Involved during the Crisis
Quantity Surveyors	9	Commercial Building/Residential Building/Road Project/ Water Supply Project
Draughtsman	2	Residential Building
HR Manager	3	Commercial Building/Residential Building/Road Project/ Water Supply Project
Site Supervisors	2	Commercial Building
Surveyors	2	Residential Building
Technical Officers	3	Residential Building

3.2 SEMI-STRUCTURED INTERVIEWS

Seven managerial-level professionals, as outlined in Table 3, who were actively involved in construction projects during the economic crisis, were selected for interview purposes.

Table 3: Respondent's profiles for semi-structured interviews

Interviewee	Designation	Type of Project Involved	Type of CIDA grading of the interviewee's organisation	Industry Experience
R1	Project Manager	Building	CS2	29
R2	Construction Manager	Building	CS2	27
R3	Project Manager	Road	CS1	26
R4	Senior Engineer	Building	CS2	19
R5	Deputy Project Manager	Building	CS1	25
R6	Engineer	Building	C1	10
R7	Senior Engineer	Building	CS2	17

These interviews aimed to gather diverse opinions and experiences related to the impact of the crisis on employees of contractor organisations. The data collected from these interviews were subjected to manual content analysis, following the methodology outlined by Georgescu (2020). Content analysis was chosen as it provides flexibility, objectivity, and rigor in analysing interview data. It is a versatile method applicable to both individual and group interviews, and it can be effectively employed in various research contexts and topics.

The objectives of the interviews were twofold: to validate and contextualise the existing literature findings within the specific conditions of the country under study and to identify the employee level most affected by the economic crisis. By involving professionals from the local construction industry in the interviews, the researchers aimed to gather practical insights and ensure the reliability of the research outcomes. The selected respondents, who held managerial positions, provided a comprehensive understanding of employment dynamics and offered a nuanced perspective on the consequences of the crisis. Additionally, the interviews sought expert opinions on strategies to mitigate the impact of the economic crisis on the most affected level of employees. These insights were valuable in formulating effective measures within contractor organisations. The profiles of the respondents can be found in Table 3.

4. RESEARCH FINDINGS AND ANALYSIS

4.1 FINDINGS OF THE QUESTIONNAIRE SURVEY

According to the questionnaire survey: (i) job losses, (ii) salary reductions, (iii) cutdown of welfare activities, (iv) reducing training and tertiary education, and (v) internal transfer to other projects, have been identified as the impacts of the economic crisis on the employees of the construction industry contractor's organisations in Sri Lanka.

4.1.1 Impact of Economic Crisis on Job Security, Financial Status/Salary, Livelihood and Professional Development

The findings revealed that the economic crisis had a significant impact on job security and financial status/salary, as identified by the majority of respondents as presented in Figure 1.

Figure 1: Impact of the economic crisis on job security, financial status/salary, livelihood and professional development

Job security emerged as a key concern, reflecting the uncertainties and challenges faced by employees in contractor organisations during the crisis. The economic downturn likely led to layoffs, reduced working hours, and increased job insecurity among the workforces. Furthermore, the financial status and salary of employees were also heavily affected, indicating the adverse economic consequences faced by individuals in the construction industry. These findings underscore the profound implications of the economic crisis on the livelihoods and well-being of employees within contractor organisations.

4.1.2 Impact of Economic Crisis on Employment

According to the literature review, some of the impacts of the economic crisis on employees of the construction industry have been identified. To validate whether they applied to Sri Lankan construction industry contractors' organisations, the respondents were asked to respond whether the impacts were identified by themselves, or they were affected by other employees of their organisations. The impacts were coded using the letter 'Q' as listed in Table 4.

Table 4: Validation of applicability of impacts

Impact Code	Impact	Probability	%
Q1	Employed with no effect on the salary	9	27%
Q2	Employed with basic salary + percentage of incentive	20	61%
Q3	Employed with a basic salary only	11	33%
Q4	Employed with no salary	4	12%
Q5	Became unemployed	9	27%

Impact Code	Impact	Probability	%
Q6	Cutdown of welfare activities	29	88%
Q7	Reducing training and tertiary education	30	91%
Q8	Internal transfers of staff to other projects	22	67%
Q9	Flexible working arrangements	18	55%

Based on the findings, it was observed that the majority of employees in contractor organisations were engaged under a compensation structure comprising a basic salary along with a percentage-based incentive scheme affected by the economic crisis. Moreover, the impact of the economic crisis was evident in various aspects, as highlighted by the respondents. These included the reduction or elimination of welfare activities provided to employees, a decrease in training and tertiary education opportunities, internal staff transfers to different projects, and the implementation of flexible working arrangements. For a detailed overview of the specific impacts reported by the respondents, please refer to Table 4.

4.1.3 Most Affected Level of Employees

In this section, the respondents were asked to identify the most affected level of employees by considering the impacts mentioned in Table 5 as per their personal experience and considering the other employee levels, which were mentioned in Section 2.2.

Table 5: Most affected level of employees as per questionnaire survey

Factor Code	Impact	L1	L2	L3	L1 & L2	L1 & L3	L2 & L3	All
Q1	Employed with no effect on the salary	21	0	1	4	0	0	3
Q2	Employed with basic salary + percentage of Incentive	2	7	1	11	0	5	6
Q3	Employed with a basic salary only	2	3	13	3	1	7	2
Q4	Employed with no salary	1	1	13	0	0	6	1
Q5	Became unemployed	2	1	19	0	0	4	3
Q6	Cutdown of welfare activities	2	3	1	2	0	2	21
Q7	Reducing training and tertiary education	1	4	1	2	0	1	21
Q8	Internal transfers of staff to other projects	1	4	2	4	0	3	17
Q9	Flexible working arrangements	5	3	1	2	0	1	18

The impacts resulting from the economic crisis were identified through a literature survey and questionnaire responses. The data revealed varying degrees of impact on employees at different levels within contractor organisations. Level 1 employees were the least affected, with their employment and salaries remaining largely unaffected. Level 2 employees also experienced a minimal impact, retaining their jobs and receiving basic salaries along with incentives. However, Level 3 employees faced a wider range of impacts, including reduced benefits, limited career advancement opportunities, unemployment, or no salary at all. Additionally, there was a reduction in welfare activities, such as training and internal transfers to other projects, across all employee levels. These findings highlight the distinct challenges faced by employees at different levels within contractor organisations during the economic crisis, emphasising the varying levels of vulnerability.

4.2 FINDINGS OF THE SEMI-STRUCTURED INTERVIEWS

4.2.1 Impact of Economic Crisis on Employment

The impact of the economic crisis on employee layoffs in contractor organisations varies based on project funding sources. Participant R1 reported minimal impact on their organisation, which was funded by a UAE client, with no job losses. However, measures were taken to reduce costs. In contrast, participant R2 stated a significant impact on their organisation, particularly in April of the current year, leading to construction work suspension and employee terminations to cut overhead costs. To cope with the crisis, organisations implemented measures such as salary deductions and freezing bonuses/overtime. R2 mentioned a 10% salary reduction in May, increasing to 20% due to non-payment for previous work. Similar deductions of approximately 20% to 40% were observed in other organisations. Welfare activities and benefits were also affected, with cancelled annual trips and discontinued allowances during the crisis period (R4, R7).

4.2.2 Most Affected Level of Employees by the Economic Crisis

In semi-structured interviews, all the identified impacts from the literature survey and questionnaire survey were combined and those were coded with the letter 'S' as mentioned in above Table 6.

Table 6: Most Affected Level of Employees as per semi-structured interviews

Factor Code	Impact	L1	L2	L3	L1 & L2	L1 & L3	L2 & L3	All
S1	Lay off employees	0%	0%	71%	0%	0%	29%	0%
S2	Reducing the number of graduates positions	14%	14%	0%	57%	0%	14%	0%
S3	Freezing salaries/bonuses/ overtime for employees	0%	0%	0%	0%	0%	0%	100%
S4	Cutdown of welfare activities	0%	0%	0%	0%	0%	0%	100%
S5	Reducing training and tertiary education	0%	0%	0%	43%	0%	0%	57%
S6	Internal transfers of staff to other projects	0%	0%	0%	0%	0%	71%	0%
S7	Flexible working arrangements	0%	0%	0%	57%	0%	43%	0%
S8	Engagement of employees in contract basis agreements	0%	0%	0%	0%	0%	71%	0%

According to the analysis, L3 employees were affected by the layoff from their employment during the economic crisis (Refer to Table 6). R2 stated that *"the lower-level employees are much affected by the crisis because, in most of the construction contract, they were employed as contract basis staff. When the construction work stopped automatically, they became unemployed"*. Further, R3 emphasised that *"in our company the lower-level employees such as site supervisors, they get paid for the number of days that they work at the site. When the construction at the site gets stopped, they automatically lose their jobs"*. R6 added that *"the lower-level employees have fewer options in the industry"*. According to the analysis of the interviews, most of the respondents have mentioned that the reduction of graduate positions has affected the upper (L1) and middle (L2) management levels. R1 stated that *"normally graduate employees are employed in the upper levels of a company, and they are well paid because of their educational qualifications"*. Further, as per the above summary, all the levels of employees have experienced freezing of salaries, bonuses, and overtime payments, Cutdown of welfare activities.

The findings of the semi-structured interviews validated the impacts that were identified through the literature survey and questionnaire survey were practical and applicable within the Sri Lankan context by achieving its objective.

4.3 STRATEGIES TAKEN TO MINIMISE THE IMPACT ON THE MOST AFFECTED LEVEL OF EMPLOYEES

After the economic crisis, R2 warns of a potential skill shortage as employees seek career changes. To mitigate this, R2 emphasises the importance of formal engagement, while R5 stresses the need to update employees on future work opportunities and secured projects. Further, R2 suggests that appointing individuals to handle multiple tasks reduces the need for extensive training. This approach minimises job losses during economic crises, as one person can seamlessly transition between tasks, ensuring job security even if one task is lost. R6 transferred employees to other organisations and recommended their placement after trying to retain them by paying salaries for three months. They searched for work opportunities elsewhere, with some employees accepting jobs that paid less but ensured they remained employed. Involvement in foreign-funded projects helps minimise the impact of the economic crisis, according to R1. Focusing on such projects enables local contractors to avoid payment delays and draw foreign currency into the country, aiding in economic recovery. R3 also suggested encouraging skilled employees to migrate to Middle Eastern countries for alternative employment opportunities.

5. CONCLUSIONS AND RECOMMENDATIONS

The research aimed to address three objectives related to the impact of economic crises on the construction industry employees and strategies to overcome these challenges. The literature review revealed that the construction industry is vulnerable to economic crises and highlighted the significant impacts on employees, such as job loss, salary reduction, decreased welfare activities, and limited training and education opportunities. The second objective involved identifying the most affected level of employees, which was determined to be the lower management level (L3). These individuals had limited options in the job market and often worked on a contract basis. The final objective was to identify strategies to mitigate the impact on the most affected employees. The study validated existing strategies, including formal employee engagement, and employing experienced individuals, while also identifying new strategies like finding work opportunities in other organisations and focusing on foreign clients. The recommendations centred on implementing these strategies to minimise the impact of economic crises on construction industry employees.

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IMPACT OF ECONOMIC DECISIONS ON BUILDING CONSTRUCTION MATERIAL PRICES IN SRI LANKA

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ABSTRACT

The economic crisis had a substantial impact on the Sri Lankan construction sector. The economic crisis was characterised by several economic problems, including currency devaluation, high inflation, and rising debt levels. Building construction materials prices have also increased drastically during the economic downturn period. These increases in the price of building materials were attributed to several economic factors including inflation rate increases, local currency devaluation and changes in government decisions and regulations, to name a few. Hence, the main aim of this research is to assess the impact of economic decisions on building construction material prices in Sri Lanka during the last 10 years. The mixed research approach was followed to achieve the aim of the study. A comprehensive literature review followed by a market survey to find building materials price data and fifteen semi-structured interviews were carried out with construction industry professionals during the empirical investigation. The collected data was analysed through materials price data analysis and code-based content analysis using NVivo. The findings revealed inflation rate, interest rate, and foreign exchange rate as the key macroeconomic factors that influence the price determination of building materials, while other economic factors and decisions also affect the building material prices in Sri Lanka. Further, this study proposed possible strategies and mitigation measures to minimise the impacts. Construction industry stakeholders can use the research findings to implement the appropriate strategies to minimise the building material price escalation impacts.

Keywords: *Building Construction Materials; Construction Industry; Economic Crisis; Price Fluctuations.*

1. INTRODUCTION

The construction sector is one of the most responsible sectors for the environmental transformation and physical development of a country (Elkhider & Salma, 2020). The built environment includes infrastructure works, building works, and other heavy engineering projects (Huang et al., 2018). Construction is one of the fastest developing sectors, which creates significant impacts on economic growth at the global level, influences on construction materials exchange, creates job markets, and also builds

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necessary infrastructure facilities for social and economic development (Sarmiento-Rojas et al., 2020). Normally, the construction sector runs together with a significant quantity of construction materials and energy utilisation (Huang et al., 2018). Materials are used extensively in building constructions (Oghenekevwe et al., 2014). Hence, building construction materials are identified as a key component of construction works, since they comprise a large portion of construction project costs and significantly impact the construction industry's growth and quality of output (Babalola et al., 2021).

Construction projects are impacted by the price fluctuation of the construction materials (Oghenekevwe et al., 2014). Increasing the price of building construction materials is a common issue at the global level and developed nations are also affected in recent years, where several developed nations have been highly confronted with the issue of rising building construction material prices (Danso & Obeng-Ahenkora, 2018). Similar to other countries globally, in Sri Lanka, the construction sector is one of the main contributors to the Gross Domestic Product (GDP) of the national economy (Central Bank of Sri Lanka [CBSL], 2021). However, the construction sector is in danger of collapsing under the ongoing economic crisis (Lanka News Wed [LNW], 2022). There are several research conducted on the construction materials price fluctuations at the global level. However, there is a lack of study on building materials price fluctuations due to economic factors specifically for the Sri Lankan construction industry during the current economic crisis. Therefore, there is a need to assess the impact of economic decisions and factors on building construction materials price fluctuations and propose strategies to minimise the impacts of building materials price fluctuations to stabilise the Sri Lankan construction industry. Hence, this paper presents the research findings on the impact of economic decisions on building construction material prices in Sri Lanka during the last 10 years and strategies to minimise those impacts. This paper starts with an introduction followed by a literature review and Section 3 presents the research methodology. The research findings and discussion are presented in Section 4 followed by conclusions and recommendations.

2. LITERATURE REVIEW

This section reviews the literature review on the building materials prices fluctuations, and relationship between economic decisions and factors and building materials prices.

2.1 IMPORTANCE OF BUILDING MATERIALS TO THE CONSTRUCTION INDUSTRY

Building materials simply defined as any materials utilised in building construction projects (Babalola et al., 2021). In the past times, most building construction materials were obtained naturally such as clay, brick, lime, wood, stone, and straws (Taylor, 2013). In the twentieth century, awareness, innovative and advanced technologies introduced better performance, more effective, and durable building materials to the construction industry around the world such as steel, reinforced concrete, metal, and plastic products, to name a few (Taylor, 2013).

Building construction materials are considered crucial inputs in the construction process and these building material costs symbolise the largest portion of the whole building cost (Oginni et al., 2014). Building construction materials have a significant part in today's technologically advanced and innovative construction environment and no engineering areas cannot have the potential to manage activities without their utilisation (Duggal, 2017). The building materials industry is a significant contributor to a country's national economy because its outputs decide both construction work's quality and quantity (Babalola et al., 2021). It is impossible to overemphasise the significance of building materials, when building materials are assembled together, they create various purpose of building structures (Babalola et al., 2021).

2.2 BUILDING CONSTRUCTION MATERIALS PRICE FLUCTUATIONS

The construction project cost depends on various factors, direct costs like cost of materials, labour costs, machinery and equipment cost, and indirect costs like construction site mobilisation costs (Isikdag et al., 2022). Furthermore, authors stated that the construction material cost is the major direct cost, and it is influenced by other various cost elements such as the cost of raw materials, cost of production, transportation, and logistical expenses. Building materials price fluctuation is a common issue in both developing and developed countries and this building material price increases lead to high construction costs (Danso & Obeng-Ahenkora, 2018).

Stakeholders involved in the construction sector, particularly, contractors face lots of challenges when the building materials price fluctuation time (Isikdag et al., 2022). It is hard to predict the construction materials prices, these cause uncertainties when making decisions during the procurement procedures because of these price fluctuations (Isikdag et al., 2022). Building materials price fluctuations make significant negative impacts on construction projects' success and these unpredicted price fluctuations affect construction project completion costs and also impact the potential for project completion (Marzouk & Amin, 2013).

2.3 ECONOMIC FACTORS INFLUENCE THE PRICE FLUCTUATIONS OF BUILDING MATERIALS

According to the several literature findings, inflation rate, interest rate, foreign exchange rate, demand and supply of materials, importation, import duties, government economic policies, energy cost, crude oil prices and transportation cost are the economic related factors that influence the price of building construction materials (Babalola et al., 2021; Kamaruddeen et al., 2020; Oladipo & Oni, 2012; Omede & Saidu, 2020). Oladipo and Oni (2012) revealed in their study that there is a strong correlation between macroeconomic variables such as inflation rate, interest rate, and foreign exchange rate, and building construction materials prices.

The changes in government economic decisions, local taxes, and charges greatly influence in an unforeseen way in building materials production and price determination (Danso & Obeng-Ahenkora, 2018). Further to the authors, building materials buyers may incur an additional cost because of the taxes and charges imposed by the government on building materials suppliers. According to Obeng-Ahenkora and Danso (2018), the prices of building construction materials are directly influenced by the government's economic decisions and fiscal policies. Further, especially in developing nations, the government's poor economic conditions also impact the construction sector due to building materials price fluctuations (Sweis et al., 2008). According to Fernando et al. (2017), construction materials price fluctuations were identified as the significant financial risk factor impacting the construction projects in Sri Lanka. The construction industry has collapsed due to skyrocketing of building materials prices, especially steel, cement, and other raw materials in Sri Lanka. Even though Gunathilake (2022) identified main causes behind these recent materials price increases in Sri Lanka, thorough investigation needed to identify the Economic factors influence the price fluctuations of building materials.

3. RESEARCH METHODOLOGY

A comprehensive literature survey was carried out to understand the theory-based information from the research area. The relationship between the economic factors and decision and the building materials prices in the global context are discussed from a wider perspective to elaborate the research problem and hence the main aim of this research is established to assess the impact of economic decisions on building construction material prices in Sri Lanka during the last 10 years. Therefore, in order to achieve the aim, and the objectives building materials price data analysis and in-depth expert opinions to identify and understand the impact in a descriptive manner are required. Thus, this research was employed through the mixed research approach. A market survey with suppliers, manufacturers and contractors was conducted to find the building materials prices and materials price data was analysed to understand the price trends during last 10 years. Subsequently, semi-structured interviews were conducted with 15 experts who are practising in the Sri Lankan construction sector. The experts were selected through purposive sampling. NVivo software was used for qualitative data analysis using code-based content analysis.

4. RESEARCH FINDINGS

The semi-structured interviews were conducted with 15 industry professionals who are well qualified and currently practising in the Sri Lankan construction sector, engaging in project management, procurement management, quantity surveying, and civil engineering in Sri Lanka. The profile of each respondent is summarised in Table 1.

Table 1: Details of interviewees of expert interview

Code	Designation	Experience
R1	Director/Chartered Quantity Surveyor/Cost and Claims Specialist	40 Years
R2	Freelancer/Manager- Contracts	35 Years
R3	Director/Charted Quantity Surveyor	20 Years
R4	Executive Director- Contracts	18 Years
R5	Contract Administrator	25 Years
R6	Commercial Manager/Contract Administrator	15 Years
R7	General manager- Estimates and Contracts	17 Years
R8	Manager- Project Monitoring and Controlling	15 Years
R9	Manager- Contracts and Procurement	14 Years
R10	Section Head- Central Tendering Unit	17 Years
R11	Construction Project Manager/Senior Operation Engineer	14 Years
R12	Construction Project Manager/Chartered Engineer	15 Years
R13	Senior Quantity Surveyor	15 Years
R14	Senior Quantity Surveyor	14 Years
R15	Chartered Civil Engineer	12 Years

Interviewees were selected to address various aspects of their expertise relating to the research area. The respondents' experience ranges from 12 to 40 years. All the respondents stated that their organisation and their current building construction projects were severely affected by the economic downfall. Respondents further discussed that, especially drastic building materials price escalations has significantly impacted the operations and performance of the construction projects. The key research findings are discussed below.

4.1 BUILDING CONSTRUCTION MATERIALS PRICE TRENDS DURING THE LAST 10 YEARS IN SRI LANKA

A comprehensive market survey was carried out to collect data on building construction materials prices during last 10 years. Number of materials were limited to 15 materials based on the opinions of the suppliers, manufacturers, and contractors. Figure 1 shows the major building construction materials' price fluctuations during the last 10 years in Sri Lanka.

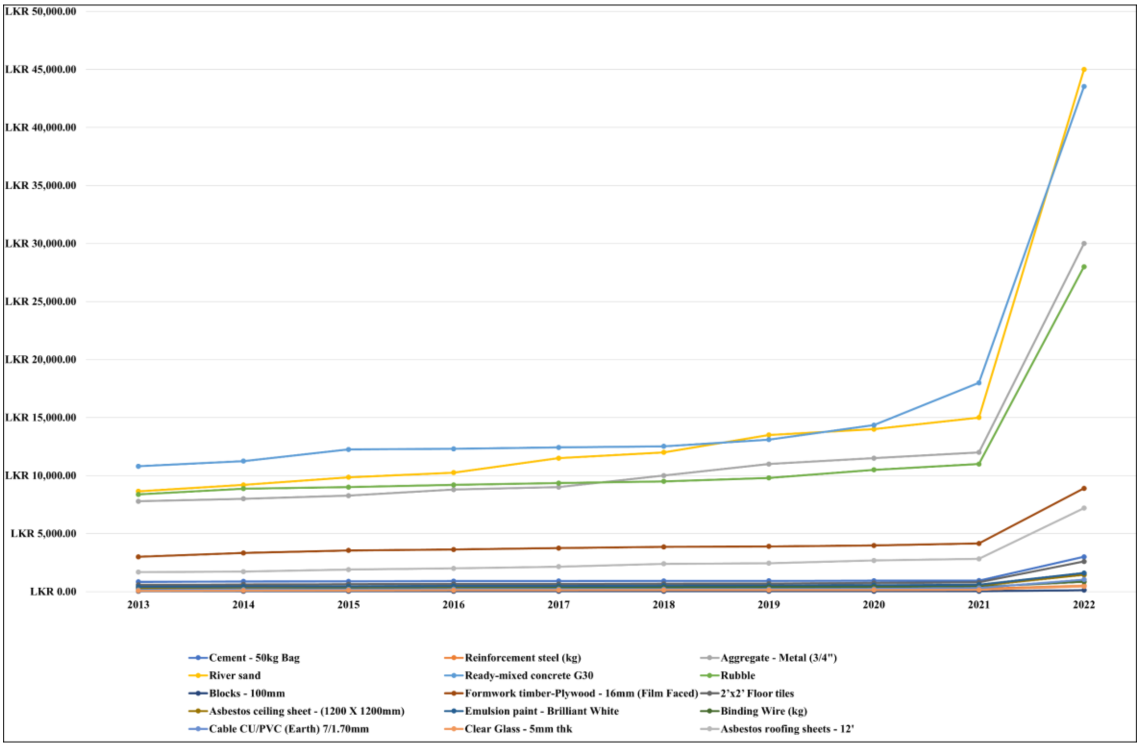

Figure 1: Building construction materials price trends during the last 10 years in Sri Lanka

The graph emphasises the upward trend of building construction materials prices in Sri Lanka over the past decade. According to the graph, building materials prices increased from 2013 to 2021, which was moderate increment, and it was reasonable and acceptable, which was in line with the annual inflation rate. However, there was a drastic increment in the price of building materials in 2022 due to the consequences of the economic crisis and post-COVID-19 pandemic impacts.

Overall, the graph clearly depicts a sharp rise in building construction materials prices in Sri Lanka in 2022, where the prices increased two to three times. For instance, the graph reveals that the reinforcement steel and aggregate average prices increased by 104% and 150%, respectively in 2022 compared to the price of the same building materials in 2021, which was double time increased, while the cement prices increased by 215.8%, which was triple time increased. The escalated percentages of individual building materials apparently indicated that the price of building materials drastically increased in 2022. Sri Lankan construction industry experienced substantial negative effects because of these extreme price rises for building construction materials.

4.2 ECONOMIC DECISIONS AND FACTORS THAT DETERMINE THE BUILDING CONSTRUCTION MATERIALS PRICES

During the semi-structured interviews, the experts were requested to identify the key economic factors that determine the building construction material prices in Sri Lanka. Figure 2 summarises the research findings.

Nodes

Name	Sources	References
Economic factors determine the price of building construction materials prices	15	144
Inflation rate	15	24
Interest rate	15	27
Foreign exchange rate	15	20
Demand for materials	15	16
Supply of materials	15	21
Importation policies and controls	15	18
Import duties	15	16
Government price controls	15	17
Energy cost	15	21
Crude oil prices	15	17
Transportation cost	15	17
BOI concessions	12	17

Figure 2: Economic factors determine the building construction materials prices

All the respondents stated that the inflation rate increase have a significant impact on the prices of building materials in Sri Lanka, as it can affect the cost of raw materials, production costs, transportation, and taxes. R4 and R14 highlighted that inflation has a direct impact and it increases the building materials prices. In Sri Lanka, inflation rate during the last 10 years tends to increase. *"Building materials prices increased slowly every year. After 2022, there was a drastic increase in the inflation rate, that mention as a hyperinflationary situation. Building materials prices suddenly increased double and triple times in Sri Lanka"*, according to R14.

Highlighting the impact of interest rate - R4 mentioned that *"if the interest rate increases, cost of production also increased because borrowing cost is higher when the interest rates are higher, so the suppliers, subcontractors, manufacturers have to revise their pricing to accommodate the higher interest charges. so that the building material price will automatically go up"*. R2 and R6 stated that interest rates can affect the cost of borrowing money for construction projects. When interest rates are high, it can make it more expensive for builders to purchase building materials, as they will have to pay more in interest on their loans.

Most of the raw materials and the building materials are imported from foreign countries. R5 emphasised that when the exchange rate is favourable, it can make imported materials cheaper for domestic buyers, while a weaker exchange rate can make imported materials more expensive while a weaker exchange rate can make local production cheaper, as the cost of production inputs is in the local currency, leading to a decrease in the prices of locally manufactured materials. R6 stated there was a moderated increment in the USD exchange rate in past years but in 2022, the foreign exchange rate drastically increased and led to significant increases in building materials prices.

R11 argued import policies and controls can also affect the price and the availability of materials. R4 highlighted that *"recently the government has restricted the importation of some building materials, which created a materials scarcity in the market, so to cater to the demand suppliers increased the prices. The opportunity for the suppliers because of this material scarcity. Hence again the building materials prices went up".*

Moreover, R1 emphasised that "*import duties are taxes imposed by the government on imported building materials, and they can make imported materials more expensive if the Sri Lankan government imposes high import duties on building construction materials. After adding the high taxes, the prices of the materials will automatically go up*". R1, R6, and R14 highlighted that the Export Development Board (EDB) levy, also referred to as a "CESS" range from 10% to 35% advert valorem on a range of imports identified as "necessary" or as competing with local industries. Further, most of the imported building materials are also subjected to the Ports and Airports Development Levy (PAL). PAL was revised by the government in December 2019, imposing tariffs ranging from 5% to 10% on various product categories and the PAL was removed for some materials by the 2018 government. Furthermore, the Sri Lankan government levies a value-added tax (VAT) on most imports ranging from 8% to 15%. Moreover, R1 and R14 mentioned that the government has imposed another Social Security Contribution Levy (SSCL) at the rate of 2.5% from 2022 October. Hence, all above economic factors have imposed a significant impact on the building construction material prices in Sri Lanka.

4.3 IMPACTS AND CHALLENGES FACED BY THE BUILDING MATERIAL INDUSTRY DUE TO THE ECONOMIC DOWNTURN

According to the respondence, the building material industry like other industries has been impacted and faced various challenges by the economic crisis in Sri Lanka. Figure 3 illustrates the impacts and challenges faced by the building materials industry due to the current economic crisis.

Nodes

Name	Sources	References
Impact of the economic crisis on the building construction materials industry	15	104
Drastic increases in building materials prices	15	15
Building materials scacity	15	15
Difficulty in obtaining credit - Issues in opening Letter of credit (LC)	15	15
Import restrictions	13	13
Difficulty in obtaining foreign exchange	12	12
Supply chain disruptions	11	11
Building materials production has been affected	10	10
Demand for building materials has reduced drastically	8	8
Tax hikes and the introduction of new taxes	8	8

Figure 3: Impacts and challenges faced by the building materials industry

The economic downturn had a substantial impact on the building material industry, resulting in several challenges. One of the significant challenges was the increase in the price of building materials. The increase in prices was due to a combination of factors, such as inflation rate increases, local currency devaluation, and changes in government decisions and regulations. Further, the downturn period led to a reduction in demand for building materials due to a decline in construction activities, which adversely affected the industry.

4.4 IMPACTS OF BUILDING CONSTRUCTION MATERIALS PRICE FLUCTUATIONS ON THE SRI LANKAN CONSTRUCTION SECTOR

All respondents stated that the economic crisis, specially, the drastic building materials price escalation heavily impacted all construction organisations and the projects. Figure 4 presents the impacts of building construction materials price escalations.

Nodes

Name	Sources	References
Impacts of building construction materials price escalations	15	138
Construction cost increases	15	20
Building product's final cost increases	15	15
The volume of construction products reduces	15	16
Client expectations for quality project delivery reduce	15	18
Increases in building construction project suspensions, terminations, and abandonment	15	19
Unemployment of construction workers and staff	15	20
Disputes between parties involved in the construction	15	16
Contractors face financial and cash flow difficulties	15	18
Causing budgeting and forecasting problems for builders	13	15
Causes delays in project completion	13	18
Affect the contractor's project planning and the master programme schedules	12	14
Affect the contractors' profit margins	10	11
Poor quality of the construction works	7	13
Failures in building construction due to less-quality materials	7	7
Contractors' fraudulent practices increase	6	9
Increased cost Claims due to building materials Price fluctuation and exchange rate fluctuation	5	5
Reduction in construction demand and amount of work	5	6
Time pressures for contractors in material procurement	4	4
Slow progress and concurrent delays	4	4
The client may reduce the scope of the works - omissions	3	3
Increase in contractors-to-project ratio	3	3
Increase in the bidding competition	3	4
Affect the growth and investments in the construction sector	3	3
Make difficult to offer affordable housing options	2	2
Impact on future construction projects	2	3
Contract frustrations for contractors	2	3
Construction firms feel stressed to obtain projects	2	2
Aggressive assumptions made for bidding	2	2
Construction firms become insolvent	2	2
Poorly motivated employees and reduction in overall performance	1	1

Figure 4: Impacts of building construction materials price escalations

Time and cost were obviously impacted, and additional costs and time were incurred due to the delay and other consequences in the construction projects. Most of the respondents stated that they have experienced the different types of impacts and consequences while drastic building materials price escalation in Sri Lanka. R1 highlighted that these impacts due to the building materials price escalation have serial impacts and R5 highlighted *"the impacts of increasing building construction materials prices have multiple chain effects, which means that the effects are interrelated and can have a ripple effect throughout the construction sector and the economy of the country"*.

Most of the respondents stated that it is obvious when the building materials price escalates, the overall construction cost will go up and if it decreases naturally construction cost will be less. Price escalations in building construction materials may have a direct impact on the construction project costs, as builders have to pay more for materials purchases if the price rises, which can lead to cost overruns in construction projects. R2, R4, R5, and R7 highlighted that building contractors are experiencing lots of consequences and they struggle to manage their ongoing projects due to the drastic construction cost increases in projects after 2022.

R6 explained, when the cost of building materials increases, there is a risk of degradation in client expectations for quality project delivery. The clients may expect a specific level of performance and quality from a construction project, but if the price of building materials rises, it may be necessary to use less expensive or second standard materials to stay within the available budget. This may result in performance and quality compromises, as well as decreased client satisfaction.

Most of the respondents stated that impacts of poor quality of the construction works, failures in building construction due to less-quality materials, and contractors' fraudulent practices are joined with the quality of building materials and products. Respondents, who are representing large scale contracting organisation did not agree with these quality-related impacts due to the building materials price escalations. They highlighted that while the building construction materials prices are high, low, or not affordable, they cannot compromise the quality of the construction works. Contractually construction works need to be done in accordance with the drawings, specifications, and other standards. The Engineer and the Client will not approve the usage of inferior or low-quality building materials. R7 highlighted *"when we consider our project's quality of the works, we are at a manageable level. we don't have such kind of building failure issues due to less quality of materials during the last 10 years"*.

R1 and R2 further argued that the poor quality of the construction works, building construction failures due to less quality materials and contractors' fraudulent practices affect the building construction projects in non-contractual constructions and small-scale constructions such as residential buildings. Contractors may use inferior quality materials or low-quality materials when the building materials prices increase to maintain their profit margins. However contractually, it may not be possible to reduce or compromise the quality of the construction works in any circumstances.

The overall construction project cost may significantly increase because of rising building materials prices, which may cause projects to be delayed, suspended, terminated, and abandoned completely. Therefore, there can be a decrease in demand for construction workers, which might lead to layoffs and unemployment. R4 and R7 argued that construction workers may face unemployment when cost of materials rise and decline in the number of construction projects.

Contractor representatives stated that most of the contractors faced severe cash flow and financial difficulties due to the high inflation period in Sri Lanka. Building materials prices increased drastically, and contractors had to procure materials at higher costs than budgeted. Contractors had to pay for materials upfront while waiting for payment from clients, leading to payment delays and impacting their project's cash flow.

4.5 STRATEGIES TO MINIMISE THE IMPACTS OF BUILDING MATERIALS PRICE ESCALATIONS

Respondents highlighted that there are no effective strategies to minimise the impacts of these challenges because the hyperinflationary building materials price escalation is new to the Sri Lankan construction industry. Figure 5 suggests possible strategies that could be used to minimise the impacts of price escalations on building construction materials.

Nodes

Name	Sources	References
Strategies to minimize the impacts of building materials price escalations	15	112
Applications of value engineering principles	15	23
Implementing efficient material management practices	15	17
Providing detailed error-free designs and comprehensive specifications	13	14
Proper planning of contractor's financial resources	13	15
Increasing the usage of local building materials	13	15
Implementing integrated project delivery methods	13	14
Encourage local production	12	14
Effective human resource management at the site	11	12
Develop an information management system for building materials	11	13
Implementation of lean construction principles to reduce building materials wastage	11	11
Bulk purchasing	10	10
On-time payments of funds	9	12
Early procurement practices	9	13
Understanding project requirements and needs	8	10
Government need to take action	8	8
Reducing site wastes	7	7
Stockpile building materials when prices are low	7	7
Accelerate design time and timely documentation	6	11
Estimate the new projects accordingly to the trends of inflation and other factors	6	6
Maintenance of control and effective administrative system	5	5
Minimising variation	5	5
Change the procurement mechanism	5	11
Applying early corrective action	4	5
Maintain good relationships with stakeholders	4	6
Having appropriate planning and management	4	5
Effective contractor and workers relationship	4	4
Effective communication with workers and stakeholders	4	4
Establish long-term agreements with manufacturers and suppliers	4	5
Maintain a central procurement system or central store system	4	4
Diversifying suppliers and materials	3	3
Go with the flexible specifications	2	2
Maintain Building materials standards	1	1

Figure 5: Strategies to minimise the impacts of building materials price escalations

According to R6, suitable strategies and mitigation measures for building material price fluctuations will depend on the availability and accessibility of resources, the impact of the price increases, and the needs of the organisation. A combination of strategies may be necessary to minimise the effects of building materials price escalations and stabilise the Sri Lankan construction sector.

This drastic building material price increment is a huge risk to construction projects. Hence, risk sharing, and risk transfer are also suitable mitigation measures for the current situation. The alternative method to handle this sort of unforeseen price escalation risk is to change the procurement mechanism. According to the respondent's statements, some suggestions for modifying the procurement mechanism in the construction contracts are given below:

- Adopt the correct alternative procurement method according to the project requirements and needs,
- Discuss between the parties and arrange different agreements that might be suitable for the current circumstances,
- Agree on USD rate for supplier's and subcontractor's works,
- Revise the BOQ to share the risk of the price fluctuations between parties in post contract stage /Re-tendering,
- Use partnering methods such as joint venture collaborations and public-private partnerships, and
- Use integrated project delivery methods.

5. CONCLUSIONS AND RECOMMENDATIONS

The research emphasises the significant role that economic decisions and factors play in the price of building construction materials in Sri Lanka, the impacts of building materials price fluctuations on the performance of the construction projects and firms and possible strategies to minimise the price escalation impacts. The comprehensive literature review, market survey and semi-structured interviews with experts in the construction sector were assisted to achieve the aim of the research. The research findings indicate that building construction materials prices have significantly impacted the Sri Lankan construction industry due to the current economic crisis. The drastic increase in building materials prices has resulted in cost overruns, delayed project delivery, quality related issues, cash flow issues for contractors to name a few. In addition, the quality of construction works can be compromised in non-contractual contracts due to the use of inferior materials to maintain profit margins during price fluctuations. Based on the research findings, it is recommended that stakeholders in the construction industry should take necessary measures to mitigate the impact of building materials price fluctuations. These measures may include risk sharing and risk transfer mechanisms in contracts, changing the procurement mechanism, and implementing suitable strategies to stabilise the construction sector. Further, encouraging the use of local building materials to reduce the impact of foreign exchange rate fluctuations and reducing the import taxes and other duties on construction materials to make them more affordable. It is also recommended to revise and update the CIDA price fluctuation formula to cover all building materials and incorporate provisions to address high inflationary situations. The Sri Lankan construction industry can be stabilised, and sustainable growth can be achieved by taking these measures.

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INCLUSION OF MARGINALISED COMMUNITIES DURING POST-DISASTER CONTEXT IN SRI LANKA: WHAT METHODOLOGY?

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ABSTRACT

Research methodology is a general research strategy that defines how research should be carried out. It includes a system of beliefs and philosophical assumptions that shape the understanding of the research questions and underpins the choice of research methods. Additionally, research methodology is an integral part of any research and helps to ensure consistency between chosen tools, techniques, and underlying philosophy. Therefore, this article shows the perspectives to choose the most effective methodology to increase the inclusion of marginalised communities during the post-disaster phase in Sri Lanka. A systematic literature review comprising of 61 articles adopted as the best-suited methodology for this research. The philosophical position of this research is interpretivism, whereas the abductive approach is utilised for theory development. Hence, more than one qualitative data collection method is used, and this research adopts a multi-method qualitative approach. Furthermore, case study and survey strategies are chosen as the most suitable strategies for this research. Two Grama Niladhari divisions affected by natural disasters in Sri Lanka are selected as the cases. Data collection techniques adopted in this research are literature review, structured interviews, desk study, stakeholder interviews, key informant interviews, focus group discussions, and expert validation interviews. Data analysis techniques are literature synthesis, relative importance index, stakeholder analysis, and code-based content analysis. Furthermore, the article discusses how researchers achieve the reliability and validity of research findings and ethical considerations.

Keywords: *Inclusivity; Marginalised Communities; Methodology; Post-disaster Phases.*

1. INTRODUCTION

It is increasingly recognised that disasters have disproportionate consequences for affected populations and that the most marginalised tend to impact disasters significantly (Sharma, 2014). Marginalisation is usually characterised by a lack of opportunity and the right of individuals and communities to use choices available to others, often due to

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economic inequality, social exclusion and lack of control over political processes. In each mainstream community, certain categories of persons are identified as vulnerable. It was argued that most of these people were not necessarily marginalised, even though women, older people, persons with disabilities and children were often marginalised because of widespread prejudice and vulnerability. In the face of natural disasters, these communities are often affected by multi-layered marginalisation and are less resilient to risk aversion in the global and local contexts. Inclusivity promotes equity and rights in post-disaster management strategies, making everybody less vulnerable (Mendis et al., 2022, 2023). Therefore, marginalised communities should be explicitly considered in preparing policies for post-disaster management (Kammerbauer & Wamsler, 2017). Without consideration, these groups will often expand higher rates of deaths, injuries, and economic losses and take longer to recover. Using data, communication, strategy, policy-based review and comprehensive decisions, marginalised communities can assist in disasters (Mendis et al., 2022). Furthermore, while focussing on what limits people's ability to reduce their risk, the policymakers' objectives for reducing disaster risk should be to emphasise understanding people's capacity to resist and recover from disasters, as well as to improve the overall resilience of people, society and systems (Maurya, 2019).

However, while the international community has adopted the ideals of resilience and inclusion, marginalised communities are usually overlooked in post-disaster management (Sharma, 2014). According to Wickramasinghe (2014), the breadth of the current community protection system is very limited, and the existing system needs to adapt more adequately to the real needs of marginalised communities in the post-disaster context in Sri Lanka. There is a dearth of literature on the participation of marginalised communities during the post-disaster phase in Sri Lanka. Furthermore, policies to support marginalised communities need to be reviewed to explore how such policies are implemented to benefit disadvantaged groups in a post-disaster situation. Thus, this research aims to enhance the inclusion of marginalised communities during the post-disaster phase in Sri Lanka. The objectives of the research are:

01. To critically review the challenges marginalised communities face in the post-disaster context.
02. To develop a stakeholder mapping to understand stakeholder engagement with marginalised communities to improve inclusivity during the post-disaster context in Sri Lanka.
03. To investigate policies related to marginalised communities in terms of their level of significance to improve inclusivity during the post-disaster phase in Sri Lanka.
04. To determine barriers to policy implementation regarding the inclusion of marginalised communities during the post-disaster phase in Sri Lanka.
05. To propose strategies to improve the inclusion of marginalised communities during the post-disaster phase in Sri Lanka.

An appropriate research methodology is critical to attaining these objectives while providing the most out of the research. Therefore, this paper aims to design the research methodology to enhance the inclusion of marginalised communities during the post-disaster phase in Sri Lanka. The continued exploration and application of this methodology will contribute to the ongoing and future efforts to promote the rights and well-being of marginalised communities.

2. RESEARCH METHODOLOGY

Research methodology is a general research strategy defining how research should be carried out (Kumar, 2011). It includes a system of beliefs and philosophical assumptions that shape the understanding of research questions and underpins research methods (Melnikovas, 2018). Initially, the authors referred to 61 research articles (consisting of empirical findings) obtained through a systematic review of the literature within the scope of the study (Mendis et al., 2023) to identify different methodologies, data collection, and analysis tools to adopt the best-suited methodology for this research. Accordingly, the following section discusses the methodological design employed to achieve the aim of this research with proper justifications.

2.1 Research Design

Researchers have developed different forms of methodological models that can be adapted to establish the research procedure for a particular research following a systematic investigation. The two most prominent research design models are the nested model developed by Kagioglou et al. (2000) and the research onion model developed by Saunders et al. (2019). Social science researchers widely use the research onion model to develop the theoretical framework. The research onion provides an effective progression through which a research methodology can be designed (Bryman, 2008). As a result, the Saunders research onion model is followed to design the methodology. Figure 1 depicts a graphical representation of the research process followed throughout the research adhering to Saunders research onion model.

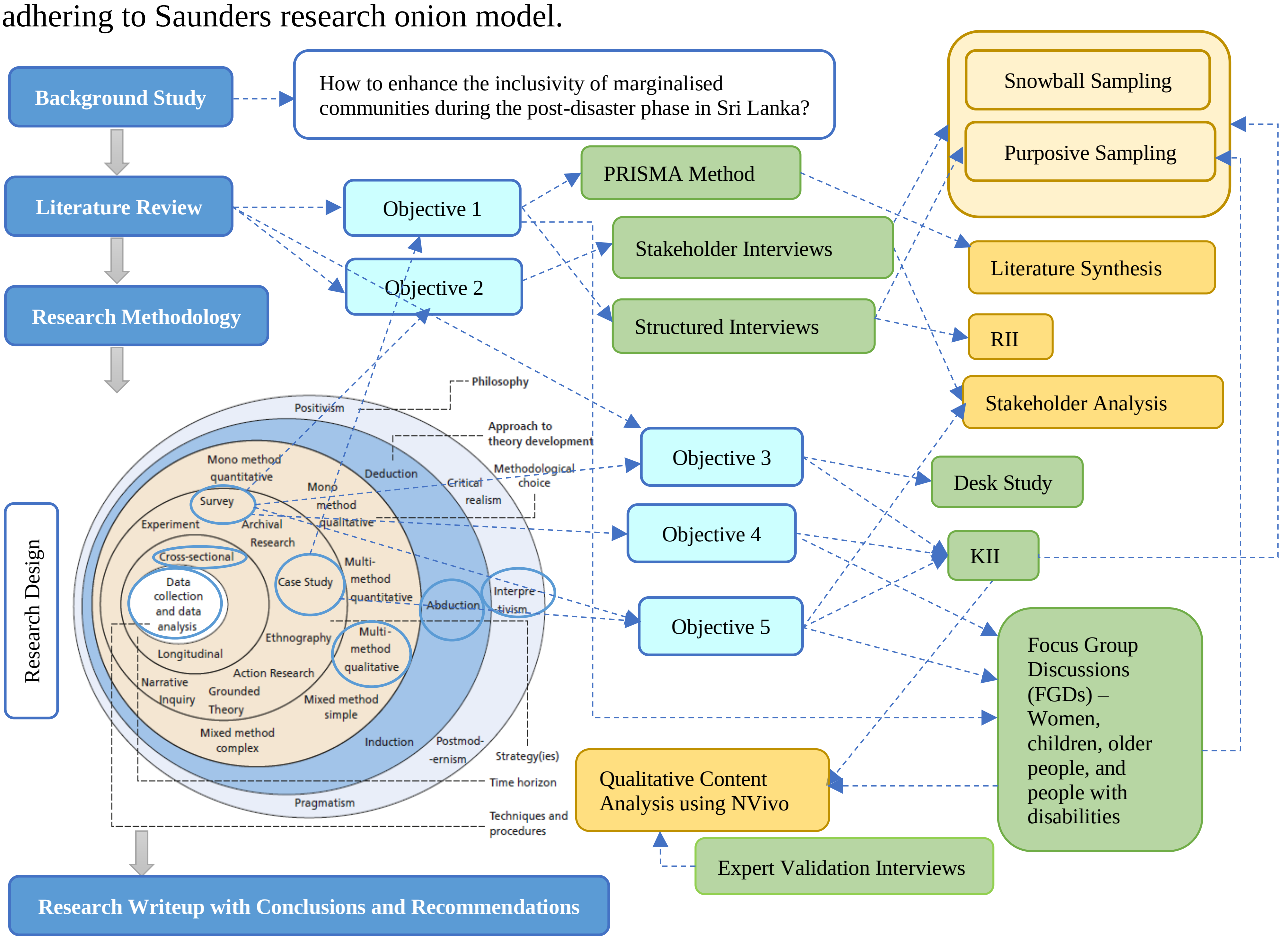

Figure 1: Graphical representation of the research process

Figure 1 shows six layers of Research Onion; philosophy, approach to theory development, methodological choice, strategies, time horizon, and techniques and procedures. To understand the next layer, the researcher must unravel each layer, beginning with the outermost layer. Consequently, the following subsections discuss the methodology adopted on each layer.

2.1.1 Research Philosophy

Research philosophy refers to the set of beliefs, assumptions, and principles that guide and influence the researcher's approach to conducting research. The Saunders research onion explains three philosophies: ontology, epistemology, and axiology. Each research philosophy has different views attached. The most significant are positivism, critical realism, interpretivism, postmodernism, and pragmatism, which influence how the researcher thinks about the research process (Saunders et al., 2019).

Ontology mainly concerns the nature of reality and its characteristics (Saunders et al., 2019). The two leading ends of ontology can be identified as realism and idealism. According to Amaratunga et al. (2015), in realism, the researcher is regarded as being born into a living, social environment with the reality that exists out there. Idealism assumes that reality begins with ideas or thoughts based on different perspectives of people. **Epistemology** concerns assumptions about proper and valid knowledge and how knowledge is communicated to others (Burrell & Morgan, 2017). There are also two extremes in the epistemology assumption. One extreme suggests that knowledge is observable, evidence-based, and objective. This extreme encourages quantifiable observations and statistical analysis. The other extreme, on the other hand, relies on knowledge based on people and their opinions, where subjectivity is encouraged (Saunders et al., 2019). **Axiology** is a set of values and ethics researchers use throughout the research process to ask how they deal with their values and ethics, as well as the values and ethics of the research participants (Saunders et al., 2019). A study can be value-laden or value-free. In a value-free study, the choice of what and how to study is determined by objective criteria, while in value-laden research, the choice is based on human values and experiences (Easterby-Smith et al., 2018).

As set out in the aim and objectives, the study expects to identify the different views of respondents regarding the challenges faced by the marginalised communities in the post-disaster phases and the stakeholder engagement with marginalised communities to improve inclusivity during post-disaster phases. Moreover, the study needs to investigate the policies related to disaster management and marginalised communities in terms of their significance level to improve inclusion, determine the gaps between policies and practises, and propose strategies to improve the inclusion of marginalised communities during the post-disaster phase in Sri Lanka. Different people can perceive marginalisation differently, as it is a subjective and intangible phenomenon. Thus, the study valued and encouraged the free flow of ideas, opinions, and perceptions of people based on their experience within the research environment and considered human interaction as the main driver of the study as in interpretivism philosophy. Hence, the study takes the ontological assumption that reality is not predetermined but is constructed socially by individuals together, the epistemological assumption that knowledge is gathered by examining the opinions and interpretations of people, and the axiological assumption that the subjective values, intuition, and biases of the researcher are essential.

2.1.2 Approaches to Theory Development

According to Saunders et al. (2019) in the Research Onion, the research approach is the second layer after the research philosophy. It relates to how the theory is developed and designed concerning being inductive, deductive, or abductive. According to Soiferman (2010), the inductive approach, or "bottom-up," begins with data collection to explore a phenomenon and allow a theory to emerge. In contrast, the deductive approach, known as the "top-down," begins with theory and then develops an empirical observation to test the theory (Park, 2020; Saunders et al., 2019). Under the abductive approach, it generates a new theory or modifies an existing one, which is tested for validity through additional data collection (Saunders et al., 2019). This research initially considered some pre-established theories or knowledge concerning marginalisation, inclusivity, stakeholder engagement, marginalised communities, disaster management, and its policy perspectives. Besides, further investigation is required through primary data collection to identify the context-specific challenges that the marginalised communities face, the stakeholders' positions, and strategies to enhance the inclusion of marginalised communities through post-disaster development programmes via required policy refinements and practical policy implementation. Hence, the abductive approach is the most suitable approach for this research.

2.1.3 Methodological Choice

The third exterior layer of the Research Onion, methodological choice, essentially entails choosing between qualitative, quantitative, and mixed methods for research (Melnikovas, 2018). Creswell (2003) mentioned that the quantitative approach mainly focuses on statistical procedures. The quantitative study would be more appropriate for the research, which initiates the research question with 'what', 'who', 'where', 'how much' and 'how many' (Smith et al., 2002). The qualitative research approach is most appropriate for cases evaluating social, attitudinal, and exploratory behaviours and beliefs (Naoum, 2007). Ritchie et al. (2014) stated that the qualitative approach is more suitable when the research question starts with 'how', 'what' and 'why'. The mixed approach is not a substitute for the qualitative or quantitative approaches but a combination of both approaches, which avoids the negative points of the two approaches (Johnson & Onwuegbuzie, 2004).

This research intends to enhance the inclusion of marginalised communities during the post-disaster phase by identifying the challenges faced by marginalised communities, improving stakeholder engagement, removing the policy gaps and barriers in policy implementation, and finally proposing strategies to enhance the inclusion of marginalised communities during the post-disaster phase in Sri Lanka. According to Riger and Sigurvinsdottir (2016), the qualitative approach is primarily concerned with understanding, explaining, exploring, discovering and clarifying a group of people's situations, feelings, perceptions, attitudes, beliefs, and experiences, which best suits this research. Although quantitative research may also capture the responses of those who have been marginalised, qualitative methods allow more unfettered communication.

2.1.4 Research Strategies

The fourth outer layer of the Research Onion model is the research strategy. Research strategies include experiments, surveys, case studies, ethnography, action research, grounded theory, narrative enquiry, and archival research (Saunders et al., 2019). As Sexton (2003) stated, the appropriate research strategies should be selected according to the philosophical position of the research. Based on the predominantly interpretivism view of the research, with the available theoretical prepositions and empirical studies, case study and survey strategies are chosen as the most suitable strategies for this research.

Case Study Strategy: A case study is an in-depth investigation into a matter or phenomenon within its real-life background (Yin, 2017). It is especially suitable to undertake case studies as a strategy when the research problem consists of "why" or "how" questions because of the need for an in-depth investigation. The selection of cases could be single cases or multiple cases. Yin (2017) states that a single case study suits a 'critical, unusual, common, revelatory, or longitudinal case'. Multiple case studies can be chosen if the result could be replicated across the cases or could be predicted the variation of results in cases due to a different contextual factor. Respectively, Yin (2017) terms these as literal and theoretical replication.

Consequently, for this research, multiple holistic case studies are used to identify the challenges marginalised communities face and propose strategies to improve the inclusion of marginalised communities during the post-disaster phase in Sri Lanka. A deep understanding of the study area is critical to accomplishing these research objectives. In addition, multiple cases are selected to apply replication in answering the research question since a single case study will not provide that provision. Two Grama Niladhari (GN) divisions affected by natural disasters in Sri Lanka are selected as cases. According to Yin (2017), the boundary of the cases concerns the period covered by the case studies, relevant social groups, organisations, or geographic areas where the type of evidence is to be collected. The case study boundary for this research is the GN divisions affected by natural disasters in Sri Lanka. The unit of analysis leads the research design to identify the data to be collected by defining the logic linking the data to the propositions and the criteria to interpret the findings (Yin, 2017). 'Inclusivity of Marginalised communities' is the unit of analysis of the research. As a result, we chose women, children, people with disabilities, and older adults impacted by natural disasters in Sri Lanka purposefully from each of the two case studies, Panangala North and Paragoda West GN divisions.

Survey Strategy: A survey can collect information from a sample of individuals through their responses to the questions (Check & Schutt, 2012). The significance of the survey strategy is that it allows the researchers to benefit from different data collection techniques, including both quantitative and qualitative such as questionnaires, interviews, and focus group discussions (Singleton & Straits, 2009). According to Jansen (2010), the survey technique generally includes quantitative features that depict numerical distributions of variables in the sample or population. However, as the author further indicated, a qualitative aspect of identifying and exploring variances in the population can also be identified within the survey strategy. Essentially, qualitative surveys do not seek to establish any numerical distribution, instead focusing on determining the diversity of a phenomenon within a given population. Furthermore, the depth provided by qualitative surveys is maintained while a reasonably large number of respondents are given voice (Davey et al., 2019; Richardson, 2004; Saraceno et al., 2007). Fink (2002) also recommended the qualitative survey method to explore in-depth opinions, perceptions, and experiences of respondents in a population regarding a particular subject matter. Consequently, the qualitative survey strategy is suitable for this research to investigate the policies related to marginalised communities and disaster management, to develop a stakeholder mapping to understand the stakeholder engagement with marginalised communities, to determine the policy gaps and barriers to policy implementation, and to propose policy-wise strategies to improve the inclusion of marginalised communities during the post-disaster phase in Sri Lanka, as this research intends to capture the experiences and opinions of policymakers and policy implementers who are involved in disaster management initiatives.

Yin (2017) states that the findings obtained under the survey strategy can be generalised to a larger population. In contrast, the case study strategy focuses on an in-depth analysis of a single case or a small number of cases to provide detailed insights and understanding of specific phenomena or contexts. Accordingly, both strategies are essential to this research to enhance the comprehensiveness and validity of research findings (Gable, 1994).

2.1.5 Time Horizon

The fifth outer layer of the research onion model describes the time frame the project is expected to be completed (Saunders et al., 2019). Two types of time horizons are specified within the research onion; cross-sectional and longitudinal (Bryman, 2008). A longitudinal study analyses a phenomenon over time to compare data (Caruana et al., 2015). A cross-sectional study is a 'snapshot' study in which the phenomenon is investigated at a specific time (Setia, 2016). This research intends to study the present situation of the inclusion of marginalised communities during the post-disaster phase in Sri Lanka. Hence, regarding time horizons, this research is a cross-sectional study.

2.1.6 Techniques and Procedures: Data Collection and Analysis

Primary data and secondary data are the two basic forms of data. Primary data can be gathered from first-hand experience and are not changed or altered (Salkind, 2010). Secondary data refer mainly to previously published sources (Smith, 2008). Data collection procedures generally give a systematic method of acquiring information to answer the research question. Data analysis compacts a significant amount of collected data to produce meaningful interpretations. Data analysis depends on the researcher's empirical thinking and interpretation style (Creswell & Poth, 2019). This study employs several data collection and analysis techniques under case study and survey research strategies to achieve research objectives. As the initial step of this research, a background study was conducted to identify the research gap and formulate the research problem, aim, and objectives.

Apart from the narrative literature review, a systematic literature synthesis is conducted by adopting Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) mainly to explore the 01st objective; challenges faced by marginalised communities in the post-disaster phases in Sri Lanka (Mendis et al., 2023). This objective is further strengthened during the primary data collection process through structured interviews and Focus Group Discussions (FGDs) under the two selected case studies. Data collected from the structured interviews with Likert scale factors are analysed using the Relative Importance Index (RII). Semi-structured interviews with key stakeholders involved with disaster management are conducted under the survey strategy to address the 02nd objective. Stakeholder Analysis (SA) is used to analyse the data collected through interviews to develop the stakeholder mapping to understand stakeholder engagement with marginalised communities to improve inclusivity during the post-disaster phase in Sri Lanka. A desk study of existing policies is carried out to get information about the policies related to marginalised communities in terms of their importance in improving inclusivity during the post-disaster phase in Sri Lanka (Mendis et al., 2022). Key Informant Interviews (KII) under the survey strategy are conducted using semi-structured interviews to achieve the 03rd objective with fundamental stakeholders to understand the level of significance of the policies identified through the desk study and to achieve the 04th objective to determine the barriers to policy implementation in the context of inclusion of marginalised communities in the post-disaster phase. To achieve 05, to propose strategies to improve the inclusion of marginalised communities during the post-disaster phase, primate data is collected from FGDs, KII, and stakeholder interviews. FGDs are conducted as the leading data collection technique within the case studies. Four FGDs are conducted, representing each marginalised community category in each case study. The data collected through the KIIs and FGDs are analysed using the qualitative content analysis method using NVivo software. Finally, five expert interviews for data validation are conducted with policymakers and experts in the disaster management sector to confirm the strategies proposed through the research. Since more than one qualitative data collection technique and the corresponding analytical procedure are adopted in this research, according to Saunders et al. (2019), this research can be recognised as a multi-method qualitative study under the methodological choice.

3. RELIABILITY AND VALIDITY OF RESEARCH FINDINGS

The scientific rigour of qualitative research, which is linked to the reliability and validity criteria used in its development, is frequently questioned due to its underpinning characteristics (Golafshani, 2015). According to Yin (2011), it is possible to use methodological strategies to ensure validity and reliability in qualitative research.

3.1 RELIABILITY PERSPECTIVES AND PROCEDURES

According to Saunders et al. (2019), reliability refers to whether your data collection techniques and analytic procedures would produce consistent findings if repeated on another occasion or if a different researcher replicated them. Table 1 presents the strategies used by the researcher to achieve reliability.

Table 1: Strategies used to achieve reliability

Strategies	Methods used to implement strategies
Multiple sources of data	Literature review (both narrative and systematic review of literature adhering to PRISMA guidelines), Desk study on policies, structured interviews, stakeholder interviews, Key Informant Interviews (KII), Focus Group Discussions (FGD), and Expert validation interviews
Creating a database	Storing all literature sources used in the research in the Mendeley database. Maintaining a handwritten journal on the research Keeping word-processed documents on research data and findings. Maintaining a database with the contact details of interviewees. Audio taping of the interviews and FGDs with the consent of participants Maintaining interview transcripts

	Tabulating the data collected using MS Excel and NVivo software
Maintaining a chain of evidence	Creating links between the interview questions, the data collected (from secondary and primary sources mentioned under multiple data sources), and the conclusions drawn.

Table 1 shows **multiple data sources** used when asking the same question from different respondents to increase triangulation. According to Flick et al. (2014), a line of enquiry can be converged by using multiple data sources. Triangulation can improve the research's validity and reliability (Given, 2008; Santos et al., 2020). **Creating a database** assists the researcher in organising and documenting the data collected. Therefore, a comprehensive database is created using the strategies stated in Table 1. As Yin (2009) claimed, such documentation should be prepared so the researcher and other researchers can retrieve it efficiently later. Therefore, creating a database can increase the reliability of the entire research. Moreover, **a chain of evidence** can also achieve the reliability of the study findings. A chain of evidence explicitly links the questions asked, the data collected, and the conclusions drawn.

According to Saunders et al. (2019), reliability aims to minimise errors and biases in a study. Reliability is a crucial characteristic of research quality; however, whilst it is necessary, more is needed to ensure good-quality research. Therefore, various forms of validity have also been identified to ensure the quality of research, as discussed in the next section.

3.2 VALIDATION STRATEGIES

'Validation' in qualitative research is considered an attempt to evaluate the 'accuracy' of the findings, as best described by the researcher, the participants and the readers. Furthermore, validation is viewed as a distinct strength of qualitative research in that the account made through extensive time spent in the field, the thick, detailed description and the closeness of the researcher to the participants in the study all add to the value or precision of a study (Elo et al., 2014). Creswell and Poth (2019) recommend using multiple validation strategies regardless of the type of qualitative approach. In addition, they recognise that qualitative research has many types of validation, and the authors must choose the types and terms that are comfortable with them. Table 2 shows nine strategies frequently used by qualitative researchers during the validation process adapted from the work of Creswell and Poth (2019). Strategies are not presented in any specific order of importance. However, they are organised into three groups by lens the strategy represents the researcher's lens, the participant's lens, and the reader's or reviewer's lens (Creswell, 2016).

Table 2: Strategies used to achieve validity

Categories of lens	Strategies for validation	Methods used to implement strategies
Researcher's Lens	Corroborating evidence through triangulation of multiple data sources (Given, 2008; Glesne, 2016; Patton, 2002, 2015;	Use of multiple and different data collection techniques; Literature review (both narrative and systematic literature review adhering to PRISMA guidelines), Desk study on policies, structured interviews, Stakeholder interviews, Key Informant

	Santos et al., 2020; Yin, 2014)	Interviews (KII), Focus Group Discussions (FGD), Expert validation interviews
	Discovering negative case analysis or disconfirming evidence (Patton, 2015; Yin, 2014)	Reveal both positive and negative analysis (within primary data analysis, secondary data analysis, and both primary and secondary data analysis [i.e., discussion section] while providing a realistic assessment of the phenomenon under study)
	Clarifying researcher bias or engaging in reflexivity (Hammersley & Atkinson, 1995; Merriam & Tisdell, 2015)	Disclose the understanding of the biases, values, and experiences that we bring to the study from the outset so that the reader understands the position from which we, as the researchers, undertake the inquiry.
Participant's Lens	Member checking or seeking participant feedback (Glesne, 2016; Merriam & Tisdell, 2015)	Solicit the participants' opinions on the credibility of the findings and interpretations through validation interviews.
	Prolonged engagement and persistent observation in the field (Glesne, 2016; Merriam & Tisdell, 2015)	-
	Collaborating with participants throughout the research process (Patton, 2015)	-
Reader's Lens	Enabling external audits (Merriam & Tisdell, 2015)	-
	Generating a rich and thick description (Creswell & Poth, 2019; Merriam & Tisdell, 2015)	Provide details when describing a case or when writing about a theme (codes) Create links between principal codes and semi-codes Provides direct quotes
	Having a peer review or debriefing of the data and research process (Creswell & Poth, 2019)	Get the involvement of specialists Submit articles to get feedback from peer reviewers

When examining the nine procedures, Creswell and Poth (2019) recommend that qualitative researchers use at least two validation strategies in any given study. Therefore, among these nine strategies, we engage in six strategies to improve the validation of this research. The methods we use to implement each strategy are depicted in Table 2.

4. ETHICAL CONSIDERATIONS

When dealing with human participants, research projects should rigorously follow ethical considerations (Alshenqeeti, 2014; Brinkmann & Kvale, 2005). As a result, human participation in this research is very high. Before collecting data, we received ethical approval from the University Ethics Committee (UERC) (Ethics Declaration /Clearance Number: ERN/2022/003). Therefore, we initially introduced research to participants through a 'participation information sheet'. Furthermore, we informed them that participation in the research was on an entirely voluntary basis. If someone wishes not to participate in the whole or part of the data collection process, he/she will be allowed to leave the process at any time, as there is no obligation for them to be part of it. The participants are coming entirely of their free will, and there is complete freedom for them to skip the questions they are uncomfortable answering. Those who agreed to participate received the 'informed consent form' (separate consent forms [two-part consent structure] were generated for children and parent/guardian) before conducting the data collection process. All guidelines and forms were translated into Sinhala where necessary.

5. CONCLUSIONS

In this paper, the authors have tried to develop an appropriate methodology suited to enhance the inclusion of marginalised communities during the post-disaster context in Sri Lanka. The adopted methodology played a crucial role in uncovering valuable insights and recommendations, shedding light on the challenges faced by marginalised communities and offering potential strategies to address their needs effectively. This methodology helps this research effectively involve marginalised communities as active participants to ensure their voices and perspectives are accurately represented. Furthermore, it allows for a comprehensive exploration of their unique experiences, needs, and challenges, providing valuable insights to improve their inclusion. At present, this research is progressing in the analysis of primary data collection under this methodology. Further exploration and application of this methodology will contribute to ongoing efforts to promote the rights and well-being of marginalised communities.

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INTERNET OF THINGS (IOT)-ENABLED INDUSTRIAL SYMBIOSIS MODEL FOR CONSTRUCTION MATERIAL SHARING: BIBLIOMETRIC ANALYSIS

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ABSTRACT

Under the umbrella of Circular Economy (CE), the concept of Industrial Symbiosis (IS) offers a heuristic solution for enhancing resource efficiency through reusing and exchanging of resources. Indeed, IS integrates the complexity of industries encouraging the use of materials and by-products as feedstock sources instead of being wasted. Digital technologies in CE transition have obtained significant attentiveness in academic research in last decade. However, while studies on the concepts of IoT, CE and IS have increased, there is a deficiency in research that systematises the literature for refining the importance of the intersection of IoT and IS in building construction. Thus, the purpose of this research is to conceptualise a IoT-enabled IS model for construction material sharing through Scopus-based systematic review of key literature. The journal articles published in Scopus database related to the fields of CE, IoT and IS were reviewed to understand their intersection towards construction material sharing. Systematic review outcomes were analysed using bibliometric analysis technique. The evolution of the publications, leading journals and authors who published the most papers on the intersection of CE, IoT and IS were mainly reviewed and a IoT-enabled IS model for construction material sharing in construction industry was conceptualised as the key implication of this research. The next stage of the research is to develop a generic symbiotic prototype for IoT-enabled construction material sharing between building construction projects, which can be applied in any context subjected to context specific enhancements.

Keywords: *Circular Economy (CE); Construction Industry; Construction Material Sharing; Conceptual Model; Industrial Symbiosis (IS); Internet of Things (IoT).*

1. INTRODUCTION

The construction industry consumes more and more materials compared to other industries. Thus, resource depletion and construction waste have been identified as a key issue in the construction industry nowadays. Further, construction industry is a key contributor of global Greenhouse Gas (GHG) emissions.

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The concept of Industrial Symbiosis (IS) offers a heuristic solution for enhancing material usage efficiency of construction through reusing and resharing of building materials between construction projects that are geographically proximate. IS has emerged to integrate the complexity of industries encouraging the use of materials' by-products, water and energy as feedstock sources instead of these resources being wasted (Frosch & Gallopoulos, 1989). Indeed, the IS networks have impacted significantly on environmental and economic growth of countries through diminution of virgin materials extraction and GHG emissions (Domenech et al., 2019). Further to the authors, the excessive materials, reusable materials and/or the material waste can be reshared as a resource with other co-located building construction projects without disposing directly for landfilling.

At present, the Circular Economy (CE) transition in construction industry has been enabled with digital technologies for improved resource management (Kristoffersen et al., 2020). Digital technologies including Internet of Things (IoT) have obtained world concern towards circular economy transition of construction industry (Yu et al., 2022). IoT is defined as *"a dynamic information network with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual things have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network"* (Van Kranenburg, 2008). IoT can be used leveraging the sharing of materials among the construction projects under the concept of industrial symbiosis through a real-time data driven platform. IoT can be used as a smart platform enabling real-time tracking and monitoring of the processes (Godinho et al., 2022). However, adopting digital technologies, specifically IoT is still modest in IS network formulation. While studies on both concepts have increased, a few of research have been focused on the importance of intersection of IoT and IS in building construction. Even though many studies are focusing on material sharing between industries under the IS umbrella (Desrochers & Leppala, 2010; Massard et al., 2014; Shi & Li, 2019; Van Beers et al., 2007;), a less or no studies were found related to IoT-enabled IS in construction industry for construction material sharing. Thus, this research aims to conceptualise a IoT-enabled IS model for construction material sharing through Scopus-based systematic review of key literature.

As the key insinuation of the research, two (02) research objectives were formulated to achieve through the systematic review;

1. To understand the intersection between digital technologies, IS and CE concepts in construction industry specifying IoT.
2. To conceptualise a IoT-enabled IS model for construction material sharing.

2. THE CONCEPT OF INDUSTRIAL SYMBIOSIS FOR CONSTRUCTION MATERIAL SHARING IN CIRCULAR CONSTRUCTION

The construction industry consumes materials in large scale showing a high resource intensity (Yu et al., 2021). For example, annual raw material consumption in the United Kingdom (UK) construction industry is around 1.8 million tons (World Economic Forum - WEF, 2015 as cited in Yu et al., 2021). The importance of material efficiency and sustainable resource management can be highlighted a vital and timely need in countries assuring the reduction of environmental impacts of construction industry (Mastos et al., 2020). Material efficiency is about *"sparing use of natural material resources, effective management of side-streams, reduction of waste, and recycling"* (Ruuska & Häkkinen, 2014).

The concept of CE has become an alternative to linear economic model in construction industry in which extending the product lifetime and close material flows is targeted to be achieved (Alcayaga et al., 2019). As stated by Ginga et al. (2020), CE is a way to optimise the use of resources through regeneration of waste in construction industry. Under the umbrella of CE, IS has become a priority action in achieving resource optimisation through exchanging resources among the geographically proximate industrial entities (Ventura et al., 2023). IS is a concept that engage traditionally separated and geographically proximate three or more different industrial entities to attain collective advantages though the physical exchange of resources including materials, energy, water, by-products, services and infrastructure (Chertow, 2007; Mallawaarachchi et al., 2021). In the traditional industrial setting, the linear industries usually approach the model of take-make-use-disposal of waste directly into the environment (Mallwaarachchi et al., 2020). IS can be used an ideal strategy for exchanging materials among the construction projects which ensures connecting waste and by-product as inputs to another process while avoiding waste and loss of valuable resources (Järvenpää et al., 2021). Further, it is an important CE practice that contributes to close the material loop through reduction of the dependency on primary or virgin materials in construction (Yu et al., 2021). IS practices includes both direct exchanges between resource providers and consumers within the construction industry and intermediaries and coordinators who provide services, such as recycling treatments and business relationship management (Chertow & Ehrenfeld, 2012).

The implementation of IS has been recognised as an effective strategy towards the optimisation of resource management and the improvement of co-operation in the context of Industry 4.0 (Scafà et al., 2020). IoT can be used leveraging the sharing of materials among the construction projects under the concept of industrial symbiosis through a real-time data driven platform. However, consideration given on such intersection between IoT, CE and IS concepts is lack in extent of literature.

The methodology adopted in this study is described subsequently.

3. RESEARCH METHODOLOGY

To complete the present study, a systematic review of literature was used as the methodological basis. Hence, key literature published showing the intersection of the fields of Internet of Things (IoT), Industrial Symbiosis (IS) and Circular Economy (CE) were first recognised through a systematic review in Scopus database. This Scopus-based review paper provides first insights into the development of IoT-enabled IS model for construction material sharing in the 08-year period from 2016 to 2023. As the initial step of the review, the literature search was conducted in Scopus database using the key words of "Internet of Things", "Industrial Symbiosis" and "Circular Economy" to search titles, abstracts and documents keywords published from 2016 to 2023 [TITLE-ABS-KEY ("Internet of Things" AND "Industrial Symbiosis" OR "Circular Economy"]. Initially there were 258 articles that were further refined by using the filters available on Scopus's search tool: (i) DOCUMENT TYPES=(Articles) AND (ii) SOURCE

TYPE=(Journals) to identify the quality literature. Accordingly, 74 journal articles were selected as the basis for bibliometric analysis.

Bibliometric analysis was used to recognise the papers relevant for the review. As stated by Grag and Sharma (2017), bibliometric analysis technique has been highly used to evaluate the contribution of the research scholars in various different fields of research, patterns of publications and, the relationship between research findings.

Hence, the analysis of literature was conducted by adopting two (02) selected bibliometric indicators of the co-occurrence of words and number of articles showing the intersection of the fields of IoT, IS and CE. As stated by Mallawaarachchi et al. (2020), number of articles reflects the scientific output, which provides a count of the quantity of works produced by a researcher where co-occurrence facilitates a basis to recognise the specific network of a given type of a research based on its development over the years. Hence, the evolution of the number of journal articles published over the years, leading journals published on the intersection of IoT, IS and CE and the leading authors who have published a high number of articles combining the field of IoT, IS and CE were distinguished. The selected bibliometric indicators were used as a basis to choose the literature for understanding the intersection between IoT, IS and CE concepts in construction industry in order to conceptualise a IoT-enabled IS model for construction material sharing.

4. RESULTS AND DISCUSSION

This section presents the key research findings related to two major areas; (i) Outcomes of bibliometric analysis, and (ii) IoT-enabled IS for construction material sharing.

4.1 OUTCOMES OF BIBLIOMETRIC ANALYSIS

As the initial step, the data derived through Scopus-based systematic review were analysed by using bibliometric analysis to track the evolution of the IoT-enabled IS concept in construction industry. The results which were analysed for the period from 2016 to 2023 are organised under three (03) key headings as: (i) Evolution of the number of journal articles published on IoT-enabled IS, (ii) Leading journals published on IoT-enabled IS, and (iii) Analysis of the leading authors in the field.

4.1.1 Evolution of the Number of Journal Articles Published on IoT-Enabled IS

In the systematic review, 78 journal articles published from 2016 to 2023 (first two months only) were chosen for analysis. During the period considered, the evolution of the number of journal articles published on IoT-enabled IS in Scopus database is presented in Figure 1.

As derived through analysis, the total number of journal articles published on the intersection of IoT, IS and CE in Scopus was 74 in which one articles has been published in year 2016. The number has been escalated to 7, 12 and 14 in years 2019, 2020 and 2021 respectively. As Figure 1 further illustrates, the number has been drastically increased to the peak of 28 in year 2022 while 7 articles were found during the first two months in year 2023.

Overall, the graph indicates an escalating growth of publications on the intersection of IoT, IS and CE over the years beginning from 2016 (01 article) to 2022 (peak of 28 articles). Many of the published articles have been focus on analysing the use of digital technologies towards a circular economy with Industry 4.0. A study conducted by Liu et al. (2023) proposes a conceptual framework of I4.0 technologies-embedded sustainable supply chain management (SSCM) as a way towards a CE.

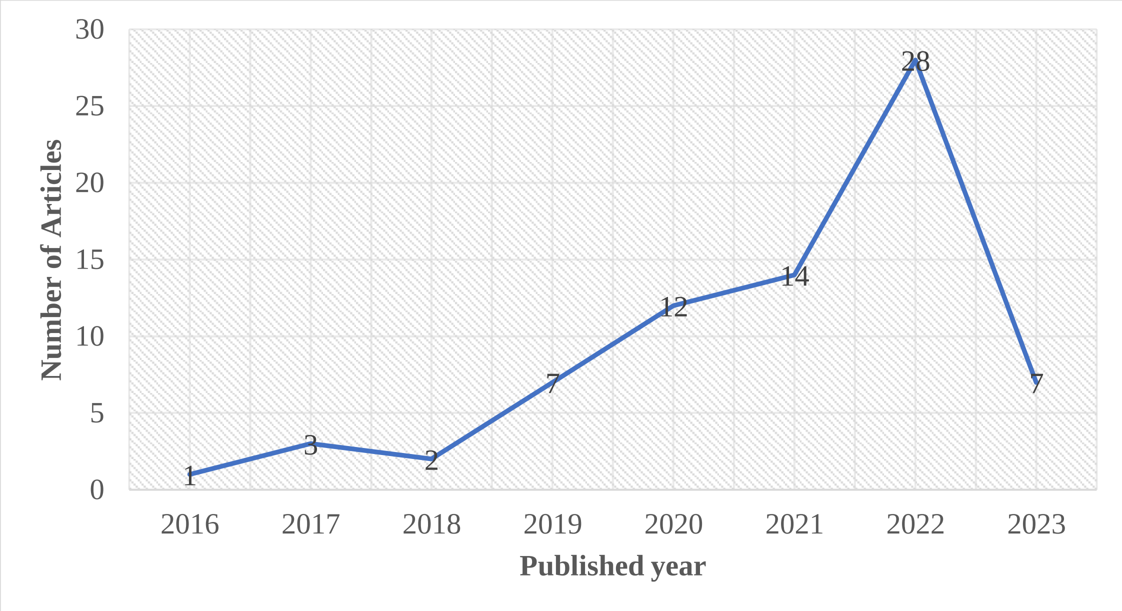

Figure 1: Evolution of the number of articles

According to a study by Akberdina et al. (2023), digital technology shows a significant contribution to sustainable CE. However, a few or no research articles were found interconnecting IOT and IS in construction industry in terms of construction material sharing thus, research gives a comprehensive underpin for conceptualising a IoT-enable IS model for construction material sharing.

4.1.2 Leading Journals Published on IoT-Enabled IS

The leading journals that have published most articles considering IoT, IS and CE intersection over the period from 2016 to 2023 are presented in Figure 2. As shown in Figure 2, ‘Journal of Cleaner Production’ was the leading journal that published the highest number of articles (04 articles) on the intersection of IoT, IS and CE during the period from 2016 to 2023. ‘Computers and Industrial Engineering’ and ‘Sustainability Switzerland’ are the second leading journals that published a high number of articles. Acta Agriculturae Scandinavica Section B, Soil and Plant Science, Science of the Total Environment, Resources Conservation and Recycling, Mathematics, Benchmarking and Journal of Advanced Mechanical Design Systems and Manufacturing are other journals that have given a major concern towards publishing articles on the intersection of IoT, IS and CE during the period from 2016 to 2023.

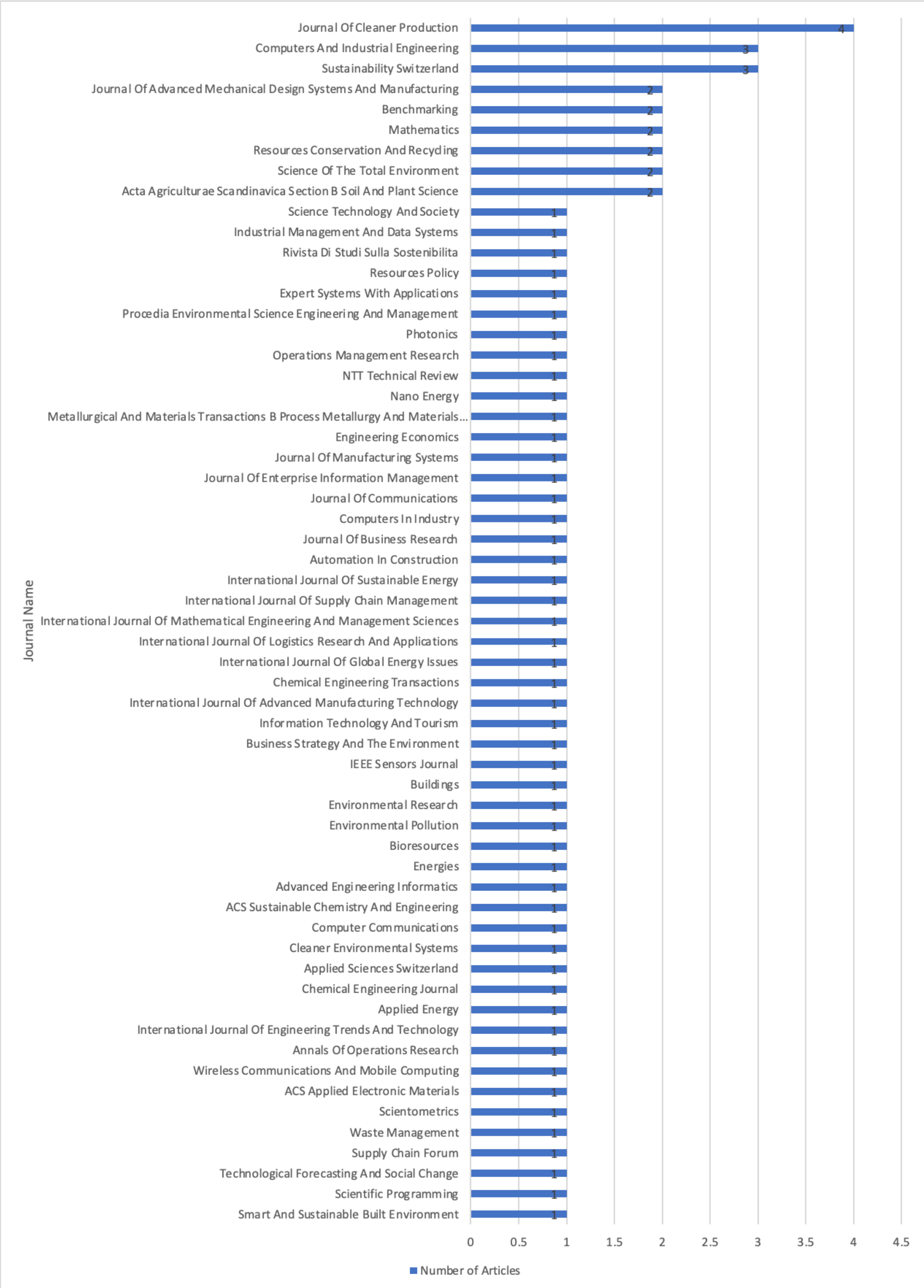

Figure 2: Leading journals that published most articles

4.1.3 Leading Authors in the Field

Various scholars have been contributed for adopting digital technology towards CE and IS. Figure 3 presents the leading authors who have published most papers on IoT, IS and CE concepts in Scopus from 2016 to 2023. As derived through analysis, the author who have published the most articles during the period from 2016 to 2023 is Chen with 3 records in Scopus. As the second highest records in Scopus, 2 articles have been published by many authors including Chen, Garrido-Hidalgo, Hsu, Olivares, Ramakrishna, Ramirez, Roda-Sanchez, Sarkis, Yamada and Yang. Since the concern given on enabling IoT in the concept of IS, number of articles published by authors is considerably less. However, Figure 3 despites a rapid growth in the number of publications over the years from 2016 to 2023.

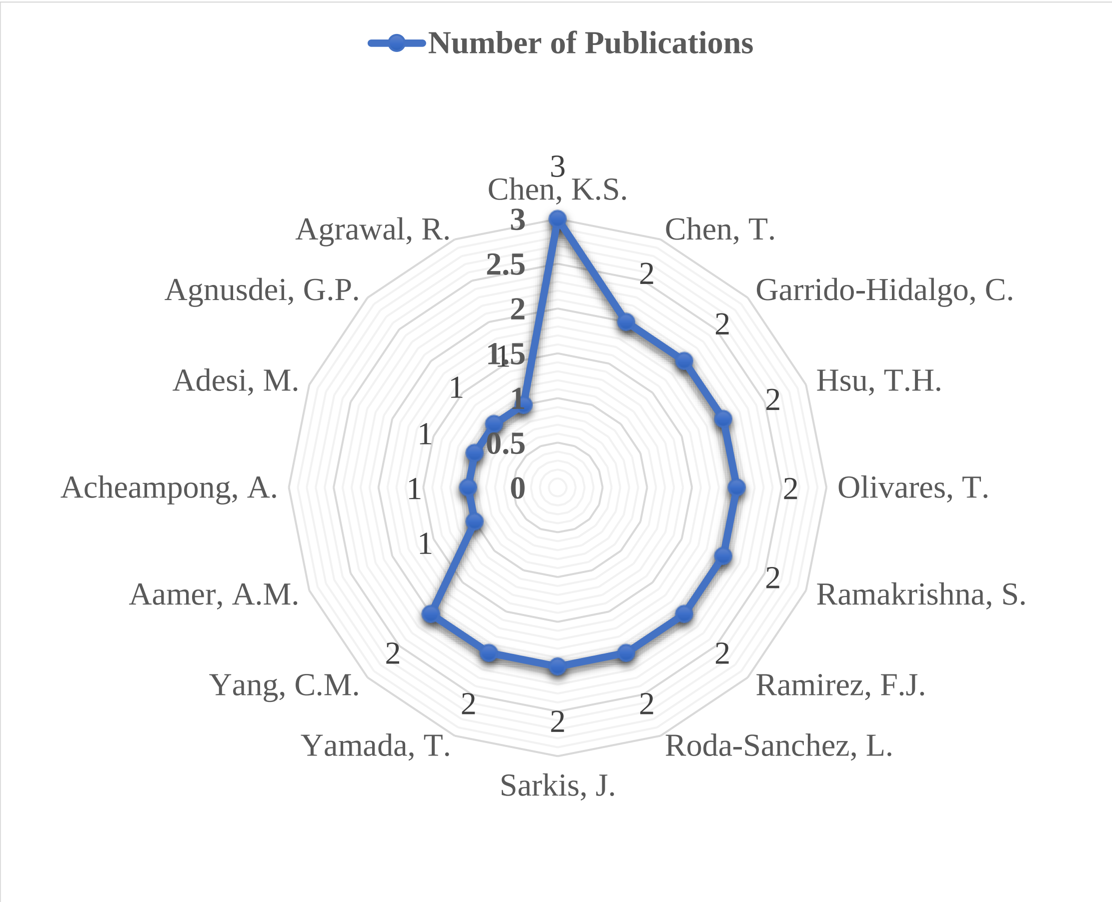

Figure 3: Leading authors in the field

As the second stage, the key literature published during the period of 2016 to 2023 in Scopus were screened and reviewed to   the intersection between IoT, IS and CE concepts in construction industry in order to conceptualise a IoT-enabled IS model for construction material sharing.

4.2 IoT-Enabled IS for Construction Material Sharing: A Proposed Conceptual Model

At present, the CE transition in construction industry has been enabled with digital technologies by tracking the flow of materials, products and components and making the data available for improved resource management (Kristoffersen et al., 2020).

Industry 4.0 is seen as a combination of digital technologies and real-time communication aiming to industrialise the manufacturing systems which includes smart sensors, IoT, big data and analytics, cloud computing, and machine learning etc (Järvenpää et al., 2021). IoT provides a valuable opportunity for the construction industry to solve its time and resource management issues and frequent defaults (Ghosh et al., 2021). The use of IoT influences the collection of large amounts of data, leading to big data, which in turn effect as data analytics tools to obtain competitive advantages (Godinho et al., 2022). As reviewed in key literature, IoT data technology can be enabled in IS for effective construction martials sharing between construction projects. IoT can be used for leveraging the sharing of materials among the construction projects under the concept of IS through a real-time data driven platform. Indeed, IoT is one of the key technologies responsible for ensuring the integration of data and communications across the industry and beyond, in constant exchange of information with the stakeholders involved (Carvalho et al., 2020). Furthermore, IoT supports to improving tracking and record keeping, improving estimation of the remaining life of used products and making decisions to improving durability of product or materials in the construction process (Rejeb et al., 2022).

Enabling digital technologies specially IoT and Big data technology into the IS network operation has been identified as an effective strategy for hindering the information and knowledge gaps between industry partners by many scholars. Information network of IS supports the exchange of symbiosis related raw data such as, types of materials available to exchange, amount to be shared, material frequency and amount required by other partners of the IS network, etc to identify the opportunities for material exchange in construction industry (Shi & Li, 2019). As stated by Järvenpää et al. (2021), information sharing through smart platform is important for successful IS as it communicates accurate and real-time information for stakeholder. According to a study by Kerdlap et al. (2019), real-time data-driven IS platform could connect waste generators, collectors, recyclers, primary and secondary consumers of the recycled materials within the construction industry, which may integrate all such industrial partners of the IS network.

Accordingly, the authors conceptualised a model to enable IoT technology in IS for construction material sharing in construction industry as presented in Figure 4.

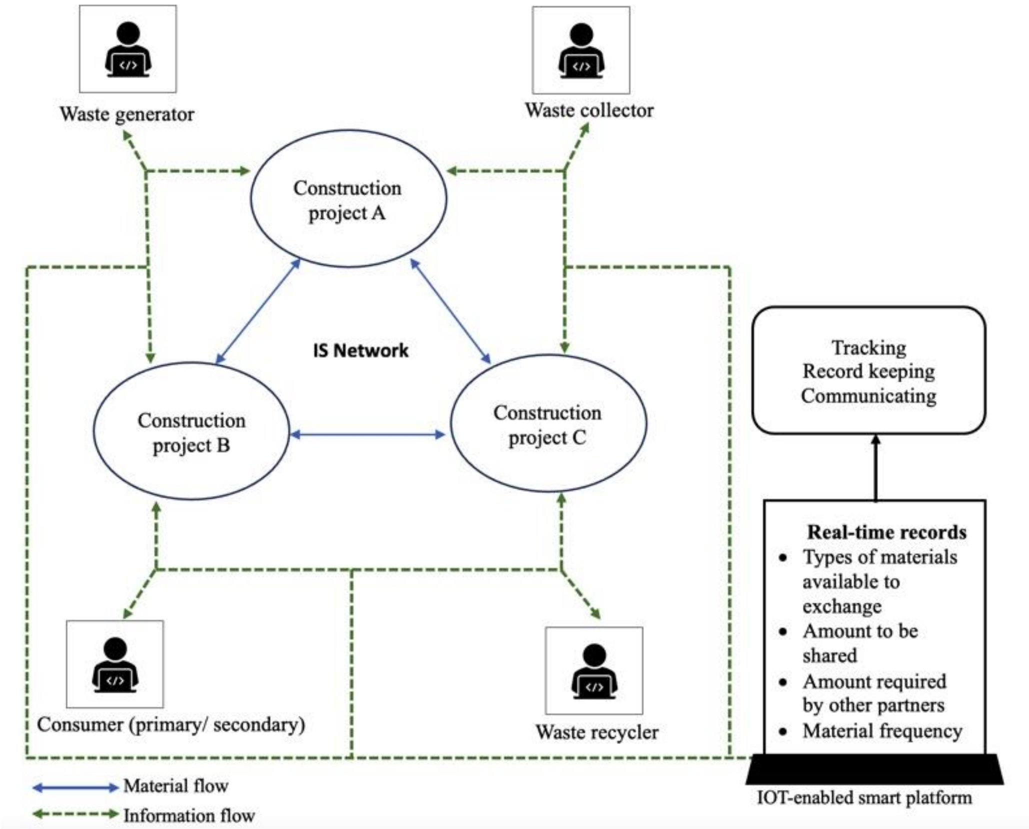

Figure 4: Proposed conceptual model for IoT-enabled IS

The proposed model was developed by clustering three construction project entities based on the theory of "at least three or more industrial entities and two material flow synergies between the entities" (Chertow, 2007). All industry partners including waste generators, collectors, recyclers, primary and secondary consumers of the recycled materials within the construction industry are connected and integrated through the IoT-enabled smart platform. Information flow, which was connected through IoT-enabled smart platform integrates all industrial entities and the stakeholders to one smarter location. This ensures real-time tracking, record keeping and communication of accurate data related to the material flow between industrial entities, such as types of materials available to exchange, amount to be shared, material frequency and amount required by other partners of the IS network.

Hence, in the proposed model, IoT has been used leveraging the sharing of materials among the geographically proximate construction projects through a real-time data driven/ smart platform.

5. CONCLUSIONS

The contribution of construction industry towards environmental degradation is a critical concern in the world, which is ever-increasing. This can be addressed through the extension of material reuse to multiple construction projects under the concept of IS. Enabling IoT could create a significant impact on the success of IS networks as it reduces knowledge and communication gaps between industry partners of the IS network.

Based on the research problem's contextualisation, this research will significantly contribute both theoretically and empirically.

This paper presents a proposed model which was developed by systematic reviewing key literature published in Scopus database during the period from 2016 to 2023. By adopting the proposed model, construction projects which are geographically proximate can be integrated to a one smart planform for timely exchanging of materials for fulfilling material needs of construction. Further, the model acclimates IoT technology by assuring real-time tracking, record keeping, and communicating material related data among the industry partners who have engaged in the IS network. Real-time data tracking and monitoring of material needs and availability of supply by each and every construction project in the network may ultimately reduce the cost of materials. Further, this research brings an innovative and heuristic opportunity to construction project owners to contribute significantly to decline the generation of GHG emissions and C&D waste for achieving sustainable development goals and climate change adaptive actions in the country. Indeed, the bibliometric analysis outcomes of the research may contribute significantly to new knowledge through the intersection of IS and IoT in the construction industry assuring the circular economy transition. The next stage of the research is to develop a symbiotic prototype for IoT-enabled construction material sharing between building construction projects, which can be applied in any context subjected to context specific enhancements and modifications.

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INVESTIGATING THE MOTIVATION FOR IMPLEMENTING UNSOLICITED PROPOSALS IN THE SRI LANKAN CONSTRUCTION INDUSTRY

T.M.P.N. Thennakoon[1], H.S. Jayasena[2] and U.S. Weerapperuma[3]

ABSTRACT

Infrastructure development can be identified as a key driver of economic growth. Most developing countries have prioritised implementing new procurement arrangements to execute public infrastructure projects throughout their life cycle efficiently. Private Public Partnership (PPP) procurement arrangement is one of the popular procurement arrangements, which can be classified as solicited proposals (SPs) and unsolicited proposals (USPs). Most countries have adopted USP for infrastructure projects among those two arrangements. Nevertheless, USPs have several drawbacks than SPs, such as corruption, low social and economic benefits, low value for money, and lack of transparency. However, governments are still developing their infrastructure projects as USPs due to the government's motivational aspects towards them. Therefore, it is controversial how those motivations have a huge impact than drawbacks in implementing USPs. Thus, this study aims to investigate the motivation for implementing USPs specific to the Sri Lankan context. Accordingly, a qualitatively based extensive literature synthesis has been conducted concerning the practices of USPs. Following the qualitative approach, data were collected through twelve (12) semi-structured interviews with industry professionals familiar with USPs implementation. The findings revealed that governments often choose USPs due to limitations in their capacity to identify and evaluate large-scale projects. These limitations can be financial and technical, including a lack of expertise. While speculation exists about corrupt practices associated with unsolicited PPPs, it is difficult to validate such claims. However, it is acknowledged that unsolicited PPPs, in their current state, offer higher opportunities for corruption. Nonetheless, accessing private financing quickly and efficiently for PPPs is also a positive motivation for choosing the unsolicited approach.

Keywords: *Governments' Motivation; Procurement; Private Public Partnership (PPP); Unsolicited Proposals (USP).*

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1. INTRODUCTION

Construction is a vast, complex, and unique industry, which is a critical economic regulator of a country (Behm, 2008). It significantly contributes to the national output (Finkenzeller et al., 2010). Further, the construction sector strongly cooperates with other key economic regulators (Rameezdeen, 2002). Infrastructure development is vital to economic well-being and long-term economic growth (Naoum & Egbu, 2015). Therefore, the success of the construction sector depends on the deliverable quality and efficiency of the construction projects. The success of a construction project is derived through fundamental attributes; scope, time, cost, and quality (Ali & Kamaruzzaman, 2010). With this, selecting a suitable procurement system is a significant step to achieving project success (Tookey et al., 2001). Naoum and Egbu (2015) stated that the procurement system is a mechanism for linking and coordinating building team members throughout the building process in a unique systematic structure, both functionally and contractually. There are different types of procurement routes, such as separated, integrated, management-oriented, and collaborative, which can be selected according to their requirements, and each procurement route has its unique characteristics (Tookey et al., 2001).

Therefore, most publicly available projects are initiated through various public procurement mechanisms. Public procurement is implemented under the authority of the government of a country or any other public sector to focus on stakeholders' satisfaction with the national development plan (Gunawardana et al., 2021). Further, Capacity Development Group Bureau (2010) argued that in the global context, public procurement had been estimated as a 15% contribution to the GDP while it becomes a 70% contribution to GDP in some developing countries such as Peru, Colombia, India, and the Philippines. Therefore, enhancing and improving the public procurement process for the nation to raise the community's standard of living and economic development is beneficial.

Torvinen and Ulkuniemi (2016) argued that publicly available projects possessed traditional procurement processes in the last few decades. However, the traditional process has been confronted with intense pressure to alter it due to significant changes in the public procurement environment. Shortage of funds, limited resources, technical improvements, and the development of new services can be considered notable drivers behind new public procurement methods (Jamali, 2007; Krtalić & Kelebuda, 2010; Pekkarinen et al., 2011). Therefore, procurement practitioners have introduced various market-based public procurement tools such as public-private partnerships, public finance initiatives, and pre-commercial procurement options (Raymond, 2008; Torvinen & Ulkuniemi, 2016; Uyarra & Flanagan, 2009). The key idea behind this closer collaboration of public procurement methods is that no single party has all the knowledge, information, resources, or ability to address emerging complex issues (Lawther & Martin, 2005). Then market-based public procurement approaches create chances for both innovative mobilisation and better achievement of public policy objectives while delivering services to taxpayers (Liu & Wilkinson, 2011).

Among these innovative public procurement approaches, the most popular model for purchasing extensive public infrastructure is the public-private partnership (PPP) (Ng et al., 2013). Instead of relying on one party as in the traditional procurement process, suppliers and procurers contribute their best skills and knowledge to the project while involved with planning, financing, maintenance, and assistance services for the procured project (Krtalić & Kelebuda, 2010). Two methods for implementing PPP are Solicited Proposals (SPs) and Unsolicited Proposals (USPs). The public sector development of the SPs and the project is required to be implemented as planned by the government with private sector involvement (Casady & Baxter, 2020; Lenferink et al., 2012; Torvinen & Ulkuniemi, 2016). When a project is implemented as an unsolicited proposal, a private entity develops it and proposes it to a relevant authority (Yun et al., 2015; Zhang et al., 2016). Nyagormey et al. (2020) pointed out that when considering PPP investment in developing countries, a significant proportion of the investments are acquired by unsolicited proposals (USPs).

However, there are several barriers that unsolicited PPP projects are faced when compared with a solicited proposal (Aziz & Nabavi, 2014). USPs are often associated with some negativities such as corruption, low social and economic benefits, low value for money, lack of transparency, risk misallocation, lack of competitive tendering process, nepotism, and lack of fairness (Hodges & Dellacha, 2007; Osei-kyei et al., 2018; PPIAF, 2017; World Bank Group, 2015). Further, USPs initiatives generate unfavourable public opinions due to their perceived favouritism and lack of competition (Aziz & Nabavi, 2014; Zawawi et al., 2016). Even though USPs have the above major drawbacks, there is a global tendency and motivation for procuring PPP projects as USPs in developing countries (Nyagormey et al., 2020; PPIAF, 2017; World Bank Group, 2015). Regarding the Sri Lankan context, according to the World Bank Group (2020), many public sector projects are procured through USPs. With this, USPs play a vital role in infrastructure development in Sri Lanka (Verite, 2021). Then it can be argued that there is a motivation for the Sri Lankan government also to fulfil the infrastructure implementation through USPs. Given the paradoxical nature of this motivation, while there are many perceived drawbacks, this paper aims to identify the motivation factors for developing infrastructure projects as USPs in the Sri Lankan construction industry. Accordingly, the literature synthesis has been developed, including PPP practices with USPs, USP drawbacks, motivation for USPs, and USP practice in the Sri Lankan construction industry.

2. RESEARCH METHODOLOGY

The research approach can be defined as plans and procedures for conducting research that covers the progression from general hypotheses to specific techniques for data collecting, analysis, and interpretation. The qualitative research approach has been used for this study because it can thoroughly analyse ideas, models, and frameworks with a theoretical foundation (Creswell, 2014). This paper addressed the research problem:

RQ: *"What are the motivations for implementing PPP projects through USPs?"*

Exhaustive literature research was conducted by reviewing conference papers, journal articles, e-books, and other publications to access knowledge on USPs. This literature survey provided limited findings about the unsolicited proposals in Private Public Partnership (PPP) projects, including major drawbacks and motivation to adopt USPs. Thus, there is a knowledge gap in comprehensively identifying the motivation factors for the Sri Lankan context. Semi-structured interviews were carried out to collect qualitative data on practitioners' lived experiences, observations, and opinions on the contexts of USPs. Thematic analysis was conducted to identify the motivation factors of unsolicited proposals (USPs) in the PPPs of the Sri Lankan construction industry while accounting for the motivation factors which are identified in the literature review.

There are no closely defined rules when selecting a sample size for qualitative research (Baum, 2000; Patton, 2002). However, according to Huberman and Miles (1994), qualitative research generally relies on small numbers to study in-depth and detailed detail. Hence, for this study, non-probability snowball sampling was used considering the limited number of practitioners exposed to USPs and related contexts. Twelve (12) experts with sound knowledge and experience in USP PPP of the Sri Lankan construction industry were interviewed. Accordingly, as mentioned above, the initial sample was limited to interviews of twelve respondents who were saturated after the ninth interview. Table 1 summarises the profile of the interviewees.

Table 1: Profiles of interviewees

Interviewee code	Profession	Designation	Years of experiences
R1	PPP Specialist	Chief operating officer	15 years
R2	Quantity Surveying/ Research Scholar	Senior Quantity Surveyor/Ph.D. Candidate	8 years
R3	PPP Specialist	Chairman	30 years
R4	Procurement Specialist	Resident Engineer	20 years
R5	PPP Specialist	Deputy Director	12 years
R6	PPP Specialist	Deputy Director	6 years
R7	Procurement Specialist	Director	15 years
R8	Resident Engineer	Director	15 years
R9	Engineer	Deputy Director	14 years
R10	Engineer	Project Engineer	13 years
R11	Procurement Specialist	Director	9 years
R12	Engineer	Senior Engineer	10 years

3. PRACTICES OF PPP IN INFRASTRUCTURE DEVELOPMENT

Because of the recent rapid economic growth, there has been a significant increase in the demand for infrastructure facilities in developing countries. Then, developing public-private partnerships (PPPs) is a strategy for enhancing infrastructure facilities in such countries. As Verma (2010) described in terms of fiscal stabilisation, cash flows, and efficiency gains, PPPs offer developing countries several benefits and prospects.

Therefore, PPP can be defined as "A method of procurement that brings together the public and the private sectors in a long-term partnership for mutual benefit. The crucial feature of a PPP is that it is designed to achieve both social and commercial goals" (Eisenberg, 2009). The combination of private funding, private project execution, and the provision of public services and facilities is the essence of public-private cooperation (Liu & Wilkinson, 2011). There are several PPP project procurement processes across the globe, including the most common methods such as build-transfer-operate (BTO), build-transfer-lease (BTL), build-operate-transfer (BOT), building-own-operate (BOO), design-build-finance-operate (DBFO), design-build-operate-maintain (DBOM) and many others (Yun et al., 2015; Zhang et al., 2016).

Further, in addition to the above common procurement methods, there are two different approaches named solicited and unsolicited proposals, globally recognised as PPP projects initiated methods (Zheng & Tiong, 2010). Depending on the decision of who develops the proposal and implements the project, solicited approach, and unsolicited approach can be differentiated (Castelblanco & Guevara, 2020b). The public sector does the development of the solicited proposal, and the project is required to be implemented following an infrastructure development plan of the government but due to the financial constraints of the government, private sector involvement is vital in this approach (Casady & Baxter, 2020; Lenferink et al., 2012; Torvinen & Ulkuniemi, 2016). In an unsolicited approach, a private entity examines and initiates a profitable project as a seeking business opportunity (Torvinen & Ulkuniemi, 2016). When a project is implemented as an unsolicited proposal, private entity is involved in developing the proposal, initiating an implementation plan, and proposing it to a relevant authority (Yun et al., 2015; Zhang et al., 2016).

4. OVERVIEW OF USP IN THE CONSTRUCTION INDUSTRY

In the USPs, a private firm approaches a public agency with a proposal for an infrastructure or service project without receiving a direct request or invitation from the government (Aziz & Nabavi, 2014; PPIAF, 2007; Zawawi et al., 2016). Therefore, a USP is an exception to the rule in which public sector organisations launch infrastructure projects. According to PPIAF (2007), the private sector proponent's financial capability is a vital factor. Then a demonstration of having strong financial strength to undertake the proposed project is an essential thing that the private proponent should be done when undertaking the project (PPIAF, 2007). Chew (2015) argued that unsolicited proposals are considered controversial. This means there are several drawbacks that unsolicited PPP projects have when compared with a solicited proposal such as corruption, low social and economic benefits, low value for money, lack of transparency, risk misallocation, lack of competitive tendering process, nepotism, and lack of fairness (Aziz & Nabavi, 2014). Then it is crucial to identify the motivation of USPs although there are several drawbacks.

4.1 REVIEW OF THE MOTIVATION OF THE GOVERNMENT FOR IMPLEMENTING PPPS AS USPS

The growing use of USPs demonstrates that many countries consider implementing PPP projects using USPs is advantageous and can make an exceptional contribution to the development of public infrastructure (PPIAF, 2014). When considering the other key motivation of a government to implement a project as a USP is the lack of financial and technical capabilities of public sectors to procure, prioritise and identify the projects (PPIAF, 2017; World Bank Group, 2007). In addition, when implementing a PPP project, a comprehensive preliminary study should be carried out to ensure the social and economic viability of the project (Ng et al., 2013). To carry out a proper and accurate preliminary study, an experienced technical team and considerable financial resource allocation are needed (Li et al., 2007). Nevertheless, in many public departments of developing countries, there is a lack of financial resources and expert knowledge in such studies. Therefore many governments have the motivation to rely on individual private developers' efforts and initiatives to procure PPP projects (PPIAF, 2014).

Another motivation for a government to select a USP for PPP is that USPs are the quickest approach to implementing PPP projects compared with a solicited approach (Hodges & Dellacha, 2007; PPIAF, 2017). Because SPs have to undergo a formal planning procedure, requested PPP projects, in some solicited projects, excessive competition is initiated, and considerable time is taken for the procurement process (PPIAF, 2017). Then many public departments move to direct negotiation instead of a lengthy tendering process. In USPs, there is only one project proponent, negotiation can be done quickly, and the cost incurred for the competitive tendering process is reduced (Osei-kyei et al., 2018). Moreover, the recurring expenses associated with competitive bidding are decreased {Formatting Citation}.

PPIAF (2014) emphasised obtaining the private sector's innovative and creative ideas and using those effectively as another motivating factor in USPs. In essence, unsolicited proposals allow private investors to develop creative approaches and long-term plans for infrastructure problems that many public departments are unable to provide (World Bank Group, 2017). Another well-known reason governments use USPs is the lack of an appropriate and comprehensive policy framework for PPPs (Hodges & Dellacha, 2007; PPIAF, 2014). Even though the PPP concept has existed for decades, many nations, especially those in developing nations, have not yet developed comprehensive policy guidelines for PPP project execution (Osei-Kyei & Chan, 2017). USPs are frequently used to carry out PPP projects because there is no detailed regulatory framework (PPIAF, 2012).

Another motivation factor is the government's interest in accessing private entity finance facilities more quickly than solicited approach. Emphatically, the unsolicited method helps public institutions tap rapidly into the private sector's money for infrastructure projects (PPIAF, 2012). Although governments could obtain private financing through the requested ways, this method occasionally requires more time. Nevertheless, with the unsolicited approach, the private sector proposes the project with its resources and capital readily accessible for development (PPIAF, 2009). However, David-Barret and Fazekas (2020) stated that the government's motivation in most developing countries to implement a project through USP is the possibility of engaging with some corrupt practices, and the absence of competitive bidding in USPs leads to government officials engaging with some fraudulent practices.

Accordingly, Table 2 presents the motivation for implementing USPs for construction projects, which were collected through past studies.

Table 2: Motivations of implementing USPs.

Motivation	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
Lack of financial and technical capabilities of public sectors to procure, prioritise and identify the projects	✓	✓	✓	×	✓	✓	×	✓	×	✓
Lack of financial resources and expert knowledge in the public sector to carry out a proper and accurate preliminary study and governments tend to rely on individual private developers' efforts and initiatives to procure PPP projects through USPs.	✓	✓	×	×	✓	×	✓	×	×	✓
Project procured unsolicited is considered the quickest approach to implementing PPP projects compared with a solicited approach	✓	✓	×	✓	✓	×	✓	✓	✓	✓
Obtaining the private sector's innovative and creative ideas from unsolicited proposals than solicited proposals	✓	×	✓	✓	✓	×	×	×	✓	×

Motivation	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
Government's interest to access private entity finance facilities more quickly than solicited approach	✓	×	×	✓	✓	×	×	×	✓	✓
Absence of a proper regulatory framework to manage the USPs	✓	✓	×	✓	×	✓	×	×	✓	✓
Corrupt practices and the absence of competitive bidding in USPs	✓	×	×	×	×	✓	✓	✓	✓	×

Sources: [1] PPIAF, 2014; [2] PPIAF, 2009; [3] Castelblanco & Guevara, 2022; [4] Osei-Kyei & Chan, 2017; [7] Osei-kyei et al., 2018; [8] Verma, 2010; [9] Hodges & Dellacha, 2007; [10] World Bank Group, 2007.

4.2 USP PRACTICES IN THE SRI LANKAN CONTEXT

According to the World Bank Group (2020), many public sector projects are procured through unsolicited proposals in the Sri Lankan context. Between 2010 and 2016, the government spent 6%-7% of the GDP on public investment (Department of national planning, 2010). Besides, due to the critical economic situation in the country, finding finances through foreign funding sources has become popular (World Bank Group, 2020). Then unsolicited proposal plays a vital role in infrastructure development in the Sri Lankan construction industry (Verite, 2021). Verite (2022) stated that one of the apparent motivations for implementing PPPs through USPs is the lack of necessary finance to fund infrastructure projects in Sri Lanka. With this, it is important to identify the other motivation factors prevailing in the Sri Lankan context to implement USPs as a suitable PPP method.

5. RESEARCH FINDINGS

Data collected were the opinions of the experts on the generic factors which were identified related to USPs. The collected data were analysed through manual content analysis. Consequently, findings through the conducted expert interviews have been discussed as follows.

5.1 MOTIVATION FOR THE SRI LANKAN GOVERNMENT YO IMPLEMENT PPP PROJECTS AS USPS

All the motivation factors identified in the literature review were checked with the respondents' opinions. All the respondents were asked whether that identified motivation factor in the literature review is valid for the Sri Lankan context. The respondents were asked to give additional motivation factors they have experienced or known. Consequently, two additional motivation factors were identified by the respondents. Further, their experiences with each motivation factor were analysed. Table 3 illustrates the findings through expert interviews.

Table 3: Motivation factors for USPs

Motivation Factors	**Experts**											
	R1	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R 10**	**R 11**	**R 12**
Lack of financial and technical capabilities of public sectors to procure, prioritise and identify the projects	✓	✓	×	✓	×	✓	✓	✓	✓	✓	✓	✓
Lack of financial resources and expert knowledge in the public sector to carry out a proper and accurate preliminary study	✓	✓	×	×	×	✓	×	×	×	✓	✓	✓
Project procured unsolicited is considered the quickest approach to implementing PPP projects compared with a solicited approach	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓	✓
Obtaining the private sector's innovative and creative ideas from unsolicited proposals than solicited proposals	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Government's interest to access private entity finance facilities more quickly than solicited approach	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓
Corrupt practices and the absence of a competitive bidding process in USPs	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Absence of a proper and comprehensive regulatory framework to manage PPPs	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Lack of developers' interest in developing a project in remote areas	✓	✓	✓	✓	✓	×	×	✓	✓	✓	×	×

R1, R2, R4, R10, R11, and R12 elaborated that the lack of financial capabilities is obvious in a country like Sri Lanka. They highlighted that most of the time public sector still uses traditional methods compared to the private sector. However, R1, R7, and R8 expressed that even though lack of financial capability is one of the motivation factors to allow USPs for PPPs, lack of technical capability is not a motivation because experts who have technical capabilities are available within the country and by having proper national policy output of the national policy can be enhanced. Accordingly, all the respondents have highlighted that financial incapability within the country is a motivation to allow USPs. However, regarding technical incapability, more than half of the respondents disagreed with technical incapability and mentioned policy directives that are needed for technical capabilities.

When considering the public sector's lack of financial resources and expert knowledge to carry out a proper and accurate preliminary study, R2 stated that the ability to take a risk regarding preliminary investigation, market survey, or feasibility study is inadequate in the public sector. Nevertheless, the private sector takes the risk and takes the proposal.

R1, R6, R10, R11, and R12 elaborated on the same idea. However, R8 expressed that when it comes to expert knowledge, the government has enough expert knowledge to carry out the proper preliminary study. R2, R3, R4, R5, R7, and R9 expressed similar opinions. Therefore, even though all the respondents agreed with the lack of financial resources to conduct the preliminary study, the lack of expert knowledge is not agreed.

Project procuring as USP is the quickest approach to implementing PPP projects compared with a SP. R1 expressed that a lengthy procedure is not there and no need to conduct a feasibility study, pre-feasibility study, and market survey by the public sector because the project proponent has done it on their own and brought it with the proposal. R2 expressed that a tendering procedure should be conducted in solicited proposals where the employer's requirements need to be finalised. However, for USPs, all these are shortened. Hence, there is a motivation to start the project within a shorter period. However, R5 stated that in the SL context, a solicited proposal is selected after a proper competitive process, and obtaining approval for the project becomes easier than USPs.

All the respondents agreed with the motivation factor that USPs can obtain creative and innovative ideas from the private sector. R7 expressed that flexibility is higher than solicited proposals because there is no need of follows donors' framework. Therefore, all the respondents have highlighted through USPs can be assessed the creative and innovative ideas of the private sector.

Motivation factor which is the government's interest to access private entity finance facilities more quickly than solicited approach is agreed by most of the respondents. R1 expressed that if an emergency infrastructure requirement occurs, such as power-generated infrastructures, the quickest and most straightforward approach to financially facilitate such type of project is implementing the project as a USP. Most respondents elaborated on the same idea. However, R6 had different opinions. R6 highlighted that if a proper competitive bidding process is implemented and can be assessed to the government finance facility quickly at a lower cost, it will not motivate a government to allow USPs.

All the respondents highly agreed with the motivation factor of potentially corrupt practices and the absence of a competitive bidding process in USPs. R7 expressed that most developing countries like Sri Lanka use these USPs as a corrupt practice because of less competitive bidding. R2 stated that after 2010 most of the development projects taken as USPs led to serious concerns of corrupt practices and government assets could have been used very corruptly. R2 continued to explain that USPs are now limited due to fear of such corruption. All other respondents elaborated on the same idea. According to them, without assessing the true value of USPs, government decision-makers may rely on this motivation factor.

When considering the absence of a proper and comprehensive regulatory framework to manage PPPs as a motivation factor, all the respondents agreed with that motivation factor. Moreover, R8 explained that although the PPP concept existed within Sri Lanka in the last few decades, the Sri Lankan government has not had proper and matured policy guidelines for PPP projects with proper paths and timelines. Further, R6 explained that as a country, there is an absence of a strategic approach, policy, vision, or proper process to use our resources under the PPP modality; the government becomes market-given and responds to the proposals not initiated by the government side. All other respondents highlighted the same idea. Therefore, this motivation factor usually prevails in a developing country like Sri Lanka.

Besides the findings in the literature review, R8 identified the motivation as an additional motivational factor: the lack of developers' interest in developing a project in remote areas. All the interviewees interviewed after R8 was asked about this motivation factor. R8 stated that if a project in a remote area is implemented as a solicited proposal and there is a lack of interest among the competitors, it is better to implement it as an unsolicited proposal for such type of project. R9 and R12 highlighted the same idea.

6. DISCUSSION

As discussed, several motivation factors are affected by the decision of the government to implement USPs for PPP projects. The government believes implementing PPP projects as USPs provides benefits and uniquely contributes to public sector infrastructure development (PPIAF, 2012). Therefore, these governments' motivation encourages and allow the PPP projects as USPs to solve the infrastructure concerns within the country quickly and address the gaps of the publicly initiated projects. These institutional motivations are formally acknowledged by governments or included in USP frameworks. When a government is required to manage USPs, it is important to identify the motivation factors related to their own country (World Bank Group, 2017).

One of the significant motivation factors identified in the literature review and the respondents' opinions is the capacity constraints of the public sector. Nevertheless, some respondents disagreed with such motivation. USPs are not always a practical way to get around capacity issues. Government institutions should look at the condition of implementing a project as a USP. It is equally challenging or more challenging than developing the project as a publicly initiated project through a competitive process. According to Kim et al. (2011), due to information gaps between the public agency and the USP proponent regarding the project's specifics, such as scope, design, construction, and operation, after implementing the project public sector finds it more difficult to shape the project actively. In addition, it becomes more challenging for the public entity to structure the contract and implement the project with the required value for money. Therefore, when relying on the capacity constraints motivation factor, it is necessary to identify whether it is more challenging or equally challenging than the publicly initiated projects.

Another significant motivation factor that most respondents agreed with is the fast project implementation through USPs. Nevertheless, some experts rejected the idea that a USP can speed up project execution, for sole-sourcing or direct negotiation. Due to USPs bypassing the public-procurement regulations may lead to public controversies and cause further delays in the projects, then although the project is going faster at an early stage, at a later stage, it takes a longer time (Brocklebank, 2014). Further, due to direct negotiation of the USPs, time delays occurred later. When a government relies on this motivation factor, it is necessary to identify the delays that can occur later and evaluate if it gains more benefits than publicly initiated projects. Otherwise, this is not a motivation factor to be relied on by the government.

Opportunities for corrupt practices are often attributed to USPs (Hodges & Dellacha, 2007). The study showed such perception among the participants. While this does not confirm the existence, this highlights the significance of potential corruption when public projects are implemented with USPs. Consequently, corrupt practices become a likely candidate for motivation to use USPs given the background context of the country.

7. CONCLUSIONS

While USPs have various drawbacks, motivational factors stimulate the industry to adopt PPP projects as USPs. This tendency to implement PPP projects as USPs can also be seen in the Sri Lankan construction industry, as a significant number of USPs have been implemented in the country during the last few decades. Simultaneously, controversial problems such as low social and economic benefits, low value for money, high transaction costs, and corruption are thought to have been created through these projects. Nevertheless, still, USPs are in practice. With the curiosity on why such motivation could exist, this study examined the motivation for adopting USPs for PPP projects in Sri Lanka. The finding revealed the underlying motivation behind governments' tendency to implement unsolicited PPPs, notwithstanding their potential contentiousness. One key motivation to opt for unsolicited mode is the capacity limitations in the public sector to identify and evaluate large-scale projects. Capacity limitations can be financial and technical, including limited government expertise. In case these limitations are not true, a lack of government policies and/or strategies to mobilize the capacity could at least be absent. Speculations were evident that USPs are preferred due to their opening for corrupt practices and absence of competition. Sensitive and controversial assertions like this are difficult to be validated. Notwithstanding the question of whether corruption occurs, it is understood that USPs in their current state provide relatively higher corruption opportunities. However, it is observed that corrupt practices need not be the only motivation if they exist; there are also positive motivations, such as accessing private entity finance facilities more quickly for PPP than the solicited approach.

The main limitation of this study is that it merely examined and considered broad justifications for using unsolicited PPP proposals rather than thoroughly examining and considering the inherent characteristics of justifications (i.e., push and pull theories). Now that the generic motivations are identified through this study, these findings help to embark on the next level of the study. Future research should be focused on the "pull and push" factors that influence the adoption of unsolicited PPPs in a particular nation or region. Moreover, future studies will also investigate the drivers behind the private sector's interest in USP agreements.

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INVESTIGATION OF THE CHALLENGES OF EXECUTING SUSTAINABLE CONSTRUCTION PRACTICES IN THE SRI LANKAN CONSTRUCTION INDUSTRY

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ABSTRACT

The construction industry has made a significant contribution to global environmental issues while forging an imperishable relationship with society and the economy of the country. There has been an increasing trend in the promotion of sustainable construction (SC) in the industry. The implementation of SC practices is a vital step in construction projects to reduce the adverse impacts on the environment economy and society. While numerous challenges affect sustainable construction projects, those challenges continue to obstruct the further implementation of sustainable construction practices. However, the execution of SC projects in Sri Lanka is not up to an acceptable sufficient level due to many challenges. Hence, this research focused on the investigation of the challenges of executing SC practices in Sri Lanka. A quantitative research approach was adopted for the fruitful achievement of desired objectives. A questionnaire survey was designed to collect data and targeted 30 professionals including quantity surveyors, engineers, project managers, architects and other professionals in the industry. The results of the analysis revealed the importance and the existing applicability of SC practices in Sri Lanka. However, the results show that the important SC practices in Sri Lanka do not apply to a sufficient level in the Sri Lankan industry. Lack of government support, increasing energy costs and lack of existing SC principles are the major challenges to the SC in Sri Lanka. Finally, the findings recommended further improvement of SC practices in Sri Lanka with the perspective of legal, educational, technical, and financial efforts.

Keywords: *Construction Industry; Sustainable Construction; Sustainable Construction Practices.*

1. INTRODUCTION

The construction industry is one of the major industries that significantly contribute to the growth and economy of the world (Wong & Vimonsatit, 2012). Tripathi and Jha (2019) stated that it is the second-largest industry, in terms of providing employment opportunities. The construction industry is a service industry that performs the planning,

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designing, construction, alteration, refurbishment, maintenance, repair, and demolition of structures as part of a nation's economy (Towey, 2017). Sustainable construction (SC) is a strategy for achieving sustainable development, which is one of the needs of the construction industry (Osuizugbo et al., 2020). Therefore, SC is a very important step in the construction industry.

When it comes to implementing SC practices, there are several challenges to be overcome. SC is a way to ensure that all construction activities are carried out sustainably, from planning to completion, while also considering economic and social factors as well as environmental impacts (Ismail, et al., 2016). Durdyev, et al. (2018); Tokbolat, et al. (2020) recognised that concerns about the cost premium of SC, as well as a lack of knowledge and awareness, have been reported as the most significant challenges, leading to a reluctance to implement the SC concept, particularly in developing countries. Even though SC practices are necessary to the industry, according to Willar et al. (2021), challenges to the execution of new practices, such as SC are constantly present. Moreover, Khalil et al. (2021) presented the challenges confronted by the construction industry in Libya while integrating sustainable practices. It indicates the complexity of implementing sustainable construction practices in the current context. In the Sri Lankan context, there are many construction projects underway hence attention needs to be paid to the SC. Palliyaguru, et al. (2018) also accept that sustainable development has typically been concerning the urban areas, urban populations, and urban issues in Sri Lanka. Furthermore, Jayalath and Gunawardhana (2017) stated that there are many challenges faced by the construction industry in Sri Lanka such as the high cost of construction materials, lack of skilled workers, pollution, delays in land acquisition, and frequent changes in regulations which could affect the SC practices.

According to Tokbolat et al. (2020), the majority of SC practices are environmentally related. However, environmentally sustainable practices are rarely executed in Sri Lanka. Although Sri Lanka has a few SC practices existing, some of them have challenges during their implementation. Therefore, it is important to investigate the challenges of executing sustainable construction practices in Sri Lanka. Hence, this research focuses on SC in the Sri Lankan context and the challenges of executing SC in the Sri Lankan construction industry.

2. LITERATURE REVIEW

2.1 SUSTAINABLE CONSTRUCTION PRACTICES

Sustainability is a challenging task, and it necessitates decision-makers flexibility and willingness to change their approaches (Hussin et al. 2013). Further, the authors stated that it is critical to balance the key elements of sustainability, including the environment, economics, and social aspects, to accomplish sustainable building. As cited by Hussin et al. (2013), SC practices can be implemented at any point during the construction process, from design to demolition. Further, Hussin et al. (2013) cited that the impact of the built environment should be addressed on a life cycle basis, from the origins of the building material, through the manufacture and installation of these materials, to their eventual demolition of the building.

Many authors conducted their surveys on many SC practices which are currently executed in the industry. Table 1 provides a summary of such indicated SC practices and how the authors contributed.

Table 1: Sustainable construction practices in the global industry

Sustainable construction practice/s	Author/s
Introduce Green building codes	Saleh and Alalouch (2015)
Green building bonds	Howe and Gerrard (2010)
Minimise resource consumption Maximum resource reuse Usage of renewable and recyclable resources Comply with prevention of air pollution regulations Create a healthy and non-toxic built environment	Tan et al. (2011)
Construction waste management	Ismam and Ismail (2014); Madurwar et al. (2013); Hussin et al. (2013); Mega (2010); Letcher and Vallero (2011); Saadi, et al. (2016)
Recycling of concrete	Senaratne et al. (2017)
Energy management	Madurwar et al. (2013); Shan et al. (2017)
Generate electricity from renewable sources	Strielkowski et al. (2017)

According to Table 1, majority of the research, scholars have discussed construction waste management as a sustainable construction practice. Furthermore, updated literature findings are emphasising the recycling of concrete and the generation of electricity via renewable sources. Moreover, the industry had taken several practical actions to encourage the development of SC practices as buildings constructed with ecology gives benefit from lower operating, development, and maintenance costs as well as improved durability. Those practices should be incorporated into construction strategies. Construction firms had to change their strategies to incorporate SC practices into their operations because it focused on the industry as legislators, employers, building users and investors become more aware of the environment (Aigbavboa et al. 2017).

2.2 APPLICABLE SUSTAINABLE CONSTRUCTION PRACTICES FOR SRI LANKAN INDUSTRY

Senaratne et al. (2017) stated that the necessity to recycle building and demolition waste, in particular, has grown critical as concrete is the most common building and demolition waste, and aggregate is the most common by-product of recycled aggregate concrete, the greater use of recycled aggregate has been investigated to promote more SC practices. Kariyawasam and Jayasinghe (2016) said that it is critical to think about how to avoid undesirable features of soil and obtain strong, long-lasting, and ecologically friendly building materials. Instead of recycling and reusing existing materials, natural resources are being consumed at an alarming rate to produce new construction materials (Senaratne et al. 2017). The author further stated that to achieve sustainability in the construction industry, the requirement of recycling construction and demolition waste had become a vital aspect. The requirement to become sustainable for the construction industry has become specious with the construction industry being a huge consumer of natural resources (Luhar & Luhar, 2019). The use of recycled aggregate in concrete is a sustainable and economical alternative to natural aggregate and is also effective for non-structural components where strength is not critical (Devi et al., 2021).

Another SC practice was identified to ensure that value is delivered to the project most effectively; the systematic process of value management can be simply divided into three main phases, namely value planning, value engineering and value analysis (Karunasena, et al. 2016). The authors further suggested that the SC team will be led by an architect, while the value planning team will be led by a quantity surveyor. The above concepts are easily applicable to the Sri Lankan construction industry.

Senanayake and Chandanie (2021) stated that more emphasis should be placed on the use of environmental, social, and economic assessments when implementing a construction project, especially at the feasibility stage. According to the authors, tax policy, project scope, scale, and functions, location advantage, the influence of domestic product and resource use policy, technology advantage, market competition, fluctuation in foreign currency, regulation in export and import restrictions, influence in domestic products and resource use policy, and budget estimate are the most critical factors to considered under economic sustainability requirements.

Green BIM technology is a significant innovation that emerged from the integration of BIM with sustainable strategies, enhancing the sustainable growth of buildings while providing better opportunities to improve green building performance (Rathnasiri, et al. 2017).

2.3 SUITABLE SUSTAINABLE CONSTRUCTION PRACTICES FOR THE SRI LANKAN INDUSTRY

Heralova (2017) stated that the sustainability performance of an individual construction project across its life cycle is a vital aspect in attaining the goal of sustainability. Waidyasekara and Fernando (2012) stated that the "Green Building" movement emerged, which later gained traction as a result of the concept of sustainability. Rathnasiri et al. (2017) supported this statement by saying that green buildings provide several benefits for building owners and users. The Sri Lankan government has already established many policies to encourage local green growth (Karunasena and Thalpage 2016). The successful implementation of SC methods is essential to address environmental issues in developing countries. According to Karunasena, et al. (2016), all experts agree that the SC and value planning concepts should be implemented at a higher level in the Sri Lankan construction industry than it is existing.

All experts agree that the SC and value planning concepts should be implemented at a higher level in the Sri Lankan construction industry than is existing. Experts agree that both of these principles should be utilised as early as possible, preferably at the planning stage of a project, because all of these stages are covered at the planning level. According to the finding of (Senanayake and Chandanie 2021), experts pointed out that tax policy should be conducted under any framework and that the government should provide tax concessions and subsidies to projects that encourage SC.

The introduction of recycled concrete to the market is a revolutionary approach (Senaratne et al. 2017). Therefore, quality and consistency could be closely regulated. Furthermore, practitioners, on the other hand, were inspired by the long-term benefits and argued that structures made of recycled aggregate could achieve a higher green rating and it was especially suggested for government projects and those requiring a high level of environmental sensitivity. While focusing on the research conducted by Senaratne et al. (2017), recycling of construction and demolition waste is becoming paramount as well as those wastes have added to SC practices. Those authors supported this statement by referring to the usage of natural and recycled aggregates. However, the above authors said that towards the sustainability of the industry, recycled aggregate must be widely used and even the natural aggregates must be replaced.

Table 2 classifies the SC practices applicable to the Sri Lankan construction industry.

Table 2: Classification of sustainable construction practices for the Sri Lankan industry

Sustainable construction practices applicable for Sri Lanka	Reference/s
Use of ecologically friendly building materials	Kariyawasam and Jayasinghe (2016)
Recycling of aggregate in concrete, Necessity of recycling building and demolition waste	Senaratne et al. (2017)
Using a systematic process of value management for sustainable construction	Karunasena, et al. (2016)
Use of environmental, social, and economic assessment on sustainable construction, Implement sustainable construction and value planning concept	Senanayake and Chandanie (2021)
Green BIM technology	Rathnasiri et al. (2017)
Green building movement	Waidyasekara and Fernando (2012)
Enforcement of policies to encourage green growth	Karunasena and Thalpage (2016)

2.4 CHALLENGES WHEN EXECUTING SUSTAINABLE CONSTRUCTION PRACTICES IN SRI LANKA

Construction activity is commonly considered to have adverse impacts on the environment, which is the basis of sustainable development for human beings (Senanayake and Chandanie 2021). Jayalath and Gunawardhana (2017) said that the Sri Lankan construction industry has not taken enough action to remedy the present issues that face the construction industry.

Table 3 provides a summary of the challenges when implementing SC practices in Sri Lankan construction. Sustainability in construction is a challenging task for contractors due to diminishing natural resources and increasing energy costs (Athapaththu and Karunasena 2018). Senaratne et al. (2017) identified that the use of recycled aggregate has been discovered to lead to a sustainable future by generating an alternative to the use of traditional natural concrete. However, the authors said that the research on recycled aggregate has found limiting factors to the use of materials due to its shortcomings related to its low strength.

Table 3: Challenges to implementing sustainable construction in Sri Lanka

Identified Challenges	Source
Diminishing natural resources, not following sustainable construction procedures	[1]
Shortcomings due to law strength of sustainable construction materials	[2]
Lack of sustainable construction principles in the Sri Lankan Industry	[3]
Unstable developing activities due to the environmental, social, and economic challenges	[1]

Identified Challenges	Source
Complexity, an increase in the cost of construction projects, risks, and the mindset of stakeholders	[4]
Lack of client awareness of SC, sustainable design costing, lack of government support, and shortages of value planning proposals on sustainable construction.	[4]
Lack of legislation and regulations on sustainable construction	[5]
Inherent capabilities of Green BIM technology	[6]
Sources: [1] Athapaththu and Karunasena (2018); [2] Senaratne et al. (2017); [3] Senanayake and Chandanie (2021); [4] Karunasena, et al. (2016); [5] Hewage and Indrani (2011); [6] Rathnasiri et al. (2017)	

The research findings of Athapaththu and Karunasena (2018) argued that contracting organisations based in Sri Lanka do not follow existing SC procedures. This is confirmed by Senanayake and Chandanie (2021) by reporting that there is no guidance for implementing sustainable development principles in the construction industry. Karunasena, et al. (2016) reported some challenges within the industry by stating that there is no standard or consistent process for both SC and value planning applications in the Sri Lankan construction industry.

The nation continues to struggle with not only environmental but also economic and social challenges as a result of the country's unstable development activities over the years (Karunasena, et al. 2016). As resources become scarcer, social, environmental, and economic sustainability is becoming increasingly important (Karunasena, et al. 2016). Because of those risks and mindsets of stakeholders, SC practices are implemented very lower. Even though that is stated, Karunasena, et al. (2016) said that employers, clients, contractors, consultants, the government, and all other stakeholders in the industry have a significant responsibility to work toward efficient design, construction, and upkeep of the built environment using sustainable techniques.

Some major challenges according to Karunasena, et al. (2016) the execution of SC practices; lack of client awareness of SC, sustainable designs costing more than regular designs when considering initial costs, lack of government support, more time-consuming at the initial stage of design, less knowledge of sustainability, consultants not coming up with sustainable and value planning proposals, shortage of value planning proposals were identified as challenges and drawbacks for SC. Similar to the above statement, Hewage and Indrani (2011) reported that in comparison to environmental protection, there is a lack of legislation and regulations in Sri Lanka that directly affect sustainability practices. Finally, releasing the developed project feasibility criteria as a sustainability guideline as project clearance will improve Sri Lankan green building practices.

When considering BIM technology for the Sri Lankan construction industry, Rathnasiri et al. (2017) reported that the inherent capabilities of green BIM technology are hidden and invisible in the Sri Lankan context because BIM has not yet been implemented in building construction, operation, and maintenance. As a result of this, the authors further stated that an effort is required to encourage and demonstrate the value of Green BIM technology for green building practitioners.

3. METHODOLOGY

3.1 RESEARCH DESIGN

According to Kothari (2004), a research design is a conceptual assembly based on which the whole research shall be conducted, in which the data shall be collected and analysed for the sake of achieving the aim of the work. The author further said that the function of research design is to obtain relevant evidence with the least amount of effort, time, and money possible. Research design guides the ultimate target of achieving the research objectives.

3.2 RESEARCH PROCESS

Abu-Dalbouh (2013) demonstrates the different steps, which were followed during the research process to proceed with research with problem exploration, data collection, and analysis. The research problem was thereafter grounded within literature to formulate the research problem of this study. Further, adhering to the following sequential process, helped to avoid errors and attain the expected results.

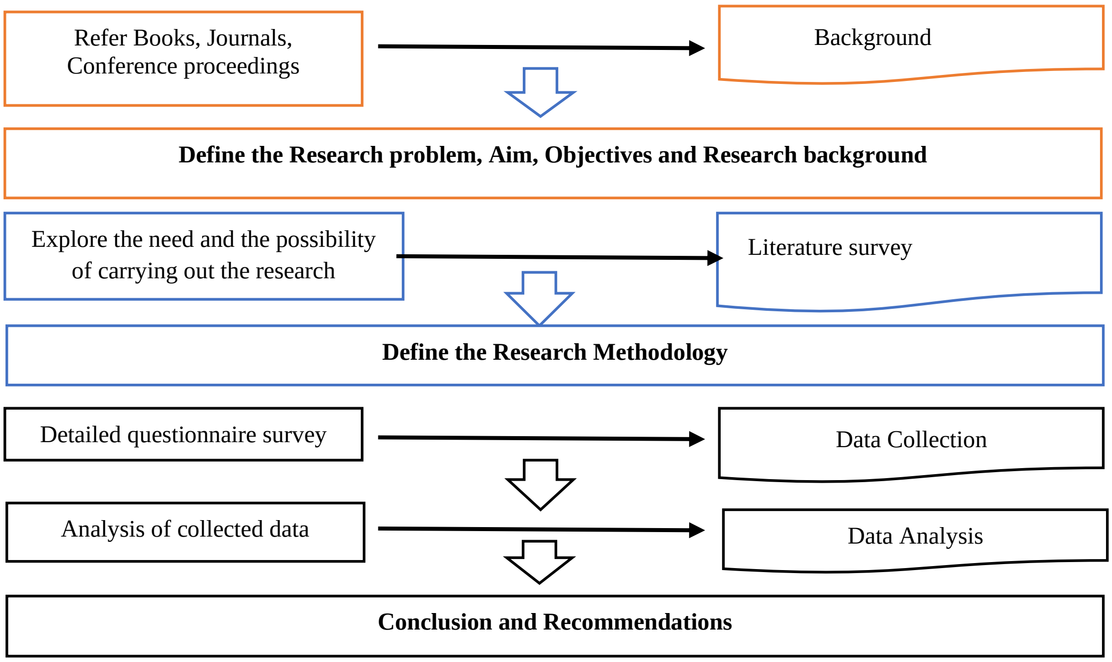

Figure 1: Research process

3.3 RESEARCH APPROACH

According to the definitions and comparison of the above research approaches, it was decided to choose a quantitative research approach for this study. This research purposes to address the problem challenging factors of executing sustainable knowledge in the Construction industry in Sri Lanka, to identify the challenging factors of executing sustainable knowledge in the construction industry in Sri Lanka, it requires in-depth inquiry to gather information related to applications and executions of SC practices in the Sri Lankan industry. To achieve the expected results of this study all the information associated with SC projects in Sri Lanka has to be investigated. Therefore, a quantitative research approach was facilitated here in this research to go through practical aspects broadly.

3.4 RESEARCH STRATEGY

Among these research strategies survey method had been chosen as the most appropriate strategy for this research due to the following reasons. The study under consideration is required to gain opinions regarding the challenges of executing SC knowledge in the Sri Lankan construction industry. Further, the identification of SC practices and procedures to be followed when providing SC knowledge in construction projects was another focus of the research. Hence, a survey strategy was used during the data collection.

3.5 DATA COLLECTION

The common data collection methods include interviews, questionnaire surveys, documentary review, observations, and audio-visual materials. To collect the data on overall project performance, some of the critical factors identified were used in the questionnaire. To achieve the objectives of this research, a detailed questionnaire survey was selected as the data collection technique. In the quantitative approach, a set of questionnaires that contains the number of questions is sent to the required professionals in the industry. Using data collection techniques to gain the essential details to establish the research problem, a questionnaire survey was developed based on the literature review with the "Likert scale" since the SC procedures in construction projects in Sri Lanka were some projects with different challenges. Table 4 shows the profile of the respondents illustrating their experience and involvement in the construction industry.

Table 4: Profile of the respondents

Category	Inclusive groups	Respondents
Type of occupation	Quantity Surveyor	60.00%
	Project Manager	16.70%
	Engineer	13.30%
	Architect	6.70%
	Safety Officer	3.30%
Level of Experience	Less than 01 year	20.00%
	Between 01 – 05	66.70%
	Between 06 – 10	13.30%
Education Level	Bachelor's degree	77.00%
	Master's degree	10.00%
	Diploma	13.00%

The above data illustrates that the majority of the respondents are quantity surveyors with between 1-5 years of industry experience. Furthermore, more than two-thirds of the respondents are with bachelor's degree as the highest educational qualification.

3.6 DATA ANALYSIS

Data analysis after data collection is influenced by the expected result of the research. SPSS, Excel software used to analyse the quantitative data gathered from the questionnaire survey. The Likert scale responses should be in a specified order in which the respondent's preferred answer is chosen. For the analysis of quantitative data collected through the questionnaire survey, the Relative Important Index (RII) technique was used, and Excel was used to calculate RII.

4. DATA ANALYSIS

4.1 COMPARISON ANALYSIS OF LEVEL OF IMPORTANCE AND EXISTING APPLICATION OF SC PRACTICES

Table 5 introduces the sustainable practice terminologies used for the research. The RII value was generated through the questionnaire survey responses obtained from 58 professionals. Table 5 comparatively presents the RII value for each sustainable practice considering their importance and existence in the construction industry. It gives an understanding to the reader of the key focus areas of sustainable practice from practical and theoretical perspectives.

Table 5: Comparison of application and importance of sustainable construction practices in Sri Lanka

Ref	Sustainable practice	RII for Application of SC	RII for Importance of SC
SP3	Minimise resource consumption	0.7067	0.9133
SP8	Energy management	0.7067	0.8600
SP11	Use of Ecological friendly building materials	0.6667	0.8866
SP5	Using recyclable resources	0.6600	0.9000
SP10	Enforcement of policies to encourage green growth	0.6533	0.8600
SP1	Using green building codes	0.6467	0.8666
SP4	Using Renewable resources	0.6467	0.9400
SP6	Construction Waste Management	0.6267	0.8733
SP2	Using Green Building Bonds	0.6200	0.8000
SP9	Green BIM technology	0.6000	0.7866
SP7	Recycling of concrete	0.5267	0.8133

Responders are asked to rate the SC practices according to the level of importance and level of the existing application in the Sri Lankan industry. Figure 2 depicts the comparison of the overall mean value of each SC practice based on parameters of importance and application in the industry. Furthermore, the illustration of the gap between 2 parameters (importance and existing application) signifies the areas which are lacking in the Sri Lankan construction industry.

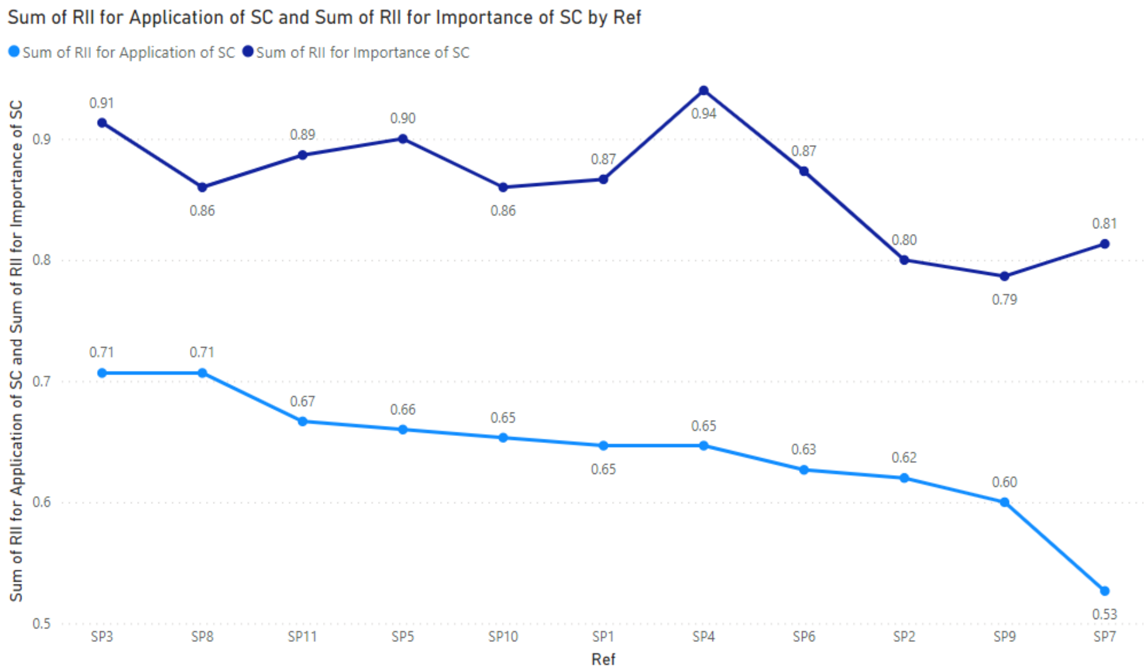

Figure 2: Comparison between the importance and application of SC practices in the SL industry

According to Figure 2, it illustrated SP4 achieved the highest mean value (4.70) for "level of importance to Sri Lanka". Then the second highest mean value (4.57) is archived by SP3. All the SC practices received a mean value of or above 4.00. That means those are "important" to the Sri Lankan industry according to the Likert scale. The mean value of SP4 and SP3 for "application of SC practices within the existing industry" are respectively 3.23 and 3.5. Even though SP4 and SP3 received the highest mean values for "importance to the SL industry", they received mean values of 3.23 and 3.50 respectively for "existing application in the SL industry".

Except for SP7, all other SC practices received on or above 3.00 for mean value. That indicates that even though all the SC practices can be considered as "important" to the SL industry, application within the existing industry of those SC practices is "Sometimes", according to the used Likert scale. Only SP7 can be depicted as "rarely applying" within the SL industry even though it ranked as an "important SC practice" to the SL industry. Furthermore, SP2 has the lowest gap among all the sustainable construction practices based on their existence and their importance as an SC practice.

Baloi (2003) agreed that the minimise resource consumption (SP3), using recyclable resources (SP5) and using renewable resources (SP4) are important SC practices. Additionally, Baloi (2003) presented that protection of the natural environment, creation of a quality-built environment, and a healthy and non-toxic environment are the main principles of sustainable construction, which is known as the SC practices. However, compliance with sustainability, design and procurement, technology and innovation, organisational structure and process, education and training, and measurement and reporting are presented as the SC practices by Tan, et al. (2011), which were not identified in this research. Hence, there is a variety of SC practices and their availability and importance in the Sri Lankan context. Hence, the importance of SC practices in the construction industry is varying based on the country. The research findings have presented the unique SC practices in Sri Lanka compared to previous research studies.

4.2 RECOMMENDATIONS TO FURTHER IMPROVE THE SUSTAINABLE CONSTRUCTION PRACTICES IN THE SRI LANKAN INDUSTRY

Findings that had been obtained from the questionnaire survey had been categorised according to the efforts. To implement SC practices in Sri Lanka, there should be influence from many sides. Those efforts are considered legal, educational, technical, and financial efforts. Figure 3 presents the efforts in which the obtained recommendations were categorised.

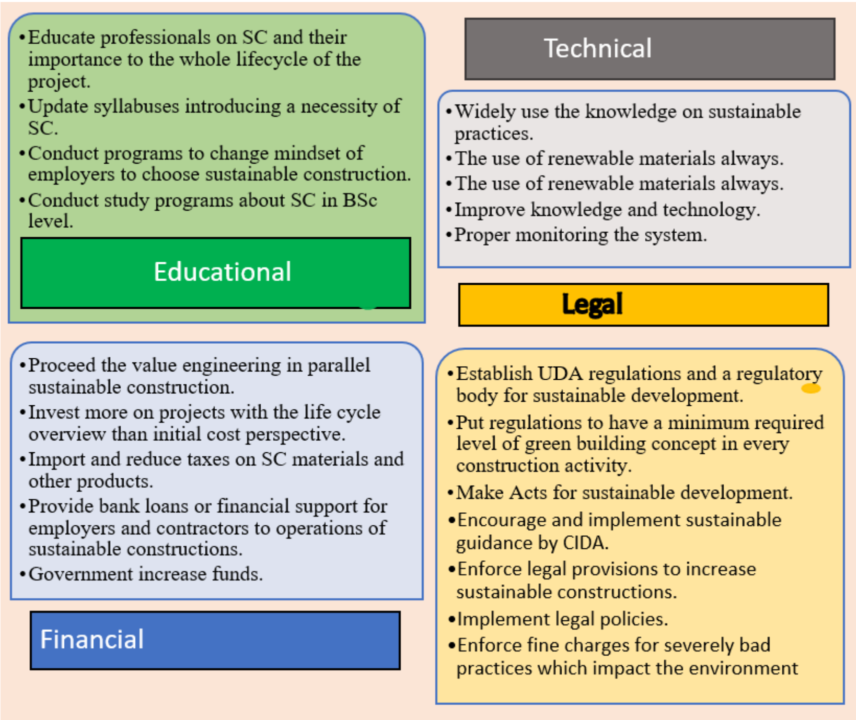

Figure 3: Recommendations to further improve the SC practices in Sri Lanka

According to Figure 4 the combination of legal, technical, educational, and financial efforts the SC practices are intended to implement in Sri Lanka. Athapaththu and Karunasena (2018) have presented a framework inclusive above finding in Figure 4 confirming the importance of these factors for the implementation of SC practices in Sri Lanka. Hence, the above 4 factors are ideal to implement SC practices in Sri Lanka. Additionally, standards, guidelines and policies are vital considerations that help the improvement of SC practices in Sri Lanka (Athapaththu, et al. 2016).

5. CONCLUSIONS

Although Sri Lanka lacks adequate SC methods, there is a great need for SC as a developing country. SC practices are the "use of ecologically friendly building materials, recycling of aggregate in concrete, the necessity of recycling of building and demolition waste, using a systematic process of value management for SC, Use of environmental, social, economic assessment on SC, Implementing SC and value planning concept, Green BIM technology, Green building movement, Enforcement of policies to encourage green growth".

The construction industry has a huge environmental impact, consumes huge energy and the construction industry is conversely depleting of natural resources. Therefore, the SC is important for environmental protection. Globally identified SC practices were subjected to identify the level of importance and applicability. Those SC practices are "Introduce green building codes, green building bonds, minimise resource consumption, maximum resource reuse, usage of renewable and recyclable resources, comply with prevention of air pollution regulations, create a healthy and non-toxic built environment, construction waste management, recycling of concrete, energy management and generate electricity by renewable sources". All the SC practices were identified as "Important" SC practices to Sri Lanka. Even if the result is like that, "recycling of concrete" observed as "rarely" applicable while others observed as "sometimes" applicable in construction projects in Sri Lanka.

Diminishing natural resources, increasing energy cost, not following SC procedures, Shortcoming due to low strength of SC materials, lack of SC principles in Sri Lanka, unstable developing activities due to environmental challenges, Unstable developing activities due to social challenges, Unstable developing activities due to economic challenges, the complexity of projects, mindset of stakeholders, lack of clients awareness of SC, lack of government support, Sustainable design costing, high time consuming, less knowledge on SC, shortages of value planning proposals on SC, lack of legislation and regulations on SC, inherent capabilities of Green BIM, and technology challenges are challenges for executing sustainable practices in Sri Lankan construction industry.

Adhere to a proper plan from the inception until the completion of a project, improve Knowledge of SC practices among stakeholders, improve rules and regulations on SC by the Government, increase the awareness of the community on SC, move to use green construction materials and implement an effective waste management plan, rate contractors according to their bias about involving sustainable projects/using a ranking method on SC for Contractors were mainly identified strategies to overcome the challenges for executing sustainable construction practices in Sri Lanka. The adaptability of those identified strategies to the Sri Lankan context was investigated by the questionnaire survey.

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IS INTEGRATED PROJECT DELIVERY SUFFICIENT TO REDUCE ADVERSARIALISM IN THE UK CONSTRUCTION INDUSTRY?

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ABSTRACT

Adversarialism is an endemic feature of the construction industry, resulting in devasting effects on productivity, cost, performance and client satisfaction within the industry. This can be explained by various factors of which adversarial 'traditional' construction contracts is one. To reduce adversarialism and to establish sustainable construction methods and practices in the United Kingdom (UK), the Integrated Project Delivery (IPD) method has been advanced as a solution. The critical review and analysis of relevant literature as well as prominent studies show that; although the use of IPD resulted in a better, healthier outcome in comparison to normal/traditional adversarial system, IPD still suffered from significant limitations, challenges and persistent barriers. These barriers thus indicate and necessitate the need for further research in determining a sufficient way in reducing adversarialism within the UK construction industry. One of the recommended empirical investigations include whether legislation has an influence on good faith towards reducing adversarialism. Another empirical investigation recommended is the premise that the barriers and challenges IPD present may likely be overcome by the implementation of statutory-backed good faith legislation, thus improving collaborative working. This paper will contribute to the wider knowledge of IPD in the industry and to improving the performance of the UK architecture, engineering and construction industry through collaborative working.

Keywords: *Adversarialism; Collaborative Working; Construction Contract Good-Faith; Integrated Project Delivery (IPD).*

1. INTRODUCTION

Adversarialism is an endemic feature of the Architecture, Engineering and Construction (AEC) industry, resulting in devasting effects on productivity, cost, performance, and client satisfaction within the industry (Latham, 1994; Bishop et al., 2009; Arcadis, 2021). This can be explained by various factors of which adversarial 'traditional' construction contracts is one (O'Connor, 2009). These adversarial contracts focus on the consequences of failure (e.g., milestone penalties, and liquidated damages), reinforcing self-protective

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behaviour and mistrust among contracting parties (Bishop et al., 2009; O'Connor, 2009). Adversarial contracting is normal in the industry (National Building Specification [NBS], 2018). To depart from this, experts have advocated that change in contractual approach towards construction contracts is needed (Latham, 1994; Egan, 1998; Murray and Langford, 2003; Cain, 2004). Therefore, to address the outlined issue(s), Integrated Project Delivery (IPD) has been advanced as a solution to sufficiently tackle adversarialism (American Institute of Architects [AIA], 2007; Ashcraft 2010). This paper explored the IPD solution to determine if it can be regarded as sufficient to reduce adversarialism, thus proffering better and healthier practices regarding construction contract negotiations.

2. LITERATURE REVIEW

2.1 THE CURRENT STATE OF CONSTRUCTION CONTRACTING

The AEC industry is highly fragmented and adversarial (O'Connor, 2009; Naoum et al., 2010). Conflict is the norm and numerous industry experts are dissatisfied with project outcomes; lamenting about inefficiency and the adversarial nature of construction services procurement and delivery (Lichtig, 2006; NBS, 2018). In the UK, the sub-optimal performance of the industry is evident. Over the last 80 years, reports have raised concerns over the industry's performance branding it 'under-performing' (Latham, 1994; Egan, 1998; Murray and Langford, 2003; Wolstenholme 2009). Presently nothing has changed as according to Arcadis (2021, 2022) conflict within the industry remains rising.

Globally, from 2020 to 2021, average disputes length increased by almost 15% (Arcadis, 2021). The UK experienced an 11.8% increase (Arcadis, 2022). From 2019 to 2020, the average UK dispute value increased to approximately $38.6 Mn, a 117% increase. Although, from 2020 to 2021, there was a dip in value at $37.8 Mn, levels remain historically high in comparison to levels from 2013 to 2019 (Arcadis, 2022). One of the most prominent factors causing conflict is non-cooperation due to fundamental differences in views and interests between parties (NBS, 2018). These differences foment a culture of hostility and distrust amongst parties leading to adversarial contracting (Bishop et al., 2009). To further elaborate, when traditionally negotiating construction contracts, clients are risk evasive, while contracting counterparties interpret contract clauses differently and for their own benefit (O'Connor, 2009). Risk assessment becomes a dark art and risk allocation an exercise in economic Darwinism (ibid). Often, risk flows down the contracting tiers to those least able to bear or control the risk causing parties to approach contractual negotiations with mistrust and self-protective behaviours (Bishop et al., 2009; O'Connor, 2009). The institutional framework of the industry does little to encourage collaboration between parties. Thus, they often end up working at arms-length in disjointed relationships, motivated by divergent objectives, hidden agendas, profit margins and bottom lines in order to squeeze value from each stage and structure of the production process (Ng et al., 2002; Bishop et al., 2009; O'Connor, 2009). Typically, it is commonplace for contractors at each point of construction or production process to exploit and undermine each other (Bishop et al., 2009). Not surprisingly, adversarial contracts combined with traditional delivery methods often produce sub-optimal results (O'Connor, 2009; Ashcraft, 2010).

2.2 COLLABORATIVE WORKING AND "GOOD-FAITH-LIKE" SOLUTIONS

Consequently, industry experts like Latham and Egan have advocated for collaborative working as a solution to combat adversarialism (Latham, 1994; Egan 1998, Wolstenholme, 2009). However, its impact has been minimal (Ng et al., 2002) due to reasons such as lukewarm attitudes within the industry (Ng et al., 2002; NBS, 2018). Experts also proposed the use of "good-faith-like" wording within standard-form contracts to potentially combat adversarialism. For example, in the UK, Latham suggested that parties should agree to deal with each other in a spirit of mutual trust and co-operation (Latham, 1994). These types of wording are prevalent in the New Engineering Contract (NEC) and to an extent the Joint Contracts Tribunal (JCT) forms. Despite their use over the last 20 years (Christie, 2019), adversarialism continues to worsen. This suggests that, trying to insert collaborative or good-faith-like wording into adversarial contracts will not solve the issue. A more drastic solution is needed and IPD has been proposed as that solution.

2.3 INTEGRATED PROJECT DELIVERY

IPD is a method of delivery which fully integrates collaborative working amongst all contracting counterparties (O'Connor, 2009; Ashcraft, 2010; Reaves, 2012). Its principles are: (i) mutual respect and trust, (ii) mutual benefit and reward, (iii) collaborative innovation and decision making, (iv) early involvement of key participants, (v) early goal definition, (vi) intensified planning, (vii) open communication, (viii) appropriate technology; and (ix) organisation and leadership (AIA, 2007; Ashcraft, 2010;). IPD evolved out of an industry frustration with construction and design mistakes, excessive costs and delays, as well as the aggressive and adversarial methods of construction contracting (O' Connor, 2009; Reaves, 2012). It goes beyond using good-faith-like wording, partnering techniques and the early involvement of construction managers in the design phase. Rather, it is a process that reinforces collaboration from the beginning of the design to the end of construction and gives every party to the project a stake in the outcome of the project (Reaves, 2012). Thus, parties share risk and reward equitably. To elaborate, IPD's compensation structure follows a project alliancing model with the goal of stimulating efficiency and alignment of interests for the benefit of the project in its entirety (Australian Department of Treasury and Finance [ADTF], 2006; Ghassemi and Becerik-Gerber, 2011). Project participants are compensated on a cost-plus basis where the owner guarantees the direct cost, but a portion of the profit and participants' bonuses are dependent on project outcome (AIA, 2007; Ghassemi and Becerik-Gerber, 2011).

Furthermore, risk management in IPD is handled differently in comparison to typical/standard construction contracts. Overall risk essentially remains the same (AIA, 2007) because risk and uncertainty are tied to the project outcome and is collectively managed by all parties to the project (Darrington and Lichtig 2018). The structural elements of IPD are intended to create a self-regulating system (Ashcraft, 2010). Therefore, by aligning the goals of all parties around collective project success, and by making each party accountable for the behaviour of others, project teams gain more control of the overall process and better mitigate the overall risk (Cohen, 2010; Ghassemi and Becerik-Gerber, 2011).

2.4 BENEFITS OF IPD

In addition to its compensation structure, and risk management (self-regulating) system there are other benefits to using the IPD method. IPD brings the skill of key project participants like developers, administrators, manufacturers, contractors, architects, planners and other professional consultants together prior to tender (Abrishami et al., 2014; Dalui et al., 2021). This ensures a project plan and structure that is optimised for quality, aesthetics, constructability, convenience and ensures collaborative working during the lifecycle of the project (Aschcraft, 2010; Dalui et al., 2021). Collaborative working can help to facilitate the delivery of construction projects to time, budget and specification by encouraging open communication, knowledge sharing, and by assisting in forming closer relationships between the parties to a project (Larson, 1997; Constructing Excellence, 2004). For example, Dodge (2017) found that 91% of contractors and owners agreed that collaborative working reduced risk on construction projects. Thus, collaborative working is required to achieve a common objective within the project team and to extend the efficiency and quality among the group (Dalui et al., 2021). This is what IPD offers.

2.5 COMPARISON BETWEEN TRADITIONAL ADVERSARIAL DELIVERY (CONTRACTING) AND IPD

Table 1 presents a comparison between traditional adversarial delivery/contracting and IPD.

Table 1: Traditional adversarial delivery (contracting) vs integrated project delivery

Traditional Adversarial Delivery (Contracting)		Integrated Project Delivery
Typically appointed/engaged on “just-as-needed” or “minimum-necessary” basis, strongly hierarchical, controlled	Teams	IPD composes of key project stakeholders, who were appointed/engaged early (from FEED design to project end), knowledge sharing, open and collaborative.
Fragmented, distinct, segregated, knowledge gathered	Process	Multi-tiered, early contributions of know-how, knowledge and expertise, information openly shared and parties/stakeholder trust and mutual respect.
Individually managed, flown down through the (tiered) supply-chain	Risk	Collectively managed, equitably and appropriately shared, creation of a self-regulating system.
Rigid, two-dimensional, and analogue	Communication s/Technology	Flexible, digitally based, virtual and Building Information Modelling (three-four- and five- dimensional)
Individualistic, individually pursued, adversarial, minimum effort for maximum return.	Compensation/r eward	Equitably shared, cost-plus bonuses, team success tied to project success and value based.
Encourages unilateral effort, poor allocation and transfer of risk and no sharing	Agreements	Risk sharing, equitable allocation of risk (i.e. who can better bear the risk), promote and support multilateral open sharing and collaboration

Source Adapted: AIA (2007); Kahvandi et al. (2020)

3. IPD AS A POTENTIAL SOLUTION TO REDUCE ADVERSARIALISM?

3.1 SUITABILITY OF IPD

IPD is not entirely suitable for all construction projects. For example, most governmental entities regardless of jurisdiction may be unable to proceed with a true IPD project because governmental procurement codes, rules, statutes and/or regulations may mean that certain professional consultants (e.g., architects) are engaged under a defined fee schedule with a prescribed contract form (Reaves, 2012). However, in the case where IPD may not be suitable, its characteristics may still be applied in negotiating construction contracts to achieve a smoother and more successful project (Reaves 2012; Kahvandi et al., 2020). This premise was explored by the Ghassemi and Becerick-Gerber (2011) study (Refer to Table 2), which examined nine industry cases with varying degrees of IPD characteristics embodied in the projects.

Table 2: IPD characteristics embodied

Case No	Early involvement (Y/N)	Shared Risk/reward (Y/N)	Multi-Party Contract (Y/N)	Collaborative decision making (Y/N)	Liability waivers (Y/N)	Jointly developed goals (Y/N)
1	Y	N	N	Y	N	N
2	Y	Y	Y	Y	N	Y
3	Y	Y	Y	Y	N	Y
4	Y	Y	Y	Y	Y	N
5	Y	N	N	Y	N	N
6	N	N	N	Y	N	N
7	Y	N	N	N	N	N
8	Y	Y	Y	N	N	Y
9	Y	Y	Y	Y	N	Y

Source: Adapted from Ghassemi and Becerik-Gerber Study (2011)

The conducted study revealed that none of the projects utilisng IPD characteristics suffered from the commonly observed issues within the industry. However, the authors discovered that IPD suffered from four main barriers/challenges, namely: (i) cultural, (ii) financial, (iii) legal and (iv) technological barriers (Ghassemi and Becerik-Gerber, 2011).

3.2 CHALLENGES AND BARRIERS FOR USING IPD

The following subsections are reviewing challenges and barriers for using IPD.

3.2.1 Cultural Challenge

Over the years the industry has mainly implemented a traditional adversarial delivery system, thus could be unwilling and/or reluctant to apply a different approach (Ng et al., 2002; Lichtig, 2006; Reaves, 2012; Viana et al., 2020). To overcome this challenge, one of the potential solutions is to implement a training system for the purported IPD project team and project stakeholders in order to demystify the method (Viana et al., 2020). Ghassemi and Becerik-Gerber (2011) conducted a survey to prove the efficiency of this solution. They found that an intensive training system appeared to help the transition from the traditional method to IPD. Therefore, the application of intensive learning and personal behavioural changes aiming to overcome cultural challenges may be considered a viable solution (Viana et al., 2020)

3.2.2 Financial Challenge

The financial challenge could be considered as an issue to select the compensation and incentive structure. Traditional adversarial contracts foster individual responsibilities that cause and inhibit collaboration. This is the industry norm (NBS, 2018). Therefore, when implementing IPD, the practice of minimum effort for maximum reward (AIA, 2007; Kahvandi et al., 2020) must be overcome. Intensive IPD training may aid in overcoming this barrier (Fischer et al., 2017), however until there is an entire shift in mindset, an openness and a willingness to accept IPD, this barrier will continue to persist.

3.2.3 Legal Challenges

The main issue regarding legal challenges could be addressed as the structure and/or framework of the contract applicable to the project, as well as the insurances and liabilities that may accrue to the project. (Viana et al., 2020). Insurances assign liabilities to each party involved in the project. This could create a complex environment related to proper management of risks and insurance allocation (Cohen, 2010; Ghassemi and Becerik-Gerber 2011). To overcome these issues, within the study conducted by Ghassemi and Becerik-Gerber (2011), some construction companies selected a (form of) contract with a multi-party agreement that was suitable for traditional insurance companies. Utility of such a contract will mitigate or eliminate the capability to build a lawsuit between the parties (Ghassemi and Becerick-Gerber 2011).

3.2.4 Technological Challenge

Technological challenges could be considered as the liability, ownership, and interoperability to implement the integrated software's into the project (Kent and Becerik-Gerber 2010; Viana et al., 2020). The IPD method integrates people and systems, thus an integrated software is essential (McCurley and Powell, 2015). BIM software is usually used on construction projects. However, this could create a problem for IPD team members who are entirely new or lacking the skills to utilise the software (Viana et al., 2020). To overcome this challenge, it has been suggested by Rachid (2021) that taking BIM training courses prior to the commencement of the project may increase the popularity and use of BIM software.

3.3 The Simonsen et al. (2019) Case Study

The case study investigated the implementation of IPD at the Tonsberg project (a hospital project in Norway). Table 3 indicates the different elements of IPD implemented into the project.

Table 3: IPD contractual behaviour and supporting elements implemented at Tonsberg project

Implemented elements of IPD	Tonsberg project
Contract	
A. Early Involvement of key participants/ stakeholders	Implemented
B. Shared risk and reward	Implemented
C. Joint project control	Implemented
D. Reduced liability exposure	Partly implemented

Implemented elements of IPD	Tonsberg project
E. Multiparty agreements	Implemented
F. Jointly developed and validated targets	Implemented
G. Fiscal transparency	Partly implemented
H. Intensified design and planning	Implemented
Behaviour	
A. Respect and trust	Implemented
B. Willingness to collaborate	Implemented
C. Open communication	Implemented
Co-location	Implemented
Lean construction	Implemented
BIM	Implemented

Source: Simonsen et al. (2019)

The Tonsberg project study produced the following findings contained in Table 4:

Table 4: Categorisation and summary of lessons learned regarding implementation of IPD

Case specific learnings	Initial barriers to overcome	Persistent barriers
I - Allocate enough time for careful selection of the right people to be involved early in the project	I - Lack of experience and knowledge to understand and make a fair contractual agreement and ensure that IPD and the supporting methods are applied as intended	I – Difficulties in determining realistic cost estimates in early phases which makes it difficult to create a fair sharing of risk and rewards
II- Freeze the conceptual design in an early stage and avoid going into detailed design before the main concept is defined (freezing the initial design also has a positive effect on cost estimates	II – A better understanding of IPD is needed for the project participants to fully understand their new roles and to get the full potential out of the collaboration	II- Joint project control is difficult to achieve because the owner has to be willing to give up power in decisions which influence the product, he/she is purchasing
III- From the start focus should be on ensuring constructability and cost efficiency of the main concept	III – Development of national templates and adoption of national regulations and laws to fit with the IPD method	III – Opposing objectives between project participants makes it challenging to jointly develop targets that all parties find acceptable, Moreover, the owner again has to be ready to give up power.
IV- Contractual documents should be adapted and signed as early as possible to increase financial transparency.	IV – Development of guidelines for applying TVD to ensure the method is applied as intended.	IV- It is difficult to achieve fiscal transparency through the entire project organisation
V- Cost estimates should be carried as an iterative process		V – Ensuring that all project participants work towards the

Case specific learnings	Initial barriers to overcome	Persistent barriers
to improve the quality of the measures		common goals (and predefined targets)
VII – in the pre-project and design phases, the co-location can be located where it is most practical for the project participants. Locating it closer to project participants lower travel expenses		VI – A risk of opportunistic behaviour of project participants which will influence as the allocation of risk rewards and liability.
VIII – Make early agreements and predefined standards on level of detail in BIM. Using BIM for communication directly to craftsmen was found challenging and required extra education of the craftsmen.		

Source Adapted: Simonsen et al. (2019)

This study revealed that the Tonsberg project had several positive outcomes. According to the data, overall, it led to increased ownership among project participants (i.e., effective self-regulation) as suggested in the literature review (Abrishami et al., 2014; Dalui et al., 2021), and fewer surprises in the construction phase due to more buildable solutions (Simonsen et al., 2019). The study also reported improved collaboration amongst the project participants as the focus was shifted toward common project goals instead of individual achievements as suggested by Reaves (2012).

However, according to the study, using IPD presented challenges. These included: (i) change of law - adapting national standards and laws, (ii) the need to develop national templates that fit with IPD, as well as (iii) developing guidelines for ensuring contractual elements and supporting methods are well understood and applied as intended. There were also persistent barriers as evidenced in Table 4. Some other barriers included (iv) difficulty in determining realistic cost estimates in the early phases of the project, (v) creating a fair sharing of risk and rewards, (vi) achieving joint project control (which means the owner being willing to give up power in decisions), (vii) developing common targets due to opposing objectives between project participants, and (viii) financial transparency. The first and second studies are eight years apart, yet the outcome of both studies reflect the position that IPD still suffers from significant limitations. Although IPD has had an impact in reducing adversarial practices, the persistent and recurring barriers revealed in both studies suggest that the implementation of IPD is not sufficient to reduce adversarialism within the industry. Thus, leading to a conclusion that a further drastic step is required to reduce adversarialism.

4. IS LEGISLATION THE FURTHER STEP NEEDED?

The introduction of laws and regulation (via the use of legislation) is established as an effective way to change practices, attitudes, and behaviours (Bilz and Nadler 2014). This is demonstrable in the UK AEC industry (Constructing Excellence, 2007; Willmott Dixon 2010). Thus, the further step needed to achieve sufficient reduction of adversarialism in the UK may be to create a statutory-backed law (via legislation) which creates a statutory duty of good faith. It may be the case that such a measure may bolster and support the IPD philosophy, changing adversarial behaviours and fostering collaborative working.

5. CONCLUDING REMARKS

This paper has established that IPD is not sufficient to reduce adversarialism within the UK construction industry due to persistent challenges/barriers. A further step is needed and the creation of a statutory duty of good faith has been proposed as the solution to attain sufficient reduction of adversarialism. Drawing on the points covered in this paper, the following propositions and hypotheses need empirical investigation:

- Legislation has an influence on good faith towards reducing adversarialism,
- IPD barriers/challenges will be easier to overcome if there is a statutory-backed law/legislation of good faith in the UK,
- Collaboration in construction projects is likely to increase if statutory-backed good faith duties are inserted into construction contracts, and
- Adversarial, hostile, lukewarm attitudes towards collaborative working are likely to change if statutory-backed good faith duties become the norm in industry standard.

The next phase is an empirical study investigating the above propositions and hypotheses and using qualitative research to advance the understanding.

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ISSUES CAUSED BY EMPLOYMENT OF MIGRANT WORKERS IN THE SRI LANKAN CONSTRUCTION INDUSTRY

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ABSTRACT

Construction is one of the industries with a very high growth rate in Sri Lanka. With this growth, recent decades have seen a considerable rise in the number of migrant workers because of globalisation, wars, conflicts, poverty, and economic developments. While this wave offers the construction industry, organisations, and migrants many benefits, it also has drawbacks. Due to several reasons, migration has an impact on the Sri Lankan construction industry. However, this migration has several negative consequences and difficulties for the industry. Therefore, it is vital to recognise them and offer solutions. This paper discussed issues caused by the employment of migrant workers in the Sri Lankan construction industry, and research aimed to develop strategies to mitigate the issues caused by migrant workers in the Sri Lankan Construction Industry. The study used a mixed-methods approach, collecting data through questionnaire surveys and semi-structured interviews. Through a questionnaire survey, the research findings identified the top 13 issues brought on by the employment of migrant workers in Sri Lanka. "Communication issues," "Language barriers," "Competition for jobs," "Outflow of currency," and "Spread of Diseases" are the top five most important issues. Through expert interviews, the definitive significant management methods for those identified significant concerns were developed. The suggested solutions are divided into two categories: Strategies that construction organisations can use to overcome the issues and Strategies that the Sri Lankan government can use to overcome the issues Implementing training sessions, forming support groups, improving visual communication, modifying Sri Lankan government rules and regulations, and promoting an open Health and safety culture are the key strategies suggested in this study.

Keywords: *Construction; Issues; Migrant Workers; Sri Lankan Construction Industry; Strategies*

1. INTRODUCTION

The success of a construction project depends on a variety of elements (Hickson & Ellis, 2014). In any given project, construction labour is the largest set of human resources (Hickson & Ellis, 2014). As such, the availability of labour resources is essential to the success of a project (Hamid et al., 2011). But due to various reasons, such as local labour

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shortages, a strong demand for unskilled labour for laborious tasks, and migrant workers' willingness to accept lower pay rates, migrant workers currently account for a significant percentage of the construction industry's workforce (Atakul et al., 2018). In the recent past, the rise of migrant construction workers has become a distinguishing feature of global construction and recent decades have witnessed a rise in migrant construction workers, which has become a distinctive aspect of global construction (Tutt et al., 2011).

The post-war period in Sri Lanka has strengthened the government and corporate sectors' readiness to invest heavily in major capital projects such as high-rise buildings, airports, ports, roadways, highway repairs, land reclamation, and water and sanitation infrastructure (Ramalee et al., 2016). This increase brought great possibilities as well as severe challenges, such as a shortage of human resources (Silva et al., 2018). Contractors engage foreign laborers (migrant workers) to work in Sri Lanka's construction industry because of the lack of local labour (Manoharan et al., 2021). According to Silva et al. (2018), some migrant workers from Bangladesh, China, and India have already been introduced to Sri Lanka, and this option was seen as a quick and easy solution to the skills gap. However, there are numerous significant economic, social, legal, and political effects of the current influx of migrant workers on local communities, particularly those from a single nation (Hamid et al., 2012). Further, on construction sites, several migrant-related problems have been reported that have an impact on both sectoral and project performance. These problems include substandard workmanship, poor construction methods, a disregard for safety, social and legal problems with education and accommodations, violations of human rights, and health and safety concerns (Atakul et al., 2018). Hence, it is crucial to recognise the issues and drawbacks and identify solutions to the negatives of using migrant workers in the construction industry (Hamid et al., 2012).

Manoharan et al. (2021) claimed that the migrant notion was embraced by the Sri Lankan construction sector as a novel idea. But for further clarification, not many studies relate to this concept. However, most prior studies in the Sri Lankan context focused only on health and safety issues relating to the construction industry. As a result, there is a research gap in the strategies employed to address the issues caused by migrant workers in the Sri Lankan construction industry. In view of this, this study explores the impact of migrant workers on the Sri Lankan construction industry. This study was conducted with the aim of developing strategies to mitigate the issues caused by migrant workers in the Sri Lankan Construction Industry.

2. LITERATURE REVIEW

The rate of migration has begun to noticeably grow due to globalisation (Atakul et al., 2018). The migration of construction workers is having a strong effect on the construction sector overall (Rahul, 2015). On the other hand, one of the short-term solutions to handle labour shortages is hiring migrant workers (Mohd Yusoff et al., 2021). They used to use low-cost workers from neighbouring countries and rural areas to fill the labour shortage in the small country's big construction sector (Anelauskas, 2017). There are other reasons for migration besides the labour shortage. Factors influencing migrant workers' employment can be categorised as follows: term availability, pay working conditions, working hours, and educational level (Marhani et al., 2012). Three of them stand out as being particularly significant: availability, educational attainment, and working circumstances (Achim et al., 2017). According to Robertson's (2018), a migrant worker is someone who crosses a "political or administrative" border and is about to, is engaged in, or has previously engaged in a paid activity in a country of which they are not citisens. Construction as a sector looks to be mostly pro-migration (Green, 2015). Under this, International (across continents), intercontinental (between countries on the same continent), and interregional migration occur on a variety of scales (within countries) (Rahul, 2015). Furthermore, three subcategories of "migrant labour" have been established: temporary migrants; highly qualified migrants; and unauthorised or undocumented workers (Robertson, 2018). Yet, in general, migrant laborers may not have the intention of settling permanently or be authorised for this purpose (Wells, 2018).

2.1 ISSUES CAUSED BY HIRING MIGRANT WORKERS IN CONSTRUCTION INDUSTRY

Table 1 shows the issues brought on because of employing migrant workers under five primary categories: socio-cultural, health and safety, project performance, legal, and economic.

Table 1: Issues caused by the employment of migrant workers in the construction Industry

No	Issue	Reference
Socio-cultural issues		
1	Contamination to local culture	[2], [3], [5]
2	Competition for jobs	[2], [5]
3	Communication issues	[3]
4	Unequal Treatments	[4], [5]
5	Accommodation problems	[2], [5]
6	Increase criminal cases	[3]
7	Spread of Diseases	[5]
Health and Safety issues		
8	Poor working conditions	[1], [3], [4], [5]
9	Language barriers	[1]
10	Communication Barriers	[4]
11	Cultural aspects issues	[1]
Project Performance issues		
12	Productivity issues	[2], [3], [5]
13	Quality issues	[3], [5]
Legal issues		
14	Human Rights issues	[4], [5]
15	Applying for a Work Permit	[4]
16	Working Visa issues	[4]
Economic issues		
17	High Cost	[2], [3], [4]
18	Outflow of currency	[5]

[1]- (Shepherd et al., 2021) , [2]- (Hamid et al., 2013) , [3]- (Hamid et al., 2012) , [4]- (Wei & Yazdanifard, 2015) , [5]- (Atakul et al., 2018)

The construction industry has a relatively bad safety track record (Buckley et al., 2016). Construction workers, who make up a significant portion of the workforce and are often non-nationals or migrants, are particularly at risk for accidents, injuries, and fatalities (Shepherd et al., 2021) and also they mentioned that there are differences between the working conditions experienced by migrant and native laborers, and these differences may have an impact on workers' safety. Because migrant employees typically start at the lowest level feasible in their professions, working conditions won't typically be at a high level (Oswald et al., 2020). The project has been impacted by the language barrier (Ian, 2006), which is not surprising given the diversity among the workers (Tutt et al., 2011). Because migrant workers usually work in small groups with their family and friends, migrants frequently have poor language proficiency in their native tongue (Al-bayati et al., 2017). Thus, it is crucial to consider language to protect the security of migrant employees (Shepherd et al., 2021).

One of the primary problems brought on by the employment of migrant workers in the construction industry is cross-cultural misunderstandings (Bust et al., 2008). According to Phua et al. (2011), if cultural diversity is managed effectively, it can improve workplace relationships, productivity, and safety as well as have a positive impact on creativity and innovation. Compared to the natives, migrant workers have different cultures (Son et al., 2018). Parallel to the rise in global construction activity, there is a growing understanding of the importance of better cross-cultural management (Bust et al., 2008). Otherwise, separate nations and immigrant minorities communicate and perceive the world in a variety of ways that are shaped by particular sets of cultural norms (Bust et al., 2008). Soon, migrant workers will nevertheless significantly boost the competitiveness of the sector (Deng et al., 2013). The employment options for local people are impacted by migrant workers, who also make the industry more competitive. Lack of quick verbal communication is one of the biggest barriers to managing migrants on construction projects effectively (Bust et al., 2008). Communication makes it possible to deliver and share ideas, opinions, thoughts, and knowledge effectively. Issues could occur that would restrict how effectively the information would be conveyed or communicated if the communication process was ineffective (Matullah et al., 2021). To maximise efficiency on the work site, personnel must communicate effectively with one another (Olanrewaju et al., 2017). Unequal treatment is another issue that mostly affects migrant foreign workers because it is uncommonly challenging for them to receive the same treatment as local employees (Wei & Yazdanifard, 2015). Further compared to non-migrant labour, migrant workers are more likely to contract diseases (Mucci et al., 2019). According to the author, pulmonary fibrosis, chronic bronchitis, and lung cancer are examples of serious illnesses that have an impact on migrants. Other symptoms of high-altitude work syndrome include headaches, asthenia, respiratory disorders (like dyspnea, chest pain, and pulmonary edema), and various diseases. The most recent instance of this is the spread of the COVID-19 illness. The most frequent amenity that companies must offer migrant workers when they are needed for a construction project is accommodation. Yet, according to Atakul et al., (2018), migrant workers who live in poor conditions sleep in partially constructed buildings with little room, unmaintained lavatories, and no electricity facility (Abdul-Aziz, 2001).

Having foreign workers who are unable to communicate in the appropriate language has caused misunderstandings between the company and its employees. The performance of the works and productivity were impacted by frequent reworks due to nonconformance to the work standards. For instance, Emad and Rahman, (2017) said that the bulk of Saudi Arabia's construction workforce is made up of foreigners from other countries, who have diverse knowledge bases, skill sets, and cultural backgrounds, making management of them challenging to assure project success.

Construction companies advertise high salaries to attract foreign workers to their nations, but once they get there, they are almost always taken advantage of and mistreated. Foreign workers have limited power to defend the rights mentioned in their contract because of the language barrier, cost of engaging a counsel, and duration (Wei & Yazdanifard, 2015). Also, most migrant workers had temporary work permits, which may cause several legal complications in projects (May, 2022).

In contrast to local workers, migrant workers see a large increase in labour costs because of insurance, medical, allowance, and Employee Provident Fund payments. However, when it comes to migrant labour, there are several additional costs for lodging, transportation, and other amenities compared to native local workers. Moreover, The balance of payments and currency flow of the economy will suffer from an overreliance on migrant workers (Hamid et al., 2012). Since this has a detrimental influence on the country's economy, it must be addressed by considering the areas that are most affected.

3. METHODOLOGY

The research has used a mixed approach to accomplish the research aim. Identification of specific issues caused by migrant workers in the Sri Lankan Construction Industry needs quantitative data to analyse because this objective is aiming to present “what are the specific issues”. However, the selection of strategies to mitigate identified issues will need expert opinion because it aims to discuss “how the strategies can be applied to mitigate these issues”. Kothari (2004), asserts that a quantitative method is more suited to answering "what" inquiries, while a qualitative approach is better suited to responding to "how" queries. Thus, a mixed approach is the ideal choice for this research. Further, a mixed-methods approach is beneficial when one of the quantitative or qualitative methodologies is insufficient to completely understand a study problem or when the strengths of both quantitative and qualitative research can produce the best insight (Creswell, 2014). Explanatory design is chosen among these design methodologies because quantitative data must be assessed before qualitative data to accurately identify the research's findings and recommend the most appropriate response. The general goal of the Explanatory Design, a two-phase mixed methods design, is that qualitative data contributes to the explanation or development of initial quantitative findings. In Exploratory design, use the outcomes of the first technique (qualitative) to construct or inform the second approach (quantitative).

A questionnaire survey was conducted to determine specific issues caused by the employment of migrant workers in the Sri Lankan construction sector. The questionnaire has three sections in addition to a brief introduction to the study. Gathering participant information was the focus of section A. The second and third sections (Section B and Section C) concentrated on identifying and analysing specific issues. In the fourth section, Likert scale questions were used to assess the frequency of multiple issues brought on by the hiring of migrant workers in the Sri Lankan construction sector. The survey was administered to 30 participants

Collected data through questionnaire survey statically analysed using relative importance index (RII).

$$Relative\ Importance\ Index = \frac{\sum w}{AN} = \frac{1n_1 + 2n_2 + 3n_3 + 4n_4 + 5n_5}{5N}$$

w -respondent's preference for each element

A -the highest weight (in this case-5)

N- the total number of respondents

n- represents the number of respondents who respond to the relevant occurrence frequency.

Under a qualitative approach to understanding more about the participants' perspectives, thoughts, and attitudes, semi-structured interviews were conducted. Using semi-structured interviews, this study identified the root causes of special issues in the Sri Lankan industry and invents mitigation strategies for the unfavourable effects of the issues presented by the employment of migrant workers in the Sri Lankan construction sector. 12 industry professionals with exposure to the research area and contractor experience engaged in semi-structured interviews. Based on the details of the literature review and the results of the questionnaire survey, interview guidelines were developed. Additionally, interviews were conducted both physically and online. The findings of expert interviews were analysed using the manual content analysis technique. Table 2 illustrates the details of 12 professionals.

Table 2: Details of the interviewees of expert interviews

Code	**Profession**	**Designation**	**No. of years of experience**	**No. of years of experience at the site**
E1	Engineer	Project Control Engineer	15	13
E2	Engineer	Site Engineer	10	6
E3	Project Manager	Project Manager	13	12
E4	Quantity Surveyor	Site Quantity Surveyor	14	12
E5	Project Manager	Project Manager	15	15
E6	Project Director	Project Director	15	15
E7	Engineer	Site Engineer	26	26
E8	Project Manager	Project Manager	21	21
E9	Quantity Surveyor	Site Quantity Surveyor	19	15
E10	Quantity Surveyor	Site Quantity Surveyor	26	22
E11	Project Manager	Project Manager	28	24
E12	Engineer	Site Engineer	12	10

4. RESEARCH FINDINGS AND DISCUSSION

4.1 QUESTIONNAIRE ANALYSIS

As per the initial phase of data collecting, a questionnaire survey was conducted to determine specific issues caused by the employment of migrant workers in the Sri Lankan construction sector. The survey was administered to 30 participants. Table 3 provides the basic characteristics of the respondents.

Table 3: Details of the respondents

Professionals	No. of Participants
Quantity Surveyors	15
Engineers	5
Architect	3
Project Manager	7

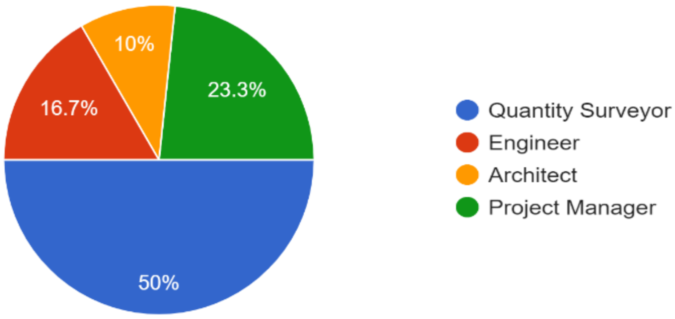

Figure 1: Respondent details according to professions

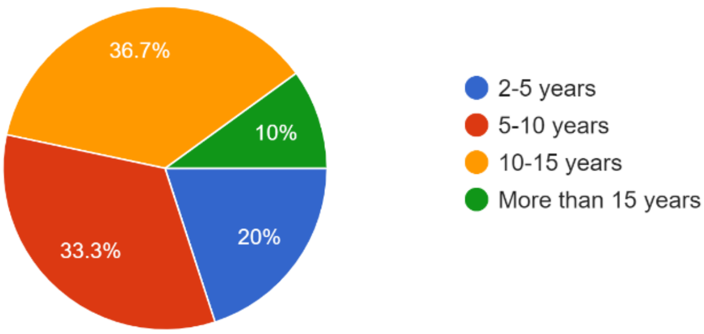

Figure 2: Respondents details of experience in construction industry

Each issue is different from the others in terms of actual occurrence. The RII approach has been applied to achieve the most accurate results from the questionnaire surveys. The RII of each issue caused by the employment of migrant workers in the Sri Lankan construction industry is shown in Table 4, and it is sorted from highest to lowest incidence.

Table 4: RII of each issue caused by migrant workers in the Sri Lankan construction industry

No	Issue	RII	Rank
1	Contamination to local culture	0.8	6
2	Competition for jobs	0.83	3
3	Communication issues	0.95	1
4	Unequal Treatments	0.66	9
5	Accommodation problems	0.67	8
6	Increase criminal cases	0.26	16
7	Spread of Diseases	0.81	5
8	Poor working conditions	0.3	15
9	Language barriers	0.92	2
10	Productivity issues	0.45	14
11	Quality issues	0.49	10
12	Human Rights issues	0.47	12
13	Applying for a Work Permit	0.47	12
14	Working Visa issues	0.49	11
15	High Cost	0.78	7
16	Outflow of currency	0.83	3

The most frequent issue caused by hiring migrant workers in the Sri Lankan construction sector., according to the questionnaire survey analysis using the RII approach, is "communication challenges." It has an RII of 0.95. The sample's responses indicate that "Language hurdles" is the second most frequently occurring problem. Its RII score is 0.92. With a 0.3 RII score, "competition for jobs" and "outflow of currency" are the third most frequent difficulties. Results indicate that "spread of diseases" is the fifth most common reason for occurrence. Its RII score is 0.81. Contamination to local culture ranks sixth among the concerns with a RII value of 0.8. According to RII values of more than 0.4, issues with high cost, accommodations, unfair treatment, quality, working visas, human rights, and productivity have occupied positions 7 through 14. The issues with the lowest RII values and lowest ranking are more criminal cases and poor working conditions. According to the table above, both concerns have RII values that are less than 0.4. According to the sample, these two problems only occasionally arise in the Sri Lankan construction sector because they both have RII values of less than 0.4. Thus, the problems brought on by migrant workers in the Sri Lankan construction industry might be regarded as minor.

4.2 EXPERT INTERVIEWS ANALYSIS

4.2.1 Specific issues caused by migrant workers in Sri Lankan construction industry

Most significant issues related to the Sri Lankan construction industry were identified through questionnaires discussed and analysed under expert interviews. There are cultural issues at work, according to the interviewees, because of the diversity of cultures, faiths, practices, and behaviours. Local workers in the construction business in Sri Lanka practice a variety of religions, and foreign workers from China, Japan, and India also follow a variety of cultures, religions, and behavioural norms. Hence, it can be difficult for both professionals and migratory workers to adapt to a new culture. Acculturative stress, culture shock, homesickness, confusion, a lack of support, prejudice, and communication difficulties are the results. Foreign migrant laborers mostly contribute to further cultural pollution in the surrounding area. since they adhere to diverse cultures and lifestyles. Therefore, local employees try to assimilate that culture and way of life. It can occasionally result in a variety of troubles with the website.

Another main issue brought on by hiring migrant workers in Sri Lanka's construction sector is competition for jobs. It is stated that some job opportunities in the construction sector were lost to local workers due to political decisions and government changes and that foreign construction companies hire their staff primarily to fill those job openings. As a result, qualified locals have fewer employment options. Further, the chances accessible to local workers are limited when some projects are given to international organisations, who then hire foreign workers as labour resources for the project. Communication issues are discussed under the two main categories of migrant workers, which are migrant local laborers and foreign workers. Nonetheless, some unskilled workers may come from China and Japan has very little interest in using the English language. Most foreign workers with professional qualifications can speak English but most local migrant workers could not be literate in writing and reading. Hence, interacting with them can occasionally be challenging.

unequal treatment is another identified issue, and it arises mainly between migrant workers from abroad and those from locally. Foreign migrant employees are more knowledgeable than local migrant workers when comparing those two groups of workers. Also, certain Sri Lankan professionals in the companies are prone to treat local migrant workers unequally due to the standard disparity between international migrant workers and local migrant workers. As a result, occasionally they negatively handled locals. Local and foreign workers staying in the same accommodation may experience accommodation issues. Moreover, the potential of a disease outbreak exists. On the other hand, poor working conditions can make employees unwell and demotivated, which has an impact on their ability to perform their duties well. As a result, the most important facility required by project workers is accommodation. High-quality accommodation, however, is more expensive and harder to come by in Sri Lanka. As a result, companies are forced to spend more money on migrant workers' accommodation. There is a very significant chance that numerous diseases will be brought into the nation by migrant workers. Hence, by having to halt the projects, the construction will be interrupted, and the development would be hampered (diseases such as bird flu, coronavirus, etc.). Also, most foreign migrant workers' lifestyles involve clubbing and unprotected sexual activity, which raise the risk of STIs, including HIV, spreading. Legal issues mainly occur since there is no standard process for requesting work permits, and occasionally there are problems with false licenses being created.

The Sri Lankan construction industry is also plagued by a few visa-related issues, including difficulties in getting visas and the occurrence of situations in which temporary workers continue to work there after their visas have expired. The high-cost issue mainly occurs by using migrant workers for a project necessitates additional expenses for accommodation, food, and transportation. However, those extra expenses can be reduced if the company employs locals in the region where the project is being carried out. One of the main effects of recruiting these foreign workers is the money outflow, which has an impact on the economy. Money or goods may be expelled in this way. It will deplete the nation's resources and money when migrant employees send a percentage of their pay, whether in cash or commodities, home to support their relatives.

4.2.2 Strategies to mitigate the negative consequences of the specific issues caused by hiring migrant workers in the Sri Lankan construction industry

Strategies can be presented under two main categories as (1) strategies that construction organisations can use to overcome the issues and (2) strategies that Sri Lankan government can use to overcome the issues. Table 5 shows proposed strategies under those two main topics.

Table 5: Strategies to overcome the issues caused by hiring migrant workers

No	Strategies
Strategies that construction organisations can use to overcome the issues	
1	Implement training sessions
2	Develop a detailed integration plan
3	Formation of support groups
4	Monitor and address discrimination and exploitation
5	Implement cost-saving measures
6	Regularly review the process
7	Develop a risk management plan
8	Improve visual communication
9	Using Fair and Formal Employment Procedure
10	Promoting an open Health and safety culture
Strategies that Sri Lankan government can use to overcome the issues	
11	Modify Sri Lankan government rules and regulations
12	Implement fair hiring policies
13	Mitigate the tendency of rural to urban migration.
14	Investment in training and re-skilling the local labour force

Language and health and safety training are the most needed training sessions for migrant workers according to the experts' opinion. Organisations can establish a training period under Language Training to train workers who migrate from countries that use their languages (such as China) in the English language. It will enhance cooperation and communication on construction projects and provide language training to both foreign and local migrant workers. Further, these training sessions are important to guarantee that local safety laws are followed and to lower the possibility of accidents and injuries on construction sites. formation of support groups for foreign and local migrant workers to provide them with a sense of community and to address any issues that arise established by this strategy. It will help encourage migrant workers to become involved in the local community and participate in local events and activities. Further, it will lead migrant workers to open communication and collaboration between all stakeholders and other professionals involved in the project. Experts provide an example of this strategy, using interpreters. It will reduce the impact of communication and language issues. Further health and safety precautions and other important information can be shared by using visual communication such as images and symbols. On the other hand, visual content grabs our attention, keeps us engaged, and helps us retain information for longer periods. Further, it's faster than reading something or having to listen to it.

When considering strategies that Sri Lankan government can use to overcome the issues, the main strategy suggested by the study is to modify Sri Lankan government rules and regulations. Under that, the government can adopt or modify migration policies to control the inflow of foreign workers and attempt to identify the migrant workers' requirements and issues that arise due to migrant worker recruitment and eventually try to decrease those issues and provide requirements to minimise those issues. Implementing fair employment practices that guarantee migrant workers receive the same wages as local workers and have access to the same protections and benefits is a must.

5. CONCLUSIONS AND RECOMMENDATIONS

The findings of the study supported the issues caused by the employment of migrant workers in the Sri Lankan construction industry. Nevertheless, it may be said that the construction industry has been negatively impacted by this outcome. A nation and an industry need to consider the negative aspects since, in the end, the stability of the nation's economy, society, and politics should come first. So, it is currently recommended to consider these issues, lessen their bad consequences, and strategically use their positive advantages. The Sri Lankan government should adopt clear norms and regulations to manage the hiring of migrant workers in the construction industry. These rules should include provisions for reasonable pay, safe working conditions, and safeguards against exploitation and abuse. Also, the government should do more to ensure that existing regulations, such labour, and immigration laws, that control the hiring of migrant workers, are strictly followed. This will guarantee that migrant employees are treated fairly and that businesses that breach the law are held accountable. Therefore, it is critical to strive toward increasing knowledge of and educating migrant workers' rights and obligations as well as employers. This can be achieved through outreach initiatives, educational campaigns, and training programs. Encouragement of migrant workers' social integration into Sri Lankan society is another suggestion that might be made. Giving them access to social services, healthcare, education, and opportunities for intercultural conversation and civic engagement is necessary to achieve this. When external factors are considered, the suggested strategies may be a very drawn-out process. To maximise its success, Sri Lankan construction industry professionals should put this concept into practice as soon as is practical. The Sri Lankan construction sector would therefore have a better position globally with a highly respected performance.

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KEY ATTRIBUTES OF CONSTRUCTION MATURITY MODELS: A SYSTEMATIC REVIEW

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ABSTRACT

Maturity Models assist organisations to evaluate their existing capabilities. A key component of a maturity model is its attributes which govern the assessing criteria of the model. Several construction maturity models exist in various platforms, however, there seems a noticeable gap in the literature on existing maturity model attributes and a model template for construction sector. Therefore, to fill that gap, this study aimed at reviewing the existing construction maturity model attributes. PRISMA literature review technique was adopted to systematically review the existing, construction related maturity model attributes. The identified attributes were analysed using thematic analysis method. The study used twenty prominent construction maturity models to identify their key attributes. These attributes were analysed, and 13 key themes were derived that described model attributes. This study summarised all the literature findings on significant existing model attributes and established the foundation on how to derive attributes relevant to construction maturity models. Further, this study adds to the body of knowledge on construction maturity model attributes and opens up avenues to develop more robust maturity models. This study contributes to the practice by encouraging the use of maturity models and attributes to enhance the existing maturity of construction firms. The results of this study can be directly used by industry practitioners to establish best practices within the construction projects. Further research is encouraged on identifying additional components of models and testing the effectiveness of the findings with empirical data in future studies.

Keywords: *Construction Maturity Models; Model Attributes; Model Components PRISMA; Systematic Review.*

1. INTRODUCTION

With continued challenges within the construction industry, there was a need to assess industry practices to identify their effectiveness (Htoo et al., 2023; Maske & Valunjkar, 2020). Many efforts have been made by academics and professionals in the construction field to measure and enhance performance. Most of these activities have resulted in the

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creation and application of frameworks and models for performance assessment that concentrate on organisational and project levels (Willis & Rankin, 2012). Eventually construction industry inclined to use Maturity Models (MM) as a tool to enhance the organisational and project capabilities to mitigate the issues that hinder effective project completion (Khoshgoftar & Osman, 2009). MMs were initially developed targeting the software industry in the United States and with the success, it expanded to many other industries. Capability Maturity Model (CMM) is a prominent MM that is considered a catalyst and many models were later developed adopting various aspects of CMM as a foundation (Brotby, 2009). Similarly, with this development many maturity models were later developed specifically targeting the construction industry (Sun et al., 2009).

There are several types of MMs extended to various areas within the broad spectrum of construction such as project management, construction management, risk management, process management, change management etc. (Khoshgoftar & Osman, 2009; Bąk and Jedynak, 2023; Nowotarski et al., 2016). A key component of all these models is the model attributes which act as the criteria that governs the maturity assessing process (Silva et al., 2021). These attributes act as the measuring apparatus of the models and provides distinctive guidelines on various construction related aspects (Jayanetti et al., 2022). However, scrutinising the existing models, less evidence is available on a comprehensive review on model attributes which provide a template or a conceptual model for construction MMs. Even though few models have elaborated upon certain attributes, there is a dearth in literature on a holistic and an explanatory study. The existing studies do not provide a detailed discussion on model attributes, relationships and do not synthesise and summarise the key findings. The theories on MMs have saturated over the years reducing novel studies. Moreover, the existing studies do not consider the key themes among the model attributes and fail to provide details on their regularity. Therefore, this study is aimed at reviewing the attributes of the existing models related to construction sector. This study is significant in two ways. Firstly, this review adds to the knowledge area of construction maturity model attributes by reviewing leading MMs and establish the foundation on developing a model template. Secondly, the industry practitioners would be able to use these attributes in developing more robust tools to evaluate the construction organisations and projects.

2. LITERATURE REVIEW

Construction maturity models have been in the constant development for few years. Initially, CMM which was developed by the Defence Department of the United states was used as a foundation to assess the maturity in the construction related organisation and projects (Nesensohn et al., 2014). With improvement the more updated version of CMM, the Capability Maturity Model Integrated (CMMI) becomes popular among many industries such as Information technology, Continuous improvement, Healthcare and Construction (Machado et al., 2021). However, since these models were not tailored to meet the dynamics in the construction sector, industry specialists began to develop more industry specific models (Marzouk et al., 2012). Providing a comprehensive report on organisation current status and capabilities, identifying maturity level of organisation, suggesting strategies to reach higher maturity (Facchini et al., 2020), providing incremental improvement guidelines (Lacerda & Wangenheim, 2018), comparing organisation with best practices to benchmark are key benefits of MMs (Machado et al., 2021).

Model attributes are the key factors that govern the assessing apparatus of the maturity models (Machado et al., 2021; Jayanetti et al., 2022). Apart from the term attributes, various models have used different terminology such as ‘Enablers’, ‘key knowledge areas’, ‘capabilities’ in terms of identifying these attributes. (Maneerat et al., 2015; Grossman, 2018; Khoshgoftar & Osman, 2009). Despite the fact of using different terms, they all elaborate the key assessing criteria of the models covering different scopes and disciplines in the construction project value adding chain from initiation to end. These attributes emphasis construction related aspects such as production efficiency, project management, supply chain integration etc. (Kwak & Ibbs, 2000; Willis & Rankin, 2012; Bendi et al., 2021). However, the literature suggests that even though these attributes are discussed in separate models individually, there is lack of evidence on critically reviewing model attributes holistically. Specially in several scenarios, the users of these models have argued that certain models ignore critically important aspects relating to construction sector, thus causing these models to be inadequate. Thus, this study attempts to identify the key attributes necessary for successful construction maturity assessment. In the process of reviewing construction MMs, the study identified 20 key construction related maturity models and presented in table 1.

Table 1: Maturity Models

Key Maturity Model	Source of Reference
Construction industry macro maturity model (CIM3)	Willis and Rankin (2012)
Project Management Maturity Model (PMMM)	Crawford (2006)
Capability Maturity Model Integrated (CMMI)	CMMI Product Team (2006)
Standardised Process Improvement for Construction Enterprises (SPICE)	Hutchinson and Finnemore (1999) Finnemore and Sarshar (2002)
Change Management Maturity Model (CM3)	Sun et al. (2009)
Organisational Project Management Maturity Model (OPM3)	Project Management Institute (PMI, 2003)
Maturity Assessment Grid (MAG) from the Strategic Forum for Construction	ICW Toolkit (2003).
Projects IN Controlled Environments (PRINCE2)	Williams (2010)
Off-site construction readiness maturity model (OCRMM)	Bendi et al. (2021)
OMG’s business process maturity model (BPMM)	Gardiner et al. (2008)
Crosby’s Quality Management Maturity Grid (QMMG)	Albliwi et al. (2014)
Construction supply chain maturity model (CSCMM)	Vaidyanathan and Howell (2007)
Berkley Project Management Process Maturity Model (BPMPMM)	Kwak and Ibbs (2000)
Portfolio, Programme and Project Management Maturity Model (P3M3)	Sowden et al. (2010)
Lean Construction Maturity Model (LCMM)	Nesensohn et al. (2014)
Project Management Process Maturity Model (PM)2	Kwak & Ibbs (2002)
Kerzner’s project management maturity model (KPM3)	Kerzner (2005)
Program management maturity model for mega construction (PmM3)	Jia et al. (2011)
Prado-PMMM Model	Archibald and Prado (2014)
Integrated BIM-IPD-LC (BIL) maturity model	Rashidian et al. (2022)

These identified maturity models have evidently represented various attributes that the models have adopted to assess construction maturity. These identified models and respective attributes are comprehensively evaluated and presented in the analysis section of the paper.

3. METHODOLOGY

The study was initiated with the aim of studying and examining the existing construction model attributes. In addressing the aim, the authors adopted Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method to systematically identify key articles. As acknowledged by many scholars, PRISMA method is well known for extensively collate all the available data that would be ideal for a specific matter of study with a predetermined selection criterion (Sohrabi et al., 2021). Specially in an area like construction maturity models, where distinct studies provide varied results, it is imperative to analyse the key models to get a holistic understanding (Rethlefsen et al., 2021). Moreover, PRISMA technique allows the researcher to expand the search until the required data is gathered, providing a systematic guide on selecting the most suitable data to the study (Page et al., 2021). In this study, the authors used 'Web of Sciences, Google Scholar, Emerald and Science Direct', as key databases. A PRISMA systematic review requires a word search to examine through data bases selection criteria for the models. In the process, the authors searched '*Construction maturity models, Project management maturity models in construction, Construction maturity, Maturity, Maturity Models, Modern Maturity Models, Construction Maturity, Construction Management Maturity Models, AEC industry maturity models'* as key search words. Figure 1 presents the PRISMA document retrieval process.

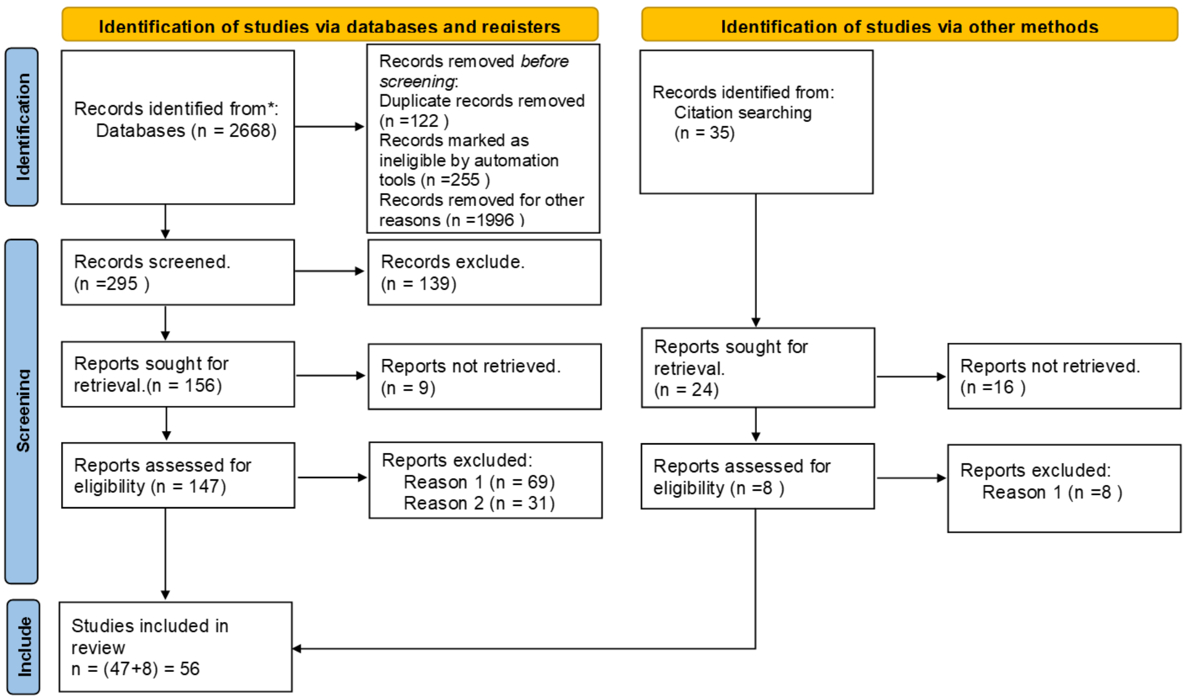

Figure 1: PRISMA process

Initially, a primary search was carried out using the above key words and from the results of that word search, 295 articles were selected for further screening. From those articles, through an abstract screening, 139 articles were excluded due to their incapability to the research scope and 156 articles were selected as suitable for further inspection. From the remaining, 156 articles were extensively studied and 47 articles were selected as suitable for the scope of the study. From those 47 articles, a reference search was carried out and another 8 articles were identified as appropriate for the study. Consequently, 56 total number of articles were selected as the final set of articles used for the study. The criteria used for selecting the models are as follows:

1. The relevancy to the construction sector,
2. The relevancy to construction project management,
3. Existence and clear explanation of model attributes,
4. Explanation of use of attributes, and
5. Published by a reliable publisher.

These selected models are extensively studied and analysed using manual thematic analysis method. Thematic analysis (TA) is a technique for methodically locating, compiling, and providing understanding of patterns of meaning (themes) within a data collection. TA enables the researcher to see and make sense of common or shared meanings and experiences by concentrating on meaning across a data collection (Braun & Clarke, 2012). Thematic analysis is well suited for qualitative studies such as reviewing model attributes in the construction sector since they support to classify, compare, transliterate, and define qualitative data (Vaismoradi et al., 2016). Since reviewing the model attributes require forming themes systematically, the study adopted thematic analysis to analyse the data.

4. ANALYSIS AND FINDINGS

4.1 THE IDENTIFIED MATURITY MODELS AND ATTRIBUTES

The study identified 20 key construction related MMs through PRISMA method which presented distinct array of model attributes. These models were selected due to the prominence given to these models by the scholars as well as they exhibited model attributes elaborately to identify the exact meanings. These selected models represent various phases and products within the broad spectrum of construction. The model attributes are presented in table 2.

Table 2: Maturity model attributes

Key Maturity Model	Key Attributes	Source of Reference
CIM3	Procurement Management, Cost Management, Quality Management, Environment Management, Human Resource Management, Health, and Safety Management.	Willis and Rankin (2012)
PMMM	Integration Management, Time Management, Cost Management, Scope Management, Quality Management, Risk Management, Human Resources Management, Procurement Management, Communications Management	Crawford (2006).
CMMI	Agreement Management, Capacity and Availability Management, Causal Analysis and Resolution, Configuration Management, Decision Analysis and Resolution, Integrated Project Management, Measurement and Analysis, Organisational Process Definition, Organisational Process Focus, Organisational Performance Management / Organisational Innovation and Deployment Organisational Process Performance, Organisational Training, Product Integration, Project Monitoring and Control, Project Planning, Process and Product Quality Assurance, Quantitative Project Management, Requirements Development, Requirements Management, Risk Management, Supplier Agreement Management, Technical Solution, Validation	CMMI Product Team (2006)

Key Maturity Model	Key Attributes	Source of Reference
SPICE	Brief and Scope of Work Management, Project Planning, Project Tracking and Monitoring, Sub-contract Management, Project Change Management, Risk Management, Project Team Co-ordination, Commitment, Ability, Activity, Evaluation, Verification	Hutchinson and Finnemore (1999) Finnemore and Sarshar (2002)
CM3	Management Process, Risk Management, Communication, Management Information, Collaboration and Leadership/Objectives	Sun et al., (2009)
OPM3	Standardisation, Measurement, Control, Continuous Improvement, Project management, Program Management, Portfolio Management,	Project Management Institute (PMI, 2003)
MA	Supply Chain Integration, Project Team Integration, Culture	ICW Toolkit. (2003).
PRINCE2	Management Control, Benefits Management, Financial Management, Stakeholder Engagement, Risk Management, Organisational Governance, Resource Management	Williams (2010)
OCRMM	Operational challenges, Broad execution strategy, Planning certainty, Operational efficiency	Bendi et al., (2021)
BPMM	Planned innovations, Change management, Capable processes, Stable processes, Reuse/knowledge management., Predictable results, Productivity growth, Effective automation, Economy of scale, Repeatable practices, Reduced rework, Satisfied commitments, Productivity growth	Gardiner et al., (2008)
QMMG	Management understanding and attitude, Problem handling, Quality improvement actions, Quality organisation status, Cost of quality as % of sales, Summary of company quality posture	Albliwi et al., (2014)
CSCMM	Process Assessment, Technology Assessment, Strategy Assessment, Value Assessment, Functional integration, Multi-project integration, Multi-firm integration	Vaidyanathan and Howell (2007)
BPMPMM	Integration, Scope, Time, Cost, Quality, Human Resource, Communications, Risk, Procurement	Kwak and Ibbs (2000)
P3M3	Management Control, Benefits Management, Financial Management, Stakeholder Engagement, Risk Management, Organisational Governance, Resource Management, Portfolio Management, Programme Management, Project Management	Sowden et al., (2010)
LCMM	Leadership, Customer focus, Way of thinking, Culture & behaviour, Competencies, Improvement Enablers, Processes & tools, Change, Work environment, Business results, Learning, Competency development	Nesensohn et al., (2014)
(PM)2	Integration Management, Time Management, Cost Management, Scope Management, Quality Management, Risk Management, Human Resources Management, Procurement Management, Communications Management	Kwak and Ibbs, (2002)
KPM3	Common Language, Common Process, Singular Methodology, Benchmarking, Continuous Improvement	Kerzner (2005)
PmM3	Integration Management, Time Management, Cost Management, Scope Management, Quality Management, Risk Management, Human Resources Management, Procurement Management, Communications Management	Jia et al., (2011)
Prado PMMM Model	Competence in Project and Program Management, Competence in Technical and Contextual Aspects, Behavioural Competence, Methodology usage, Computerisation, Usage of the convenient Organisational Structure, Strategic Alignment	Archibald & Prado (2014)

Key Maturity Model	Key Attributes	Source of Reference
BIL	Leadership, Customer Focus, Way of Thinking, Culture & Behaviour, Improvement Enablers, Competencies Processes & Tools, Work Environment, Business Results Learning & Competency Development	Rashidian et al., (2022)

4.2 THEME DEVELOPMENT FOR MODEL ATTRIBUTES

Analysing the models, the authors were able to identify patterns and close relationships among many model components even though the models used different terminologies. For instances, CMMI uses the term *Process Performance*, whereas BPMM offer the term *Operational Efficiency* to describe the same characteristic within the construction projects (CMMI Product Team, 2006); Bendi et al., 2021). Thus, by the use of thematic analysis, following key themes were identified among models. Table 3 represents how the themes were developed dissecting the model attributes.

Table 3: Identification of key themes in model attributes

Key Attribute (Key Theme)	Contributions from the models
Operational Efficiency	Brief and Scope of Work Management, Project management, Program Management, Portfolio Management, Measurement and Control, Management Control, Process & tools Assessment, Project Time Management, Project Planning, Project Tracking and Monitoring, Operational challenges, Capacity and Availability Management, Value Assessment, Capable processes, Stable processes, Common Process, Repeatable practices, Reduced rework, Productivity growth
Strategic Human Resource Management	Organisational Training, Collaboration and Leadership, Project team integration, Business results, Leadership, Competencies, Improvement Enablers, Requirements Development, Organisational Governance, Resource Management, Broad execution strategy, Strategy Assessment
Knowledge Management	Continuous Improvement, Planned innovations, Effective automation. Multi-project integration, Economy of scale, Technology Assessment Reuse/knowledge management, Learning, Competency development
Project Quality Management	Quality Management, Process and Product Quality Assurance, Project Monitoring and Control, Measurement and Analysis, Predictable results Benchmarking, Singular Methodology
Consideration for customer value	Benefits Management, Stakeholder Engagement, Satisfied commitments. Customer focus, Value Assessment
Supply Chain Integration	Sub-contract Management, supply chain integration, Functional integration, Multi-project integration, Multi-firm integration, Portfolio Management, Integrated Project Management
Communication	Common Language, Organisational Process Definition, Management Information
Change Management	Risk Management, Way of thinking, Culture & behaviour
Procurement Management	Procurement Management, Agreement Management, Sub-contract Management
Standardisation	Standardisation, Benchmarking, Singular Methodology
Cost Management	Cost Management, Financial Management
Environment Management	Environment Management
Health and safety Management	Health and Safety Management

As depicted in table 3, 13 key attributes were identified within the studied construction maturity models. As evidenced, prominence was given to production/construction component of the value chain. Thus, operational efficiency was identified as a key theme covering broad aspects like construction management, process management, project management, work scope management, identifying operational challenges, process measurement etc. Strategic human resource management (SHRM) and Knowledge Management are also identified as key themes. Among the model attributes, SHRM is a key theme covered many areas related to construction maturity such as developing capabilities and competencies, leadership, and drive of organisation to its aim and goals, identifying the skills requirement and creating project teams. Knowledge Management is also a much-noted theme among model attributes in areas such as continuous improvement, technological advancements, innovations, knowledge sharing etc. Quality Management is a key theme highly visible throughout the model attributes due to its importance in construction sector. Key aspects like quality control, project monitoring and control and quality assurance are referred under this theme.

Customer satisfaction is also a key theme among model attributes. Stakeholder engagement, satisfied commitments, delivering customers need were seemed to be key considerations among model attributes. Supply chain integration is also another key factor that has taken the emphasis among model attributes. As many scholars have also expressed, upward and downward supply chain integration is widely accepted among the key model attributes. Successful communication throughout organisation is also identified as a key theme which resonated among model attributes. Clear communication channels, Defined processes were few of the key factors considered in this regard. Change Management, Procurement Management Standardisation and Cost Management were also identified as common attributes among the studied models. Lastly, even though not commonly visible as other themes, Environmental Management and Health and Safety Management were also identified themes amongst the evaluated model attributes.

4.3 DISCUSSION

As per the analysis, all the models have emphasised the importance of operational efficiency as a key indicator of construction maturity models. This notion is well supported by many industry practitioners and scholars as they emphasised the importance in efficient operation to minimise the deficiencies in the construction sector (National Research Council, 2009; Anees et al., 2013; Choudhry, 2017). Many models have identified that SHRM to be a key success factor for reaching higher construction maturity. On a similar note, numerous studies have proven that building a competent work force, enabling the employees, and leading them to strategic goals of the organisation is particularly important in reaching higher levels in construction industry (Kaewnaknaew, 2022; Druker et al., 1996). This argument is justified in many models since many models such as PM2, CMMI, SPICE, CM3, PRINCE 2, BPMM, CSCMM, CIM3, BPMPMM, P3M3 have all adopted Human Resource Management as a key attribute in structuring the models (Finnemore & Sarshar, 2002; Fryer et al., 2013; Gardiner et al., 2008; Pane & Sarno, 2015; Sun et al., 2009; Vaidyanathan & Howell, 2007; Willis & Rankin, 2012).

Numerous models have identified the importance of Knowledge Management as a key driver for success in the gradually improving construction industry. This is further confirmed by the evidence in literature (Regona et al., 2022). Models such as OPM3 have discussed about using project integration techniques in order to enhance the efficiency and the swiftness of works (Machado et al., 2021). Several models such as PM2, CMMI, SPICE, OPM3, BPMM have mentioned this attribute to be essential to assess construction maturity (Finnemore & Sarshar, 2002; Khoshgoftar & Osman, 2009; Pane & Sarno, 2015). Project Quality Management is an attribute, which was overwhelmingly accepted by many models. This idea is well supported by the scholars as they outline maintaining quality is a key essential in construction project success (Hoonakker et al., 2010; Ashokkumar, 2014). Evident by the collected data PM2, MAG, PRINCE 2, OCRMM, CSCMM, CIM3, BPMPMM, P3M3 have highly emphasised the ways and means of Quality Management enhancing the overall maturity of firms.

Customer centric approach clearly remains a common attribute among majority of the models. As proven by the literature, in any business, the importance of customer satisfaction is paramount for success (Stoppel & Roth, 2017). Thus, the models have mentioned various process areas which can be placed under the theme, customer centric approach. Models such as CMMI, CIM3, OCRMM have identified client focus to be one of major attributes (Bendi et al., 2021; Gudergan et al., 2015).

Supply chain integration and clear communication among all the channels through the value chain is also identified to be a key assessment criterion in construction maturity. Many scholars and industry specialists have proven that better supply chain integration is paramount (Sari et al., 2023). Proving the notion, many models have clearly outlined the importance of supply chain integration in measuring construction maturity. CMM, CMMI, MAG, CIM3, BPMPMM have mentioned that clear links and in-house supply chain integration as key criteria in maturity assessment (Kwak & Ibbs, 2000; Pane & Sarno, 2015; Willis & Rankin, 2012). Clear communication is identified as a key theme for measuring maturity. In construction environment, a considerable amount of data is shared and it needs to be communicated among all the relevant stakeholders to maintain speed and accuracy (Wikforss & Löfgren, 2007). PM2, CM3, OPM3, MAG, QMMG, BPMPMM, P3M3 have adopted communication as a core attribute (Machado et al., 2021; Sun et al., 2009).

Change Management is a key attribute that has resonated among several models as an important factor relevant to reach higher maturity. This attribute goes in line with aspects such as Risk Management and creating a culture inducive to new methods. Many scholars have proven that creating an environment where new ideas and change is welcomed, creates a better atmosphere for improvement (Dainty et al., 2007; Ankrah, 2007). Procurement Management has always been a key driver of success in the field of construction (Araújo et al., 2017). However, out of the 20 MMs studies, only six MMs have explicitly expressed this attribute. This suggests that even though procurement is a key part of the value chain of construction, majority of the models have failed to integrate it in the model assessing criteria as a key attribute.

A key barrier for success in construction industry is the lack of standardisation (Ahmed et al., 2021). A model which has been used as a benchmark to develop other construction maturity models is CMMI. The CMMI clearly cited that standardised work practices is a key assessing factor in their maturity assessment (Software Engineering Institute, 2006). Following the same principle, many models such as, SPICE, MAG, OCRMM, BPMM, CSCMM, BPMPMM have identified the importance of standardisation in construction and considered it to be a core criterion to assess construction maturity.

Cost Management is undisputedly a key measure for evaluating the success of construction related projects (Potts & Ankrah, 2008). Contemplating with that notion, majority of the examined models have expressed the inclination to include a factor covering this attribute. Finally, Environmental Management and Health and Safety Management are the least favoured attributes among the models. Predictably, the literature provides a clear explanation that supports this phenomenon. Many studies have concluded that even though environmental and Health and safety management are important aspects in the construction sector, firms tend to offer less significance to these factors as they do not directly elevate the financial prowess (Morel et al., 2001; Muhammad et al., 2015). Thus, models have not extensively considered these two attributes.

4.4 THE WAY FORWARD

Identifying attributes of construction related maturity models is the first step of a larger research on developing a conceptual maturity model template for construction sector. The literature suggests that apart from key attributes, there are several other key components that are imperative in assessing construction maturity as shown in figure 2.

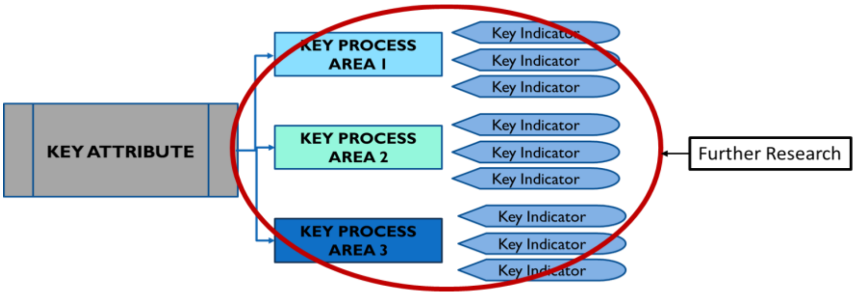

Figure 2: Key model components

Therefore, further research must be carried out to identify how these key attributes can be understood under various key process areas that would elaborate a key attribute in numerous aspects. The next step of the study would be to identify key indicators that would enable to assess these criteria practically in the construction process. Ultimately, identifying all these key model components and themes would provide a foundation to develop a conceptual model template.

5. CONCLUSIONS

Even though several construction MMs exist, a gap was identified on a comprehensive review on model attributes. Therefore, this research was initiated with the aim to review the existing construction MM attributes and to identify their themes and patterns. PRISMA systematic review method identified 20 key construction maturity models and their respective attributes, and they were analysed using thematic analysis. Through the analysis, 13 key themes were identified. These themes were then examined corresponding to the MMs and their relationship comprehensively. Findings of this study contribute to both the knowledge base and industry. This paper integrates all the key attributes relating to prominent construction related MMs and explain the current state of knowledge. The study identified key themes among model attributes and opens new avenues to develop a resilient MM template covering all the relevant aspects of construction. From an industry perspective, practitioners have the ability to use the findings to organise their work practices and develop more pragmatic models to solve impending issues in the construction industry. Further this study encourages the use of MMs and attributes in the field of construction to attain better results and to reach higher maturity. This research is limited in terms of construction maturity model attributes. Therefore, scholars are encouraged to study in more depth to identify functional aspects and key indicators of these attributes and their behaviour.

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LEAN ICEBERG MODEL TO MINIMISE BARRIERS FOR DIGITAL TWIN IMPLEMENTATION: SRI LANKAN CONSTRUCTION INDUSTRY PERSPECTIVE

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ABSTRACT

Digital twin technology holds immense potential for the construction industry in developing countries, while providing numerous benefits. Yet, financial, cultural, infrastructural and technological barriers hinder the implementation of digital twin. Researchers have emphasised the importance of considering both visible and invisible barriers of digital twin implementation. 'Lean Iceberg Model' (LIM) emphasises that most of the underlying barriers and problems in a project are invisible and unaddressed, and it is critical to solve these underlying issues to achieve effective implementation. The study aims to develop a LIM to minimise barriers for successful digital twin implementation in the Sri Lankan construction industry. This study adopts an interpretivism stance and employs a qualitative research approach. Semi-structured interviews were conducted with 15 experts chosen through purposive sampling. VBA script was employed to analyse the data. LIM highlights the unseen aspects such as leadership, commitment, employee engagement, and organisational strategy as crucial to the successful digital twin implementation. Thus, a comprehensive approach is required to contemplates the technical aspects with the organisation's overall strategy, employee engagement, and leadership commitment. Moreover, cultural values, norms, leadership, and social networks are also examined to determine their impact on digital twin implementation. A framework for minimising the barriers to the implementation of digital twins in the Sri Lankan construction industry using the LIM has been developed incorporating the findings, which will offer valuable insights for construction industry professionals and policymakers interested in implementing digital twin to improve construction project management.

Keywords: *Barriers; Construction Industry; Digital Twin; Lean Iceberg Model; Sri Lanka.*

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1. INTRODUCTION

The construction industry has been one of the most vital sectors in Sri Lanka's economic development (Perera et al., 2020). However, there are various challenges in the construction industry, such as limited resources, environmental constraints, and a shortage of skilled labour (Silva et al., 2018). Furthermore, the construction industry in Sri Lanka is facing numerous challenges, including low productivity, excessive costs, and limited adoption of modern technologies (Manoharan et al., 2020). Information technology advancements hold enormous potential for the construction industry to face these challenges (You et al., 2020).

Digital twin has emerged as a promising tool in transforming the construction industry. The concept of digital twin technology has revolutionised the construction industry, and its implementation in developing countries have had far-reaching benefits (Sepasgozar et al., 2021). Developing countries have been able to leverage digital twin technology to leapfrog traditional construction methods and adopt more modern and efficient approaches. It can facilitate the digitalisation of various assets, systems, and processes in different sectors related to construction industry (Tchana et al., 2019). Adopting digital twin technology can provide a range of benefits that can help to overcome these challenges and support the growth of the construction industry in developing countries (Shahzad et al., 2022).

Digital twin technology has the potential to address some of these challenges by improving efficiency, reducing costs, and improving collaboration among stakeholders (Singh et al., 2021). This adoption can help accelerate economic development and increase competitiveness in the global market (Melesse et al., 2021). The digital twin concept is primarily based on advanced data and information processing software such as machine learning tools, optimisation and search algorithms, and other AI tools (Badenko et al., 2021). The digital twin concepts refer to a building model that captures real-world data and generates dependable prototypes of the building through technologies such as sensors, drones, lasers, and other wireless technology. The project collects information from multiple sources, such as analytics, algorithms, and artificial intelligence, to continue to understand a project's functionality, functionality, or efficiency, whether built or functional (Akomah et al., 2020). This is possible because of the digital twin notion, a real-time computer version of physical characteristics. Sensors that continually monitor environmental changes and recalculate the quality of current measurements and pictures often create digital data (Khajavi et al., 2019). It can help with planning, tracking, and monitoring, operations and risks, problem identification, improvements, performance improvement, maintenance, and forecasting future resource requirements (Acampa et al., 2020). Moreover, it can enhance process efficiency to increase productivity, reduce energy consumption, and forecast future resource requirements. This technology provides the ability to discover the source of product defects and analyse product efficiency barriers.

Nonetheless, the construction industry has been slow to adopt digital technologies. Several factors contribute to this trend, including the complex nature of construction projects, fragmented supply chains, and the lack of interoperability between different systems (Teisserenc & Sepasgozar, 2021). Implementing the concept of a digital twin requires overcoming a number of technical, sociological, organisational, and commercial barriers. Meanwhile, due to the lack of awareness of modern technology and knowledge transfer, the local industry is not entirely able to meet all this increased technical demand. Furthermore, no deliberate effort appears to have been taken to ensure an adequate level of current technology and knowledge transfer (Kuruwitaarachchi et al., 2020). Yet, various models exist within the construction industry, offering valuable insights into identifying barriers and establishing an effective framework for implementing digital twin technology, such as the SWOT model (Namugenyi et al., 2019; Palomares et al., 2021), the six thinking hats model (Chien, 2020; Göçmen & Coşkun, 2019), the transtheoretical model (Jiménez-Zazo et al., 2020), LIM (Alejandro-Chable et al., 2022; Grigg et al., 2020).

LIM is important for implementing a new concept as it helps to ensure that all of the necessary elements are in place for success. The model shows how the cultural elements of LIM, such as leadership and engagement, are just as important as the technical elements, such as process management and technology (Grigg et al., 2020). LIM emphasises that the majority of underlying barriers and problems of a project are placed invisibly below the surface level and unaddressed, and it is crucial to address these underlying issues to achieve an efficient application. Several researchers have focused on the implementation of digital twins, as seen in studies by (Barricelli et al., 2019; El Jazzar et al., 2020; Neto et al., 2020; Opoku et al., 2023), which have explored their applications in a global context. However, there is a lack of research in the Sri Lankan context (Munasinghe & Pasindu, 2021). Therefore, the study aims to develop a LIM to minimise barriers for successful digital twin implementation in the Sri Lankan construction industry.

2. LITERATURE REVIEW

2.1 DIGITAL TWIN IN THE CONSTRUCTION INDUSTRY

A construction project involves coordinating various stakeholders and collecting and managing large amounts of data. Bou-Hatoum et al. (2020) highlighted that a construction project can be compared to a nexus, where different stakeholders interact to accomplish the project from planning to decommissioning. Digitalising various assets, systems, and processes across different industries has been made possible in recent decades due to technological advancements namely, the Internet of things(IoT), artificial intelligence, and cloud computing (Mabkhot et al., 2018). These technologies form the foundation of the digital twin concept, which involves the integration of a virtual object with its physical counterpart throughout the life cycle (Borowski, 2021).

The use of advanced data analytics and artificial intelligence can enable construction companies to make informed decisions, optimise resources, and increase efficiency (Alexopoulos et al., 2020). For instance, real-time data collected through IoT devices can provide insights into the project's progress, allowing the stakeholders to make timely decisions to keep the project on track.

This connection enables real-time monitoring and control of the physical product through its digital twin, allowing for predictive maintenance and simulation-based analysis. As per Grieves and Vickers (2017), a digital twin is a virtual representation of a physical product that can mirror its current state. Hu et al. (2018) stated that the connection between the product and its twin makes it possible to reflect the present status of the physical product to its digital counterpart. The availability of current and historical data on the digital twin enables predictions of future behaviour (Sivalingam et al., 2018). Similarly, Ayani et al. (2018) vindicated that simulations can be run using Digital twins.

The construction sector began to view digital twins as a significant facilitator for its digital transformation, with the potential to improve the industry's dismal digitalisation record (Brilakis et al., 2019). The system has received the least attention within the architectural, engineering, and construction businesses (Ammar & Nassereddine, 2022). Researchers think that the combination of IoT and building information modelling (BIM) prepared the ground for developing a digital twin in the built environment (Davila-Delgado & Oyedele, 2021).

Digital twin construction is also a new mode of construction production management that uses data streaming from a variety of site monitoring technologies and artificial intelligence functions to provide accurate status information while also proactively analysing and optimising ongoing design, planning, and production (Agostinelli et al., 2020). Digital twin construction creates a data-centric way of construction management by combining BIM technologies and procedures, lean construction thinking, the digital twin concept, and artificial intelligence. The digital twin construction offers detailed descriptions of its basic information concepts and data processing routines.

While BIM tools provide excellent representations for product design, they often lack essential features necessary for construction when it comes to Digital Twins (Pan & Zhang, 2021). The stream of monitored data that flows from the physical artefact to the digital processes is essential to the connection between physical and digital twins (Beckman et al., 2021). People monitor building work progress in contemporary, traditional construction practices mostly by direct observation and measurement. This physical labour is time-consuming and prone to mistakes (Cheng & Teizer, 2013).

2.2 BENEFITS OF DIGITAL TWIN IN THE CONSTRUCTION INDUSTRY

Digital twin technology provides significant benefits to the construction industry as shown in Table 1.

Table.1: Benefits of digital twin in construction

No	Benefits	References
01	Enhanced collaboration	[1][2][3]
02	Higher accuracy	[4][5]
03	Real-time responsiveness	[6][7][8]
04	Safety monitoring	[9]
05	Health monitoring of structures	[10]
06	Cost-saving by avoiding rework	[11][12]
07	Reducing human errors and data entry errors	[13]

Sources: [1] Wang et al. (2021), [2] Ozturk (2021), [3] Tao et al. (2022), [4] Zheng et al. (2019), [5] Lim et al. (2020), [6] Ma et al. (2020), [7] Jiang et al. (2021), [8] Peng et al. (2020), [9] Jiang et al. (2022), [10] Liu et al. (2020), [11] Piroumian (2021), [12] Warke et al. (2021), [13] Sepasgozar et al. (2020)

Digital twins enhance collaboration by providing a platform for stakeholders to interact and share information, leading to better collaboration between teams (Wang et al., 2021). By enabling design validation and testing, Digital twins ensure that the final product is accurate, reliable, and efficient (Zhang et al., 2021). Data is collected through sensors and other monitoring devices embedded within the structure and is then transmitted to the virtual model in real-time (Ma et al., 2020). Through accessing to this real-time data, stakeholders can quickly identify and respond to issues as they arise, leading to increased efficiency and productivity (Jiang et al., 2021). Digital twins can be used to monitor the safety of structures in real-time (Liu et al., 2020), identifying potential hazards before they become a problem, which can reduce the risk of accidents and injuries, promoting safety in the workplace (Jiang et al., 2022). Digital twins can automatically collect and process data, reducing the risk of data entry errors that can lead to inaccuracies and delays (Sepasgozar et al., 2020).

Digital twin technology offers various industries a wide range of benefits, including enhanced collaboration, greater accuracy, real-time response, high security, health monitoring of structures, cost savings, and error reduction. These benefits make digital twin technology an attractive solution for companies seeking to improve their operational efficiency, reduce costs, and increase productivity.

2.3 BARRIERS TO IMPLEMENTATION OF DIGITAL TWIN IN THE CONSTRUCTION INDUSTRY

There are several barriers to the implementation of digital twin in the construction industry, such as ethical issues, security and privacy concerns, development costs, uneven distribution of resources, and technical limitations, and digital twin technology has the potential to revolutionise the construction industry by improving efficiency, accuracy, and cost-effectiveness. Table 2 illustrates the barriers to the implementation of digital twin in the construction industry.

Table 2: Barriers to the implementation of digital twin in the construction industry

No	Barriers	References
1	Technological	[1] [2] [3] [4]
2	Social	[5] [6] [7]
3	Organisational culture	[5] [8] [9] [10]
4	Financial	[5] [11] [12]
5	Machine learning techniques	[5] [13] [14]
6	System optimisation	[5] [15] [16]
7	Search algorithms (for assessing and exploring potential forward-looking building plans)	[5] [1]
8	Existing construction management systems and procedures	[17]
9	Computer Literacy	[17] [18]

Sources: [1] (Sacks et al., 2020), [2] (Yevu et al., 2021), [3] (Peansupap & Walker, 2006), [4] (Yevu et al., 2022), [5] (Wanasinghe et al., 2020), [6] (Drummond & Coulet, 2022), [7] (Qi & Tao, 2018), [8] (Neto et al., 2020), [9] (Khasanov & Krasnov, 2019), [10] (Agrawal et al., 2022), [11] (VanDerHorn & Mahadevan, 2021), [12] (Boschert & Rosen, 2016), [13] (Priyanka et al., 2022), [14] (Min et al., 2019), [15] (Lim et al., 2020), [16] (Barni et al., 2018), [17] (Zomer et al., 2020), [18] (Kretschmann, 2015).

Implementing digital twin construction will necessitate overcoming several technological, social, organisational, and commercial obstacles. Machine learning techniques, optimisation, search algorithms , and other AI tools are crucial to digital twin development (Sacks, Girolami, et al., 2020). It can be difficult to modify existing construction management systems and procedures and the personnel competent in their application. This has been experienced with the advances such as lean construction and BIM (Zomer et al., 2020). Construction Tech start-up enterprises with access to venture funding and personnel with the necessary AI capabilities will be better positioned to innovate in the transition to digital twin construction than traditional construction companies (Sacks, Girolami, et al., 2020). There are several concerns and challenges when focusing on the improvement of lean construction with the use of digital twin construction (Barricelli et al., 2019).

The mitigation of these barriers can be achieved by applying lean construction principles, which serve as a viable approach within the construction industry's framework, emphasising collaboration, communication, and continuous improvement. By involving all stakeholders in the construction process and encouraging open communication, lean construction can reduce misunderstandings and delays.

2.4 LEAN CONSTRUCTION AND DIGITAL TWIN

Lean construction is an approach which helps to decrease the duration of the project, whole life cycle cost of the project, and non-value adding activities with the intention to increase the quality of the project and health and safety, adapting to continuous improvement, improvement in labour performance, more satisfaction, and better value for an employer (Parameswaran & Ranadewa., 2021). Lean culture is an essential aspect that determines how things are done in a company and are influenced by the management system (Iranmanesh et al., 2019). Culture represents the conventions and values of a company (Tarurhor & Emudainohwo, 2020). Organisations that adopted lean practices reported that companies with a high adoption of lean culture throughout the organisation implemented lean techniques more effectively than those with a low adoption of lean culture that just used lean principles on the shop floor (Aberdeen Group, 2006). Lack of knowledge about lean practices is a major barrier to gaining the competitive advantage of lean construction. (Parameswaran & Ranadewa., 2023). The digital twin is a highly impactful technology that organisations can utilise to improve their processes and reduce wastage (Psarommatis & May, 2022). Digital twin is a powerful tool that enables organisations to optimise their processes, reduce waste, and improve overall performance (Julien & Hamzaoui, 2023). The use of digital twin as a lean tool is extensively studied and has been effective in various industries. The key to leveraging digital twin as a lean tool is to ensure that organisations have access to the necessary technology and expertise to implement it effectively (Barkokebas et al., 2023).

2.5 LIM TO MINIMISE BARRIERS IN DIGITAL TWIN IMPLEMENTATION IN THE CONSTRUCTION INDUSTRY

Figure 1 shows the visible and invisible aspects of the LIM. The visible features are those above the waterline in the iceberg model, whereas the unseen aspects are those below the waterline. Technology tools, techniques, and processes are located above the waterline and are simple to visualise, comprehend, and implement. Strategy and alignment, leadership and behaviour, and engagement are the suppressed underlying concepts (Pearce & Pons, 2017).

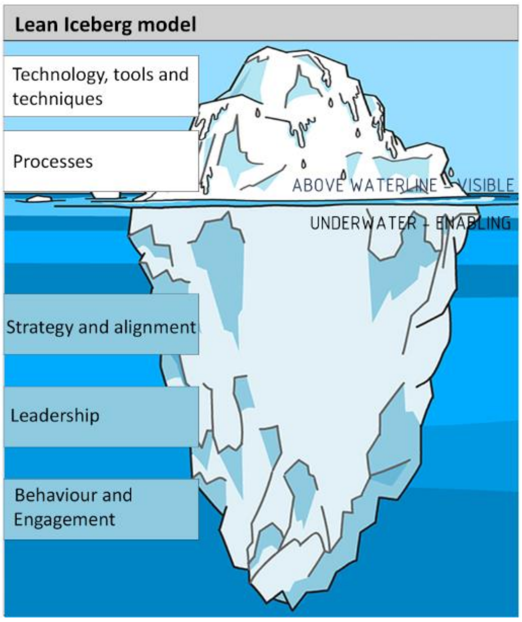

Figure 1: Lean Iceberg Model

Technologies, tools, and techniques demonstrate the visible features of the LIM that are utilised to optimise the digital twin process (Ivanov et al., 2020). These are the technological tools required for digital twin implementation, such as simulation software, sensors, and data analytics tools (Pearce & Pons, 2013). These tools enable the creation of digital replicas of physical assets and processes, allowing for optimisation and continuous improvement (Kostromin & Feoktistov, 2020). In the LIM for digital twin implementation, the processes refer to the series of activities required to implement and utilise digital twin technology (Bao et al., 2019).

With the implementation of digital twin technology, many organisations are looking to leverage its potential benefits. However, as with any modern technology, several barriers need to be overcome for successful implementation. From the literature, various barriers have been identified, and those are technological, social, cultural, financial, machine learning techniques, system optimisation, search algorithms, existing construction management system and procedure, and computer literacy. Therefore, the framework is developed with the analysed findings of the study.

3. METHODOLOGY

To explore the theoretical understanding of the concept of digital twins and LIM in the Sri Lankan context, a review of the literature was conducted. The study aimed to gather different perspectives from experts in the field and therefore adopted an interpretivism stance. To achieve this, a qualitative approach was employed as the research approach. The empirical data was collected through semi-structured interviews with experts in Sri Lanka who were selected through purposive sampling. The use of semi-structured interviews is preferred in qualitative research as it allows for a structured flow of questions to be asked of the interviewees. To gather data, fifteen (15) expert interviews were conducted and analysed using a VBA script. Excel VBA script is used to analyse content in a systematic and efficient manner. The findings of this study provide a deeper understanding of the implementation of digital twins in the Sri Lankan construction industry and are useful for future research on the topic. As mentioned, expert interviews were conducted with experts who have knowledge of the implementation of digital twin or developing and implement expert systems. Table 3 illustrates the profile of the experts.

Table 3: Profile of the experts

Details (Expert)	Profession	Designation	Organisation type	Field of expertise	Experience in the industry
E1	Quantity Surveying	Quantity Surveyor	Consultant	BIM and Quantity Surveying	4 years
E2	Quantity Surveying	Quantity Surveyor	Contactor	BIM and Digital Twin	4 years
E3	Quantity Surveying	Quantity Surveyor	Contractor	BIM and Quantity Surveying	4 years
E4	Quantity Surveying	Quantity Surveyor	Contractor	BIM and Quantity Surveying	4 years
E5	Engineering	General Manager	Contractor	BIM and Project Management	20 years
E6	Software Engineering	Team leader	BIM tools provider	BIM	4 years
E7	Software Engineering	Team leader	BIM tools provider	BIM	5 years
E8	Software Engineering	Team leader	AI developer	IoT and AI	10 years
E9	Software Engineering	General manager	AI developer	IoT and AI	8 years
E10	Software Engineering	Software Engineer	AI developer	IoT and AI	4 years
E11	Software Engineering	Software Engineer	AI developer	IoT and AI	5 years
E12	Software Engineering	Software Engineer	AI developer	IoT and AI	5 years
E13	Software Engineering	Software Engineer	AI developer	IoT and AI	4 years
E14	Software Engineering	Software Engineer	AI developer	Project implementing	3 years
E15	Project management	Project Manager	Software Developer	Project implementing	3 years

4. ANALYSIS

4.1 BARRIERS TO IMPLEMENTING DIGITAL TWIN IN THE CONSTRUCTION INDUSTRY

When it comes to the implementation of the digital twin in Sri Lanka, several barriers were discovered through the literature and expert interviews. These barriers must be overcome for the successful implementation of digital twin. Table 4 vividly shows the barriers to implementing digital twin depending on the empirical findings.

Table 4: Barriers to implementing a digital twin in the construction industry.

Description	Count	Expert Index
Financial barriers	12	E1,E2,E3,E4,E6,E7,E9,E10,E11,E12,E13,E15
Limited infrastructure	8	E1,E5,E9,E10,E12,E13,E14,E15
Organisational culture barriers	8	E2,E6,E7,E9,E11,E12,E13,E15
Complexity	5	E4,E5,E7,E8,E11
Technological barriers	5	E2,E3,E7,E8,E11
Regulatory barriers	2	E5,E14
Limited understanding of the potential benefits	2	E1,E10

Financial barriers were cited as a significant obstacle to implementing a digital twin in the construction industry by twelve respondents. E1 emphasised, "*Digital twin requires specialised hardware, software, and data, which can be expensive to purchase and maintain".* Furthermore, E8 insisted, "*Cost of training personnel to use and manage it. Additionally, there may be ongoing costs associated with data storage, security, and network infrastructure in Sri Lanka".* All other experts mentioned the purchase and maintenance cost of specialised hardware, software, data, data storage, security, and network infrastructure and the cost of the professionals. Eight experts mentioned many issues that pop up with the limited infrastructure. Such as issues in data transferring, slow performance, noised and inaccurate data, limited scalability, and security issues. E1 elaborated that "*a 'digital twin' requires a robust and reliable internet and data infrastructure to function effectively. If these are not widely available, it may be difficult to implement digital twins*". E5 stated, "*Limited infrastructure may make it difficult to ensure the security of the data being transmitted and stored, increasing the risk of data breaches and other security issues".* Further, E12 insisted, "*If the data collecting and transmission infrastructure is inadequate, it may be difficult to collect enough data to generate an accurate digital twin model".*

The organisational cultural barrier was mentioned by the eight experts. E1 emphasised, "*Digital twins may need a change in how people work and communicate. If there is a reluctance to change or a lack of awareness of the benefits of digital twins, adoption may be hampered".* As the E2 and E12 view, "*Employees may be confused about what a digital twin is and how it may be utilised, resulting in a lack of engagement with the project*". Further, E11 mentioned, "*Employees may be reluctant to the concept of a digital twin and the changes it may bring, making acceptance and implementation difficult*". Five experts pointed out the complexity of the digital twin as a barrier to implementation. E5 emphasised that '*Digital twins can be complex to create and maintain, requiring specialised skills and expertis'.* Further, E14 explained, "*The complexity of a digital twin varies according to the system being modelled as well as the amount of detail and accuracy required. The number of variables and interactions in the system, the necessity for real-time data and updates, and the integration of numerous data sources are all factors that might contribute to complexity".* The view of the complexity of E8 and E4 of the digital twin is the level of autonomy, and the decision-making capabilities necessary in the digital twin might influence complexity.

Five respondents stated technological barriers as the barriers to digital twin implementation. From the experts' standpoint, companies need access to the necessary hardware, software, and reliable data communication method to use digital twins. If these technologies are not widely available or are too expensive in Sri Lanka, it may be difficult for companies to adopt digital twins. Regulatory barriers, E5 insisted, "*National and international norms and standards may apply to digital twins. If these restrictions are unclear or difficult to follow, digital twin adoption may be hampered"*. Limited understanding of potential benefits, E1 emphasised: "*Digital twin is a complex technology, and it can be difficult for some companies to understand how they can be used to benefit their operations. This lack of understanding may make it difficult to justify the investment in the digital twin"*. Technical barriers, organisational culture barriers, and finical barriers were pre-identified during the literature review. The LIM provides a comprehensive approach to the implementation of digital twins. The five phases of the framework, namely technologies tools and techniques, process, strategy, leadership and behaviour, and engagement, are interconnected and interdependent. Successful implementation of the digital twin requires a holistic approach that addresses all these phases.

4.2 PATTERN MATCHING FOR THE BARRIERS

Comparing the study's findings with existing knowledge can also help identify gaps in the literature and suggest areas for future research. Table 5 shows the barriers, which have been identified the literature and during the data analysis.

Table 5: Empirical and literature findings for barriers

Description	Count	Expert Index
* Financial barriers | ***Literature***	12	E1, E2,E3,E4,E6,E7,E9, E10, E11,E12,E13,E15
Limited infrastructure	8	E1, E9,E10,E5,E12,E14, E15, E13
* Organisational Cultural barriers | ***Literature***	8	E6, 12,E2,E7,E9,E11,E15, E13
Complexity	5	E5, E8, E4,E14,E15
* Technological barriers | ***Literature***	5	E2, E3,E7,E8,E11
Regulatory barriers	2	E5, E14
Limited understanding of the potential benefits	2	E1, E10
** Social | ***Literature***	-	Not recognised by experts
** Machine learning techniques | ***Literature***	-	Not recognised by experts
** System optimisation | ***Literature***	-	Not recognised by experts
** Search algorithms | ***Literature***	-	Not recognised by experts
** Existing construction management systems and procedures | ***Literature***	-	Not recognised by experts
** Computer Literacy | ***Literature***	-	Not recognised by experts

In Table 5, marked (*) rows show confluence barriers that have been identified in the literature and mentioned during the data collection. Marked (**) show the identified in the literature review phase.

4.3 LIM TO MINIMISE BARRIERS IN DIGITAL TWIN IMPLEMENTATION IN THE CONSTRUCTION INDUSTRY

Upon integrating the empirical findings of the study, the following model has been formulated and presented in Figure 2. Sankey diagrams provide a powerful tool for understanding and visualising the interconnections between different components of a system in the final framework (Riehmann et al., 2005). The model aims to provide a comprehensive understanding of the observed facts and the findings discovered and to facilitate further investigations in the field. The development of the model was based on the analysis of the collected data and the identification of the underlying patterns and relationships among the variables. As maintained a greater value of connections to invisible elements than visible elements (Eranga et al., 2022). The relationship had been formulated with the findings of the above analysis. Several authors disclosed technological barriers (Peansupap & Walker, 2006; Yevu et al., 2021, 2022;), organisational cultural barriers (Agrawal et al., 2022; Khasanov & Krasnov, 2019; Neto et al., 2020; Wanasinghe et al., 2020) and system optimisation (Barni et al., 2018; Lim et al., 2020; Wanasinghe et al., 2020) as the main barriers in the implementation of digital twin. It is evident from the LIM that the significance of the invisible elements is greater than that of the visible elements. The model emphasises that a significant portion of an organisation's strategy, leadership, behaviours, and engagement are not immediately apparent or observable, and thus may be overlooked or undervalued. Therefore, a comprehensive understanding of an organisation's dynamics necessitates appreciating these intangible yet crucial components.

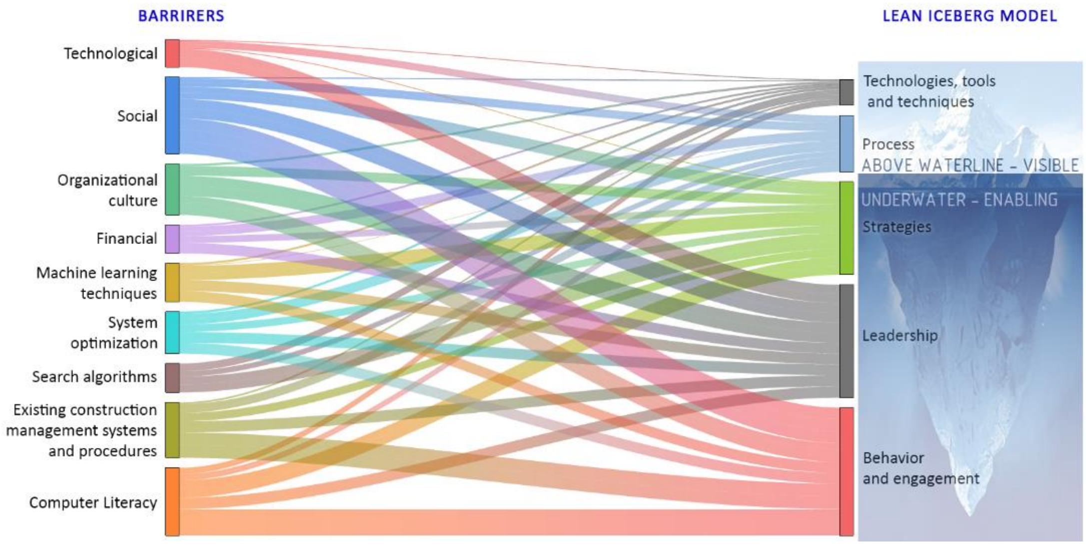

Figure 2: LIM relationship to minimise barriers in digital twin implementation.

5. CONCLUSIONS

Various barriers, including technological, organisational culture, and system optimisation, hinder implementing the digital twin. Literature findings have identified these barriers. Furthermore, the LIM has been used to analyse the connections between visible and invisible elements in the industry, revealing that the latter is more significant in determining an organisation's success in implementing digital twin. LIM highlights the importance of understanding intangible elements such as an organisation's strategy, leadership, behaviours, and engagement, which are often overlooked but crucial in achieving success in digital twin implementation. Therefore, a comprehensive understanding of an organisation's dynamics requires careful consideration of both visible and invisible elements to overcome the barriers and successfully implement the digital twin.

Empirical findings have revealed that financial barriers are the major barriers to the implementation of digital twins in Sri Lanka. This is due to the excessive cost of purchasing and maintaining specialised hardware, software, and data, as well as the cost of training personnel to use and manage them. Limited infrastructure and organisational cultural barriers were also identified as significant obstacles, as they can affect data transfer, slow performance, accuracy, scalability, and security issues. Complexity and technological barriers were also mentioned, as companies need access to the necessary hardware, software, and reliable data communication methods. Regulatory barriers and a limited understanding of potential benefit**s** identified as potential barriers to digital twin adoption. These findings indicate that firms need to address these barriers to successfully implement digital twins in Sri Lanka. Accordingy, the further research will be conducted to propose strategies through the LIM to minimise barriers to digital twin implementation in the Sri Lankan construction industry.

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LEAN SIX SIGMA TOOLS FOR IMPROVING ADMINISTRATIVE PROCESSES IN DIFFERENT SECTORS: A SYSTEMATIC REVIEW

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ABSTRACT

Lean Six Sigma (LSS) is widely accepted as an effective management concept in minimising wastes and variation of the processes. However, few studies can be found to integrate LSS for improving administrative processes in manufacturing and services industries. Out of the practicing LSS tools, identification of the most suitable LSS tools for each stage of LSS is vital to streamline the administrative process. Although, studies were conducted on lean implementation in different sectors in ad-hoc manner, dearth of studies were focused to compare the existing literature in detail. Therefore, the study aimed to conduct a systematic literature review (SLR) on LSS tools used in administrative processes in different sectors for every LSS stage. This SLR was conducted to addressing the above-mentioned research gap by adopting to the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) 2020 guideline for healthcare, education, public administration and other sectors. The initial repository comprised with 1817 and the final repository was comprised with 23 articles. The SLR has contributed to the theory by exploring suitable LSS tools and techniques for each DMAIC (Define, Measure, Analysis, Improvement, and Control) stages of LSS. Out of the identified tools, SIPOC and project charter can be recommended for the define stage whereas, process map is suggested for the measure stage. Further, Cause and effect analysis, Value Stream Mapping (VSM) and control charts are recommended for analysis, improvement and control stages. Further, some specific LSS tools were screened as a specifically applied to a particular sector. Ultimately, the results will propose to industry by applying appropriate LSS tools for administrative processes in different sectors which are not transformed into LSS incorporated internal environment.

Keywords: *Administrative Process; DMAIC; Lean Six Sigma; Lean Six Sigma Tool; PRISMA.*

1. INTRODUCTION

Administrative processes are referred as totality of generic processes and in extremely polymorphous activity in any organisation (Marume, 2016; Coughlan & Lister, 2018). Many researchers indicated that, 70% to 80% of all costs to deliver any service or product

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are comprised with the administrative processes (Ventura et al., 2020). The study by Berwick and Hackberth (2012) highlighted that the complexities in administrative processes are responsible for higher cost of production in healthcare. Consequently, Richmann et al. (2022) stated that 31% of US healthcare cost incurred with billing and insurance related activities which are one of the main administrative functions. Similarly, cost of administrative processes is remarked as high in healthcare (Kaplan and Porter, 2011; Richmann et al., 2022) as well as in higher education (Leslie & Rhoades, 1995). In addition, administrative processes may be formulated with entry points, completion of tasks with key actions and with some prerequisites with subjective paths for each individual (Coughlan & Lister, 2018). Hence, some variations may associate with administrative processes. Further, Kaplan and Porter (2011) emphasised on reducing non-value adding activities (NVAA) through standardising time in administrative processes. Therefore, administrative processes are required to regulate by adapting waste reduction principles and reduce variation with in the whole process. This underpins with the principles of lean six sigma (LSS). LSS is a business development methodology aiming to maximise shareholder's value through improving quality, speed customer satisfaction and reducing cost (Laureani and Antony, 2012). Similarly, Singh et al. (2023) indicated LSS as a technique to improve the operational effectiveness and efficiency of an organisation to achieve the competitive edge.

Laureani and Antony (2012) remarked that LSS uses tools from both toolboxes to obtain the better results than adopting Lean and Six Sigma separately. As per the recommendation by George (2003) the combination of these two concepts is deployed in organisational context by early 2000s' (Cudney & Furterer, 2020). Hence, the integrated approach of lean and six sigma is widely accepted in accomplish the business performances enhancement now (Antony et al., 2017). Similar to lean though LSS originally designed for manufacturing sector the application of LSS practices have been diversified in to various sectors as healthcare, education, finance, and public administration (George, 2003 and Singh & Rathi, 2019). Even though, Singh and Rathi (2019) investigated the LSS adaptation to different sectors as healthcare, human resource management and finances, the insight to types of LSS tools was not studied. Although, LSS application was popularised in industry sector recently LSS in servicers sectors is overreaching to manufacturing sectors (Singh & Rathi, 2019). Further, author has explored that LSS has highly implemented in financial, healthcare and educational sector about 40%, 36% and 24% respectively (Singh & Rathi, 2019).

Cudney et al. (2018) conducted a systematic review on application of lean and LSS for the processes including, academic and administrative functions of higher education. Demast et al. (2013) systematically reviewed the deploying LSS in financial sector. But, the most applicable tools were not studied. Moreover, Kuiper et al. (2022) argued that LSS tools selected in healthcare sector revolve around quick response and swift setup in terms of maximum inventories and patients in the operations. Besides, the lean implementation to administrative processes is still at the fledgling stage. Hence, it is vital to study on lean tools and its application in different sectors. Rodgers and Antony (2019) investigated on LSS application to public sector areas as healthcare, education, central government. Indeed, broader studies without limiting to public or private sectors are in need. However, application of tools in each stage of LSS was not studied. Henceforth, study in relation to tools applied in LSS stages are still lag in in-depth study. Hence, a systematic literature review (SLR) is vital to ascertain the research aim and objectives.

The aim of the research is to investigate the LSS tools and techniques in administrative processes in different sectors as education, healthcare, public administration and others. The objectives include, to identify the LSS tools and techniques used in administrative processes, to explore specific LSS tools used in administrative processes in different sectors, to evaluate the adaptation of LSS tools and techniques in administrative processes in different sectors at specific LSS stages, to suggest future research direction for the use of LSS tools and techniques in administrative processes.

2. DMAIC APPROACH IN LSS

Many researchers have utilised LSS tools and techniques to assess the improvements in the process. More to then, LSS can be embedded with Six Sigma five-phase methodology referred as DMAIC (Define, Measure, Analysis, Improvement, Control) (Laureani & Antony, 2012). George (2003) stated that tools applicable in each DMAIC stage are vital to place the human resource accordingly. Thomas et al. (2017) introduces DMAIC approach as the central driver of LSS which the appropriate lean and Six Sigma tools can be applied in each stage of DMAIC. Snee (2010) and Cano et al. (2012) recommended that since LSS is a problem-solving approach and no any improvement process is effective than DMAIC approach in LSS. By these justifications DMAIC is the most appropriate approach in LSS journey and suitable tools and techniques should be applied to achieve the desired outcome of each stage.

The '*define'* stage simply known as project charter and define the project scope, objectives, internal and external stakeholders, and roles and responsibilities of the team (Cano et al., 2012). In addition, Hafiish (2022) mentioned that, problems of the process can be initially identified at define stage. At '*measure'* stage, the flow of value through current state of the process is achieved (Hafiish, 2022; Salah et al., 2010). In next stage, '*analysis'* may continue with value stream analysis (Salah et al., 2010) or including other six sigma and lean tools such as, Pareto analysis, Failure mode effect analysis (FMEA). Next, '*improve'* phase is adjusted to make the flow in an expected way as designed in future state of the value steam analysis (Salah et al., 2010). Further, provide control procedures, continuous review and ensure the improvements have been done at the '*control'* stage (Conde et al., 2022; Salah et al., 2010). Further, the typical LSS tools applicable to processes were initially proposed by George (2003). Accordingly, both lean and six sigma tools are incorporated in DMAIC stages. Although, many LSS tools can be deployed some of the authors have recommended highly compatible LSS tools for many sectors. Therefore, applicable LSS tools in each stage of DMAIC are required to explore in to different sectors.

3. METHODOLOGY

The PRISMA 2020 statement comprises with advances in methods to identify, select, appraise, and synthesise studies with 27-item checklist (Page et al., 2021). In here, five reliable search engines are selected for the study as Scopus, Science Direct, Emerald, Taylor and Francis and Google Scholar. Further, Kuckertz and Block (2021) and Wijewickrama et al. (2021) have confirmed that above publishers are reputable databases for the search process of systematic literature review. Asnan et al. (2015) stated that around 1990s, the lean application to manufacturing sector is at widely accepted and Womack and Johnes (1996) disclosed its applicability to the service sector. Therefore, the ideology of diversion "lean" from manufacturing to service sector was planted in

1996. Hence, the systematic literature review has conducted from 1996 to 2022 timeline. As the initial step a search string with several keywords relating to the administrative processes and LSS which is presented in Figure 1.

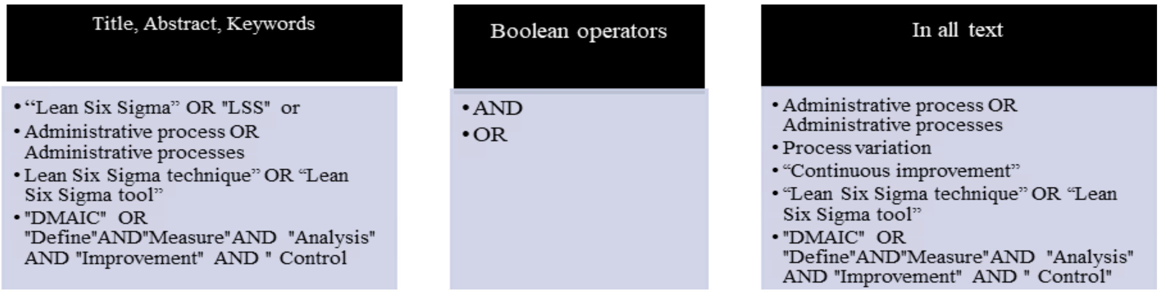

Figure 1: Search string used for SLR

According to Figure 1, search string is comprised with LSS related terms, "Lean Six Sigma Tools", "Lean Six Sigma techniques" and "administrative processes". The keywords are used to in-depth search in title, abstract, keywords search and in all text of the sources. Consequently, screening process has to be done to select the relevant studies out of the initial repository.

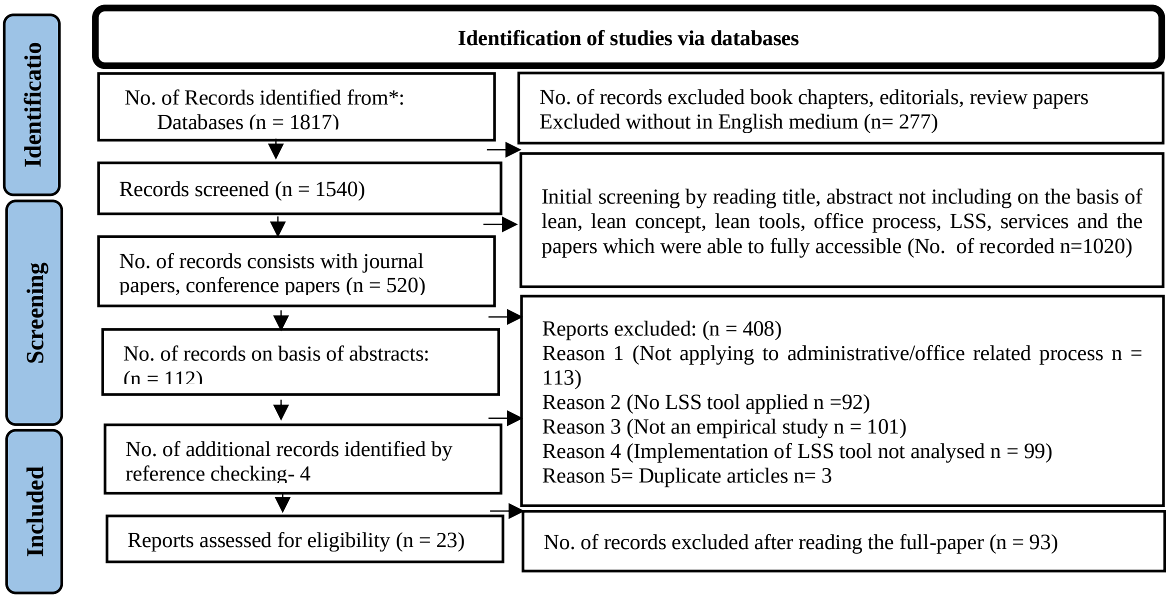

Figure 2: PRISMA flow diagram

The preliminary screening process was performed by including journals, conference papers, and unpublished thesis while excluding chapters, editorials and publications except in English. Further, administrative processes are inseparable in-service sector, industry or public sector. Hence, the relevant articles were further screened thorough reading of full articles. The PRISMA flow diagram used for the study is given in Figure 2. Initially 1817 articles were selected from the searched protocol. After the first screening, 1540 articles were subjected to the subsequent screening. Progressively, the articles refined up to 112 based on the 4 reasons: not applying to administrative/office related process, no LSS tool was applied, not an empirical study and implementation of LSS tools but not analysed. Meanwhile, the 4 articles were added to the repository and refine through reading full paper and totally 93 articles were rejected from the screening and further removing the duplicates. As a result of the above robust selection process the final repository contains 23 articles and subsequently, subjected to content analysis.

4. RESULTS AND DISCUSSION

After the screening process the infiltrate of 23 studies were extensively subjected to the content analysis. The findings are presented in following sections.

4.1 LSS TOOLS AND TECHNIQUES APPLIED IN ADMINISTRATIVE PROCESSES OF DIFFERENT SECTORS

As per Figure 3, various types of tools and techniques were applied to streamline the administrative processes in different sectors. These tools are comprised with both LSS and Six Sigma tools. Out of them, Process map is the highly used tool in LSS incorporated administrative processes irrespective to any sector. Consequently, SIPOC, Cause and Effect diagrams, Control plan, CTQ, Project charter, Standardisation of process and Value stream mapping (VSM) are frequently used tools and techniques in administrative processes. Further to then, VSM and process maps are considered as lean tools while SIPOC, Cause and Effect diagrams, Control plan, CTQ, Project charter are known as Six Sigma tools. Further, Brainstorming and Standardisation of process are highly used techniques in administrative processes. Overall, above tools and techniques are investigated as commonly used tools and techniques in streamlining the administrative processes under LSS. Further, above tools and techniques are also adapted in most of the administrative processes in education, public administration and other sectors.

The tools and techniques used in administrative processes are mentioned in Figure 3.

4.2 SECTOR SPECIFIC LSS TOOLS AND TECHNIQUES USED IN ADMINISTRATIVE PROCESSES

According to Figure 3, many specific LSS tools and techniques can be distinguished specifically applied for a particular sector. Contrary, most of the statistical techniques are widely used in healthcare related administrative processes. For instance, $\boldsymbol{\chi}^2$ test, ANOVA table, two sample-t test are some of the specific techniques used for healthcare sector. Apart from that calculation of cycle time, VOC, GEMBA, Kanban also demarcated as specifically used in healthcare sector. In education sector, affinity charts, takt time calculations are specifically applied in streamlining the administrative processes while, spaghetti charts, run charts, kaizen are particular to public administration sector. Further, lean consumption map is exclusively used for improving tax services in Indonesia (Sunaryanto & Sysh, 2019). However, sector specific LSS tools are still not tested for the administrative processes in other sectors.

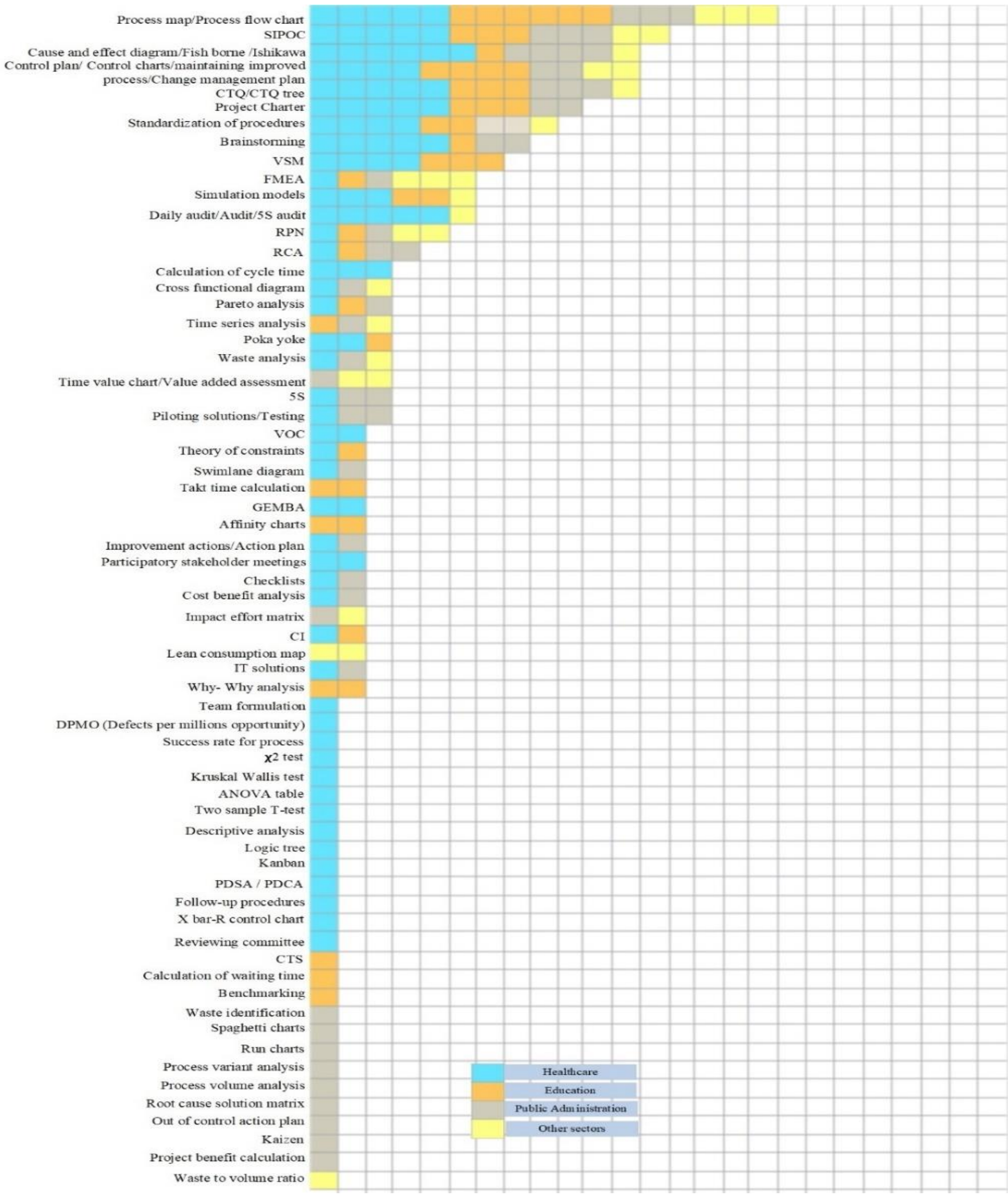

Figure 3: Different LSS tools and techniques used in administrative processes

4.3 DMAIC STAGE SPECIFIC TOOLS APPLIED IN LSS ADMINISTRATIVE PROCESSES IN DIFFERENT SECTORS

Tools and techniques used at DMAIC stages in different sectors were segregated and presented in Table 1.

Table 1: Tools applied in LSS administrative processes in different sectors at different stages of DMAIC

LSS phase	Type of Tool/Technique	SECTOR																											Total
		HEALTHCARE									Sub-total	EDUCATION						Sub-total	PUBLIC ADMINISTRATION					Sub-total	OTHER SECTORS			Sub-total	
		A	B	C	D	E	F	G	H	I		J	K	L	M	N	O		P	Q	R	S	T		U	V	W		
Define	Project Charter	√	√	√	√					√	5	√	√				√	3	√			√		2				0	10
	CTQ/CTQ tree		√	√					√		3				√	√	√	3			√	√		2			√	1	9
	SIPOC		√	√	√	√				√	5	√	√				√	3	√	√		√		3	√	√		2	13
	VOC				√	√					2							0						0				0	2
	Process map					√					1			√				1						0				0	2
	Team formulation						√				1							0						0				0	1
	Theory of constraints							√			1						√	1						0				0	2
	CTS										0	√						1						0				0	1
	Stakeholder analysis										0							0				√		1				0	1
	Waste identification										0							0					√	1				0	1
Measure	Process map/Process flow chart		√		√					√	3	√	√			√	√	4	√	√	√			3	√	√	√	3	13
	Calculation of cycle time			√		√			√		3							0						0				0	3
	CTQ	√				√					2							0		√				1				0	3
	DPMO (Defects per millions opportunity)		√								1							0						0				0	1
	SIPOC						√				1							0						0				0	1
	Swimlane diagram						√				1							0		√				1				0	2
	Spaghetti charts										0							0					√	1				0	1
	Cross functional diagram						√				1							0		√				1		√		1	3
	Success rate for process							√			1							0						0				0	1
	VSM								√		1			√	√			2						0				0	3
	Calculation of waiting time										0	√						1						0				0	1
	Collection of voice of process (VOP) data										0	√						1						0				0	1
	Time series analysis										0		√					1		√				1				0	2
	Takt time calculation										0			√			√	2						0				0	2
	Run charts										0							0	√					1				0	1
	Waste analysis										0							0	√					1				0	1
	Lean consumption map										0							0						0		√		1	1
	5S										0							0			√			1				0	1
	Process volume analysis										0							0				√		1				0	1
	Process variant analysis										0							0				√		1				0	1
Analysis	χ^2 test	√									1							0						0				0	1
	Kruskal Wallis test	√									1							0						0				0	1
	Brainstorming	√	√								2							0	√			√		2				0	4
	VSM		√		√				√		3						√	1						0				0	4
	Cause and effect diagram/Fish borne /Ishikawa			√	√	√	√	√		√	6		√					1	√		√	√	√	4			√	1	12

LSS phase	Type of Tool/Technique	SECTOR																										Total
		HEALTHCARE									Sub-total	EDUCATION						Sub-total	PUBLIC ADMINISTRATION					Sub-total	OTHER SECTORS			Sub-total	
		A	B	C	D	E	F	G	H	I		J	K	L	M	N	O		P	Q	R	S	T		U	V	W		
	GEMBA		√	√							2							0						0				0	2
	Pareto analysis		√								1				√			1	√					1				0	3
	ANOVA table		√								1							0						0				0	1
	Simulation models			√					√		2	√						1						0				0	3
	Two sample T-test			√							1							0						0				0	1
	RCA			√							1				√			1	√		√			2				0	4
	Descriptive analysis				√						1							0						0				0	1
	IT solutions					√					1							0						0				0	1
	FMEA					√					1		√					1		√				1	√	√	√	3	6
	RPN					√					1		√					1		√				1	√	√		2	5
	Logic tree							√			1							0						0				0	1
	Poka yoke								√		1					√		1						0				0	2
	Affinity chart										0			√			√	2						0				0	2
	Why- why analysis										0						√	1						0				0	1
	Piloting solutions										0							0	√					1				0	1
	Added value analysis										0							0				√		1		√	√	2	3
	Waste analysis									√	1							0						0	√			1	2
Improvement	Improvement actions/Action plan	√									1							0					√	1				0	2
	Simulation models		√								1	√						1						0	√			1	3
	Kanban			√							1							0						0				0	1
	Brainstorming				√		√			√	3				√			1						0				0	3
	Affinity charts										0						√	1						0				0	1
	PDCA/PDSA				√						1							0						0				0	1
	VSM (FS)					√					1			√				1	√					1			√	1	4
	5S									√	1							0				√		1				0	2
	Daily audit/Audit/5S audit					√	√				2							0						0				0	2
	Participatory stakeholder meetings					√	√				2							0						0				0	2
	Pilot testing						√				1							0						0				0	1
	Checklists							√			1							0				√		1				0	2
	Follow-up procedures							√			1							0						0				0	1
	Cost benefit analysis								√		1							0			√			1				0	2
	FMEA										0		√					1						0			√	1	2
	RPN										0		√					1						0				0	1
	Why-Why analysis										0						√	1						0				0	1
	Impact effort matrix										0							0		√				1		√		1	2
	Root cause solution matrix										0							0				√		1				0	1
	Time series analysis										0							0						0		√		1	1
	Time value chart/Value added assessment										0							0						0		√	√	2	2

LSS phase	Type of Tool/Technique	SECTOR																											Total
		HEALTHCARE									Sub-total	EDUCATION						Sub-total	PUBLIC ADMINISTRATION					Sub-total	OTHER SECTORS			Sub-total	
		A	B	C	D	E	F	G	H	I		J	K	L	M	N	O		P	Q	R	S	T		U	V	W		
	Benchmarking										0					√		1						0				0	1
	IT Applications										0							0			√			1				0	1
	Lean consumption map										0							0						0	√			1	1
	Control plan/ Control charts						√	√	√	√	4	√		√	√		√	4	√	√				0	√		√	2	12
	Poka yoke	√									1							0						0				0	1
	Daily audit/Audit/5S audit	√	√							√	3							0						0	√			1	4
	X bar-R control chart	√									1							0						0				0	1
	Standardization of procedures	√	√	√				√			4		√				√	2	√			√		2	√			1	9
	Reviewing committee			√							1							0						0				0	1
	CI				√						1					√		1						0				0	2
	Out of control action plan										0							0		√				1				0	1
	Run charts										0							0	√					1				0	1
	Piloting solutions										0							0	√				√	1				0	1
Control	Kaizen										0							0			√			1				0	1
	Project benefit calculation										0							0				√		1				0	1
	Waste to volume ratio										0							0						0		√		1	1

A- Basta et al. (2016), B- Bhat et al. (2014), C- Bhat and Jnanesh (2014), D- Cheung et al. (2016), E- Daly et al. (2021), F- Kovach and Borika (2018), G- Laureani et al. (2013), H- Southard et al. (2012), I- Antony et al. (2022), J- Furterer et al. (2019), K- Li et al. (2019), L- Oko and Kang (2015), M- Sunder and Mahalingham (2018), N- Svensson et al. (2015), O- Webb and Furterer (2019), P- Antony et al. (2017), Q- Ginanjar and Sysh (2019), R- Kim (2020), S- Kregel and Coners (2018), T-Zefaj (2021), U- Artadi and Syah (2019), V- Sunaryanto and Sysh (2019), W- Lee et al. (2013)

LSS tools are deployed at DMAIC stages in different sectors has been studied. In order to assess the administrative factors, lead to the inefficiencies, VSM, Gemba walks, SIPOC tools are used by Cheung et al. (2016). However, Tortorella et al. (2016) revealed the use of VSM is successful at the journey of lean initiatives in healthcare. Similarly, Argiyantari et al. (2021) adopted with Gemba walks, VSM, Pareto analysis for delaying the transportation in pharmaceutical products. Obviously, these tools have to be included in LSS process. At each stage some of the tools are frequently used and some of the tools are not frequently used. Several papers reported that SIPOC tool is highly recorded in define stage while project charter and critical to quality (CTQ) characteristics are also frequently used in administrative processes related studies (Basta et al., 2016; Cheung et al., 2016; Furterer et al., 2019; Li et al., 2019). According to the Basta et al. (2016) aim of the define phase of LSS is to select and design the project to reach the target. Additionally, Bhat et al. (2014) disclosed that the scope of the project and the areas to be improved will be identified in this stage. Thus, a tool which can be deployed to scan the respective organisation environment may effective to use. Next, process maps or flow charts are abundantly applied at the measure phase.

Further, VSM can be derived from process flow charts including performance data, information flow with linking the works (Cheung et al., 2016). Therefore, VSM can use in measure phase too. However, in most cases time related parameters are concerned measure stages such as calculating cycle time (Bhat & Jnanesh, 2014; Cheung et al. 2016; Southard et al. 2012), takt time calculation (Oko & Kang, 2015; Webb & Furterer, 2019) calculation of waiting times (Furterer et al., 2019). Kaspin (2022) assured that cause-and-effect analysis can be utilised in analysis phase. This study investigated that, not only that tool, FMEA, RPN, and VSM tools are also applicable. By reviewing the above Figure, tools and techniques used in measure and analysis phases are comparatively high. Indeed, the application of VSM in improvement phase. Apart from that, impact effort matrix, daily audit, FMEA, Checklist, Kanban tools are used. In Control phase, control plan, Standardisation, CI, 5S audits are adapted. However, some of the strategies were coincided in some phases such as SIPOC, CTQ and process maps tools are in both define and measure phases, FMEA, why-why analysis are coincided in analyse and improvement phases. Not only the common tools but some of the tools are identical for a particular phase in LSS. Obviously, Project charter tool is specific for the define phase (Webb and Furterer, 2019; Antony et al., 2017; Kregel and Coners, 2018) whereas cause and effect diagram tool (Kovach and Borika, 2018; Laureani et al., 2013), GEMBA (Bhat et al., 2014; Bhat and Jnanesh, 2014), pareto analysis (Sunder and Mahalingham, 2018; Antony et al., 2017) are specifically used at the analysis phase. Moreover, PDCA, Kanban tools are identical to improvement stage while control plan, standardisation, Kaizen, continuous improvement are explicated for the control phase. By recapitulating the above findings when designing a LSS approach to streamline an administrative process in any sector suitable tools and techniques can be selected from the above tools and techniques in a respective phase.

Nevertheless, some of the tools and techniques are widely used in a particular sector but not adapted to other sectors. For instance, theory of constraints is applied in both healthcare and education sectors and it can be adapted to the public administration and other sectors such as construction, manufacturing etc. Furthermore, process maps are widely used in all sectors at measure phase. Contrary, calculating cycle time is specifically studied in healthcare sector and still not adapted to the education, public administration and other sectors. Bhat and Jnanesh (2014) calculated the cycle time at the operations in Outpatient Department in Indian rural hospital while Daly et al. (2021) calculated the cycle time of scheduling Orthopedic surgical processes at the measure phase. Despite waiting times of students in commencing the tutoring sessions were studied in education sector (Furterer et al., 2019). In analysis phase cause and effect diagram is highly applied in healthcare and public administration sector whereas less studies relating to administrative processes in education sector. In spite of that, effects of adapting RCA is studied in relation to the education sector as well. Additionally, RPN, FMEA tools are adapted in many sectors in fewer studies. On the other hand, the applicability of why-why analysis, Poka-yoke and logic tree tools related to public administration sector and other sectors (finance, banking, construction) can be studied. Obviously, VSM is recorded as the highly used tool at Improvement phase in every sector. Although PDCA is accepted in applying healthcare sector but lesser studies in relation to other sectors such as education, public administration, logistics, construction. Moreover, out of control action plan, Kaizen, run charts are adapted in public administration sector and still not adapted to education, healthcare and other sectors. Indeed, there is a potential to use these tools in DMAIC stages of a LSS process.

5. CONCLUSIONS

This SLR was conducted to synthesis the body of knowledge of LSS application and through the content analysis. 66 LSS tools and techniques were investigated as applicable in administrative processes. Overall, Process map, SIPOC, cause and effect diagram, control plan, Process change management plan, CTQ, Project charter, Standardisation of procedures are highly applied in all sectors. Further, it was revealed number of LSS tools which are applicable in each stage of DMAIC approach. However, the most applicable tools were investigated. At define stage, SIPOC, project charter tools are highly acceptable irrespective to a sector. Further, process map can investigate as the highly recommended tool in measure stage in administrative processes. Cause and effect analysis is screened as a specifically used in analysis stage. In improvement stage, VSM was investigated as the most applicable tool while, control charts and standardisation of process for the control phase. Moreover, when considering the specific LSS tool for a particular sector, waste identification and stakeholder analysis was specifically used at the define stage in public administration sector. In healthcare sector, DPMO and SIPOC was specifically applied at the measure stage. Further, most of the statistical methods as Kruskal Wallis test, x^2 test, are specifically used in healthcare sector. This SLR contributes to industry, when designing LSS approach in any sector any of tool can be selected from the tools and techniques clustered in each phase. Furthermore, the study contributes to theory by investigate on frequently used tools and specific tools for DMAIC stages in above sectors.

6. THE WAY FORWARD

The development of the usage of LSS tools and techniques with the chronological order is not analysed. Still, some of the tools and techniques are specifically used in a particular sector such as Kanban tool is used for healthcare sector, Kaizen tool used for public administration sector. However, the applicability of these tools in administrative processes in other sectors can be investigated. Hence, considering the sector-wise comparison, some sectors have limited studies on adapting LSS in administrative processes. Therefore, the studies are linked with administrative processes in other sectors like physical infrastructure projects, banking, and tourism industries. Further, this study emphasises the necessity of adapting LSS tools in administrative processes in any sector to restructure the administrative processes and direct to improved performances of the organisation. Consequently, the specific tools and techniques explored in particular sector can be tested for the other sectors to enhance the novelty of the future studies. Finally, this study is a part of the initial study and these findings will be validated through an empirical study.

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LEGAL AND POLICY PROVISIONS FOR PROTECTING ENERGY AND TELECOMMUNICATION INFRASTRUCTURE AGAINST HAZARDS: COMPARISON BETWEEN SRI LANKA AND OTHER COUNTRIES

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ABSTRACT

In the recent years, Sri Lanka's focus on its infrastructure has grown due to its significance to the country's economy, security, and quality of life. A resilient critical infrastructure system is crucial in reducing the impact of natural and human induced risks and weaknesses. In this context, comprehensive knowledge of a nation's legal and policy framework would be of great assistance in building pathways towards strengthening the resilience of critical infrastructure systems. Concerning the need, this study aims to assess the ability of the existing legal and policy framework for complex, interdependent infrastructure systems in Sri Lanka to protect its energy and telecommunication infrastructure against natural and human-induced hazards. The objectives of the study include: (1) determining the existing legal and policy framework for energy, telecommunication infrastructure in Sri Lanka; and (2) comparing the legal and policy provisions for protecting these infrastructures against hazards in Sri Lanka with the international context. The study involved a comprehensive literature synthesis to understand the scope of critical infrastructure in the global context. Further, preliminary interviews were conducted to obtain the direction for the identification of the existing legal and policy framework related to the infrastructure sectors in Sri Lanka. Finally, the study examined the available provisions in the framework, alongside a desk study, to assess their effectiveness in safeguarding critical infrastructure. A comparison between Sri Lanka and the international context highlighted significant gaps in the legal and policy framework, particularly in terms of protecting the nation's infrastructure.

Keywords: *Critical Infrastructure; Law and policy; Resilience; Protection of Infrastructure.*

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1. INTRODUCTION

Critical infrastructure is comprised of systems and assets. They can be either virtual or physical. These infrastructures are essential and any disruption to them can have a serious impact on a nation's economic stability, public health and safety, national security, and quality of life. According to Randeniya et al. (2022, p.11) critical infrastructure can be identified as "system of identifiable sectors whose destruction or incapacity would have an enervative impact on the economic sustainability, public health and safety, quality of life, and national security of a country". The identified infrastructure sectors are energy, water, telecommunication, finance, transportation, and essential services. Only two infrastructure sectors were considered for this study due to the overwhelming amount of information relating to all six sectors and the difficulty of presenting all six in one study. The critical infrastructures that are being analysed in this study are:

- Energy, and
- Telecommunication.

The current infrastructure, which has been standing for the past twenty years, has started to deteriorate in quality. The manner in which the government and the inhabitants renew and protect the infrastructure will determine the quality of life for future generations as well as national security and disaster resilience (Adams, 2017). Even though the local laws and policies have been implemented concerning the infrastructure and the gaps have been identified for the protection of the infrastructure, some of the infrastructure's legal and policy frameworks have failed to stipulate the criminal and civil penalties clearly. Having a proper legal and policy framework would support the legitimacy of the organizations in charge of the infrastructure and therefore sustain their longevity. Due to the global character of the information and knowledge on the economy, minimum common international standards have long been acknowledged as crucial. Government policies and how they are reflected in the law influences how infrastructures and services developed are used. The development of the country and the interconnect ability of national legal systems are facilitated by such shared standards. (Pournader et al., 2020). Currently there are no studies conducted under legal and policy frameworks in Sri Lanka considering the infrastructure sector. This study aims to assess the ability of the existing legal and policy framework for complex, interdependent infrastructure systems in Sri Lanka to protect its energy and telecommunication infrastructure against natural and human-induced hazards.

The quantity and variety of infrastructures have become more threat-resistant over the last few decades, and they have begun to secure their ongoing operation and development at the national level. Natural disasters, mechanical malfunctions, inadequate design, or human action ranging from theft/arson to terrorist attacks can all cause disruption or the destruction of its operation.

2. LITERATURE REVIEW

Most of the countries have legal elements relating to the protection of infrastructure. These elements address issues such as infrastructure protection, civil and criminal penalties against improper use of the infrastructure and protects any intellectual property pertaining to the infrastructure. Some countries have specific legal means when addressing critical infrastructure protection but most of the other countries have no specific legal provisions regarding critical infrastructure protection. Even where countries do have specific provisions on dealing with the critical infrastructure, differences exist between the countries on how to protect the infrastructure. Most frequently the critical infrastructure protection is done through applying industry norms and standards.

In the study, laws and policies are being discussed at both the national and international scale. Countries such as Australia, Canada and United States of America were taken into consideration for the study to compare with the Sri Lankan context due to them being developed countries and having the strongest infrastructure systems. As well as, being the countries, which are known for taking best care of its' citizens therefore the best care towards the overall infrastructure system from both physical and social point of view.

3. METHODOLOGY

3.1 DATA COLLECTION

For this study, six preliminary interviews were done to collect the empirical data on the acts which are most important when it comes to the infrastructure sectors and secondly, a desk study-literature review was conducted to examine the gaps and protective measures taken in the Sri Lankan regulatory framework. The preliminary interviews were conducted among professionals attached to energy and telecommunication infrastructures with an experience of over twenty years to analyse the findings derived from the desk study and to finally determine whether Sri Lanka has addressed the issues regarding the protection of critical infrastructures. During the preliminary interviews, the interviewees were asked whether there were any specific policy or legal framework implemented towards protecting the infrastructure sector and if so, to elaborate on how the protection measures are taken towards the infrastructure. Furthermore, the interviewees were asked whether there were any legal and policy frameworks towards building resilience of the particular infrastructure sector. According to the information given in the interviews, the next section presents the legislations that were taken into consideration.

4. DATA ANALYSIS

4.1 INTERNATIONAL CONTEXT

4.1.1 Telecommunications Infrastructure

Telecommunication is at the heart of the transition towards a digital society. Cybersecurity is the primary foundation that guarantees the safety of the digital economy, inspires confidence in all users, and promotes economic growth. The importance of digital technology for sustaining the economy is demonstrated by the swift adoption of it by homes and businesses after the COVID-19 outbreak. To enhance the benefits of the digital world, the controlling of the threats which comes along must be done.

Australia

One of the biggest hazards to Australians is malicious online activity. The epidemic brought attention to how everchanging cyber threats are. Opportunistic cybercriminals have modified their techniques to profit on Australians connecting, working, and learning online (Burchaers et al.,2022)

The Australian government has “the Security of Critical Infrastructure Act 2018” as the main governing body. Civil penalty provisions of this Act can be enforced using civil penalty orders, injunctions, and enforceable undertakings may be accepted in relation to compliance with civil penalty provisions. Additionally, in order for this Act to apply to a specific asset, the Minister can privately proclaim it to be a vital infrastructure asset. A private declaration would be made only if there was an imminent risk to national security.

The Australian Government has acted in strengthening the protection of Australian citizens, their data and critical infrastructure from the most complex threats. Through spending a sizable sum of money, the Australian Government has improved the AFP's (Australian Federal Police) capacity to look into and to prosecute cybercriminals. The AFP has been able to create target development teams to strengthen technical cyber capabilities, and improve operational capacity (Critical Infrastructure Centre, 2020).

National Critical Infrastructure Resilience Framework (NCIRF)

This is a governmental policy that aims to protect energy and telecommunication infrastructure from potential disruption. It seeks to strengthen the resilience of critical infrastructure to physical, cyber, and human threats, and to ensure that it can remain operational in the face of any potential disruption. The framework is designed to ensure that Australia’s critical infrastructure is secure, resilient and able to provide services when needed. It sets out a range of measures that energy and telecommunication infrastructure operators, owners and users can take to protect their assets, as well as strategies for responding to and recovering from any disruption. By strengthening the resilience of critical infrastructure, the NCIRF helps to ensure that Australia’s energy and telecommunication networks remain reliable, secure, and available to users.

United States of America

Attacks on government computer systems, bank computer systems, and systems utilized in interstate and international commerce are prohibited by the Counterfeit Access Device and Computer Fraud and Abuse Act of 1984.

In this they have stipulated criminal penalties, including asset forfeiture, for unauthorised access and improper use of federal government or financial institution computers and networks, or in interstate or international commerce or communication, and improper use of protected information, causing damage to or threatening to cause damage to a computer, using the computer to commit fraud, trafficking in stolen computer passwords. It has also provided a statutory exemption for intelligence and law enforcement activities and criminalised electronic trespassing on and using federal government systems outside the scope of allowed access. (Fischer, 2014).

Homeland Security Act of 2002

According to Guermazi and Satola (2005) the Department of Homeland Security undertakes several responsibilities for the safety of the information infrastructure that were previously handled by other authorities (Department of Homeland Security). It mandates that DHS offer information on threats and vulnerabilities, support for crisis management, and technical assistance with regard to recovery plans for critical information systems to state, local, and private entities. Additionally, this enhanced some of the criminal penalties for cybercrime and permitted the Secretary of Homeland Security to designate eligible technologies as being subject to specific safeguards from liability in claims connected to their use in response to an act of terrorism. Furthermore, the DHS demanded collaboration between the sector-specific agencies and the DHS Office for Infrastructure Protection (Fischer, 2014; Roche,1998).

Communications Act of 1934

The Federal Communications Commission (FCC) was created and granted control over domestic and foreign wired and wireless commercial communications. That provides the president with control over communications equipment and stations during emergencies. (Fischer, 2014).

4.1.2 Energy Infrastructure

Canada

To improve the safety and security of the operation of a regulated facility, the Canadian government passed the "Canadian Energy Regulator Act (S.C. 2019, c. 28, s. 10)". Under this law, the Commission may, by order, direct the holder to repair, reconstruct, or alter part of the regulated facility and may also order that, until the work is completed, that part of the regulated facility will not be utilised or be utilised in accordance with any conditions specified by the Commission. Anybody that violates a rule imposed under section 96, is guilty of an offense and liable (Canadian Energy Regulator Act, 2019).

- If found guilty on indictment, a fine of no more than $1,000,000, a period of no more than five years in prison, or both; or
- Upon summary conviction, a fine of no more than $100,000, a period of no more than one year's imprisonment, or both.

Energy policy acts as a proxy for the function and value of many other interrelated sectors from telecommunication, agriculture, defence, manufacturing, finance and transportation.

The Canadian energy regulator Act acknowledges that the owners and operators bear the primary duty for enhancing the resilience of critical infrastructure. The perfect combination of security measures which addresses intentional and unintentional incidents, business continuity procedures which handles disruptions and guarantee the continuation of essential services, and emergency management planning which ensures that adequate response protocols are in place to address unforeseen disruptions and natural disasters can increase the resilience of critical infrastructure.

Nuclear Liability and Compensation Act (S.C. 2015, c. 4, s. 120)

This act states that if damage are caused by a preventive measure taken under subsection 20(1) in relation to an operator's nuclear installation or in relation to any transportation for which the operator is responsible, then only that operator and no one else is liable for damage that occurs within Canada or its exclusive economic zone.

The continued criminal actions of robbery, vandalism, public order extremism, and extreme weather conditions all pose threats to the energy system, but terrorism and cyberattacks also carry significant hazards. The primary terrorist hazard emanates from international Islamist extremism as epitomised by way of al-Qaida. Digital assaults may be perpetrated through broadly one-of-a-kind groups or individuals with diverse motives. Much of Canada's national crucial infrastructure is now both constructed upon or monitored and controlled with the aid of cyber data and communications technologies (ICT) which makes it prone to electronic attacks and the cascading consequences of disruptions in different important infrastructures. Vital energy infrastructure structures include many one-of-a-kind agencies and groups which can be connected to every other electronically in the area and to different infrastructure sectors via records structures. Reliance on SCADA technology in addition will increase vulnerability to network disasters and digital attacks making the energy quarter as a whole very inclined. Cyber-attacks may be launched to obtain or corrupt facts, disrupt offerings or plan similarly assaults on infrastructure. The supply and integrity of those structures and the records transmitted is incredibly dependent on top physical, non-public and technical shielding protection procedures (Energy Policy, 2015).

Extreme climate events cause significant strain on power distribution systems. In general, the consequences of environmental hazards entail incident responses, emergency management and adaptation to such environmental occurrences. Numerous regions in Canada have experienced severe natural disasters resulting in loss of life and extensive property damage. Generally, Natural failures encompass an expansion of meteorological and geological hazards of which floods are the maximum frequent and the main motive of assets harm and death. Hurricanes, earthquakes, and wildfires also are a part of the natural chance panorama and might result in the discontinuity of power substances which in turn are probably to have an effect on recuperation efforts (Energy Policy, 2005).

The Public Safety Act (2002)

A number of legislative amendments had been enacted to offer Regulators with a clear statutory basis for regulating the safety as well as the safety factors of interprovincial and worldwide energy belonging an exchange necessitated with the aid of a growing realisation that the oil, gas and nuclear/electric power centres have been appealing, high price/high impact goals for terrorists (Public Safety Act, 2002).

Critical Infrastructure Resilience Strategy (CIRS)

This was established to safeguard Canada's electricity and telecommunications infrastructure against terrorism, malicious cyberattacks, and natural catastrophes. The three key areas of the plan are risk management, collaboration, and awareness and education. It promotes public-private collaboration to create efficient critical infrastructure protection plans. Enhancing the security and resilience of Canada's energy and telecommunications networks is another goal of the CIRS. In order to maintain the security and dependability of the nation's energy and telecommunications networks, this entails stepping up cybersecurity precautions and strengthening coordination between the federal, provincial, and territorial governments. The CIRS contributes to the defense of Canada's energy and communications infrastructure against foreign threats by performing these actions (Department of Home Affairs, 2018).

United States of America

Federal Power Act

This established the Federal Energy Regulatory Commission (FERC) and granted it control over the transmission and sale of electricity across state lines. Over the past several years, worries regarding the electric grid's susceptibility to cyberattack have grown significantly. Even though the Power Coverage Act of 2005 (P.L. 109-58) gave FERC responsibility for creating reliability standards for power structures, challenges to that authority and to the usefulness of the standards-improvement process to effectively respond to unexpectedly emerging cybersecurity threats have raised questions about the need to strengthen FERC's authority to address those threats, especially given the advancement of the intelligent-grid era. After deliberations it was decided that FERC would not be given jurisdiction over electric powered infrastructure and with response to the cybersecurity concerns, in the 112th Congress, S. 1342, FERC was given expanded cybersecurity authority (Department of Energy, 2018).

National Infrastructure Protection Plan (NIPP)

It is an extensive collection of plans, methods, and initiatives created to safeguard the vital infrastructure of the country against criminal activity. The National Infrastructure Protection Program (NIPP) offers a framework for public and commercial institutions to coordinate their efforts to safeguard the country's energy and telecommunication facilities from conventional and emerging security risks. The NIPP also specifies risk management procedures that businesses should use to safeguard their vital infrastructure. The NIPP aims to ensure that energy and telecommunication infrastructures are secured from dangers like terrorism, natural disasters, and cyber-attacks by coordinating efforts among government, business, and other stakeholders (Department of Homeland Security, 2013).

4.2 SRI LANKAN CONTEXT

4.2.1 Telecommunication Infrastructure

Sri Lanka Telecommunications Act (No. 25 of 1991) - Sect 47

According to the act, anyone who intentionally destroys, removes, tampers with, or interferes with any telecommunication set up line, post, or other items that are a part of or used in any telecommunication system or inside the service of any carrier will be found guilty of an offense and subject to a fine of no more than 20,000 rupees, a term of imprisonment of either description of no more than six months, or both such punishments, upon conviction (Telecommunications Act 27, 1996 & Singh, 2019).

State of Cybercrime Legislation

According to Singh (2020); Oxford Business Group (n.d.) these Acts deal with the main statutes that address offenses including unauthorised access to a computer, data, or network, unauthorised use of malware, launching denial-of-service attacks, unauthorised interceptions, and unauthorised data use.

- Computer Crimes Act No. 24 of 2007
- Payment Devices Frauds Act No. 30 of 2006
- Intellectual Property Act No. 36 of 2003

According to United Nations (2007) there are other statutes that support the implementation of the Budapest Convention for Cybercrime. These include:

- Mutual Assistance in Criminal Matters Act No. 25 of 2002 (Amended in 2018)
- Financial Transactions Reporting Act No. 6 of 2006

The Mutual Assistance in Criminal Cases (Amendment) Act, which outlines the conditions under which certain nations, including Sri Lanka, may give aid in criminal cases. It's also important to note that Sri Lanka works to complete its data protection and cyber security laws in 2019 (Lawnet Ministry of Justice, 2019).

The Cybersecurity Bill passed all the preliminary procedural stages, and it is waiting for cabinet approval and enactment. The Act's goals are to protect the Critical Information Infrastructure, ensure that Sri Lanka's National Cyber Security Strategy is implemented effectively, prevent, mitigate, and respond to cyber security threats and incidents effectively and efficiently, establish the Sri Lanka Cyber Security Agency, and empower the institutional framework to provide a safe and secure cyber security environment (Ministry of Technology, 2019).

Cyber Security Act, No. of 2019

To protect the critical information infrastructure and effectively and efficiently prevent, mitigate, and respond to cyber security threats and occurrences.

4.2.2 Energy Infrastructure

Ceylon Electricity Board Act (1987)

The electricity board act has not taken any major precautions towards the infrastructure protection, but it has stipulated the parties responsible for the construction, maintenance and operation of the generation stations and sub stations also the penalties for the ones who cause harm to the structures (CEB Act, 1987).

Electricity Act No. 20 of 2009

In this the electricity board has taken protective measures by Strengthening of Centralised Monitoring System (CMS) which monitors and records the quality of electricity supply and helps to detect power outages, power theft and other irregularities. This improved network security, and a system maintenance was also implemented to provide for the installation of security devices in electricity networks to prevent power theft and other illegal activities and to require electricity operators to ensure that all electricity infrastructure is maintained in an efficient and safe manner. Also, the regulatory framework was improved to ensure the efficient and reliable supply of electricity and to protect the public from dangerous and hazardous situations that can arise due to the electricity infrastructure.

In this a separate security unit was established within the Ministry of Power and Renewable Energy to coordinate energy security policies and to monitor the energy supply chain. An energy security policy was developed to ensure the continuity of energy supply (National Energy Policy, 2015).

An independent security council was also established to monitor and review energy security policies of the government. This can be considered as an important milestone due to the establishment of an energy security information exchange system to share critical information among stakeholders which has not been done before in the energy sector prior to this policy. Also strengthening cyber security measures to protect the critical energy infrastructure were taken with this policy

5. RESEARCH FINDINGS AND DISCUSSION

According to an interviewee, the national energy policy covered the Sri Lankan energy sector and the protection of the infrastructure, but it has not referred to the protection of the structural or physical buildings of the infrastructure sector, rather it has talked about the protection of the people who work there and any personnel who can be affected by the infrastructure sector. Energy sector in Sri Lanka does not have many protective measures in the legal area but they have stipulated the penalties which follow those who damage the properties and structures. Furthermore, when considering the telecommunication sector, interviewees have stated that the TRCSL (Telecommunication Regulatory Commission Sri Lanka) protect consumers as well as operators, and are feeding information updating operators, consumers. CERT-cybercrimes, which investigates and provides reports regarding issues, but they do not pursue structural protection of the infrastructure.

It was found that the Canadian government has measure taken against damages by human personnel which goes from $1,000,000 to $100,000. The USA has stated about the penalties which would be given for any acts relating to disruption of power due to the sensitivity of the infrastructures and by considering the national security, economic stability, and the quality of life of the citizens in the country. Moreover, USA has measures taken against the cyber threat due to most of the functions being automated and digitised. Starting from manufacturing sector to the healthcare sector, the telecommunication sector has penetrated within the other sectors and due to the complexity and diversity of the systems, the possibility of getting a cyber-attack is high. Therefore, necessary precautions were taken in the cybercrimes Act in relation to the penalties that accompany the crimes, whereas in Australia they have enforced using civil penalty orders or injunctions, and enforceable undertakings are accepted in relation to compliance with civil penalty provisions for noncompliance with the law.

All three countries, Canada, Australia, and USA have their own penalty systems to enforce once a person would inflict damage on the structures but in Sri Lanka the judicial system does not talk about the penalties which would come with the cyber vulnerability. Neither Australia nor USA have provided specific laws on the protection of the telecommunication structures, but they do have protection measures taken pertaining the information concerning the telecommunication infrastructure. In Sri Lanka, the judicial system does not have many polices to protect the infrastructures, but it does cover the information regarding telecommunication. The energy infrastructure in USA, Canada has taken the protection of the energy infrastructure from both, physical and cyber harm. Such attacks lead to disruption of power which would eventually build up towards economic chaos due to the high dependency on the energy sector. These countries have become heavily dependent on top physical, non-public, and technical shielding protection procedures for safeguarding the energy sector due to the high digitalisation of the sector. Furthermore, these countries have imposed heavy penalties anyone who causes harm to the structures. The individuals would get both civil and criminal penalties including imprisonment, probation, fines or a combination of these. However, the severity of the penalties would be determined by the nature and extent of the damages caused.

According to the study it was clear that while USA has the National Infrastructure Protection Plan (NIPP) which provides a comprehensive framework for enhancing the protection of the nation's critical infrastructure. This plan includes guidance on how to reduce risks associated with natural disasters, cyber threats, and other hazards. Additionally, the USA has a number of laws, regulations, and policies related to disaster management, infrastructure security, and resilience. Canada has the Critical Infrastructure Resilience Strategy (CIRS) provides guidance on how to protect critical infrastructure against natural disasters, cyber threats, and other hazards. Additionally, the Canadian government has several laws, regulations, and policies related to disaster management, infrastructure security, and resilience. Australia has the National Critical Infrastructure Resilience Framework (NCIRF) provides guidance on how to protect critical infrastructure against natural disasters, cyber threats, and other hazards. Additionally, the Australian government has several laws, regulations, and policies related to disaster management, infrastructure security, and resilience. Sri Lanka does not have specific legal and policy provisions for protecting infrastructure against hazards. The country does, however, have a number of laws and regulations related to disaster management and resilience under particular acts and policies that provide guidance for infrastructure protection.

6. CONCLUSIONS

The primary aim of this study was to identify the existing legal and policy framework for energy, telecommunication infrastructure in Sri Lanka and to compare the legal and policy provisions for protecting these infrastructures against hazards in Sri Lanka with the international context.

The legal and policy framework for energy, telecommunication infrastructure in Sri Lanka is set out in the Ceylon Electricity Board Act (1987), Electricity Act No. 20 of 2009, Telecommunications Act No. 25 of 1991 and the National Energy Policy (2015). Also, these were identified as the existing legal and policy framework for energy, telecommunication infrastructure in Sri Lanka. The Electricity Act provides for the regulation of the generation, transmission, distribution, and supply of electricity, as well as the establishment of the Sri Lanka Electricity Regulatory Commission (SLERC). The Telecommunications Act governs the regulation of the telecommunication industry in Sri Lanka, including the licensing of telecommunications service providers. The National Policy on Energy and Telecommunications sets out the overall policy framework for the energy and telecommunications sectors in Sri Lanka, while the National Energy Policy provides a roadmap for the development of the energy sector in Sri Lanka.

Despite the steps taken by the Sri Lankan government, there is still room for improvement in the protection of infrastructure from natural and human-induced hazards in Sri Lanka, for instance, there is a need to better integrate existing the laws and regulations into a unified framework that covers all aspects of infrastructure protection, and to strengthen the implementation of these laws and regulations. In addition, there is a need to develop more effective policies and strategies to address the specific needs of each type of infrastructure, such as water and energy. Finally, there is a need to increase public awareness and education about natural and human-induced hazards and their impacts on infrastructure.

Thus, the study findings can be used as a reference when conducting further studies on energy and telecommunications infrastructure.

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LEGAL AND REGULATORY FRAMEWORK RELATED TO UNSOLICITED PROPOSALS IN VARIOUS COUNTRIES: A SYSTEMATIC REVIEW FOR PROCUREMENT STAGE

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ABSTRACT

An Unsolicited Proposal (USP) is a privately initiated process that is an alternative to the solicited procurement method. Public Private Partnerships (PPPs) that are launched on an unsolicited basis, become popular among governments since they enable faster delivery of projects and avoid the time-consuming process of competitive tendering. If improperly managed, USPs may lead to numerous public rallies and protests, poor value for money, a failure to meet the nation's true sociological and economic necessities, and the satisfaction of only a handful of public and private officials. Most governments accept and recognise USPs by integrating various management systems into their procurement processes to mitigate the negative effects of it. Strengthening the existing legal and regulatory framework is one such management system. The authors conducted a detailed study of the existing legal and regulatory framework of countries that are having matured and developed PPP environments and a provision to entertain unsolicited PPPs. Based on the findings from the detailed study, a conceptual framework was developed for the procurement of USPs that can be utilised to reform existing legal and regulatory frameworks of host countries.

Key Words: *Legal and Regulatory Framework; Public Private Partnership; Unsolicited Proposal.*

1. INTRODUCTION

The most common way of the private sector participation in infrastructure delivery is through a public-planning process in which the government proposes a project idea, conducts required research, and then launches a competitive-tender process to select the most competent bidder (Public-Private Infrastructure Advisory Facility [PPIAF], 2017; United Nations Commission on International Trade Law, 2020; World Bank [WB], 2017). An Unsolicited Proposal (USP) is a privately initiated process without receiving

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an explicit demand from the government entity that is an alternative to the competitive-tender process: solicitation (Fernando, 2020; PPIAF, 2014 & 2017; WB, 2017).

Many governments believe that implementing Public Private Partnerships (PPPs) using USPs is beneficial and can provide a distinctive contribution to public infrastructure development (PPIAF, 2014 & 2017). Various research and academic studies highlighted that frequently associated with anti-competitive behavior such as favoritism, corruption, misappropriation of government resources, and incompetence discourage unsolicited PPPs (Delmon, 2015). Most of the regimes acknowledge unsolicited PPPs by adopting inbuilt various management systems into their procurement procedures to mitigate the detrimental impact of USPs (Osei-Kyei et al. 2018; PPIAF, 2017; WB, 2017). Adopting a strong legal and regulatory framework is one such strategy (PPIAF, 2017; WB, 2017). Accordingly, various countries around the world that used unsolicited PPPs, have strengthened their legal and regulatory framework to mitigate the inherent drawbacks of USPs (WB, 2017). An investigation of such legal and regulatory frameworks is imperative to reform the legal and regulatory framework of the other countries that are willing to accept unsolicited PPP.

Therefore, this paper aims to review the legal and regulatory frameworks adopted by various countries in the world to manage the procurement of unsolicited PPPs. Accordingly, the paper begins with a brief outline of the study, followed by the adopted research method. Then, the data collected from the literature are presented and analysed to visualise the various legal and regulatory frameworks adapted to the procurement of unsolicited PPPs. Based on the results, a conceptual framework is developed finally to reform other countries' legal and regulatory frameworks.

2. METHODOLOGY

An extensive review of the literature facilitates the researcher to reinforce the base of the study by gathering prevailing knowledge regarding the research area (Khallaf et al., 2018). Thus, a comprehensive literature analysis was brought to explore the existing legal and regulatory framework related to unsolicited PPPs in various countries. The deductive approach begins with a theory and then creates an empirical observation to support the theory, moving from a more general to a more specific level (Park et al., 2020). In doing so, the deductive approach was selected for this study and accordingly, the legal and regulatory framework related to the unsolicited PPPs, which is the broad theme of the study, was narrowed down to its procurement stage. Accordingly, a detailed investigation was executed with selected ten (10) countries by investigating various acts, statutes, regulations, and guidelines enacted by such countries. Figure 01 illustrates the steps that were followed to perform the literature review after identifying the research problem.

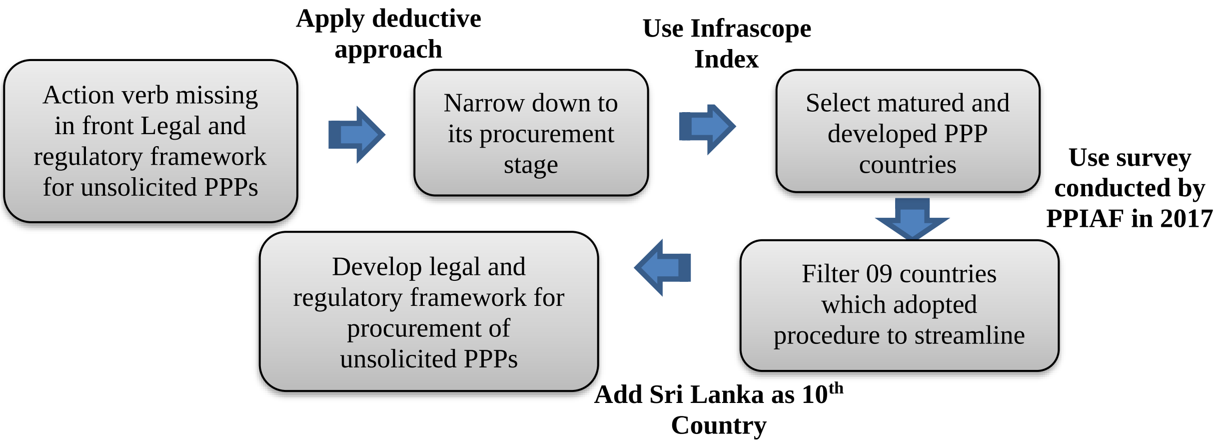

Figure 1: Flow diagram of study selection

Finally, based on a synthesis of the literature a conceptual framework was developed to draft the legal and regulatory framework or modify existing legal and regulatory framework for the procurement of unsolicited PPPs to suit for the host country.

2.1 SELECTION OF COUNTRIES

The Infrascope Index is a measure for assessing a country's ability to execute efficient and sustainable PPPs (Economist Intelligence Unit [EIU], 2019). According to the EIU (2019), the Infrascope Index assesses the PPP environments of 65 countries under 05 areas: enabling laws and regulations, institutional structure, maturity, investment and business climate, and financing. Accordingly, EIU has released its reports regional-wise: (i) Asia, (ii) Latin America and the Caribbean, (iii) Africa, and (iv) Eastern Europe, Central Asia, and the Southern and Eastern Mediterranean. Table 1 structures the counties, regional-wise, and the descending order of the assigned Infrascope Index to them. As per Infrascope Index, there are 3 countries with a matured PPP environment, 25 countries with a developing PPP environment, 34 countries with an emerging PPP environment, and 3 countries with a nascent PPP environment. Accordingly, 28 countries have matured and developed PPP environments. Further, table 1 shows that the majority of regions, including Sri Lanka, fall into the category of the counties having a growing PPP environment.

Table 1: Infrascope index of various countries in regional-wise (Source missing)

Latin America and the Caribbean		Asia		Africa		Eastern Europe, Central Asia, Southern & Eastern Mediterranean	
Country	**Index**	**Country**	**Index**	**Country**	**Index**	**Country**	**Index**
Chile	79	Thailand	83	South Africa	71	Slovakia	64
Colombia	77	Philippines	81	Morocco	52	Jordan	63
Peru	77	China	80	Kenya	51	Turkey	61
Jamaica	76	India	77	Egypt	51	Serbia	60
Guatemala	74	Bangladesh	66	Tanzania	49	Morocco	59
El Salvador	73	Vietnam	66	Ivory Coast	46	Egypt	55
Brazil	72	Indonesia	61	Tunisia	45	Ukraine	50
Costa Rica	72	South Korea	61	Uganda	45	Romania	48

Uruguay	72	Pakistan	61	Rwanda	44	Albania	48
Honduras	66	Kazakhstan	58	Ghana	43	Belarus	46
Mexico	66	Mongolia	54	Cameroon	38	Bulgaria	45
Ecuador	63	Georgia	48	Nigeria	37	Georgia	41
Nicaragua	63	Armenia	45	Zambia	34		
Panama	60	Sri Lanka	45	Angola	31		
Argentina	60	Timor-Leste	44	Congo	21		
Trinidad & Tobago	56	Tajikistan	41				
Dominican Republic	55	Papua New Guinea	28				
Bahamas	53					Matured	
Paraguay	53					Developed	
Barbados	37					Emerging	
Venezuela	8					Nascent	

The PPIAF aids the governments of developing countries in enhancing the structures, laws, and regulations that permit the creation of viable infrastructure with the participation of the private sector (PPIAF, 2017). Volume III of Policy Guidelines for Managing USPs in Infrastructure Projects by PPIAF in 2017 had been reviewed the experience of selected countries that practice USPs. It was highlighted that 16 counties (Argentina, Australia, Chile, Colombia, Indonesia, Italy, Jamaica, Jordan, Gana, Kenya, Mexico, Peru, Philippines, Senegal, South Africa, South Korea, and Tanzania) are using the Swiss challenge method, bonus system, best and final offer method, direct negotiation, full competition or merged method to entertain unsolicited PPPs.

This study selected countries that are reported as a country having matured and developed PPP environments as per Infrascope Index and as a country practicing unsolicited PPPs as per the PPIAF report in 2017. Accordingly, 09 countries (Argentina, Chile, Indonesia, Jordan, Mexico, Peru, Philippines, South Africa, and South Korea) were shortlisted. Out of 16 countries reported in PPIAF, Gahana, and Australia were disregarded since they entertain full competition and Kenya was eliminated since it follows direct negotiation, and Italy, Senegal, and Tanzania were removed in the absence of Infrascope Index while Colombia and Jamaica are excluded due to fewer sources to review their legislative framework for unsolicited PPP. In addition, Sri Lanka was added as the tenth country, as the authors intend to analyse USPs in Sri Lanka as further research. Therefore, the existing legal and regulatory framework of selected ten (10) countries was discussed hereinafter.

3. LEGAL AND REGULATORY FRAMEWORK FOR PROCUREMENT OF UNSOLICITED PPPS

3.1 ARGENTINA

Argentina is a civil country with a greater influence of Spanish legal tradition on its civil code (Corrá & Carbó, 2021). The criteria for managing USPs are laid out in PPP contract law (2016), which states that the private proponent must first submit a preliminary project description to the appropriate agency or ministry to screen whether the project serves the public interest and is part of the strategy plan. EIU (2019) stated that once the original proponent submits a thorough proposal, it is modified and negotiated between the proponent and the appropriate agency to solidify project characteristics and agree on the proposal's reimbursement cost. Then, to compete with the original bid, competitive proposals are requested from third parties (Corrá & Carbó, 2021). The original proponent's bid is selected if the difference between the best bid and the original proponent's bid is less than five percent (5%) and unless the best bidder and the original proponent are forced to re-submit their best and final proposals (EIU, 2019). In addition, PPP contract law (2016) highlighted that if no competitive offers are received, USP can be launched with direct negotiation. Therefore in Argentina, USP for PPP is adopted by the best and final offer method with slight modification and there is space for direct negotiation if no competitive offers.

3.2 CHILE

Chile is a civil country with a greater effect of Spanish legal tradition on its civil code (EIU, 2019). As per Article 02 of the Concessions Law in 2017, a preliminary description of USP should be first submitted to the appropriate agency or ministry by the private proponent. The initial proposals are then screened to verify whether the project is government goals and development plans, and if accepted, the private party is required to perform detailed studies and produce a full proposal. According to Article 12 of Concessions Law in 2017, the government subsequently puts the project out for competitive tender, and revived offers are assessed and ranked, granting a predetermined bonus to the original proponent (between 3% and 8% depending on the project). If the original proponent is not the winner, the winner should pay for the proposal's development costs. In addition, the Concessions Law in 2017 emphasised that USP can be initiated by direct negotiation if no competing proposals are received. Accordingly, Chile implemented the bonus method to incorporate USPs into PP and there is space for direct negotiation if no competitive offers.

3.3 INDONESIA

Indonesian law is founded on a civil law system, intermixed with local customary law and Roman-Dutch law (Asian Development Bank, 2016). According to PPP regulation No. 38 of 2015, a private proponent may initiate USP upon the submission of a proposal to the line ministry or appropriate government agency. Further, PPP regulation states that the proposal is screened under criteria of technically integrated with the infrastructure delivery master plan, the project is economically and financially feasible, and the financial capability of the private proponent. According to Article 2(a) of the Regulation, the procuring entity calls for a competitive tender to compete received USP. According to article 14 (5) of the Regulation, while evaluating competitive tenders, the original proponent is given a 10% bonus to the procurement score and the opportunity to match the lowest bidder's offer. It reveals that Indonesia has implemented a system to embrace USPs in PPP by merging the bonus approach and the Swiss challenge method.

3.4 JORDAN

Jordan's legal system is mostly based on the French Civil Code and the Ottoman Majalla, with Islamic law applied to family law (EIU, 2017). As per Article 11 of the PPP Law in 2020, any private entity can submit a USP directly to any government authority. Furthermore, under Article 11 of the said PPP Law, a private party making a USP is required to prepare a feasibility assessment and a sustainability report. According to Article 35(c) of the said PPP law, a USP must go through a bidding process by allowing a decided discount to the original proponent. In addition, Article 35(c) of the PPP law (2020) states that if the winning bidder does not win, the original proponent should be compensated for the cost of preparing the USP. It demonstrates that Jordan incorporated the bonus approach in PPP Law to accept USPs.

3.5 MEXICO

Mexico's legal system is based on civil law, including elements of the Roman and French legal systems (EIU, 2019). Article 26 of the PPP regulation in 2018 states that anyone interested in implementing an unsolicited PPP may submit a proposal to the appropriate federal agency or entity. According to Article 29 of the PPP Law, during the evaluation of USPs, it is considered, whether the project is of public interest and whether it provides social returns consistent with the national development plan. Articles 30 and 31 of the said PPP Law provide that if the procuring entity considers the project suitable, it should follow the public tendering process to call counter proposals and in the evaluation, the promoting party of a USP is entitled to a decided incentive which is not more than 10%. Besides, Article 31 of PPP Law states if the promoting party does not win the bid, it is entitled to reimbursement for the costs of conducting the studies. Accordingly, Mexico integrated the bonus system into PPP Law to entertain USPs.

3.6 PERU

Peru is a Latin American country that operates under a system of civil law (EIU, 2019). Once USP is accepted from preliminary investigation, as per Article 88 of the PPP Regulations in 2018, expressions of interest are called from third parties to verify the market interest. If no third parties express an interest, the project is awarded straight to the original proponent with direct negotiation, as outline in Article 89 of the PPP Regulations. If there is a market interest and proposals are called from third parties and the original proponent's offer exceeds the lowest third-party offer, the original proponent is given the option to match with the lowest third-party offer under Article 93 of the PPP regulation. If the original proponent can match the lowest offer or if the original proponent's offer does not exceed the lowest offer, the project is awarded to the original proponent, unless the third party’s lowest offeror is selected. Therefore, to consider unsolicited PPPs, Peru adopted the Swiss Challenge approach and the direct negotiation method is possible if the absence of market interest for USP.

3.7 PHILIPPINES

Customary law, Roman civil law, Anglo-American common law, and Islamic law, make up the Philippine legal system (Werneck & Saadi, 2015). USPs are codified in the Build Operate Transfer Law and amended by Implementing Rules and Regulations in 2014, which spell out the process for submitting unsolicited proposals for a PPP and also investment incentives for project developers (Werneck & Saadi, 2015). According to the resolution, once the original proponent's USP has been accepted in the preliminary investigation, the implementing agency or local government unit invites competitive offers. As per Regulations in 2012, the original proponent has the opportunity to match the lowest third-party offer if their offer is higher than that of the lowest third-party offer. If the original proponent can match the lowest offer or if the original proponent's offer does not exceed the lowest offer, the project is awarded to the original proponent, unless the third party's lowest offeror is selected. Accordingly, the Philippines implemented the Swiss Challenge approach into PPP Legislation in bringing USPs into consideration.

3.8 SOUTH AFRICA

South Africa's legal system is a mixture of Roman-Dutch civil law, English common law, customary law, and religious personal law (EIU, 2015). In 2008, the National Treasure of the Republic of South Africa published a practice note on USP for use with PPPs (PPP legal resource center, 2021). According to Section 2.1 of the practice note, once USP is received by a government entity, preliminary examination was executed and in compliance with Section 5.1 of the practice note, if such USP is accepted from a preliminary screening, an Expression of Interest (EOI) is issued to verify market interest for the USP. If there is no response, the project will be implemented through direct negotiation with the original proponent. If there is a market interest for USP, the accounting authority invites bids in a competitive setting and the two most beneficial bids are chosen in the first round and they are invited to give the best and final offer together with the original proponent (Baillie & Faber, 2021). Further, Baillie and Faber (2021) stated the winner is also expected to compensate the initial proponent for project development costs if the original proposal is not successful. Accordingly, South Africa integrated the best and final offer approach and direct negotiation method into the existing legislative framework to entertain unsolicited PPPs.

3.9 SOUTH KOREA

South Korea's legal system is based on the Republic of Korea's Constitution, which is a civil law system (Asian Development Bank, 2016). Once USP is received by a government institution, the Public and Private Infrastructure Investment Management Center examines it to ensure whether it is in line with the government's infrastructure investment plans and priorities and includes a value-for-money study (EIU, 2018). Then, competitive offers are called and an extra point of 10% is awarded to the original proponent at the bid evaluation (EIU, 2018). Further, EIU (2018) stated that if the promoting party does not win the bid, it is entitled to reimbursement for the costs of conducting the studies for and preparation of USP. In addition, Asian Development Bank (2020) stated that the negotiation is conducted directly with the original proponent if no other alternate proposals are presented. Accordingly, South Korea incorporated direct negotiation strategies and the bonus method into the country's current legislative framework in order to entertain USPs for PPPs.

3.10 SRI LANKA

Sri Lanka's legal system is a mix of English common law, Roman-Dutch civil law, and customary law (PPIAF, 2017). Line ministries and state agencies were instructed in reference 237 (a) of Part II Guideline in 1998 to process received USPs in the manner prescribed for solicited proposals, and only in urgent and exceptional circumstances such USPs are allowed to be considered directly with cabinet approval. In Supplement 23 to Part II Guideline Reference: 237, it allowed direct negotiation methods to deal with USPs without going through the normal procurement procedure from the year 2011. Later, Supplement 30 to Part II Guideline Reference: 237 superseded the said Supplement 23, the Swiss Challenge procurement option should be used to launch USPs. In September

2019, by circular No. PFD/PPP/Guidelines/2019, Ministry of Finance declared that the Swiss Challenge procurement method was abolished owing to its inherent deficiencies and instructed to adopt the methodology recommended in Part II Guideline in 1998 again. As a result, although Sri Lanka used a variety of strategies, including full competition, direct negotiation, and the Swiss Challenge option, to entertain USPs over a period, all USPs for PPPs are currently entertained on the basis of full competition.

4. ANALYSIS

It was discovered that counties having the civil legal tradition, the common legal tradition, or a mixture of legal tradition with customary and religious law, make space for unsolicited PPPs. A thorough examination of the legislative and regulatory frameworks pertaining to USPs in the selected 10 counties reveals that there is space for USPs within all of these frameworks. Accordingly, table 2 summarises the legislative and regulatory environment in USP procurement in selected countries.

Table 2: Summary of the legislative and regulatory environment related to USP procurement of selected countries

Country	Legal tradition	Institute to submit USP	Criteria of preliminary evaluation	Requirement of secondary submission	Call EOI to verify market interest	Provision to convert USPs to competition	Special requirement for negotiation	Provision to reimbursement of cost of proposal to original proponent
Argentina	Spanish legal tradition on its civil code	Line ministry/ government agency	Project serves public interest and is a part of strategy plan	Yes	No	Yes	When no bids are received once competitive proposals are called, negotiate with original proponent	Yes
Chile	Spanish legal tradition on its civil code	Line ministry/ government agency	Project is within government goals and development plan	Yes	No	Yes	When no bids are received once competitive proposals are called, negotiate with original proponent	Yes
Indonesia	Civil law tradition with local customary law and Roman Dutch law	Line ministry/ government agency	Project is integrated with master plan economic and financial feasibility and financial capability of proponent	No	No	Yes	No	No
Jordan	French Civil Code and the Ottoman Majalla, with Islamic law	Line ministry/ government agency	Project is feasible and sustainable	No	No	Yes	No	Yes
Mexico	Civil law tradition with elements of the Roman and French legal systems	Federal agency/ government entity	Project is in the public interest, provides social returns and is in national priority	No	No	Yes	No	Yes
Peru	Civil law tradition	Implementing agency/ local government agency	No specific criteria	No	Yes	Yes	When no EOIs are received, negotiate with original proponent	No
Philippine	Customary law, Roman civil law, and Anglo-American common law, and Islamic law	Implementing agency/ local government agency	No specific criteria	No	No	Yes	No	No

South Africa	mixture of Roman Dutch civil law, English common law, customary law, and religious personal law	Accounting authority	No specific criteria	No	Yes	Yes	No market interest after calling EOIs, negotiate with original proponent	Yes
South Korea	Civil law tradition	Line ministry/ government agency	Project is the government's infrastructure investment plans and conduct value for money study	No	No	Yes	When no bids are received once competitive proposals are called, negotiate with original proponent	Yes
Sri Lanka	Mix of English common law, Roman-Dutch civil law, and customary law	Line ministry/ government agency		No	No	No	In urgent and exceptional circumstances, direct negotiation method is possible with cabinet approval	No

As shown in table 2, USP may be received by line ministry or government agency or PPP unit and then preliminary screening is executed to verify the project is feasible and acceptable to the government according to own criteria to their counties. If a USP is deemed to be a non-feasible proposal or fails to meet other initial requirements, it is rejected. It was noted that the criteria for the preliminary screening are whether the project is in the public interest, in line with government objectives and development plans, economically and financially possible, delivers social benefits, becomes a national priority, and the proponent is financially capable. Afterward, only acceptable proposals are taken into detailed evaluation based on specified criteria as per counties' legal and regulatory framework. Argentina and Chile, request the original proponent to present a secondary submission in order to solicit negotiated or modified project characteristics. As shown in table 2, all nations other than Sri Lanka have provided a space to compete with USPs. In South Africa and Peru, EOIs are called to determine market interest for unsolicited PPPs, and if there is interest, only competitive offers from third parties are solicited unless the direct negotiations method is utilised to accept the unsolicited PPP. The strategies adopted by various regimes to turn USPs into competition are outlined in table 3.

Table 3: Mechanisms used by various regimes to convert USP to competition

Country	Way of Converting USPs to Competition				
	Swiss challenge	**Bonus system**	**Best and final offer**	**Merged system**	**Remark**
Argentina				x	If price deference between best offer and original bid is more than 5%, final offers are called from both. Unless project is awarded to original proponent. Merged system based on of bonus and best & final offer method. If no competitive offers are received, direct negotiation method can be adopted.
Chile		x			Allow 3-8% discount to original proponent. If no competitive offers are received, direct negotiation method can be adopted.
Indonesia				x	Allow 10% bonus to original proponent when competitive bids are called and request to match with lowest offer in original proponent is not the lowest at the evaluation. Merged system based on of bonus and Swiss challenge system
Jordan		x			Decided % of discount is applied to original proponent at the evaluation
Mexico		x			Decided % of discount is applied to original proponent at the evaluation
Peru	x				If there is market interest for USP Swiss challenge method is used unless direct negotiation method is used.
Philippine	x				Only USP Swiss challenge method is used.
South Africa			x		Select two most advantageous bids from competitive offers to give best and final offer with original proponent. If no competitive EOIs are received, direct negotiation method can be adopted.

South Korea	x	Allow 10% bonus to original proponent when competitive bids are called. If no competitive offers are received, direct negotiation method can be adopted.
Sri Lanka	Not applicable	Call competitive bids and request to original proponent to participate competition. No additional advantage is given to original proponent. Only in exceptional circumstances such USPs are allowed to be considered directly with cabinet approval

As shown in table 3, the Swiss challenge method, bonus system, best and final offer method, or a mix of the said methods are used to convert USPs to a competitive basis. Peru and the Philippines utilise the Swiss Challenge method, Chile, Jordan, Mexico, and South Korea use the Bonus system while South Africa adopts the Best and Final Offer methodology. In addition, Indonesia uses a hybrid system that included the Swiss Challenge and Bonus systems and Argentina uses a merged system of bonus and best and final offer method. In Sri Lanka, unsolicited PPPs were initially solely considered by calling competitive bids and later by direct negotiation and the Swiss challenge technique. In the year 2019, the Swiss challenge method was abolished after a short period of its introduction, and government entities were instructed to continue with the competitive procedure without providing any further benefits to the initial proponent. However, Sri Lanka provides a space for direct negotiation only in exceptional and urgent circumstances with cabinet approval.

According to the detailed analysis of the legal and regulatory framework for procurement of USPs in selected 10 countries, a conceptual framework was developed, as shown in Figure 02, by considering different processes followed by various countries in order to visualise an ideal approach for procurement of unsolicited PPP that is suitable for host countries.

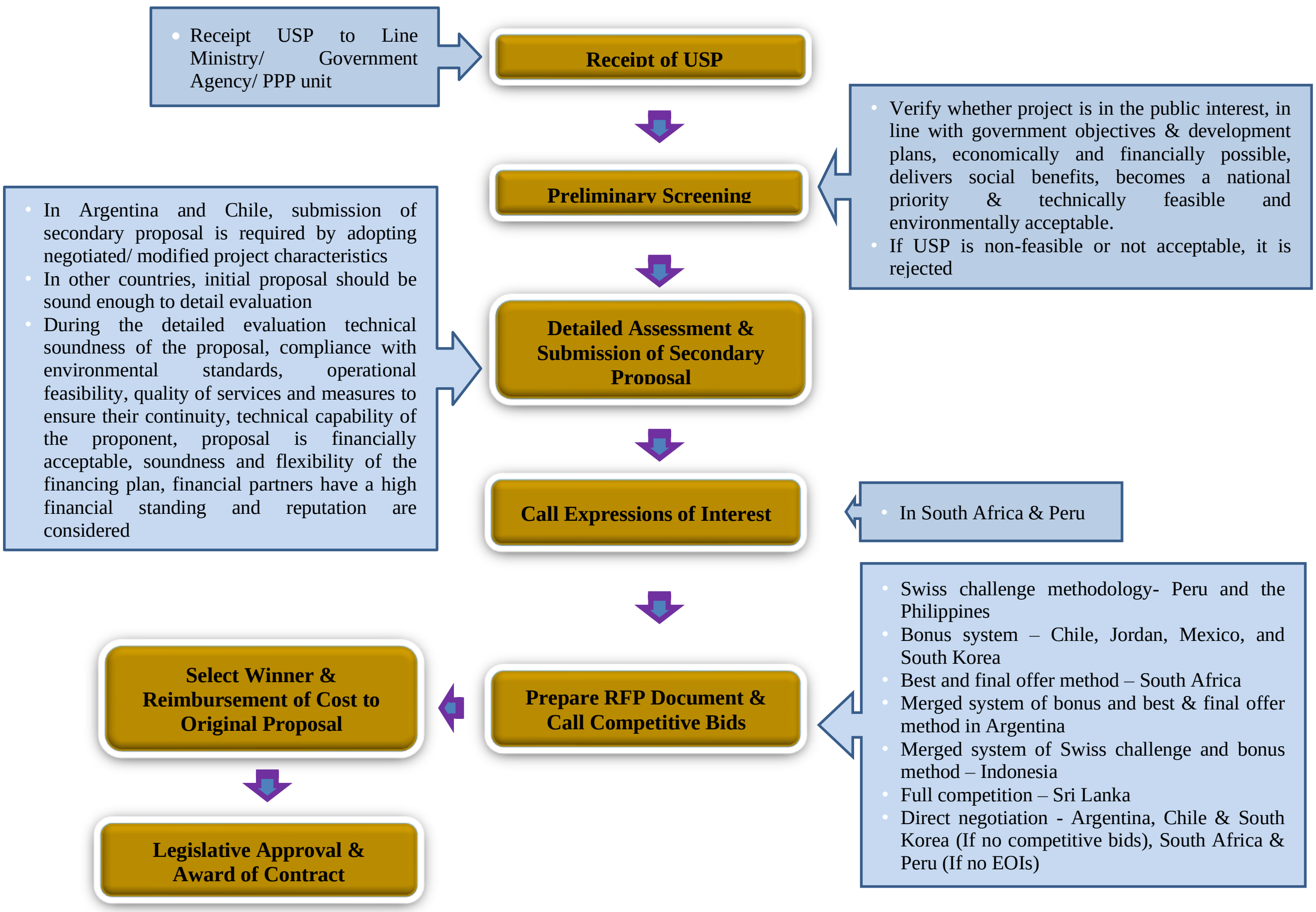

Figure 2: Conceptual framework to develop an ideal approach for procurement of unsolicited PPP

The first stage of an unsolicited PPP procurement begins when a private entity approaches a public body or line ministry or PPP unit with a proposal for a service or infrastructure project without getting a formal invitation from the government body. Secondly, every unsolicited PPP proposal undergoes a preliminary evaluation and detailed assessment. A USP is disregarded if it is found to be a non-feasible proposal or if it does not satisfy other initial requirements of the country. Afterwards, some countries called secondary proposals in order to solicit negotiated or modified project characteristics. Then USPs are forwarded to competition by adopting the Swiss challenge method, bonus system, best and final offer method, or combined method of them. Some countries called EOIs to verify the market interest for USPs before calling counter offers. If there is no response for EOIs or no counter offers are submitted from third parties, USPs are implanted by adopting a direct negotiation method. There is a provision in most legal regulatory frameworks, to reimburse the original proponent for project development costs if the original proponent does not become the winner.

5. CONCLUSION

This study presents the findings of a systematic review of existing legal and regulatory frameworks related to unsolicited PPP procurement of selected ten countries. According to table 1, 28 nations have matured and developed PPP environments, while the majority of regions including Sri Lanka fall into the category of countries with growing PPP environments. This study reveals that counties with various legal traditions have provided a space to entertain unsolicited PPPs in their legal and regulatory framework. USP is initiated with receipt of such proposal to line ministry, government department, or PPP unit. Subsequently, it is followed by preliminary screening and detailed assessment. Various countries have adopted different criteria owned to them for preliminary screening and detailed assessment of the USP. As summarised in table 2, some countries negotiate and modify the received USP to match with the country's PPP policy and government goals and objectives, and the original proponent is required to submit a secondary proposal by addressing such changes. According to this study, the key highlight is that USPs compete using the Swiss challenge methodology, the bonus system, the best and final offer method, or a combination of the aforementioned methods as summarised in table 3. Further, it was revealed that some countries adopt a practice to call EOIs to verify the market interest to submit counter proposals. However, there is space for the direct negotiation method if no offers are received from the competition or no EOIs are received. However, though Sri Lanka has entertained USPs using a number of approaches over time, including full competition, direct negotiation, and the Swiss Challenge option, all USPs for PPPs are presently accepted on the basis of full competition.

According to a detailed investigation of the legal and regulatory framework for procurement of USPs in 10 selected countries, it was revealed that such countries developed their own system to entertain unsolicited PPPs and such systems include both common and unique steps to them. Based on that, the developed conceptual framework, shown in figure 2, can be used to visualise an ideal approach for procurement of unsolicited PPP suitable for host countries that are willing to embrace USPs.

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MAINTENANCE INVENTORY MANAGEMENT IN THE HEALTHCARE FACILITIES IN SRI LANKA: A STUDY ON CURRENT ISSUES AND POSSIBLE IMPROVEMENTS

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ABSTRACT

Effective inventory management in any organisation is essential as it aids in keeping organisational resources under control while managing time and expenses to enable efficient operations of facilities. Inventory management in maintenance management is crucial as this service is found to be essential to streamline maintenance management activities effectively. However, maintenance management in healthcare facilities is considered a top critical function as it has to maintain and ensure patients' quality of life and life safety. Hence, to have smooth maintenance management, well-performing maintenance inventory management is required. Accordingly, this study aims to evaluate current maintenance inventory management practices in healthcare facilities in Sri Lanka to uplift the practices by identifying the current context. A qualitative research approach was adopted. The three case studies were conducted with semi-structured interviews with three professionals in healthcare facilities. The findings of case studies present existing issues in maintenance inventory management such as unpredictable demand, high administrative expenses, lack of awareness of inventory handling, lack of support from management, hiding slow-moving items, and quality issues. The study will emphasise the possible improvements that can be implemented to overcome those identified issues, particularly for healthcare facilities.

Keywords: *Healthcare Facilities; Improvements; Issues; Maintenance Inventory Management.*

1. INTRODUCTION

Effective maintenance has a significant impact on a company’s success such as keeping operations stable, reducing the likelihood of unplanned downtime, improve reliability and availability (Chen et al., 2017). Maintenance management involves a wide range of operations and functions, and it can be defined as the effective and efficient use of resources to guarantee that the process and its facilities are kept operational to the standards demanded by the users (Oliveira et al., 2012). Similarly, maintenance

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management consists of managing mechanical, electrical, and plumbing (MEP) systems, monitoring quality assurance, and maintaining operational efficiency and workplace safety (Dhillon, 2002).

If there is a fault in the maintenance procedure, the organisation cannot continue its core business. Especially, maintenance is crucial for healthcare facilities as it ensures the smooth operation and continuity of services, including emergencies and lifesaving care (Olanrewaju et al., 2018; Yousefli et al., 2017). Furthermore, maintenance management in healthcare facilities ensures that improved productivity results in safer and more dependable equipment, lower service costs, fewer equipment outages, increased income, and more efficient use of labour within the facility (Kihiu et al., 2012).

Since maintenance and inventory management are strongly connected, inventory management is crucial for an efficient maintenance management system (Bousdekis et al., 2017). Further, it was revealed that maintenance inventory is one of the most important factors for the proper maintenance management system and it causes to avoid unnecessary costs and time wastage. The goal of maintenance inventory management is to have the proper inventory in the right quantities on hand to repair or improve assets, while also taking into account the budgets and storeroom spaces (Bousdekis et al., 2017).

When it comes to healthcare facilities, maintenance inventory is one of the major inventory types (Yousefli et al., 2017). The author further revealed that it is important to have a well-maintained structure for maintenance inventory management to ensure operational quality. Therefore, it is important to have a systematic and well-structured approach to the maintenance inventory handling process. Celebi et al., (2008) stated spare component inventories are frequently handled if at all, using generic inventory management methods, with little attention devoted to controlling characteristics unique to spare parts. Furthermore, control is typically centred on local inventories rather than the entire supply chain. According to the authors, it is clear most organisations do not pay much attention to the maintenance of inventory management systems.

In the Sri Lankan context, most studies have been done regarding medical equipment inventories of healthcare facilities. Some of those are, Dasanayka (2001) researched medical equipment performance in Sri Lankan public sector hospitals and Jayawardena (2017) conducted a study on hospital equipment management in Sri Lanka. But, there is a lack of studies on the maintenance inventory management in healthcare facilities in Sri Lanka. Accordingly, the study aims to investigate the current maintenance inventory management practices in healthcare facilities in Sri Lanka. The supportive research objectives are:

O1: Review the concepts of maintenance management, and inventory management concerning healthcare facilities.

O2: Identify the current maintenance inventory management practices that are adapted in the healthcare facilities in Sri Lanka.

O3: Identify the existing issues and possible improvements that need to be done to ensure the successful performance of maintenance inventory management in the healthcare facilities in Sri Lanka.

2. LITERATURE REVIEW

This section reviews literature on inventory management, maintenance inventory, maintenance inventory management techniques, maintenance inventory for healthcare facilities and potential issues of maintenance inventory handling process.

2.1 INVENTORY MANAGEMENT

2.1.1 Inventory Management Procedure

Priniotakis and Argyropoulos (2018) stated that there are four primary types of inventories: raw material, work-in-progress, finished goods, and maintenance, repair, and operating. As expressed by Singh and Verma (2018), the inventory management process includes planning, managing, and regulating inventory to minimise the investment in inventory while balancing supply and demand. Bose (2006) mentioned that a proper inventory management process involves rationalising the stocks and it can result in sizable savings a scientific system of control can significantly lower the investment in inventory, often by as much as 50% or even more.

2.1.2 Inventory Management Techniques

Gordon and Gupte (2016b) stated monitoring the supply, storage, and accessibility of goods is known as inventory management. The author further mentioned this is done to make sure there is a sufficient supply without going overboard. Different inventory management techniques can be listed as ABC Analysis, Vendor Managed Inventory, Inventory Turnover Ratio (ITR) and Re-Order Point (ROP) (Gordon & Gupte, 2016a; Priniotakis & Argyropoulos, 2018).

ABC Analysis: Nabais (2010) stated ABC analysis is an inventory management and control system which helps support inventory storage because it offers an appropriate layout for the central warehouse, which facilitates material flows and picking. Wild (2017) stated that in the ABC method, the stock is divided into three categories according to value and turnover.

Further to the author:

- A = 10 % of stock numbers, giving 65 % of turnover,
- B = 20 % of stock numbers, giving 25 % of turnover, and
- C = 70 % of stock numbers, giving 10 % of turnover.

Vendor-Managed Inventory (VMI): Gordon and Gupte (2016b) stated VMI system enables the vendor to plan, monitor, and control inventory for their clients. As ordering responsibilities are transferred to the vendor, people who were directly involved in the ordering process can then transfer their duties to customer services and special order treatments (Gronalt & Rauch, 2008).

Inventory Turnover Ratio (ITR): Rao and Rao (2009) stated inventory turnover is a vital performance indicator for determining how well inventory management is working. Gordon & Gupte (2016a) cited ITR can be defined as a cost- and inventory-minimisation strategy. There are four inventory types under ITR, Slow Moving Inventory (SMIs), Dormant Inventories (DIs), Obsolete Inventories (OIs) and Fast-Moving Inventories (FMIs). Further, it was revealed, ITR is calculated as shown in E.q. 01:

ITR = Materials consumed cost / Average amount of inventory held over time … (Eq. 01)

Reorder point (ROP): Priniotakis and Argyropoulos (2018) stated inventory replenishment is started using the Re-Order Point (ROP) approach based on inventory level. Further, as revealed, the ROP is set at a level determined by adding a safety stock to the anticipated demand for the replenishment period, as in the equation (Eq. 02):

$$ROP = D \times LT + SS \quad \ldots \text{(Eq. 02)}$$

Where:
D = The average forecasted demand
LT = The average Lead Time
SS = The Safety Stock

2.2 MAINTENANCE INVENTORY

The maintenance tasks greatly rely on the availability of supplies such as lubricants, valves, pipe fittings, paints, angle and channel iron, controllers, and nuts and bolts for machinery and manufacturing equipment (Dhillon, 2002). The author further claims that such objects should be maintained properly to lower maintenance costs, minimise downtime for staff and equipment, and increase output. Hence as observed, controlling inventory is crucial to maintenance. To manage maintenance inventory properly, there should be a correct inventory management approach. In some cases, maintenance-related spare parts inventories are distinct from typical industrial inventories (Celebi et al., 2008). As further explained by the author, the maintenance strategies determine the demand for spare parts inventories rather than consumer consumption.

2.3 MAINTENANCE INVENTORY MANAGEMENT TECHNIQUES

The appropriate inventory management techniques for maintenance inventory handling should depend on the maintenance policies or maintenance techniques of the organisation (Celebi et al., 2008). For preventive maintenance, it may be possible to order parts that arrive just in time for usage, and it may not be necessary to stockpile repair components at all (Ahamad et al., 2011). Further for unplanned maintenance, it is necessary to keep safety stock for sudden failures. Antosz and Ratnayake (2016) described that spare components are kept in storage to make maintenance tasks easier to complete in the case of equipment failure. But as the above author elaborated, many organisations face the problem of maintaining a significant number of obsolete spare parts in stocks, resulting in excessively high storage costs. Table 1 presents the maintenance inventory management techniques which were proposed by different authors.

Table 1: Maintenance inventory management techniques

Maintenance Inventory Management Techniques	Source
Hybrid approach	(Muniz et al., 2021)
Re-order point method	(Porras & Dekker, 2008)
System-oriented inventory model	(Basten & van Houtum, 2014)
ABC classification technique	(Prachuabsupakij, 2019)

2.4 MAINTENANCE INVENTORY FOR HEALTHCARE FACILITIES

Vich et al. (2009) stated that maintenance inventory is a critical factor in the healthcare sector, to achieve maximum availability, minimal downtime, and proper response to vital components of the installations and medical equipment. It becomes necessary to optimise the storable spare parts. The maintenance spare part classification of the healthcare facility is presented in Figure 1.

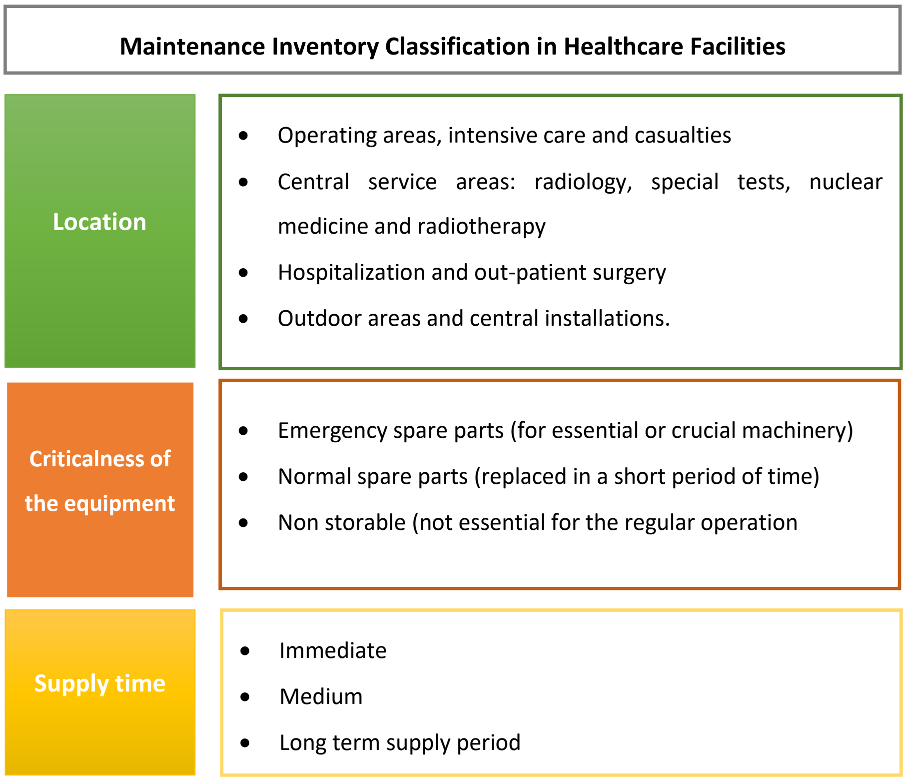

Figure 1: Maintenance inventory classification in a healthcare facility

2.5 POTENTIAL ISSUES OF MAINTENANCE INVENTORY HANDLING PROCESS

Zhang et al. (2021) stated managing the maintenance inventory is crucial to ensuring that the required item is available at the lowest possible economic and environmental cost. The author further contends the management of spare parts faces several issues due to the large number and variety of spare parts and the intermittent demand patterns that are common among spare parts. In addition, it is challenging to predict the relationship between the consumption of spare parts the product usage, the number of damages, and the maintenance required. As a whole, the issues in maintenance inventory handling are unpredictable demand, significant administrative expenses, hidden slow-moving items, quality issues, lack of awareness of people who handle the inventory and the lack of support from management (Zhang et al., 2021; Baluch et al., 2013).

3. RESEARCH METHODOLOGY

A comprehensive literature review was developed by addressing maintenance management, maintenance practices in the healthcare facilities, maintenance inventory in the healthcare facilities and inventory management techniques in the healthcare facilities. Draper (2004) stated qualitative research typically begins with "what," "how," and "why" questions rather than "how much" or "how many" questions. Further, it also looks at the answers each person gives to these questions in the context of their meanings and interpretations. The qualitative research approach was selected as suitable approach since the research problem of the study is "What are the current maintenance inventory management practices, issues and possible improvements required in healthcare facilities in Sri Lanka?" The study aims to investigate the current issues and improvements required for existing maintenance inventory management systems in healthcare facilities. Hence, the case studies research method was applied under the qualitative research approach. Accordingly, three hospital facilities were selected on both medium and large scales. Because both medium and large-scale hospitals handle a considerable amount of maintenance inventories. Interviews were conducted with managerial-level respondents who are involving in maintenance inventory management in hospitals. The selection of respondents was based on purposive sampling technique. The collected data were analysed by using manual content analysis.

Table 2: Details of the selected cases

Cases	Details
Case A	Location: Gampaha District, Established year: early two thousand, Scale: Medium scale, Bed capacity: 70, In the hospital, maintenance inventories are handled by the maintenance manager and not a separate inventory management division for maintaining inventories. The maintenance manager keeps records of maintenance inventories and handles inventories as per the requirements of the hospital.
Case B	Location: Colombo District, Established year: Mid nineteen eightees, Scale: Large scale, Bed capacity: 400, In the hospital, maintenance inventories are handled by the stock division under the inventory manager. The inventory manager is the main responsible person for handling maintenance inventories.
Case C	Location: Colombo District, Established year: early two thousand, Scale: Large scale, Bed capacity: 350, The maintenance procedure of the hospital is handled by the engineering department. There is a separate stock to keep maintenance inventories which are supervised by the inventory officer.

Table 3: Profile of the respondents of the cases

Cases	Respondents	Role	Experience in years
Case A	AR	Maintenance Manager	20 years
Case B	BR	Inventory Manager	12 years
Case C	CR	Electrical and Mechanical Engineer	15 years

4. RESEARCH FINDINGS

4.1 CURRENT INVENTORY MANAGEMENT TECHNIQUES

According to responses of all three cases, reorder point technique is used by them as a maintenance inventory management strategy. But the way of determining the re-order point differs in each case. In Case of A, AR mentioned "*Re-order point is used to make new orders for maintenance inventories"*. In the case of B, BR stated "*re-order point of stock inventories have been defined. But this re-order point is not defined for all maintenance inventories"*. When it comes to Case C, CR mentioned, "*currently we used the re-order point method to determine when orders should be placed for inventories"*. That means the re-order point technique is used to handle the ordering process of maintaining inventories. But the way of deciding the re-order point is different in each case. In Case of A, reorder point is decided by the maintenance manager. AR mentioned, "*Re-order point will decide by manually checking the available number of spare parts in the inventory stock". In Case of B, re-order points of major stock items are entered into* *a system. BR stated "Currently ordering process stock inventory is done through HIS, Hospital Information System. Here reorder point for each item is added and when the inventory level achieved the re-order point, the HIS system will indicate it. After that, place orders for new inventory stock". In Case of C, CR mentioned "inventory officer determines the re-order point of each inventory. According to that orders are placed through the procurement department".* Thus, it is identified that re-order point is the inventory management technique currently use in maintenance inventory management processes.

4.2 ISSUES IN THE CURRENT INVENTORY MANAGEMENT PROCESS

Potential issues of the inventory management process were identified in the literature review. Those identified issues were presented to respondents of case studies to ensure their existence in practical scenarios of healthcare facilities under the context of maintenance inventory management.

Table 4: Issues in the maintenance inventory management process

Theme	Identified issues through literature	Availability in cases		
		Case A	Case B	Case C
Issues in the current inventory management process	Unpredictable demand	x		x
	High administrative expenses	x	x	x
	Lack of awareness of inventory handling		x	x
	Lack of support from management	x	x	x
	Hide slow-moving items	x		
	Quality issues	x	x	x

Unpredictable demand: Out of three cases, respondents of Cases A and C highlighted there are issues due to unpredictable demand. The respondent of Case A, AR mentioned "*sometimes demand maintenance inventories vary with unexpected maintenance works. Therefore, some problems happened due to unavailability of inventories to perform sudden maintenance activities".* The respondent of Case C, CR mentioned "*actually unpredictable demand is a problem. In sudden breakdowns, it is difficult to find the required spare parts in a short period. It may cause long breakdowns. To manage those situations up to some extent, some corrective actions are taken such as using repaired old spare parts or using alternative/ standby machine o equipment".* But in Case B, BR mentioned *"if we considered inventory requirement department vice there are no much variations in demand. We have established plus and minus levels for inventory requirements by considering past data. Inventory demand fluctuates within these plus and minus levels if there is no special event".*

High administrative expenses: Respondents of all three cases mentioned significant amount of administrative expenses is required for the whole maintenance inventory management procedure. In Case A, AR mentioned "*administrative expenses for maintenance inventory handling is high because the administrative cost associated with different stages like ordering, procurement process, and keeping at the stock".* In Case B, BR mentioned, "*administrative cost may be high because organisations have to allocate a significant amount of money for the administrative cost associated with ordering, keeping, and discarding procedures of maintenance inventories".* CR also affirmed that the administration cost of the maintenance inventory handling process is high.

Lack of awareness of maintenance inventory handling: Out of three cases, Case B and Case C have issues with a lack of awareness of persons who handle the maintenance inventory. In Case B, BR mentioned "*it is necessary to have enough technical knowledge for persons who handle the maintenance inventory to define the re-order level of inventory and decide what is the exact inventory type which is required to perform relevant maintenance activity. If not, it affects the quality of maintenance work and a usable lifetime of machinery and equipment".* In Case C, CR mentioned, *persons who work with maintenance inventory handling should have awareness of required maintenance inventories for maintenance activities. There were some problems in our maintenance inventory handling process lack of awareness of workers and their mistakes".* However, in the case of A, AR mentioned the opposite opinion that "*there were no issues due to a lack of awareness of people who handle the maintenance. The maintenance inventory handling process is done by the maintenance manager. The maintenance manager is responsible to determine the re-order level of inventories, keeping inventories the stock and maintaining records".*

Lack of support from management: All respondents of Cases A, B and C mentioned they have this issue. In the case of A, AR mentioned "*lack of support from management is one of the problems in maintenance inventory management*". BR affirmed that the top management has not had much interest in the maintenance inventory handling process within the facility. CR also agreed with AR and BR.

Hide slow-moving items: Out of three cases, the respondent of case A has this problem. In the case of A, AR mentioned, "*sometimes slow-moving items are kept a long period in the stocks. Those items may be hidden due to lack of visualisation".* But respondents of Case B and Case C have provided opposite responses. In Case B, BR mentioned "*we maintain separate excel sheets to record information of slow-moving inventories which have warranty periods. When relevant inventory reaches the warranty period, it can be checked through an excel sheet. After reaching the warranty period, the renewal procedure is implemented. Then this problem can be avoided up to some extent and it helps to avoid problems with expiring inventories at the stock*". In case, CR mentioned "*inventory officer maintains records of fast-moving items and slow-moving items separately. Through these records, they manually check the available amount of inventories at the stock*".

Quality issues: All respondents mentioned there are issues with low-quality maintenance inventories. In Case A, AR mentioned "*quality is the most important factor. There are issues with low-quality inventories due to problems in the inventory supply process. There are difficulties to receive inventories with the required quality level. Because suppliers do not have exact inventory and they provide inventories with same properties but without required quality*". Case B and Case C affirmed the response of Case A. In Case B, BR mentioned "*quality problems are raised due to limited supplier base. If the required inventory is not available in existing supplies, they provide alternative inventory which has not required quality level. In addition, in the ordering process, sometimes orders are placed without mentioning the exact brand name, serial numbers and other specifications. Then it causes to receive low-quality inventories".* In Case C, CR mentioned "*Sometimes suppliers are not capable to provide inventories with all requirements. And also, there are difficulties finding inventories with exact quality*".

Further, it is observed, current maintenance inventory management procedures in healthcare facilities have issues which were identified in the literature review. In addition to the identified issues in the literature, respondents in some cases mentioned additional issues. AR mentioned, "*there are issues with lack of accuracy in forecasting process and parts are not available when needed due to poor procurement practices and poor replenishment".* BR mentioned, "*issues with inventories are not properly stored in the store room and spare part substitution*". Thus, it is identified that there are more issues in the current maintenance inventory management process.

4.3 IMPROVEMENTS THAT NEEDS TO BE MADE IN THE CURRENT INVENTORY HANDLING PROCESS

The possible improvements which are suggested by the respondents of three cases for mitigating all the identified issues are tabulated as shown in Table 5.

Table 5: Improvements for identified issues.

Identified issues	Improvements	Respondents		
		AR	BR	CR
Demand is unpredictable	• Properly analyse requirements of maintenance inventory			x
	• Keep additional inventories for emergency	x		
	• Forecast inventory requirements by considering past data		x	
High administrative expenses	• Increase the effectiveness of record keeping procedure	x		x
Lack of awareness of inventory handling	• Allocate a separate division in the supply department to handle the maintenance inventory supply process		x	
	• Invest in the training program for the person who handles maintenance inventory.			x
Lack of support from management	• Aware of the importance of the maintenance inventory handling process	x		
	• Present financial benefits of proper maintenance inventory handling process		x	x
Hide slow-moving items	• Keep records separately for all slow-moving items		x	
	• Keep slow-moving items separately in the stock			x
Quality issues	• Improve the ordering process with the indication of the exact brand and quality level		x	
	• Increase the number of suppliers who have high capabilities			x
	• Make a strong supplier base.	x		
Lack of accuracy in the forecasting process	• Documenting all receipts for components against purchase orders or outside repair orders, as well as receipts for parts that have been returned to the storage.	x		
Parts are not available when needed.	• Improve the effectiveness of the procurement process	x		
Inventories are not properly stored in the storeroom.	• Organise the storeroom, slot parts properly depending on part volume and characteristics; use ID numbers		x	

Identified issues	Improvements	Respondents		
		AR	BR	CR
Spare part substitution	• Properly place an order with all specifications.		x	

Improvements to overcome unpredictable demand: Respondents of Case A and Case B have recommended improvements to overcome the unpredictable demand for maintenance inventories. In Case A, AR mentioned, "*To overcome issues due to unpredictable demand, it is better to keep an additional amount of inventory to use in an emergency".* The respondent of case C proposed a different opinion. CR mentioned *"the maintenance requirement of the facility should be properly analysed by comparing past demand changes. It helps to predict what are the required maintenance inventories to perform maintenance activities successfully".*

Improvements to overcome high administrative expenses: *All* respondents in three cases have proposed improvements to overcome significant administrative expenses. Respondents of Case A and Case C have proposed similar improvements. According to those two respondents, they proposed to increase the effectiveness of the current record-keeping procedure. In Case A, AR mentioned, "*administrative expenses can be reduced through proper record keeping. Because it helps to avoid destroy inventories due to expiry, and ensure available inventory level*". In Case C, CR mentioned "*proper record keeping helps to avoid unnecessary administrative expense. For that it needs a system which can record inventory information easily and frequently check the number of available inventories".* Respondent of Case B mentioned different opinions to avoid high administrative expenses. BR mentioned "*persons should be allocated effectively for maintenance inventory handling process. It helps improve communication procedures within departments and avoid necessary expenses".*

Improvements to overcome the lack of awareness of inventory handling: Respondents of Case B and Case C have proposed improvements to overcome the lack of awareness of people who handle the inventory. In Case B, BR mentioned "*to improve inventory ordering process, It is better to allocate separate division in the supply department to handle the maintenance inventory supply process. Then they have enough technical knowledge regarding maintenance inventories, and it helps to get correct inventories as per the requirements".* In Case C, CR mentioned "*persons who handle maintenance inventory take important decisions regarding inventory ordering process and keeping. Therefore they should know relevant subject areas. Therefore it needs to invest in the training program for the person who handles maintenance inventory*".

Improvements to overcome lack of support from management: All respondents in three cases have provided improvements to overcome the lack of support from management. In Case A, AR mentioned "*proper maintenance inventory handling process is important to perform maintenance activities effectively. Therefore, it is better to be aware of the importance of the maintenance inventory handling process".* Respondents of Case B and Case C provided the same kind of improvements to overcome this issue. They have proposed to present the financial benefits of a proper maintenance inventory handling process. BR mentioned "*maintenance inventories have considerable involvement in the maintenance budget of the facility. Therefore, it is better to be aware top management regarding the importance of proper maintenance inventory management system".* CR mentioned, *"to get the involvement of top management, it is better to be aware of management regarding financial benefits of maintenance inventory handling".*

Improvements to overcome hiding slow-moving items: Respondent of case A has mentioned two improvements to overcome hidden slow-moving items. AR mentioned "*to avoid hiding slow-moving items in the stocks, it is better to keep separate records for all slow-moving items and keep slow-moving items separately in the stock. Then it is easy to check the amount of available slow-moving items in the stocks".*

Improvements to overcome issues with quality: Respondents of all three cases have proposed improvements to overcome quality issues. In Case A, AR mentioned, "*to get quality inventories it is necessary to have a strong supplier base. Then inventories can be received at required quality level".* In Case B, BR mentioned "*In the hospital, the inventory ordering process is done through HIS (Hospital Information System). In the HIS, separate codes are used to identify different inventories. But this code does not specify the exact item with its specifications. It leads to receiving items with low quality, low durability and not fitted to the maintenance work. Therefore, it is necessary to improve the current ordering process*". In Case C, *CR mentioned "to avoid issues with low-quality inventories, it is better to Increase the number of suppliers who have high capabilities. It helps to get inventories with required quality level".*

Accordingly, the above-identified improvements can be initiated in healthcare facilities to overcome current issues in maintenance inventory management.

5. CONCLUSIONS

The current maintenance inventory management technique of three healthcare facilities was identified as the Re-order point technique. In some cases, reorder point of maintenance inventory is determined manually and in some cases, a computerised system is used to store data about re-order levels. But there is no specific procedure to determine the re-order point. In some cases, the re-order point is determined by checking the available inventory quantity in the store and in some cases it is determined by using past consumption data and safety stock levels. Even though case study facilities implemented maintenance inventory management techniques, there were issues with their current system. In the literature review, unpredictable demand, high administrative expenses, lack of awareness of inventory handling, lack of support from management, hide slow-moving items, and quality issues were identified as possible maintenance inventory management issues in healthcare facilities. Among those issues, high administrative expenses, lack of support from management, and quality issues were identified as the top issues in the practical scenario through the case studies. In addition to the identified issues in the literature review, additional issues were mentioned by respondents of the case studies such as issues with lack of accuracy in the forecasting process, poor procurement practices, poor replenishment, issues with storage process and spare part substitution. According to the perceptions of respondents in case studies, improvements were identified for existing issues in the maintenance inventory management system. Thus, it is identified that existing maintenance inventory management in healthcare facilities should be improved for proper operation in maintenance management procedures.

6. RECOMMENDATIONS

Reis et al. (2017) stated lean management emerges as a viable alternative to improve overall operational performance in inventory management while increasing flexibility, lowering costs and decreasing lead times. Lean has been implemented in a diverse range of organisational contexts such as operation rooms, hospital departments, hospital-based pharmacies, etc. and specialities such as emergency medicine, surgery, gastroenterology, etc. Kanban is a lean methodology that employs the pull method. It is a useful technique in a medical environment to manage different types of inventories. Accordingly, it is identified that Kanban is a suitable inventory management technique to overcome issues in the maintenance inventory handling process in healthcare facilities in Sri Lanka.

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MANAGEMENT OF CARBON FOOTPRINT IN APPAREL INDUSTRY: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Climate change is a significant challenge confronting humanity today. Public and private experts in developed and developing countries along with a few non-governmental organisations (NGOs) worldwide are attempting to reconcile monetary expansion with its adverse effects on climate change. The apparel sector is now the second-largest industrial polluter, contributing 10% of the world's carbon emissions. Therefore, the main aim of this study is to investigate potential strategies to minimise carbon footprint (CFP) in the apparel sector. The study selected a systematic literature review based on the PRISMA method methodology and content analysis was used as the analysis technique. The findings spotlight that energy, solid waste, wastewater, packing waste fabric and accessories and fuel are the primary sources in emitting the GHG emission in the apparel sector within various life cycle stages. Therefore, the study found various potential strategies to reduce CFP in the apparel sector, focusing on raw material-based GHG emissions, energy-based GHG emissions, solid waste-based GHG emissions, and waste water-based GHG emissions. Moreover, the study shows common strategies that will lead to reduce CFP in the apparel sector. The results from this study provide a handful of guidance to apparel sector stakeholders, other industry stakeholders, non-governmental organisations (NGOs) and other relevant authorities to address the CFP in the manufacturing industry.

Keywords: *Apparel Sector; Carbon Emission; Carbon Footprint; Climate Change.*

1. INTRODUCTION

Climate change is defined as a shift in the climate that can be directly or indirectly linked to human activity and goes beyond natural climate variability witnessed over comparable periods (United Nations, 1992). With the discussion of climate change, the sustainable development requirements concept was introduced and development that satisfies current requirements while not jeopardizing the ability of future generations to satisfy their own needs can be defined as sustainable development (World Commission on Environment and Development, 1987). Global warming is the leading cause of this deteriorating environmental situation (Mikhaylov et al., 2020). The phenomenon known as "global warming" has been going on for a while, but it results from both natural and human-

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caused processes (Mella, 2022). However, the constant rise in atmospheric GHG is the main underlying reason for global warming (Muhardi et al., 2020; Tumpa et al., 2019).

These GHG emissions often reach the atmosphere due to numerous industrial activities (Akhtar et al., 2017; Jia et al., 2020). The increased scales of manufacturing and advancements in automation in industries have amplified the levels of GHG in the environment (Prerna & Charu, 2018; Zhang & Chen, 2019; Zhu et al., 2018). Among them, the textile and related industry stands out as having a more significant environmental impact and causing greater environmental damage (Akhtar et al., 2017; Zhou et al., 2022). The apparel sector is heavily criticized for having adverse environmental effects across its supply chain operations (e.g., waste generation, resource consumption, carbon footprint) (Niinimäki et al., 2020). The production of textiles and clothing uses a lot of energy, water, and other natural resources, quickly producing much waste (Gupta et al., 2020). According to Akhtar et al. (2017), the apparel sector emitted 19.8 tons of carbon into the atmosphere individually. In addition to that, Okafor et al. (2021) stated that the apparel sector is now the second-largest industrial polluter behind the oil industry in the manufacturing sector, contributing 10% of the world's carbon emissions (Guru et al., 2022; Islam et al., 2020). Therefore, stakeholders of the apparel industry give more attention to taking measures for the reduction of carbon emissions (Gunathilaka & Gunewardena, 2014). Hence, various studies have been done in the apparel sector in terms of environmental sustainability of textiles and apparel: A review of evaluation methods (Luo et al., 2021), life cycle environmental impacts of the apparel industry in Sri Lanka: analysis of the energy sources (Muthukumarana et al., 2018), blockchain enhanced emission trading framework in fashion apparel manufacturing industry (Fu et al., 2018), analysis of carbon-off setting targets towards sustainable economic development in apparel sector organization in Sri-Lanka (Gunathilaka & Gunewardena, 2014), carbon emission evaluation based on the multi-objective balance of sewing assembly line in the apparel industry (Zhang & Chen, 2019) and analysing the barriers to green apparel manufacturing implementation (Guo, 2022), etc. Yet, there is no review was carried out for the management of carbon footprint in the apparel industry. Therefore, this paper aims to explore the management of carbon footprint (CFP) in the apparel industry globally using a systematic literature review approach. The paper is structured as follows. First, it provides the steps of the methodology approach. Next, research findings are based on a systematic literature review. Finally, it is followed by the conclusions and way forward.

2. METHODOLOGY

A thorough examination of the literature assists in gaining essential insights from earlier research by analysing and comprehending the relevant topics (Saunders et al., 2017). Systematic reviews, like Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), are meticulous investigations that compile all relevant data that meets a predetermined set of eligibility requirements to examine a particular area of interest (Sohrabi et al., 2021). For example, the PRISMA guideline is a four-phased flow diagram that moves through identification, screening, eligibility, and inclusion (Benachio et al., 2020).

2.1 SEARCH STRATEGY

In the initial phase, the research question of "How to manage the carbon footprint in the apparel sector" was developed using the PICO (Population, Intervention, Comparator, and Outcomes) approach (Aslam & Emmanuel, 2010). Using the terms in the research question to define the keywords for the literature survey is made possible by the PICO technique (Damsari et al., 2022). However, depending on the kind of study issue, a comparison may not always be necessary or acceptable (Hewitt-Taylor, 2017) because there is no comparator to compare with the intervention in the research question; the Comparator (C) component was ignored in this study. Accordingly, the identification of the PICO components of the research question created for the study is shown in table 1.

Table 1: PICO elements of the research question

Population	Intervention	Comparator	Outcomes
Apparel Sector	Carbon footprint	-	Management

A simple logic grid was created to conduct an initial search to find the pertinent key and index terms to include in the thorough search strategy based on the identified PICO elements of the research question. Table 2 presents the fundamental logic grid with the alternate terms for the PICO elements.

Table 2: Logic grid with identified keywords added

Population	Intervention	Comparator	Outcomes
Apparel Sector	Carbon footprint		Management
Apparel Industry	Green House Gas*		Impact*
Textile Sector	Carbon Emission*		Assessment
Textile Industry	GHG*		Feasibility
	CO_2		Evaluation
	Climate Change		Minimisation
	Environment*		Analysis
	Sustainabl*		Appraisal
			Challeng*
			Barrier*

As indicated in Table 2, wild card characters ('*') were introduced to several terms to maximise the search results in literature databases. When creating the final search strategy, quotation marks were utilised to extract the exact term, the PICO elements were combined using the Boolean operator "AND," and the detected synonyms for each element were linked using the "OR" operator. The final search string was created as follows:

("apparel sector" OR "apparel industry" OR "textile sector" OR "textile industry") AND ("carbon footprint" OR "greenhouse gas*" OR "carbon emission*" OR GHG* CO_2 OR "climate change" OR environment* OR sustainabl*) AND (Management OR Impact* OR Assessment OR Feasibility OR Evaluation OR Minimisation OR Analysis OR Appraisal OR Challeng* OR Barrier*)

The search method was modified once the last search was completed by choosing appropriate filters under the search fields, publication year, subject/research area, document type, and language as shown in Table 3.

Table 3: Filters assigned for the literature search

Categories	Filters
Search Fields	Title, Abstract, Keywords
Publication Year	From January - 2018 to January - 2023
Document	Journal Article, Conference paper
Type Language	English

2.2 STUDY SELECTION

It is advisable to use several databases while looking for pertinent references in systematic reviews. Unfortunately, because search algorithms' syntax varies depending on the database, searching databases is complicated and time-consuming (Bramer et al., 2017). Accordingly, two highly regarded databases, such as Scopus and Web of Science, were used for the search. With over 49 million registered users and 20,000 magazines from over 5,000 publishers, Scopus is the largest abstract and citation database of peer-reviewed literature (de Sousa Jabbour et al., 2019). In addition, it houses the most extensive corpus of research in several academic subjects, including science, medicine, technology, social sciences, the arts, and humanities (Fahimnia et al., 2015), and it is the most peer-reviewed database in the world (Dangelico, 2016). Furthermore, Coletta et al. (2021) stated that databases made searching literature in various worldwide scientific journals and prestigious conference proceedings possible. Therefore, Scopus and Web of Science are selected as appropriate for retrieving reviewed articles for conducting a systematic literature review.

2.3 DATA EXTRACTION

In the initial phase of the database search, 1,912 records were found, consisting of 158 from Scopus and 1,754 from the Web of Science. After further removal of 89 records duplicates, a total of 1823 records remained. Based on publication year (January -2018 to January - 2023), type of document (Journal articles and conference proceedings), and the language of the document (English), 771 records were excluded. Studies that did not include the specific CFP in apparel sector topics were 926 and excluded. From the remaining 126 records, "03 records" were excluded due to the non-availability of access to the entire paper. Further, after carefully and thoroughly reviewing in relevance to our criteria and research questions, 88 records were further excluded. Finally, the eligibility assessment resulted in a total of 35 publications in this study's systematic literature review. The PRISMA flow diagram in figure 1 illustrates the procedure modified to extract pertinent information from records obtained through structured searches conducted in bibliographic databases (Liberati et al., 2009).

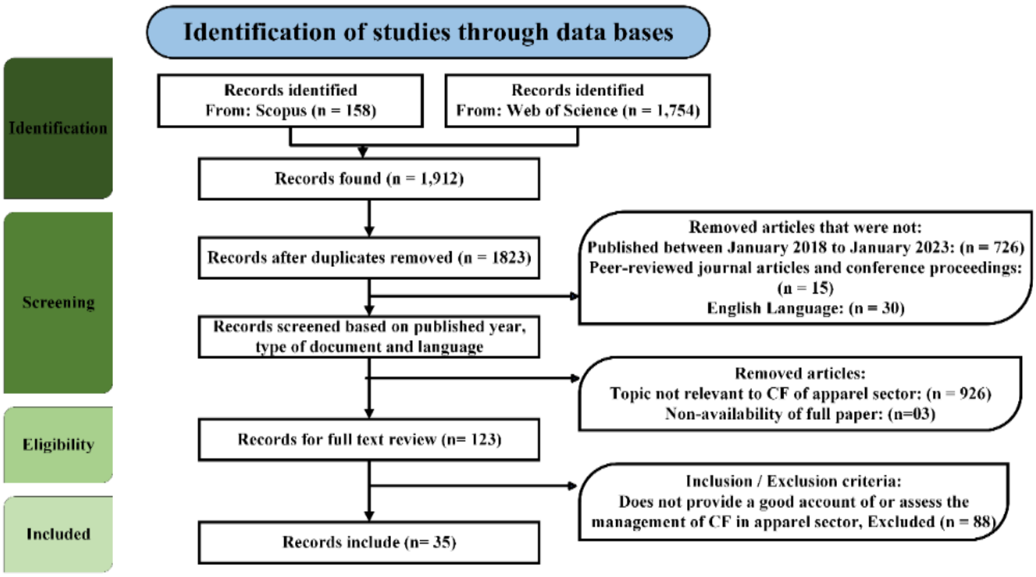

Figure 1: PRISMA flow diagram of the study

3. FINDINGS

3.1 GENERAL OBSERVATION

The chronology reflects the rapid growth of interest in CFP in the apparel sector as 29 articles of 35 articles were published in the last three years (6 in 2020, 7 in 2021, and 16 in 2022). Many publications (n = 19) have been focusing on Asia, reflecting a substantial interest in Asia, where the industry has more focus on CFP, as Asia is the main hub of the textile and apparel sector. Ten out of 19 articles in Asia have been published in China. Since, China has the world's largest textile industry and thus plays an important role in the global textile chain (Peng et al., 2022) and CFP in the global apparel sector (Lin et al., 2018a). There is an increasing focus on the global apparel sector in recent times (n = 10). However, there are only a limited number of studies from Spain (n=01), Portugal (n=01), France (n=01), Ethiopian (n=01), UK (n=01), Sri Lanka (n=01), Thailand (n=01), Bangladesh (n=01) and Chile (n=01). Accordingly, the growth of CFP in apparel sector literature concerning publication year and the region has recently increased. In the distribution of papers, 33 articles out of 35 appeared in 27 journals and the other 2 articles are from conference proceedings. Furthermore, 24 articles (72.72%) out of 33 articles appeared in 19 environmental management journals. Most articles published in environment management journals include the *Journal of Cleaner Production* (05), *Science of the Total Environment* (02), and each other journal published one article respectively.

3.2 SOURCES OF GHG EMISSION IN THE APPAREL SECTOR - CRADLE TO END

13 out of the 35 studies that were assessed talked about the CFP of the apparel industry at different life cycle stages. Table 4 shows the life cycle stages and the associated carbon emissions sources included in the research.

Table 4: GHG emission sources in the apparel sector (Cradle to End)

Life Cycle Stage	Sources of GHG Emission	References
Raw material extraction	Energy	[1], [2], [3]
	Solid waste	[1], [3], [4], [5], [6]
	Wastewater	[1], [3]
Industrial manufacturing	The chemical process of textiles	[1], [7]
	Energy	[1], [7], [8], [9], [10], [11]
	Wastewater	[1], [3]
	Solid waste	[1], [4], [5], [6], [12], [13]
Transportation (within the country)	Fuel	[1], [8]
	Packing waste at the end of the production chain	[1], [4], [5]
Consumer use	Energy	[1]
	Water	[1], [3]
	Packing waste (cartons)	[1], [5]
End-of-life disposal	Solid Waste	[1], [4], [5], [6], [8]
	Energy for Recycle	[1], [4], [5], [6], [8]

[1] (Luo et al., 2022), [2] (Ozturk et al., 2020), [3] (Qian et al., 2021), [4] (Mishra et al., 2022), [5] (Nunes et al., 2018), [6] (Zhou et al., 2022), [7] (Zhang & Chen, 2019), [8] (Espinoza Pérez et al., 2022), [9] (Jaitiang et al., 2019), [10] (Lin et al., 2018), [11] (Zhou, 2021), [12] (Bizuneh & Tadesse, 2022), [13] (Stefan et al., 2022)

Luo et al. (2022) revealed that raw material extraction, industrial manufacturing, transportation (within the country), consumer use, and end-of-life disposal are the main life cycle stages in the apparel sector. Payet (2021) stated that the raw material extraction phase is the highest GHG emission stage. Industrial manufacturing is the apparel sector's second-largest GHG emission phase (Zhang & Chen, 2019). Energy mainly contributes to the industrial manufacturing phase GHG emission (Espinoza Pérez et al., 2022; Jaitiang et al., 2019; Luo et al., 2022; Zhang & Chen, 2019). However, limited studies have been carried out to manage the energy in the apparel sector (Ozturk et al., 2020). According to previous studies, textile waste plays a significant impact on the GHG emission, and in each LCS stage, waste produced (Bizuneh & Tadesse, 2022; Luo et al., 2022; Mishra et al., 2022; Nunes et al., 2018; Stefan et al., 2022; Zhou et al., 2022). Only 15% of these textile goods are recycled after use, with more than 66% going to landfills (Shirvanimoghaddam et al., 2020). Therefore, it significantly impacted the GHG emission and environmental aspects (Stefan et al., 2022). Moreover, wastewater can be identified as another significant GHG emission source produced by the apparel sector (Bailey et al., 2022; Luo et al., 2022; Qian et al., 2021; Wang et al., 2022).

3.3 STRATEGIES TO MINIMIZE GHG EMISSIONS IN THE APPAREL SECTOR

The control of greenhouse gases has gained importance as global warming has received more attention, particularly in the textile industry (Zhu et al., 2018). Accordingly, 19 articles out of 35 elaborated on the strategies that can be led to minimizing the GHG emission in the apparel sector in some of the LCS. The summary of the strategies to minimise CFP in the apparel sector is shown in Table 5.

Table 5: Strategies to minimize CFP in the apparel sector

Strategies	References
To elaborate eco-design of the product, including the circular economy	[7], [12]
Using new raw materials that have a less environmental impact	[8]
Targeting energy saving in fabrication	[8]
PET bottle to textile	[8]
Recycled PET-based textile is an eco-friendly fabric	[8]
Processes by safe biochemical processes, which affect the properties of fibers and textiles	[8]
Use of Enzyme biocatalysts for treatment processes of fibers and textile material	[8]
Biopolymers and biomasses as new materials for surface modification of textiles	[8]
Optimization of chemical uses	[8]
Utilise environment-friendly textile dyes/substitution of input material used in a process (replacement of chemical dyes with natural dyes)	[11], [8]
Process alternatives: pulsating rinse technology	[8]
Create a new source of raw materials	[1], [2], [3], [4], [5], [8]
Additives using a valorised technique using the circular economy concept or recycle	[1], [2], [3], [4], [5], [8]
Re-use	[1], [7], [8]
Implementation of Industry 4.0 and additive manufacturing to reduce the rate of waste generation in production processes	[8]
Wastewater treatment technologies to reduce water consumption and water pollution/development of wastewater treatment on site	[7], [8], [15]
Auxiliaries to mitigate water eutrophication	[7], [15]
Water recycling and re-use	[8]
Development of high-performance membrane Nano reactor for textile wastewater treatment	[8]
Use clean energy / renewable energy generation / low-carbon electricity	[7], [9], [10], [11], [12], [13], [14], [17]
Lowering the processes temperature for energy saving	[8]
Using automated dosing machines and controllers for production	[8]
Modification of technology/equipment	[8], [18]
To reduce unsold items	[7]
Development of enzyme systems and extending their applications in surface treatment for functionalization of textile substrates	[8]
Multifunctionality of the Textile for use in more comprehensive applications: intelligent textiles.	[8]
Introduce GHG management commitment and policy	[16]
Introduce GHG management target and program	[16]
Switching to high-efficiency equipment and waste heat recovery	[17]
Increase the technical inputs, significantly increase research and development (R & D) expenditures	[18]
Accelerate the elimination of backward production capacity	[18]
Improve the relevant legal system	[12], [19]

[1] (Bizuneh & Tadesse, 2022), [2] (Leal et al., 2022), [3] (Mishra et al., 2022), [4] (Stefan et al., 2022), [5] (Zhou et al., 2022), [7] (Payet, 2021), [8] (Shirvanimoghaddam et al., 2020), [9] (Espinoza Pérez et al., 2022), [10] (Ozturk et al., 2020), [11] (Qian et al., 2021), [12] (Zhou, 2021), [13] (Chang & Zhu, 2022), [14] (Peng et al., 2022), [15] (Wang et al., 2022), [16] (Zhu et al., 2018), [17] (Jaitiang et al., 2019), [18] (Lin et al., 2018), [19] (Chang & Zhu, 2022)

All 19 articles above have provided 32 strategies to minimise CFP in the apparel sector. Out of the 19 articles, Shirvanimoghaddam et al. (2020) study provided 19 strategies, and that study can be identified as the most solutions provided article. However, 11 of 32 strategies focus on minimizing the CFP in the raw material extraction phase. These strategies are to using of new raw materials in the apparel industry that have a less environmental impact, targeting energy saving in fabrication, PET bottle to textile: recycled PET-based textile is an eco-friendly fabric made of recycled PET, processes by safe biochemical processes, which affect the properties of fibers and textiles, use of Enzyme biocatalysts for treatment processes of fibers and textile material, biopolymers and biomasses as new materials for surface modification of textiles, optimization of chemical uses, utilize environment-friendly textile dyes, the substitution of input material used in a process (replacement of chemical dyes with natural dyes), process alternatives: pulsating rinse technology (Shirvanimoghaddam et al., 2020). and elaborate product eco-design, including the circular economy (Payet, 2021). Zhou (2021) stated that the government should strengthen the top-level design to reduce environmental impact.

Furthermore, Shirvanimoghaddam et al. (2020) revealed that bamboo, silk, and hemp are the new raw materials in the apparel industry with less environmental impact. However, silk has been a material that has more than 2500 years of history. Moreover, using Internet of Things (IoT) technology for different stages of farming (smart farming) helps to minimize the CFP under the raw material extraction phase. Moreover, Mishra et al. (2022) revealed that recycled fiber also could be used as new raw materials in the apparel sector. Accordingly, studies have shown that recycling (Bizuneh & Tadesse, 2022; Leal et al., 2022; Mishra et al., 2022; Shirvanimoghaddam et al., 2020; Stefan et al., 2022; Zhou et al., 2022) and re-use (Bizuneh & Tadesse, 2022; Payet, 2021; Shirvanimoghaddam et al., 2020) are the most suitable strategies to minimized the CFP releasing through textile wastes. In addition, Shirvanimoghaddam et al. (2020) added that implementing Industry 4.0 and additive manufacturing to reduce the rate of waste generation in production processes is essential. Furthermore, Luo et al. (2022) highlighted that apparel sector stakeholder needs to focus more on water footprint in the apparel sector. The apparel sector's water footprint can also be identified as a significant CFP source (Bailey et al., 2022; Luo et al., 2022; Qian et al., 2021; Wang et al., 2022). Accordingly, studies suggested to do wastewater treatment (Wang et al., 2022), auxiliaries to mitigate water eutrophication (Payet, 2021; Wang et al., 2022), water recycling and re-use and development of high-performance membrane Nano reactor for textile wastewater treatment (Shirvanimoghaddam et al., 2020) are the most suitable strategies to minimize CFP in the wastewater of apparel sector.

The studies suggested that using renewable energy (Chang & Zhu, 2022; Espinoza Pérez et al., 2022; Jaitiang et al., 2019; Ozturk et al., 2020; Payet, 2021; Peng et al., 2022; Qian et al., 2021; Zhou, 2021) and lowering the processes temperature for energy saving (dying, printing, finishing) (Shirvanimoghaddam et al., 2020) are the most suitable strategies to reduce CFP releasing from energy. Moreover, Shirvanimoghaddam et al. (2020) suggested that using automated dosing machines and controllers in different production steps also led to saving energy consumption. Finally, the studies shown a modification of technology/equipment (Lin et al., 2018; Shirvanimoghaddam et al., 2020) to reduce unsold items (Payet, 2021), development of enzyme systems and extending their applications in surface treatment for functionalization of textile substrates, multifunctionality of the textile for use in more comprehensive applications: smart textiles (Shirvanimoghaddam et al., 2020), introduce CFP management commitment and policy, introduce CFP management target and program (Zhu et al., 2018), switching to high-efficiency equipment and waste heat recovery (Jaitiang et al., 2019), increase the technical inputs, especially to increasing research and development (R & D) expenditures, accelerate the elimination of backward production capacity (Lin et al., 2018) and improve the relevant legal system (Chang & Zhu, 2022; Zhou, 2021) common strategies led to minimized CFP in the apparel sector.

3.4 SUMMARY

The study found that energy, solid waste, fabric and accessories waste, water, fuel, and packing waste are the primary GHG emission sources coming under various life cycle stages in the apparel sector. Therefore, based on the GHG emission sources, suitable strategies to minimise CFP in the apparel sector were found and summarised, as shown in Figure 2.

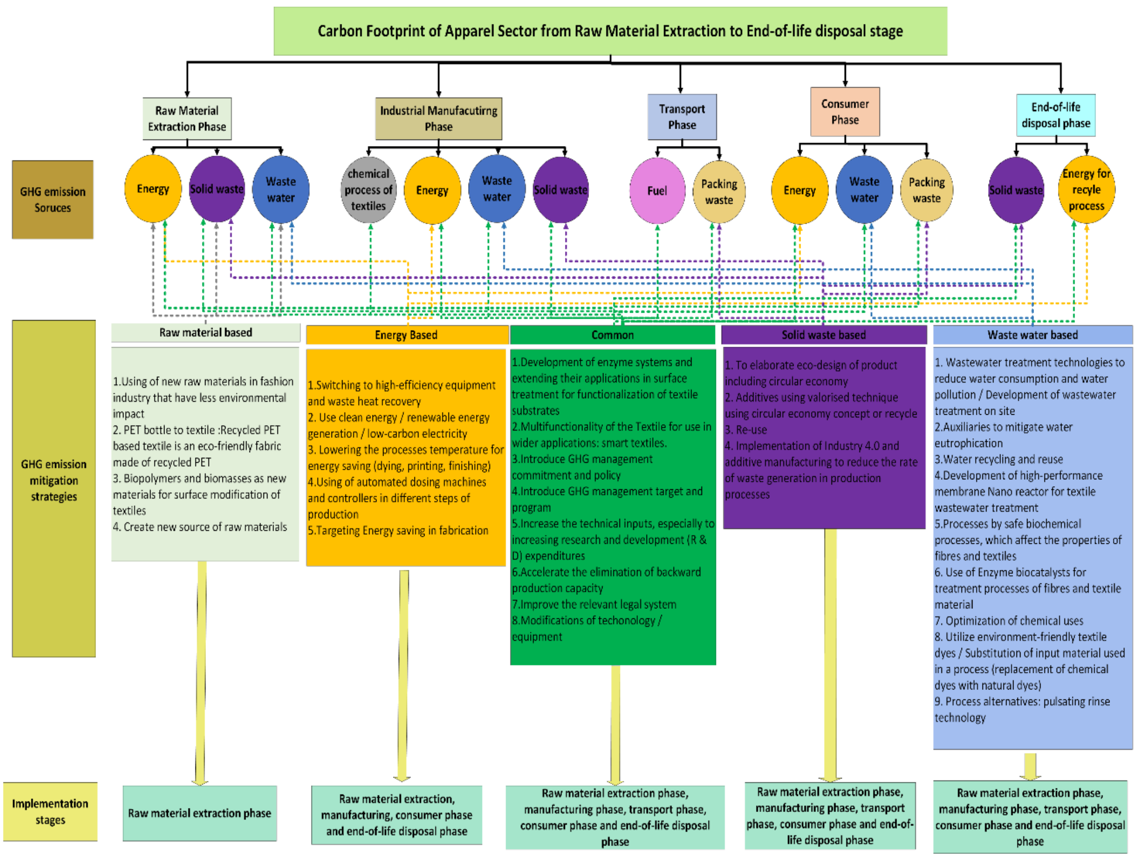

Figure 2: Summary of strategies to minimise CFP in the apparel sector (Raw material phase to end-of-life phase)

4. CONCLUSIONS AND WAY FORWARD

4.1 CONCLUSIONS

The main aim of this study was to investigate the management of CFP in the apparel sector. A systematic literature review was carried out to identify the GHG emission sources and strategies to minimise CFP in the apparel sector using PRISMA systematic analysis. Accordingly, energy, solid waste, wastewater, packing waste, the chemical process of textiles, and fuel are the primary sources emitting CO_2 and other GHG emissions at the various production stages of the apparel sector. However, the review also shows energy is a significant contributor directly and indirectly to GHG emissions in the apparel sector. The results lead to conclude that using new raw materials, switching to high-efficiency equipment, using clean energy / renewable energy generation / low-carbon electricity, elaborate eco-design of the product including circular economy, additives using a valorised technique using the circular economy concept or recycling, re-use, wastewater treatment technologies to reduce water consumption and water pollution, water recycling and re-use, optimization of chemical uses and utilize environment-friendly textile dyes/substitution of input material used in a process (replacement of chemical dyes with natural dyes are the critical potential strategies to minimize CFP emitting from wastewater in the apparel sector. Finally, the study concluded and recommended that introducing CFP management commitment and policy, introducing CFP management targets and programs, increasing the technical inputs, especially to increasing research and development (R & D) expenditures, accelerating the elimination of backward production capacity, improving the relevant legal system and modifications of technology/equipment are common strategies that will lead to reducing CFP in the apparel sector.

4.2 LIMITATIONS

This study has some limitations despite its contributions. Only the databases Scopus and Web of Science have been used for the search. Therefore, other relevant publications regarding the management of carbon footprint in the apparel industry be missing. For this reason, the research findings might not fully reflect the whole available literature on the management of carbon footprint in the apparel industry. Notwithstanding the careful selection of the relevant papers, not all keywords may have been captured in the literature search. In the review of literature, the selection of relevant papers and identification of the strategies for the management of carbon footprint in the apparel industry might have been affected by subjective judgments. The above-mentioned limitations generate fertile grounds for further research and should be considered when interpreting the findings of the research. This study recommends the use of a variety of data sets and a more extensive range of literature.

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MANAGEMENT OF SOCIAL SUSTAINABILITY AND QUALITY ASPECTS OF RURAL ROAD CONSTRUCTION IN SRI LANKA

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ABSTRACT

Though the rural roads are the final link of the transportation system, they provide the most critical connection between the city and the rural community. Further, the quality of rural roads is a significant factor to be maintained. On the other hand, maintaining quality has both positive and negative impact on social sustainability, which has been identified as one pillar of sustainability. Apart from these facts, there is a lack of research studies regarding the social sustainability and quality of rural roads at the construction stage. Although the term "social" was introduced into sustainability lately, quality is an intangible aspect. Therefore, this research was conducted to address the research gap in managing the effects of the quality of rural road construction on social sustainability. Data for the research was collected through a literature review, semi-structured interviews with conducting among fifteen selected relevant professionals of the project and an industrial document review from the documents maintained by the contractor. The research attempts to show what effects can be identified and the strategies that can be followed to overcome those effects. For that, ten social sustainability factors and fifteen quality aspects of the construction phase has taken. According to the geographical condition of the selected project area, the number of effects related to each social sustainability factor was different. Further, it was found that few quality aspects impact multiple social sustainability factors. The findings of this research prove that both accessibility and safety-related effects have been encountered critically while achieving the selected quality aspects of the rural roads during the construction stage.

Keywords: *Construction; Quality Aspects; Rural Roads; Social Sustainability Factors.*

1. INTRODUCTION

An entire country's growth and development depend on its infrastructure (Babar & Ali, 2022). Transportation is one such infrastructure that provides much more solutions to the problems encountered by the public in the country. Worldwide, around a billion people reside in rural areas without access to paved national road networks (Asher & Novosad, 2020). Transport infrastructure is a fundamental category of the transport system of any city or state (Skorobogatova & Kuzmina-Merlino, 2017). According to Stefaniec et al.,

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(2021), although the importance of social sustainability is discussed more, the current literature still underestimates its magnitude. Furthermore, to have a strong and fruitful economy, there should be a better connection between the urban and rural zones.

Rural roads are the final connection of the transport network; however, they usually give the principal connection when providing an entrance for the remote community (Donnges et al., 2007). Usually, most poor communities in developing countries live in these remote areas. Therefore, rural roads are the critical component, which addresses this gap to reduce these countries' geographical poverty (Golmohammadi, 2018). Nevertheless, on the other hand, these rural roads allow access to many rural settlements and their residents (Golmohammadi, 2018).

In order to have the maximum connectivity to habitation through the rural roads, their quality should be managed well (National Rural Roads Development, 2007). For that, significant aspects of the quality of rural roads should be identified. Since Sri Lanka is still a developing country, funding agents are willing to invest in developing infrastructure. Asian Development Bank (ADB) is a funding agent highly interested in fulfilling social requirements. Over the past few years, there has been considerable development of the rural road sector in Sri Lanka under the Integrated Road Investment Programme (iRoad), which works with the association of the ADB and supports the necessary finance (Sakamoto, 2014). Through eliminating poverty, the ADB project aimed to promote economic development and social integration by connecting people (Asian Development Bank, 2014).

Even though there have been several studies on the economic and environmental aspects of construction projects, the social side has never received as much attention (Hendiani & Bagherpour, 2019). Further, in the literature and in practice, social sustainability has received less attention than other aspects of sustainability (Rostamnezhad, 2022). Moreover, it is important to manage the negative social impacts of social sustainable projects (Treviño-Lozano, 2021). Therefore, this study is focused on discussing the effect of achieving social sustainability on the quality of rural road construction in Sri Lanka, where less attention has been given. In other words, to resolve the problem of “How to manage the effects of quality aspects of the rural road construction on social sustainability?”

This research aimed to identify the effects on the quality of rural road construction when achieving social sustainability. The aim was reached through four main objectives:

1. Identify social sustainability factors applicable to rural road construction,
2. Identify quality aspects of rural road construction applicable to social sustainability factors,
3. Investigate the effects of quality aspects on social sustainability factors in rural road construction, and
4. Investigate the strategies to overcome the effects of quality aspects on the social sustainability of rural roads.

The paper is structured as follows: The literature review is presented next and the research method adopted are presented in Section 3. Next, the results obtained by analysing the collected data are presented and discussed. Finally, the conclusions and further directions are presented.

2. LITERATURE REVIEW

2.1 ROAD QUALITY ASPECTS

Achieving acceptable performance levels from construction activities can be considered quality in the construction sector (Mishra, 2021). Since quality involves many different factors, such as changes to the physical infrastructure and the services it offers, it is difficult to determine quality in absolute terms (Mamabolo, 2016). In developing countries, high-quality infrastructure in rural villages is vital for economic development. In addition, these roads have been selected to increase input through agriculture, reduce prices, and grow local markets (Lun et al., 2013).

The Quality Aspects (QA) under the road construction stage were identified through different publications within the literature review is included in Table 1.

Table 1: Summary of literature on quality aspects in road construction stage

Quality Aspects	A1	A2	A3	A4
Design speed	X			
Distance for sight	X			
Road alignment	X			
Traffic barriers/guardrails	X			
Driveways and access points	X			
Lighting	X			
Utilities	X			
Landscaping and plant materials	X			
Bicycle accommodations	X			
Bridge and culvert replacement	X			
Roadway, right-of-way widths	X			
Pipe culvert	X			
Fixing of sign boards	X			
Procedures of controlling quality	X	X	X	
Contractor QC willingness and QC	X	X	X	X
Evaluation and availability of material		X	X	X
Material properties		X		X
Used method of construction		X	X	
Aggregate quality and crushing process		X	X	X
Gradation and crushing process, asphalt content		X	X	
Changes in mix design		X	X	
Use of marginal material		X	X	
Mixture placement and compaction operation		X	X	X
Condition of roadbed soil		X	X	

Sources: A1: The Valleys Planning Council (2008); A2: Rahangdale (2020); A3: Minde & Ghadge (2018); A4, Al- Hassan (1993)

Thirty-two (32) road quality aspects found in the literature were summarised to twenty-four (24) by considering the meanings and removing duplicates.

2.2 SOCIAL SUSTAINABILITY OF ROADS

According to Abdel-Raheem and Ramsbottom (2016), sustainability targets a connection between the given project and the system's social, environmental, and economic dimensions covered through the project. In order to provide fair access to resources, social sustainability tries to satisfy current needs without affecting the capacity of future generations to satisfy their own needs (Abdel-Raheem, 2016). Thus, this research focused on the Social Sustainability Factors (SSF) of road construction.

The SSF's were identified through different publications under the literature review. The summarised SSF from the literature is included in Table 2.

Table 2: Summary of literature on social sustainability factors in road construction stage

Quality Aspects	A1	A2	A3	A4
Accessibility	X		X	X
Availability of job opportunities	X		X	
Affordability	X			
Safety and security	X			X
Social cohesion	X	X		X
Diversity with employees and community		X		
Vitality of a community		X		
Minimising usage of non-renewable resources		X		
Changing attitudes and practices		X		
Tracking measures for social sustainability		X		
Awareness of social sustainability		X		
Global networking for social sustainability		X		
Responsibility and accountability		X		
Townscape Design			X	
Provision of social infrastructure			X	
Culture and heritage			X	
Knowledge transfer				X
Land acquisition				X
High level of vibration				X
Disposal of debris				X
Disruption of traffic				X

Sources: A1: Sakamoto (2014); A2: Abdel-Raheem (2016); A3: Chan & Lee (2016); A4: Almahmoud (2020)

Total of 23 SSF found in literature for the road construction stage were summarised to 21 by analysing the meanings and the words of the said SSF's.

2.3 RURAL ROADS

Transport is essential for producing goods and services (Véron-Okamoto & Sakamoto, 2014). Usually, rural roads are the last branch of the transportation system, but they provide an essential connection by giving entrance for the rural population to the city (Donnges et al., 2007). Rural roads connect villages and provide access to markets and services (Golmohammadi, 2018). They connect different types of social communities and give access to rural public and private property with a minimum speed in design (Bhandari et al., 2012). The connectivity enabled by rural roads has been identified as a critical solution for the community development of country areas. Rural poverty is caused by poor access to urban areas (Sankaranarayanan & Krishnakumari, 2021). Previous research has found that the type and condition of roads are linked to socioeconomic development in terms of employment, family, planning, income, and health (Sankaranarayanan & Krishnakumari., 2021). In order to overcome such issues, there is a need to develop connectivity between rural areas and urban areas.

2.3.1 The iRoads as Rural Roads

Over the past few years, the rural road sector in Sri Lanka has enormously developed under the iRoad Programme, taking ADB as the funding agent (Véron-Okamoto & Sakamoto, 2014). The iRoad programme was a proposal from the Road Development Authority (RDA) under the Ministry of Highways, Ports and Shipping (MOHPS) which was proposed in order to enhance the transportation connection with the urban and rural.

Therefore, many have proven that investing in rural roads will solve the economic and social development difficulties plaguing rural communities.

2.4 MANAGING EFFECTS OF QUALITY ASPECTS ON SOCIAL SUSTAINABILITY FACTORS

The social framework significantly impacts how people live their daily lives. The factors that make life easier, such as the physical characteristics of a home, a secure neighbourhood, the presence of schools, public transportation, parking, and green areas nearby, improve people's happiness with their homes and have an impact on their quality of life (Grum & Grum, 2020). Ensuring that the road infrastructure is planned, built, and maintained in a way that meets the requirements of the local community and improves their quality of life is one way to manage the impacts of quality factors on social sustainability in roads. A comprehensive strategy that considers the needs of the local community, the environment, and the safety of all users is needed to manage the impacts of quality aspects on social sustainability in roads. It is possible to design road infrastructure that improves everyone's quality of living by considering these factors.

3. METHODOLOGY

Data from both primary and secondary sources have been used to accomplish the four objectives of this research. Case study research strategy was used with semi-structured interviews and a project document survey as the primary sources, and the secondary data were obtained through a literature review. According to Bengtsson (2016), content analysis allows for correct inferences from verbal, visual, or written data to define and quantify certain occurrences systematically and objectively, which was the most suitable way to analyse this qualitative data. Thus, the gathered data were structured into generalised themes that shaped the research using content analysis by taking into consideration of their meanings and eliminating repetitions.

The non-probability sampling method has been used here since all the related parties cannot be interviewed due to the time constraint. Under this type of sampling, there is no known probability that every single individual in the whole community will be selected for the sample (Bhardwaj, 2019). Accordingly, this research is based on the answers given by fifteen (15) interviewees, as denoted in Table 3. The answers cannot be a simple “yes” or "no", and their points should be elaborated. Therefore, the questions that were used to collect data were predominantly open-ended.

Most importantly, document data of the project were collected. A qualitative method is studying and understanding the interpretation that groups or individuals are assigned to a social or human problem (Sukamolson, 2007). Depending on these features, a qualitative approach was preferred to fulfil the objectives of this research.

The data were collected from a one completed project from a selected period from 2015 to 2020 in the Nuwara Eliya district. This project covered the whole district under the five divisional secretariats: Walapane, Hanguranketha, Kothmale, Nuwara Eliya, and Ambagamuwa. The total number of roads they covered was forty-three (43), with 180km in the whole district, under three packages. According to the study conducted by Liyanage et al. (2021), Central Province has flat, rolling, and mountainous terrains on 200 roads which contains more road structures. Consequently, this research is limited to Nuwara

Eliya District by considering the high involvement of road structures, which is a significant aspect of the quality of roads.

Conducting 15 interviews with the relevant professionals in person were not practical with the pandemic. Therefore, interviews were conducted via the Zoom platform and by phone calls, as the secondary resource soft copies of the complaint registers of three packages maintained by the environmental officers of the contractor's organisation were reviewed. Comments from both the technical staff and community were obtained through the interviews and document review respectively.

Table 3: Composition of interviewees

Package	Contractor	Consultant	Client
01	Environmental Officer - I1 Project Manager - I4	Assistant Residential Engineer - I9 Quality Assurance Manager - I10	Social Officer - I13
02	Environmental Officer - I2 Quality Assurance Manager - I5	Environmental Specialist - I7 Social Officer - I11	Project Engineer - I14
03	Environmental Officer - I3 Technical Officer - I6	Environmental Specialist Assistant - I8 Technical Officer - I12	Environmental Officer - I15

All the 15 interviewees named from I1 to I15 as in Table 03 were selected from related professionals covering the whole three packages. Further they were from contractor, consultant and client organisations who are having the knowledge about both social sustainability and road quality.

4. RESULTS AND DISCUSSION

4.1 SOCIAL SUSTAINABILITY FACTORS APPLICABLE TO RURAL ROAD CONSTRUCTION

This section focuses on social sustainability factors (SSF) encountered in rural roads during construction. Twenty-one SSF's finalised from the literature were validated through interviews, five were identified as having a relation to rural road quality aspects, and some five new SSF's added. The first column of Table 4 shows ten social sustainability factors that are related to rural road construction. The **bolded fonts** of the Table 4 represent the newly added SSFs and QAs from the primary data collected from interviews and industry document review.

Table 4: rural road quality aspects which cause effects on social sustainability factors

Social Sustainability Factor (SSF)	Quality Aspect (QA)
1. Accessibility (SSF 1)	1.1. Roadway and right-of-way width 1.2. Traffic Barriers/ Guardrails 1.3. Utilities 1.4. Pipe culvert 1.5. Bridge and culvert replacement 1.6. Fixing of Sign Boards **1.7. Drainage facility**
2. High level of vibration (SSF 2)	2.1. Mixture placement and compaction operation
3. Disposal of Debris (SSF 3)	**3.1. Cleanliness**
4. Safety (SSF 4)	4.1. Utilities 4.2. Pipe culvert 4.3. Bridge and culvert replacement 4.4. Landscaping and plant materials

Social Sustainability Factor (SSF)	Quality Aspect (QA)
5. Culture and Heritage (SSF 5)	5.1. Roadway and right-of-way width 5.2. Utilities
6. Dust (SSF 6)	**6.1. Priming**
7. Land donation (SSF 7)	7.1. Roadway and right-of-way width 7.2. Driveways and access points **7.3. Embankment protection**
8. Disturb to agriculture property (SSF 8)	8.1. Roadway and right-of-way width **8.2. Tack Coat** 8.3. Utilities
9. Storm water entering into the lands (SSF 9)	9.1. Pipe culvert **9.2. Drainage facility**
10. Land Erosion (SSF 10)	10.1. Landscaping and plant materials

Accessibility (SSF 1) means the ease of reaching or interacting with a destination. Okamoto and Sakamoto (2014) emphasised that this (SSF) is affected due to road quality aspects. Secondary data also identified this as a social sustainability factor in rural road construction. As for SSF 2, a high level of vibration occurs in the process of obtaining the required quality through compaction. Literature surveys (Almahmoud, 2020) and industrial data identified this social sustainability factor. The third factor, 'Disposal of Debris' (SSF 3), is also identified in the literature survey (Almahmoud, 2020) the unsuitable material generated from road construction is identified as appropriately disposed of to minimise public and environmental issues.

Since the construction industry always carries some risks 'safety' (SSF 4) is a significant factor in construction (Sakamoto, 2014); Almahmoud, 2020). SSF 4 was identified from the literature and was confirmed by an industry survey. When introducing new things to the rural community, they usually get worried about their safety. They also think this threatens them, even though it fulfils their infrastructure facilities. Culture and heritage (SSF 5) also play a significant role in the sustainability of a community which is identified in both literature and industrial survey.

Furthermore, this preserves the identity of the place. Traditional and archaeologically essential structures are the tangible proofs of their culture. Therefore, preserving and respecting the heritage and characteristics of the places is essential.

Fine dust or powder of tiny particulates of earth or waste matter can be considered dust. It has numerous environmental effects and is a nuisance in the surrounding environment. Especially in road construction, dust (SSF 6) is created due to soil compaction, priming activities, and wind blowing through the unclean road surface area. This factor is also not found in the literature, thus a new factor from primary data. The next factor, 'Land donation' (SSF 7), was also a new factor not in the literature. Additional land should be acquired when there is insufficient road width to construct the road. However, the iRoad project (integrated road investment programme) did not follow the land acquisition process. Instead, the landowner has donated the required land area with a simple agreement between the landowner and the client. In most cases, this donated area was a very narrow land strip, and the landowners donated it willingly.

On the other hand, agricultural properties on either side of the construction road could be disturbed differently. For example, the vegetable beds or any cultivation could be directly damaged when those are within the ROW. Further, removing unsuitable materials could have effects on this. Thus, 'Disturb to agriculture property' (SSF 8) was a newly added SSF by industrial data review. Moreover, because of road construction activities, existing land shapes could change, and access ways could be temporarily blocked. Then, during the rainy season, storm water enters the adjacent lands and damages structures and vegetation. Hence, ‘storm water entering into the lands’ (SSF 9) was also identified as a new SSF, not in the literature. Soil erosion is the removal of topsoil due to biological and physical activities. It causes loss of soil fertility and soil depredation, and finally, it impacts the sediment area. Land erosion can occur in the road construction industry due to removing topsoil and de-silted partials in an unplanned manner without following proper soil erosion practices. Consequently, Land Erosion (SSF 10) was also a newly identified SSF from the industry data.

4.2 QUALITY ASPECTS OF RURAL ROAD CONSTRUCTION APPLICABLE TO SOCIAL SUSTAINABILITY FACTORS

Twenty-four quality aspects related to road construction from the literature were validated through interviews, and ten were identified as having a relation with SSFs. While categorising the quality aspects identified from literature into what social sustainability factors are effects from these quality aspects, five new quality aspects were newly identified. The second column of Table 2 shows fifteen rural road quality aspects affecting social sustainability.

Accordingly, Roadway and right-of-way width, traffic barriers/guardrails, utilities, pipe culvert, bridge and culvert replacement, fixing of sign boards and drainage facility were identified as the quality aspects needed to consider for rural road sustainability factor of ‘Accessibility’ (SSF 1). ‘Drainage facility’ was a newly identified factor from industry data. A drainage facility is a network of artificial structures, such as storm water sewers, canals, detention structures, and retention structures, intended to gather, convey, store, divert, or discharge storm water. While the quality aspect of ‘Mixture placement and compaction operation’ was categorised under the High level of vibration (SSF 2), the newly identified quality aspect of ‘Cleanliness’ was associated with the newly identified SSF, ‘Disposal of Debris’.

The four quality aspects of: utilities, pipe culvert, bridge and culvert replacement and landscaping and plant materials were already in literature and recognised as causing effects of SSF of safety. Further, the interviewees identified that ‘Culture and Heritage’ (SSF 5) is affected by rural road quality aspects of the roadway and right-of-way (row) width and utilities found in the literature. The entire amount of land acquired for road development is the right of way (ROW). Its width must be sufficient to handle every component of the road's cross-section, any upcoming widening of the road, and any upcoming installation of public utility facilities alongside the road. Further, utilities come under road construction referred to services and mains for water lines, pipes for storm sewers, and pipes for sanitary sewers and trenching for gas and electric lines.

Priming means adding a bituminous binder, a newly added QA from the industry data review, under the newly identified SSF of ‘Dust’. While interviews newly added all the other four SSFs, few quality aspects affecting the rural road SSFs were identified. Other than to SSF 5, land erosion (SSF 7) and disturb to agriculture property (SSF 8) also affects the road quality aspect of roadway and right-of-way width, which means the entire amount of land acquired for the development of the road

Furthermore, ‘Embankment protection’, ‘Drainage facility’ and ‘Tack Coat’ were newly identified QAs of rural roads based on primary data. These have been identified as affecting to the SSFs of: ‘Land donation’ (SSF 7), ‘Disturb to agriculture property’ (SSF 8), storm water entering into the lands' (SSF 9), and Land Erosion (SSF 10), receptively. Moreover, all these four social sustainability factors were newly identified from the industry survey.

4.3 EFFECTS OF QUALITY ASPECTS ON SOCIAL SUSTAINABILITY FACTORS IN RURAL ROAD CONSTRUCTION

Table 5 contains all the effects of QAs on SSFs in rural road construction identified through semi-structured interviews with 15 interviewees. These effects have been summarised through content analysis and categorised according to each SSF and QA. Table 3, presents the interviewees identification codes.

Most of the effects were encountered concerning SSF1. I1 emphasised on this by saying "Accessibility was the major factor on which we had to focus". When maintaining the given ROW, placing traffic barriers and guardrails, replacing culverts, providing drainage facilities, doing excavations for utilities, and placing sign boards, existing access points for public and private property get blocked, damaged, or have to close. I2 strongly agreed such effects on QA’s by mentioning "Accessibility related issues were encountered immensely." Further, water flew into properties when laying pipe culverts due to excavations. Due to SSF2 mixture placement and compaction operation in roads, high vibration occurs on public and existing structures. That vibration also makes cracks in existing structures. To achieve SSF 3, must deposit debris to have a clean carriage way effect on the public.

Secondly, most of the effects were encountered concerning SSF4 since safety is critical in the construction industry. I4 also mentioned “safety was the key factor we have paid our attention on” by evidencing this. It causes accidents due to the excavations done for providing utilities, accidents due to the excavations done for pipe culverts, and high-water flow rates through culverts that damage the public. Moreover, landscaping and plant materials come up with sudden landslips. When moving into SSF 5, traditional and archaeological structures usually lie within the ROW. Moreover, they have to dig near traditional and archaeologically valuable places when providing utilities.

In SSF6, when doing priming, a high generation of dust affects the public. Moreover, I6 said “Dust controlling was a critical issue we faced”. When landscaping and planting materials beside the road, land erosion can happen. When moving into SSF 8 and disturbing agricultural property, there are occasions where vegetation lies within the ROW, and when applying tack coat, it splits on tea plantations beside the road. Further, excavations for utilities had to be done through existing vegetation.

As per SSF9 when storm water enters the lands, water blocks through culverts due to less maintenance and drainage. This is also confirmed by I12 by saying “Eliminating issues on providing drainage facility need to be addressed crucially”. With SSF 10, there are effects when insufficient width for road, driveways, and access points make it difficult to access public and private property. While doing embankment protection, there is vegetation within the area.

The **bolded fonts** in Table 05 represent the newly identified SSF’s and QA’s which were not in the literature. Further, I1-I15 denotes the interviewee numbers.

Table 5: Effects on rural road quality when attaining social sustainability and strategies to overcome

Social Sustainability Factor (SSF)	Quality Aspect (QA)	Effects	Ways of Overcome
SSF 1	1. Roadway and right-of-way width	When maintaining the given ROW existing access points for public and private property get blocked or damaged **(I2, I3, I4, I5, I6, I7, I8, I9, I10, I11, I12, I13, I14, I15)**	• Can shift the CL of the road. • Can provide new access points. • Can provide temporary access points.
	2. Traffic Barriers/ Guardrails	Access for existing property get blocked temporally or permanently and also get damaged **(I1, I2, I4, I6, I7, I8, I9, I10, I11, I12, I13, I14, I15)**	• Provide new access points
	3. Utilities	When doing excavations for utilities, access points for public and private property get blocked, damaged or have to close **(I1, I4, I6, I7, I8, I9, I10, I11, I12 I13, I14, I15)**	• Can provide new access points by placing cover slabs
	4. Pipe culvert	Access for houses and farms gets blocked and damaged by the excavations done and by flowing water **(I3, I4, I5, I6, I7, I8 I9, I10, I11, I12, I13, I14, I15)**	• Can adjust the place of the pipe culvert. • Can provide new places to access.
	5. Bridge and culvert replacement	Replaced culverts block existing access points and cause damages **(I4, I6, I7, I8, I11, I13, I14, I15)**	• Can shift the old access points and provide new ones
	6. Fixing of sign boards	Access gets blocked due to the placement of signboards **(I1, I2, I3, I4, I5, I6, I7, I8, I9, I10, I11, I12, I13, I14, I15)**	• Can Shift the place of fixing sign board. • Change the place of access accordingly.
	7. Drainage facility	Existing accessibility of private and public property gets blocked **(I3, I4, I5, I6, I7, I8, I14)**	• Place cover slabs over drains and provide new access by providing drainage facilities according to the drawing.
SSF 2	1. Mixture placement and compaction operation	High vibration on public & existing structures and cracks due to vibration **(I1, I3, I4, I5, I6, I7, I9 I10, I11, I12, I13, I14 I15)**	• Reduce the vibrate strength of compactor and increased the number of turns. • Provide payments through insurance for damages or can use small-scale rollers.
SSF 3	**1. Cleanliness**	Effect of depositing debris in order to have clean carriageway **(I4, I6, I8)**	• Dispose them into approved locations only
SSF 4	1. Utilities	Cause accidents due to the excavations done for providing utilities **(I1, I2, I3, I4, I5, I6, I7, I8, I9, I10, I11 I12, I13, I14, I15)**	• Spot the relevant places with safety barricades and safety sign boards. • Can provide temporary humps.
	2. Pipe culvert	Cause accidents due to the excavations done for pipe culverts **(I1, I2, I8, I14)**	• Spot the relevant places with safety barricades and safety sign boards. • Can provide temporary humps
	3. Bridgeand culvert replacement	High flow rate of water through culverts and damage public **(I8, I9, I10, I11, I12, I13)**	• Provide retaining walls to avoid the damage

Social Sustainability Factor (SSF)	Quality Aspect (QA)	Effects	Ways of Overcome
	4. Landscaping and plant materials	Sudden landslips **(I3, I4, I5, I6, I8, I9, I10, I11, I12, I13)**	• Provide temporary formwork or wood shuttering near the slipping areas
SSF 5	1. Roadway and right-of-way width	Traditional and archaeological structures lie within ROW **(I1, I2, I3, I4, I5, I6, I9, I10, I11, I12, I13, I14, I15)**	• Shift the road CL on that place
	2. Utilities	Had to dig near a traditional and archaeologically valued place **(I2, I9, I15)**	• Can shift the place of excavation and put a bypass in pipeline
SSF 6	**1. Priming**	High generation of dust and its effects on public (**I1)**	• Use manual techniques instead machines • Watering the road surface within selected • time intervals
SSF 7	1. Roadway and right of way width	Not enough width for road **(I1, I4, I6, I7, I14)**	• Land was donated to the RDA by discussing
	2. Driveways and access points	Difficulty in accessing in to public and private property **(I7)**	• Apply cover slabs and provide the access point
	3. Embankment protection	Vegetation within the area **(I7)**	• Negotiation and get donated the land
SSF 8	1. Roadway and right-of-way width	Vegetation within the ROW **(I15)**	• Wait until harvesting
	2. Tack Coat	Splitting of tack coat on tea plantations beside the road **(I2, I3, I4, I5, I6)**	• Make temporary coverings by tarpaulin
	3. Utilities	Excavations for utilities through vegetation **(I4, I6)**	• Wait until harvesting
SSF 9	1. Pipe culvert	Water block through culverts due to less maintenance **(I11, I13)**	• Clean the blocked culverts
	2**. Drainage facility**	Drainages get blocked **(I11, I13)**	• Clean the drainage paths
SSF 10	1. Landscaping and plant materials	Land erosion can happen **(I1, I11, I13, I15**)	• Turfing can be done and packing sand • Provide small boulder packing as a temporary solution

4.4 STRATEGIES TO OVERCOME THE EFFECTS OF QUALITY ASPECTS ON SOCIAL SUSTAINABILITY OF RURAL ROADS

Similar to the effects, ways to overcome those effects also have been identified through the interviews. In the last column of Table 3 strategies to overcome the effects of quality aspects on the social sustainability of rural roads are shown. These strategies have been summarised through content analysis and categorised according to each SSF and QA. According to the interviewees, they have followed these strategies within the iRoad project and what they propose with the vast industrial knowledge they gained.

As strategies to overcome the effects related to SSF 1, most interviewees came up with the solution of replacing the existing access point and providing new access points or temporary access points by using cover slabs. To reduce the damage due to high vibration

(SSF 2), they gave solutions such as reducing vibrate strength, increasing turns and providing insurance for damages.

To reduce the effects of disposing of debris (SSF 3), they have introduced approved locations place; dump yards to dispose of them without disturbing the public. To overcome the effects related to SSF 4, they have come up with solutions like spotting the relevant places with safety barricades and sign boards, providing retaining walls, and providing temporary formwork or wood shuttering near slipping areas. Effects related to SSF 5 can be overcome by shifting the road CL on that place and can shift the place of excavation and putting a bypass in the pipeline. For the effects related to priming, manual techniques were used to water the road surface within a selected time interval.

As strategies to overcome effects related to SSF 7, they have used turfing to provide sand and boulder packing as temporary solutions. To overcome the effects of disturb agricultural property, making temporary coverings by tarpaulin and waiting until harvesting was followed. For the effects of 'storm water entering into the lands', the blocked culverts and the drainage paths can be cleaned.

Land was donated to the RDA by discussing applied cover slabs and providing the access point, get discussed and get donated the land was the strategies to overcome the effects related to SSF 10.

5. CONCLUSIONS AND FUTURE DIRECTIONS

QAs of rural road construction were identified through a literature review, semi-structured interviews, and an industrial document review. The research newly identified SSF's related to rural road construction, such as debris disposal, dust, land donation, disturbance to agricultural property, storm water entering the lands, and erosion. Under the investigation of effects on the quality of rural road construction to social sustainability factors, five new SSFs and five new QAs of rural roads during the construction phase were identified. Among these QA's, a few cause effects on more than one SSF. Then the effects related to each QA and ways to overcome them were also identified. Nevertheless, the effects identified and how they are overcome regarding each quality aspect vary from one SSF to another. As the recommendation among the effects, most were related to accessibility and right-of-way (ROW) widths. To overcome this effect, it is better if the relevant government authorities, like the Road Development Authority or the Local Authority, can mark the ROW of the road. Marking the ROW will reduce the impact on the public and the road's quality while construction is underway.

This research introduces new social sustainability factors and new quality aspects related to road construction. For those willing to do their research related to these key topics, they can take them as literature. Further effects and the strategies to overcome them can also be used in future researches. On the other hand, the RDA, designers, consultants from the road projects, contractors, project managers, and social officers can use this as a guide for future problems. Due to the limited time frame, only qualitative data was collected. However, one can extend this research to a quantitative approach by measuring and giving value to each tangible quality aspect. Apart from these limitations, conducting interviews via an online platform and the safety measures taken to protect each respondent's identity also acted as limitations for this study. However, the research findings can be used to manage the effects of QAs on SSFs in rural road construction projects in Sri Lanka.

As the future direction, one can evaluate this for the whole country since this research only collects data from one construction organisation (contractor, consultant, and client) and is limited to the Nuwara Eliya district. Therefore, in addition to the quality aspects and social sustainability factors summarised in this research, various new quality aspects and social sustainability factors may be identified by expanding this research to the whole country.

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MEASURES TO MITIGATE TERMINATION OF CONSTRUCTION CONTRACTS IN SRI LANKA

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ABSTRACT

Termination of construction contracts has significant impact on the construction industry. But none of the past literature has addressed on how termination can be managed effectively specific to Sri Lankan context given the unique cultural, economic, and legal contexts of Sri Lanka. Therefore, this research aims to investigate and provide practical strategies for managing the termination of construction contracts. Initially, the literature review provided an understanding of contract termination. Subsequently, this study used qualitative approach involving case study and expert opinion. Under the case study, the documentary review was conducted that focus on fifteen terminated building projects in Sri Lanka over the past five years to understand the termination phenomenon in Sri Lankan context. Finally, an expert opinion was obtained to gain deeper understanding of the findings. The collected data was structured through manual content analysis and descriptive analysis. The study found that Western and Northern provinces of Sri Lanka have higher termination rates due to urbanisation, and economic development. Complex approval processes, and bureaucratic inefficiencies are the common reasons for contract termination in commercial and residential building projects. Public projects are more vulnerable to termination due to political considerations. Employers are more likely to terminate contracts than contractors, possibly due to financial instability and higher quality expectations. Finally, combination of mitigation strategies should be customised to minimise the risk of termination. These strategies can be implemented with modifications to fit the local context, but challenges such as lack of awareness, bureaucracy, and resistance to change may arise.

Keywords: *Contract termination; Measures; Mitigation; Sri Lanka.*

1. INTRODUCTION

The construction sector is crucial for the country's economy (Manoharan et al., 2022). However, due to the complexity of construction projects, they involve substantial risks (Hinze, 2012). Contractors face the challenging task of delivering blameless outcomes within the employer's requirements and a limited budget (Abeynayake & Kumara, 2013).

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To achieve successful outcomes, coordination among individuals with different skills and interests is necessary (Flanagan & Norman, 1993).

Construction projects are usually regulated by extensively detailed contractual documents and conditions that establish and regulate the parties' respective rights and obligations (Siang, 2011). A construction contract is legally enforceable, and the parties agree on specific terms to allocate the risks, obligations, responsibilities, and liabilities (Bakey, 2018). Failure to comply with these terms is a breach of the contract, and the other party is entitled to claim the remedy under the contract (McKendrick, 2022). Abu-Eed (2012) noted that contract termination is a natural phenomenon in the construction industry when a project is no longer necessary or feasible. Termination is guided by specific clauses in the contract (Ade-Ojo et al., 2017). It discharges the parties from further obligations (Siang, 2011).

The COVID-19 pandemic has caused a standstill in businesses worldwide, including Sri Lanka's construction industry (Kawmudi et al., 2020). In Sri Lanka, the economy is in a poor state due to long-term structural issues and recent policy missteps, which have also affected the construction industry (Wijeratne, 2022). The industry is expected to be immediately impacted by new laws and regulations implemented by the government, as it is engaged with multiple stakeholders and the environment (Soyza, 2022). It may lead to the termination of projects in the long run (McLoughlin, 2022). Construction contracts are naturally considered as risky. Risks should be actively managed, decreased, transferred to another party, or accepted as part of a decision-making process, but ignoring risks is not a viable option (Lam et al., 2007). Hence, as a developing country, it is essential to investigate the practical measures to avoid or mitigate terminations in Sri Lankan construction projects for the betterment of the employers, contractors and the nation's development.

2. TERMINATION OF CONSTRUCTION CONTRACTS

A contract is terminated at a moment when a legally binding contract period is ended before it has been fulfilled by performance as a result of one or both parties' actions. Once a contract has been terminated, none of the parties involved is obligated to perform the duties mentioned in the contract (Bakey, 2018). However, even after termination, the parties may still be eligible for damages and the extent and nature of these damages depend on the termination policies outlined in the construction contract (Wittbrodt & Eaton, 2009).

2.1 TYPES OF TERMINATION

Depending on the viewpoint of various professionals, two main types of termination can be generally characterised as termination by convenience and termination for default (Brumback, 2012).

Convenience is appropriate or agreeable to the needs or purpose (Cohen & Wojak, 2011). When the government exercises its power to stop all or any of the work being performed under a contract before the contract expires "when it is in the Government's interest," this is referred to as termination for convenience (Manuel et al., 2015). The contractor does not have the authority to terminate or suspend the agreement for convenience; only the owner does (Brumback, 2012). One of the contract's parties "defaulted," which results in termination for default (Benarroche, 2019). Moreover, the author stated that what this means is that they failed to perform something they were required to do. Both the contractor and the employer can terminate the agreement under the termination for breach (Dilts & Pence, 2006).

2.2 REASONS FOR TERMINATION OF CONSTRUCTION CONTRACTS

Contract termination in the construction industry can be caused by various factors that are applicable globally and locally, even though specific reasons may differ depending on the context. It can be broadly categorised as location-related factors, project-related factors, employer-related factors, and time-related factors that influence project termination in the construction industry. On the other hand, Table 1 provides a detailed overview of the main factors based on the party involves in the creation of the termination phenomenon considering the construction industry.

Table 1: Factors of termination of construction contracts

Code	Factors
Q	**Contractor Related Factors**
Q1	Lack of experience in the line of work (Enshassi et al., 2006)
Q2	Frauds (Enshassi et al., 2006)
Q3	Failure to achieve the rate of progress as scheduled (Hamdia, 2008)
Q4	Lack of team spirit in the project team (Chan et al., 2001)
Q5	The low margin of profit due to competition (Enshassi et al., 2006)
Q6	Contractors bankrupting or insolvent (El Karriri et al., 2011)
Q7	Average number of full-time employees (shortage of employees) (Dilts & Pence, 2006)
Q8	Ability to manage cost and time organisation (cash flow and schedule) (Chan et al., 2001)
R	**Employer Related Factors**
R1	Lack of capital (Enshassi et al., 2006)
R2	Change in the funding source (Dilts & Pence, 2006)
R3	Change in the type of work (Enshassi et al., 2006)
R4	Difference of local currency exchange with contract currency (Enshassi et al., 2006)
R5	Employer delay in the contractor’s interim payments (El Karriri et al., 2011)
R6	Bankruptcy of employer (Abeynayake & Kumara, 2013)
S	**Both Parties Related Factors**
S1	Lack of clear expectations (Anderson, 2010)
S2	Neglect (Enshassi et al., 2006)
S3	Poor communication / coordination between involved parties (Abu-Mousa, 2005)
S4	Difficulty to get permits (Abu-Mousa, 2005)
T	**External Factors**
T1	Internal political troubles; such as rebellion, civil war, or disorder (El Karriri et al., 2011)
T2	Change in regulatory problems (Dilts & Pence, 2006)
T3	Increment in material prices (El Karriri et al., 2011)
T4	Inflation in world (Kartam & Kartam, 2001)
T5	Legal restrictions and injunctions (Abeynayake & Kumara, 2013)
T6	Acts of God (Natural disaster) (Kartam & Kartam, 2001)

2.3 STRATEGIES TO MITIGATE OR AVOID TERMINATION

Termination of construction contracts can be a costly and disruptive event for all parties involved. Therefore, it is essential to have strategies in place to mitigate or avoid termination. To avoid costly and disruptive termination of construction contracts, parties can implement several strategies. These include drafting clear and comprehensive contracts, maintaining effective communication (Allen, 2017), conducting regular site inspections, incorporating alternative dispute resolution mechanisms, and including termination clauses that allow for negotiation and dispute resolution. By implementing these strategies, parties can better manage risks and conflicts that may arise during construction projects, thereby reducing the likelihood of termination and minimising the associated costs and disruptions.

3. RESEARCH METHODOLOGY

This study employed qualitative research methodology utilising case study and expert opinion. A method for meaningful individuals or groups to investigate and comprehend the contributing components to social or human difficulties is qualitative research (Creswell, 2009). According to Myers (2013), qualitative researchers contend that qualitative research is the best method for understanding people's motives, reasons for their behaviours, and the context of their beliefs and actions. The qualitative method was selected for this study for conducting an in-depth analysis of the termination phenomenon in the Sri Lankan context, aiming to identify the authentic causes and effective preventive measures. Qualitative approaches enable a comprehensive exploration of the complexities surrounding the termination of construction contracts.

The termination of construction contracts is a complex issue that requires an in-depth investigation of the various factors that can influence contract termination. A case study methodology is appropriate for this because it allows for a detailed investigation of specific cases and can provide insights into the contextual factors that contribute to contract termination (Dainty et al., 2001). As per Yin (2009) multiple case study design was chosen to identify commonalities and differences in how the termination of construction contracts is managed.

Since all the selected projects have already been terminated, observation is not an appropriate method. Moreover, interviews take a lot of time. So, professionals may not be willing to give interviews. Therefore, the documentary review was carried out as the primary data collection method under the case study. This method provides access to historical records related to termination, which can be used to learn from past mistakes and develop effective strategies for future projects. Additionally, expert opinion was sought as focus group interview to validate the accuracy of the documentary review results. Further, the manual content analysis and descriptive analysis approaches were used to ensure a more thorough and nuanced analysis of the collected data.

For this study, information was gathered from well-reputed firms and construction practitioners. Hence, according to Kothari (2004) the judgemental sampling under the non-probability sampling technique was chosen for this research. To reduce the time constraints and practical inconvenience of data collecting, the sample size was determined by considering the effectiveness of the study.

Relevant documents and archival records were referred to grasp information on cases regarding the termination. These documents were collected from Construction Industry Development Authority (CIDA) registered firms of contractors and consultants. CIDA registered organisations are selected to avoid anomalies and maintain uniformity. Moreover, documents were collected for 15 terminated building projects in Sri Lanka over the past 5 years to identify the trend and nature of the termination phenomenon in Sri Lankan construction industry. The expert opinion was conducted as focus group interview with a Contract Administration Manager and two Senior Quantity Surveyors and they have over 15 years of experience in the field. This suggests that the experts have significant knowledge and expertise in the area of contract administration, which is directly relevant to the research topic. In addition, the experts have previous experience in project termination, which is likely to have provided them with valuable insights into the reasons and consequences of project terminations.

4. RESEARCH FINDINGS

4.1 DESCRIPTIONS OF PROJECTS

This research aimed to investigate the mitigation measures for the termination of construction contracts in Sri Lanka. Establishing the representative nature of a sample consisting of 15 projects in the Sri Lankan construction industry presents challenges due to the absence of a statistical body that collects data on all terminated projects in the country. As a result, accessing the necessary information requires individually contacting each company involved. However, due to time constraints, difficulties in accessing information, and confidentiality concerns, it was only possible to gather a sample of 15 projects. Despite the small sample size, the findings were still useful for gaining insights into the termination of construction contracts in the Sri Lankan context. The characteristics of the 15 building projects are provided in table 2 and table 3. Furthermore, factors that were not previously mentioned in the literature are highlighted in different colour to distinguish them from other factors.

Table 2: Brief introduction to the selected projects

Project	Type of building	Location (Province)	Duration (Months)	Contract Sum (Mn)	Commencement	Termination	Type of Termination
P1	Residential	Western	30	1,723	2020	2021	Termination by Employer
P2	Commercial	Northern	12	139	2018	2021	Termination by Contractor
P3	Commercial	Northern	12	250	2018	2021	Termination by Contractor
P4	Commercial	Western	12	300	2018	2022	Termination by Employer
P5	Residential	North central	6	88	2021	2022	Termination by Employer
P6	Educational	Northern	7	20	2019	2022	Termination by Contractor
P7	Residential	Sabaragamuwa	48	1,600	2017	2021	Termination by Employer
P8	Residential	Sabaragamuwa	6	11.5	2016	2018	Termination by Employer
P9	Commercial	Western	12	231	2017	2022	Termination by Employer
P10	Residential	Sabaragamuwa	6	7.5	2017	2019	Termination by Employer

Project	Type of building	Location (Province)	Duration (Months)	Contract Sum (Mn)	Commencement	Termination	Type of Termination
P11	Commercial	Western	12	56	2018	2022	Termination by Employer
P12	Commercial	Uva	15	277	2018	2022	Termination by Contractor
P13	Residential	Northern	6	12	2019	2022	Termination by Contractor
P14	Commercial	Northern	12	25	2018	2021	Termination by Contractor
P15	Commercial	Western	12	299	2017	2022	Termination by Employer

Table 3: Major courses of termination of selected projects

Project	Contractor	Employer	Main reasons for termination
P1	Private	Public	Failure to achieve the rate of progress as scheduled (Q3) Lack of experience in the line of work (Q1) Average number of full-time employees (shortage of employees) (Q7) Lack of team spirit in the project team (Q4)
P2	Private	Public	Employer delay in the contractor's interim payments (R5) Government change (T7)
P3	Private	Public	Employer delay in the contractor's interim payments (R5) Government change (T7)
P4	Private	Public	Failure to achieve the rate of progress as scheduled (Q3) Contractor's bankrupting (Q6)
P5	Private	Public	Failure to achieve the rate of progress as scheduled (Q3)
P6	Private	Public	Employer delay in the contractor's interim payments (R5) Government change (T7)
P7	Private	Private	Bankruptcy of employer (R6)
P8	Public	Public	Bankruptcy of contractor (Q6) Failure to achieve the rate of progress as scheduled (Q3)
P9	Private	Public	Failure to achieve the rate of progress as scheduled (Q3) Ability to manage cost and time organisation (cash flow and schedule) (Q8)
P10	Public	Public	Bankruptcy of contractor (Q6) Failure to achieve the rate of progress as scheduled (Q3)
P11	Private	Public	Failure to achieve the rate of progress as scheduled (Q3)
P12	Private	Public	The employer failed to hand over the site and give instructions for the right to access the site to commence the works (R7)
P13	Private	Public	Employer delay in the contractor's interim payments (R5) Government change (T7)
P14	Private	Public	Employer delay in the contractor's interim payments (R5) Government change (T7)
P15	Public	Public	Failure to achieve the rate of progress as scheduled (Q3) Contractor's bankrupting (Q6)

4.2 TERMINATION BEHAVIOUR BASED ON VARIOUS PARAMETERS

The termination behaviour of the projects was analysed based on various parameters such as location, time, type of employer, and type of project as per literature (Section 2.2).

4.2.1 Based on Location and Type of Project

The research was carried out in Sri Lanka. Data could only be collected from five provinces due to time and access limitations. According to Figure 1, among which 15 projects, most of the terminations have occurred in the Western and Northern provinces. Moreover, the majority of commercial and residential building projects were terminated in Sri Lanka over the past five years.

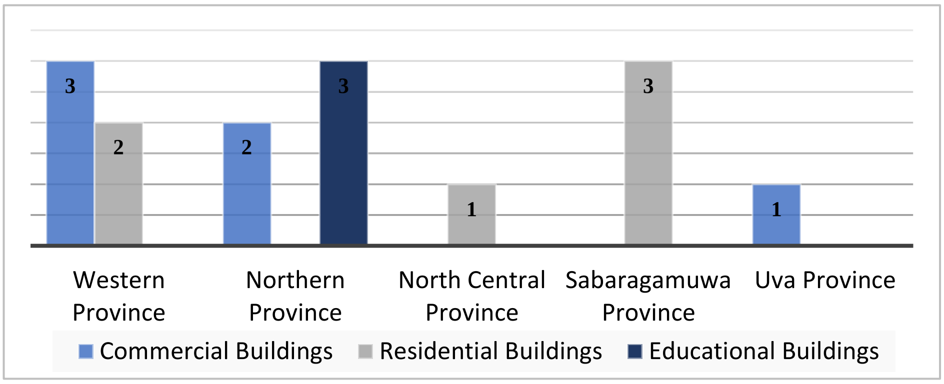

Figure 1: Research location and type of building

As per expert opinion, the Western and Northern provinces have more construction projects than other provinces due to various factors such as population growth, urbanisation, and economic development. With more projects happening, there is a greater chance of issues arising that can lead to project terminations. Commercial and residential building projects were mostly terminated in Sri Lanka due to lack of adequate funding and resources for these types of projects, as they tend to be larger in scale and require more financial investment. Additionally, commercial and residential projects often involve a more complex and lengthy approval process, which can lead to delays and increased costs. This can be especially challenging in Sri Lanka, where bureaucratic processes can be slow and inefficient.

4.2.2 Termination Year of the Projects

The documentary review was carried out for the last five years. In 2020-2022, Sri Lanka has faced the worst situation due to the economic crisis and COVID-19. When considering the commencement date of the project, duration of the project, and reasons for the termination in accordance with Tables 2 and 3, the above termination was not occurred by this economic crisis and COVID-19 situation. Hence, Figure 2 shows the construction projects that have been terminated in Sri Lanka in the last five years.

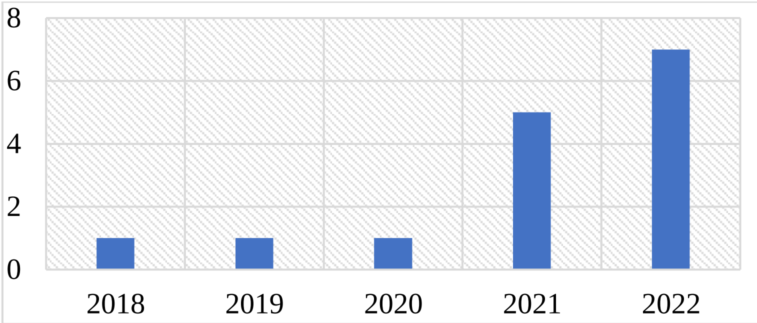

Figure 2: Year of termination

As a result, the majority of the projects were terminated in 2022 due to failure to achieve the rate of progress as scheduled, contractors bankrupting, employer delay in the contractor's interim payments, and Government change.

4.2.3 Employer of the Projects

Figure 3 illustrates whether the employer of the project was public or private. Ultimately, it is evident from the above depiction that in the Sri Lankan construction industry, 93% of government building projects are terminated over the last 5 years.

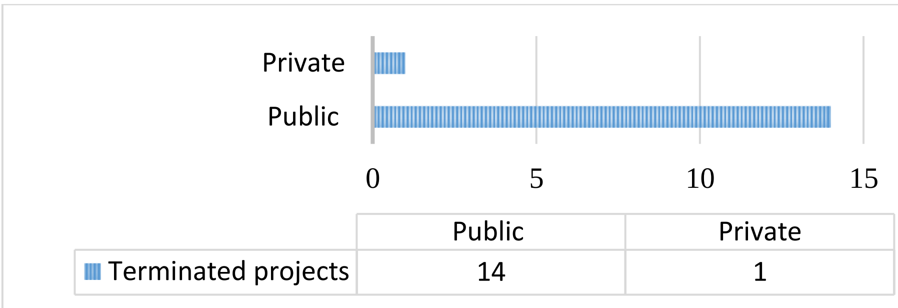

Figure 3: Employer of the projects

Experts mentioned that in terms of public projects versus private projects in Sri Lanka's construction industry, it is possible that there are differences in the termination rates between the two sectors. Public projects are typically funded and overseen by the government. These projects are often undertaken for the benefit of the general public and may be subject to political considerations. On the other hand, private projects are typically funded and overseen by private companies. These projects are often undertaken for profit and are subject to market conditions and competition. If most of the terminations are occurring in public projects rather than private projects, it is possible that political considerations may be a factor in these terminations. Public projects may be subject to changes in government policies or funding priorities, which can lead to delays or terminations of projects. Additionally, political considerations may lead to changes in the leadership of government agencies overseeing these projects, which can lead to disruptions and delays.

4.2.4 Type of Termination

A construction contract can be terminated by either contractor or employer. Figure 4 demonstrates that most of the projects (65%) were terminated by the employer and 35% of projects were terminated by the contractor.

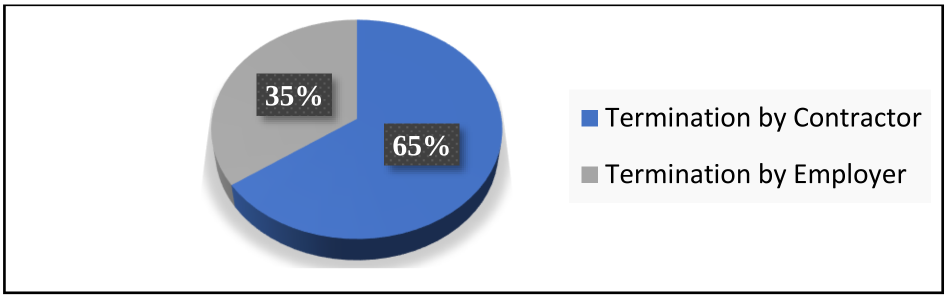

Figure 4: Type of termination

Most of the projects were terminated by the employer rather than by the contractor because of employers are more likely to have greater financial resources and can be able to afford to terminate a contract if they are not satisfied with the work. On the other hand, contractors cannot have the same level of financial stability and cannot be able to afford to terminate a contract even if they feel that it is necessary. Moreover, employers have higher expectations for the quality of work and adherence to timelines. If a contractor is not able to meet these expectations, the employer may feel justified in terminating the contract. These justifications have been mentioned by the experts.

4.3 MAIN REASONS FOR THE TERMINATION

Figure 5 explains the factors that were affecting the termination of the construction contract.

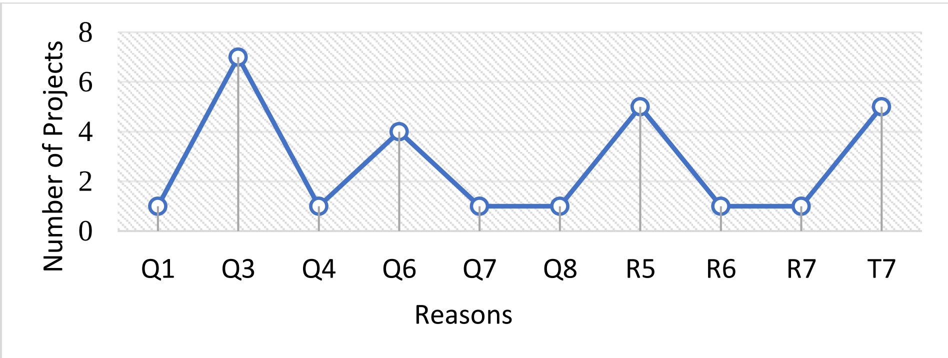

Figure 5: Reasons for the termination

It is evident that most of the projects were terminated because of contractor faults (Q). The majority of the projects were terminated due to the contractor's failure to achieve the rate of progress as scheduled (Q3) and the next majority of the projects were terminated due to employer delay in the contractor's interim payments (R5) and the government change (T7). Followed by a small percentage of the projects were terminated as a result of the lack of experience of the contractor in the line of work (Q1), lack of team spirit in the contractor's project team (Q4), shortage of full-time employees in the contractor's organisation (Q7), contractor's ability to manage cost and time organisation (cash flow and schedule) (Q8), the bankruptcy of the employer (R6), and the employer failed to hand over the site and give instructions for the right to access to the site to commence the works (R7). Further, some projects were terminated due to the bankruptcy of the contractor (Q6). Addressing these issues requires careful planning and execution by all stakeholders involved in the project, including the contractor, employer, and government, to ensure successful project completion.

4.4 STRATEGIES TO MITIGATE TERMINATION

Construction projects are complex, and the failure of one factor can lead to project termination, causing significant losses for both the contractor and employer. To avoid this, various mechanisms can be implemented. However, it is important to note that no single mechanism can guarantee the success of a construction project, and therefore, it is necessary to implement a combination of these mechanisms and tailor them to fit the specific project requirements. In addition to the strategies mentioned in the literature, the following strategies provided by the experts. Parties can also consider implementing proactive risk management plans, which involve identifying potential risks and taking steps to prevent or mitigate them. This can include conducting thorough due diligence on contractors and subcontractors, setting clear expectations and milestones, and developing contingency plans for unforeseen events. Parties can also consider utilising project management tools and technologies to track progress and identify potential issues early on. Additionally, providing training and education to all stakeholders on the project can help ensure that everyone understands their roles and responsibilities and is better equipped to manage any issues that may arise. By taking a proactive approach to risk management and project planning, parties can minimise the likelihood of contract termination and ensure a smoother, more successful construction project.

4.5 SUMMARY OF THE FINDINGS

The summary of the research findings is presented in Figure 6 under:

- the factors for termination of construction contracts, and
- the strategies to mitigate or avoid termination of construction contracts.

Factors for termination of construction contracts	**Strategies to mitigate or avoid termination of construction contracts**
1. Contractor's failure to achieve the rate of progress as scheduled	1. Conducting thorough due diligence on contractors and subcontractors
2. Employer delay in the contractor's interim payments	2. Setting clear expectations and milestones
3. Government change	3. Developing contingency plans for unforeseen events
4. Bankruptcy of the contractor	4. Utilising project management tools and technologies to track progress
5. Lack of experience of the contractor in the line of work	5. Providing training and education to all stakeholders on the project
6. Lack of team spirit in the contractor's project team	6. Drafting clear and comprehensive contracts
7. Shortage of full-time employees in the contractor's organisation	7. Maintaining effective communication
8. Contractor's ability to manage cost and time organisation (cash flow and schedule)	8. Conducting regular site inspections
9. Poor occupational health and safety in site management of the contractor	9. Incorporating alternative dispute resolution mechanisms
10. The bankruptcy of the employer	10. Including termination clauses that allow for negotiation and dispute resolution
11. The employer failed to hand over the site and give instructions for the right to access to the site to commence the works	

Figure 6: Summary of the findings

5. CONCLUSIONS

In conclusion, this research highlighted the importance of effective project management practices and minimising errors in the early stages of a project to avoid termination. The study focused on the termination of building projects in Sri Lanka over the last five years, with the majority of terminations occurring in the Western and Northern provinces, and most projects being commercial and residential buildings. The main reasons for termination were the contractor's faults, employer delay in interim payments, and government change, with the majority of terminated projects being government building projects. To prevent project termination, it is crucial to ensure proper communication and cooperation between all parties involved and to have a contingency plan in place in case of unexpected events. By implementing these strategies, project stakeholders can increase the likelihood of completing projects on time, within budget, and to the satisfaction of all parties involved.

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MERITS AND DEMERITS OF OFF-GRID SOLAR SYSTEMS: KEY STAKEHOLDERS' PERSPECTIVES

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ABSTRACT

In today's world, energy and human life are inextricably linked. Due to the scarcity of fossil fuels and rising prices, the world is shifting to renewable energy sources to acquire energy. The economic downturn and the government's inability to import fuel have exacerbated the energy crisis in the Sri Lankan context. Every day, prolonged power outages become a part of people's lives, which drives people to find alternative solutions. Even though solar PV systems are a popular renewable energy source in Sri Lanka, having an on-grid solar system has no advantages during power outages. Thus, Sri Lanka has an apparent demand for off-grid solar systems. Therefore, this study investigates the merits and demerits of utilising off-grid solar systems from key stakeholders' perspectives. Three key stakeholders were identified: government authorities, off-grid solar service provider companies and off-grid solar users. Twenty-five semi-structured interviews with key stakeholders were conducted after a thorough literature review. The collected interview data were analysed manually using content analysis. The study's findings revealed the significant merits of using off-grid solar systems in the Sri Lankan context as; the benefit of an uninterrupted power supply and reducing the national grid demand. The study revealed significant demerits: unavailability of proper regulations, capital-intensive investment, no return on investment and the lack of qualified people in the off-grid solar sector. The respective industry practitioners and stakeholders can use the knowledge gained from this study to promote and utilise future policy implications in the off-grid solar sector.

Keywords: *Energy Crisis; Government Authorities; Off-Grid Solar Service Provider Companies (OGCs); Off-Grid Solar Systems; Off-Grid Solar Users.*

1. INTRODUCTION

Energy is a critical commodity and a natural resource, without which human existence is highly doubtful (Anandan et al., 2022). Human urbanisation and industrialisation have relied heavily on the increasing consumption of non-renewable energy sources over the last three decades (Islam et al., 2022). However, the world's reliance on non-renewable resources has created significant global issues and challenges, such as future non-renewable fuel shortages, electric utility stability, and environmental impacts (Rehman et

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al., 2022). Patel et al. (2022) stated that the energy crisis and climatic change justify using Renewable Energy Sources (RESs) utilisation and improvement. Solar, wind, biomass, hydropower, geothermal, and tidal energy are commonly available RESs for meeting energy demand (Abubakr et al., 2022; Yong et al., 2023). Solar energy is the most plentiful natural resource that can be converted into electrical and thermal energy by altering sunlight (Ashraf et al., 2023). Meliala et al. (2021) pointed out that derived solar energy is widely applied to residential electrification as off-grid, on-grid, or hybrid systems. Installing an off-grid Photovoltaic (PV) system is a systemic approach to capturing solar energy (Akinsipe et al., 2021). Off-grid power systems are non-grid power systems that operate independently and are classified as decentralised and distributed (Mugisha et al., 2021). Qaiser (2022) reported that South Asian governments face challenges such as high dependency on fossil fuels, the increasing gap between demand and supply of fossil fuels, and the advancing import prices due to the increase in global prices.

In Sri Lanka, electricity is generated primarily from three sources: hydropower, thermal power (coal and fuel oil), and other non-conventional RESs such as wind and solar power (International trade administration, 2022). As a small island, Sri Lanka has the viability to develop renewable energy systems because it has abundant sunlight during the year along with wind resources (Kolhe et al., 2014). However, Sri Lanka is experiencing its worst economic crisis since 1948, with imports stalling, running low on fuel and medicine, and rolling power outages (Jayasinghe, 2022). Perera (2023) pointed out that the focus on fuel and electricity has shifted towards RESs due to the massive energy demand crisis Sri Lanka is currently experiencing. Therefore, this study aims to investigate the merits and demerits of Off-Grid Solar (OGS) systems as a solution to the energy crisis in Sri Lanka.

There is a growing trend of research on OGS in many areas, such as challenges, feasibility studies, and benefits worldwide, especially in the Global South (Patel et al., 2022; Groenewoudt & Romijn, 2022; Kundu & Ramdas, 2022). Though there are many studies on on-grid and hybrid solar systems, it is rare to find studies focused on OGS systems in Sri Lankan context. However, Sovacool (2015) discussed OGS systems when expanding rural access to renewable energy from Sri Lanka's Energy Services Delivery Project (ESDP). Kolhe et al. (2014) have conducted a techno-economic analysis of off-grid hybrid renewable energy systems for Sri Lanka. In particular, to the author's knowledge, comprehensive studies on the merits and demerits of OGS systems from the key stakeholders' perspectives have not been conducted. Thus, the current study aims to investigate the merits and demerits of utilising off-grid solar systems from the key stakeholders' perspective.

The paper is structured as follows. Section 2 describes the initial literature findings to identify the merits and demerits of using OGS systems. The methodology of the study is presented in Section 3. Section 4 describes the data gathered through semi-structured interviews with data analysis. Section 5 discusses the research findings from the data analysis for the Sri Lankan context. The conclusion summarises the study, makes recommendations and points out future research directions for key stakeholders and industry practitioners.

2. LITERATURE REVIEW

2.1 OFF-GRID SOLAR PV SYSTEMS

Photovoltaic (PV) systems are commonly used in grid-connected and standalone operation modes (Koko, 2022). A review by Mishra et al. (2023) revealed that most of the research on renewable systems for power supply has focused on standalone systems for isolated locations. Karthikeyan et al. (2017) highlighted that an OGS PV system is not connected to the power grid, eliminating power quality issues and electricity billing. Aklin et al. (2017) claimed that OGS technologies are an affordable and clean solution to satisfy basic electricity needs. Moreover, OGS technologies have the potential to meet the twin goals of universal energy access and low-carbon technology diffusion (Singh, 2016, 2017). Global Off-Grid Lighting Association (GOGLA, 2018) demonstrated that even in countries where the government aims to provide grid-based solutions to the large majority, off-grid solutions can still help stimulate electrification.

2.2 MERITS OF USING OFF-GRID SOLAR SYSTEMS

Gill-Wiehl et al. (2022) discovered that OGS systems benefit not always monetarily. Off-grid renewable energy options are a practical electrification option that can be quickly scaled up, environmentally friendly, adaptive to local conditions, and, most significantly, empower rural communities, especially women and young people (International Renewable Energy Agency [IRENA], 2019). Because, Solar Home Systems (SHSs) are standalone, the advantages of usage variety cannot be realised (Nasir et al., 2019). Due to the presence of solar power, OGS rural applications are very appealing and offer many benefits, including enhanced skill development, productivity, food security, and income generation (Meyer & Solms, 2022). OGS energy appliances improve comfort, safety, food security, and productivity (Hirmer & Guthrie, 2017). Mugisha et al. (2021) discovered that OGS systems improve rural health, Information and Communication Technology (ICT), and micro-enterprises. A review by Radley and Lehmann-Grube (2022) revealed that OGS expansion has positively impacted economic development in the Global South. OGS solutions may appear to be simple devices, but they significantly impact the quality of life, according to GOGLA (2020b). An investigation conducted in Kenya found moderate beneficial environmental effects, higher satisfaction from better illumination, increased people's time spent watching Television (TV), and the financial advantages of SHSs, despite the considerable electrification and expenditure consequences (Wagner et al. (2021).

2.3 DEMERITS OF USING OFF-GRID SOLAR SYSTEMS

Though OGS solutions can help individuals with their energy requirements, people have faced numerous financial, technical, and political obstacles (Singh, 2017). Service issues in OGS products are common, resulting from improper product use, manufacturing and installation issues, and inclement weather (Kundu & Ramdas, 2022). Moreover, Akter and Bagchi (2021) claimed that OGS power has the drawback of having a high upfront cost. According to Bhattacharyya and Palit (2021), the evidence suggests that decentralised solutions are considerably more expensive than central grid supplies, raising questions about fairness, equity, and justice. While OGS products provide some relief from darkness for the energy poor, Samarakoon et al. (2021) conclude that they are commodities prone to reproducing structural forms of injustice and do not always represent a sustainable solution to energy poverty in the Global South.

On the other hand, there were frequent discussions about whether the energy provided by the OGS sector is sufficient to effect meaningful change in the energy sector (GOGLA, 2020b). Galan (2021) identified a lack of policy coordination and a disconnect between the government and the OGS sector as central issues in their study. One limitation of the market-based development strategy for the off-grid sector is that companies have so far been unable to distribute products without endangering local environments (Groenewoudt & Romijn, 2022). OGS systems also have the unintended consequence of exacerbating intergenerational challenges, such as inefficient use of finite resources through mass consumption of short-lived devices and the growing ecological burden of E-waste (Samarakoon, 2020). Kinally et al. (2022) also declared a significant ecological risk from OGS products due to the growing volume of unabated waste.

3. METHODOLOGY

A literature review was conducted to identify gaps in existing research, including journals, conference proceedings, books, and electronic resources. The study has chosen a qualitative approach to match the research aim. A survey was used as the research strategy, and semi-structured interviews were employed as the data collection method.

Gathering insights from stakeholders is vital when conducting qualitative research on OGS systems. Users can provide valuable feedback on their experience with these systems. At the same time, sellers, such as OGS companies, can offer insights on selling and maintaining these systems during the current energy crisis. Additionally, it may be helpful to investigate the government authority's perspective on using these systems due to these OGS systems as a prevailing topic with power outages in Sri Lanka. By taking a holistic approach to this research, the researchers could comprehensively understand the merits and demerits of OGS systems. Therefore, as summarised in Table 1, the profile of respondents, Government Authority (GA) experts, Off-Grid Solar Service Provider Company (OGC) Experts and Off-Grid Solar Users (OGUs) were chosen as key stakeholders to obtain perspectives on using OGS systems.

Table 1: Profile of respondents

Key Stakeholders	Respondent	Profession	Awareness of the OGS concept
Off-Grid Solar Users (OGUs)	U1	Engineer	Well-Known
	U2	Entrepreneur	To Some Extent
	U3	Engineer	Well-Known
	U4	Electrical Engineer	Well-Known
	U5	Electrical Engineer	Well-Known
	U6	Electrical Engineer	Well-Known
	U7	Engineer	Well-known
	U8	Entrepreneur	To Some Extent
	U9	Professor	Well Known
	U10	Entrepreneur	To Some Extent
Government Authorities (GAs)	G1	Project Manager	Well-Known
	G2	Assistant Director	Well-Known
	G3	Director	Well-Known

Key Stakeholders	Respondent	Profession	Awareness of the OGS concept
	G4	Assistant Director	Well-known
	G5	Director	Well-Known
	G6	Assistant Director	Well-Known
	G7	Deputy General Manager	Well-Known
Off-Grid Solar Service Provider Companies (OGCs)	C1	Assistant Engineer:	Well-Known
	C2	Head of Engineering	Well-Known
	C3	Director	Well-Known
	C4	Director	Well-known
	C5	Engineer: Sales	Well-Known
	C6	Electrical Engineer	Well-Known
	C7	Electrical Engineer	Well-Known
	C8	Electrical Engineer	Well-Known

Accordingly, twenty-five semi-structured interviews were conducted using the snowball sampling method for key stakeholders. Snowball sampling can effectively analyse vulnerable groups or individuals under special care allowing researchers to access susceptible populations (Naderifar et al., 2017).

An interview guideline was prepared by engaging literature review findings of the merits and demerits of conducting semi-structured interviews. The collected data were analysed through manual content analysis, and findings were compared with the literature to ensure the reliability and validity of the findings. The developed framework was further validated by presenting it to the key stakeholders of the research study.

4. DATA COLLECTION AND ANALYSIS

The respondents were asked to comment on the merits and demerits of the literature findings and asked for additional merits and demerits of using OGS systems in the Sri Lankan context.

4.1 MERITS OF UTILISING OFF-GRID SOLAR SYSTEMS

4.1.1 Off-Grid Solar Users' Perspective

U1, U5 and U8 mentioned that solar is a renewable energy source with long-term benefits compared to coal power plants. U3 partially agreed to positive impacts on climate by explaining, "*Though the OGS systems have no direct CO_2 emission compared to fossil fuels, improper use and disposal of batteries can harm the environment*". U8 stated, "*Despite Sri Lanka being 100% electrified, OGS systems will benefit some locations with difficulty connecting to the grid*". U9 elaborated on how comfortable life is "*We do not need to look for lamps, torches, or other items during power outages. Using an OGS system, people can live comfortably during this energy crisis*". U2 emphasised that uninterrupted power supply is a limited benefit due to system capacities. U10 explained that OGS systems would positively impact reducing national grid demand.

4.1.2 Off-Grid Solar Service Provider Company Experts' Perspective

C5 elaborated that using OGS is safer than using kerosene lamps, yet there is a safety risk if the inverters are not properly earthed. C6 explained, "*During the energy crisis, people lack energy for long periods, making it challenging to complete their daily tasks.*

However, people with an OGS system can usually go about their daily life". C3 partially agreed to enhanced safety as a benefit and pointed out, "*On the one hand, there is increased safety from theft and vandalism. On the other hand, these systems have fire risks*". C8 stated, "*The risk associated with these systems is uncommon. The possibility of catching fire is negligible, primarily if good products and proper craft are used*". Further to C8, these systems have the benefit of community-based technology dividends. In contrast, C2 pointed out, "*There is currently no funding or incentive for rural communities to invest in these types of OGS systems to reap the benefits of the community-based technology dividend*". C3 explained, "*Depending on the application type used by this system, there may be some cost savings. For example, even if the initial cost is high, fuel and maintenance costs will be saved over having a generator*".

4.1.3 Government Authority Experts' Perspective

G3 pointed out, "*Even though we are 100% electrified, there are some areas where accessing the grid is prohibitively expensive. It can easily establish OGS for those areas to improve the energy access*". However, G5 mentioned, "*Though the enhanced energy access may depend on the situation, using OGS is not sustainable*". G2 commented, "*I do not think there are unique health benefits because sometimes these systems may cause safety hazards*". G5 agreed that there might be long-term health benefits. All the experts mentioned that the uninterrupted power supply is the main benefit of using these systems in the Sri Lankan context. G4 pointed out that "*Solar is a renewable energy it reduces the CO2 generation rather than coal or fuel's electricity. Therefore, these systems positively impact climate*". According to G1, cost savings are another benefit compared to fuels and kerosene in the long term. G3 declared, "*OGUs' energy independence and satisfaction with electricity requirements will help reduce government spending on large power plants. Therefore, there is a direct benefit to the national economy because if a large power plant is required, loan schemes are the financing option for the government*".

4.2 DEMERITS OF UTILISING OFF-GRID SOLAR SYSTEMS

4.2.1 Off-Grid Solar Users' Perspective

According to U2, "*The main hindrance to the OGS sector, whether there is an economic crisis or not, is that the authorities do not favour customers and businesses*". Though a few people mentioned no ROI as a disadvantage, U3 elaborated that ROI is not a primary concern explaining, "*Though ROI is based on the applications of OGS systems, having mental freedom and comfortability from an uninterrupted power supply is invaluable*". According to U7, climate conditions are an issue because users cannot expect the same conditions on cloudy, rainy days. U1 said that the lack of reliability happened due to low-quality equipment. However, U5, U6, U4, and U7 believed low-quality equipment was not a problem because the brand's purchase determined the quality. U3 explained that if solar panels are not cleaned, lichen will grow on them, and it is a disadvantage that the systems must be maintained at least three times a year. According to U6, these systems are not currently regulated by the government. U10 said that users' lack of awareness could be identified as a drawback to using OGS systems.

4.2.2 Off-Grid Solar Service Provider Company Experts' Perspective

According to C5, regarding OGS, no unfavourable restrictions exist. C3 pointed out that not having proper regulations for OGS systems is a drawback. C1 explained that, despite the high capital investment, there is no monetary Return on Investment (ROI) from OGS systems. Further, C4 clarified, "*These systems are unreliable and, after the crisis, will be obsolete for customers who require constant power*". C2 partially agreed to the lack of reliability, saying poor product quality may cause reliability issues. However, C5 said reliability depends on the system's capacity. C2 expressed, "*The primary issue with OGS systems is the lack of experience. To avoid problems, installers must carefully select equipment and educate customers*". Although there are qualified and experienced installers, C6 pointed out that many more inexperienced, unqualified people are doing OGS installations, which is a disadvantage. According to C7, maintenance issues depend upon the system components' brand. C8 indicated, "*Though using OGS systems helps to reduce national grid demand, more energy is wasted by these systems*".

4.2.3 Government Authority Experts' Perspective

G6 highlighted that it is an issue where people and companies lack technical and management capabilities. Though G1 argued that these systems are unreliable, G2 and G7 disagreed. For instance, G7 pointed out, "*People using OGS systems due to some accessibility issue or reliability issue from the grid, which evidence in these systems is reliable*". However, G4 discussed, "*Battery issues are the main concern leading to unreliable OGS systems*". Another drawback mentioned by G1 and G3 was the lack of people's awareness regarding these systems. Nevertheless, G4 disagreed with the lack of awareness as a drawback and explained, "*People do not mindlessly go for a solar system. Technical persons already know how the system works and who have less awareness can rely upon the service provider companies through service and maintenance agreements*". G7 and G3 highlighted that lacking qualified personnel is a significant drawback in Sri Lanka's OGS sector. Moreover, G7 and G4 identified not having proper regulations as another drawback for these systems. G5 explained that setting up an OGS system is a highly capital-intensive procedure with the battery prices, and most people cannot set a system capacity to match their daily power requirements due to this drawback.

5. DISCUSSION

As per the analysis of the study, Figure 1 highlights the key stakeholder perspectives on using OGS systems. The left side of the figure depicts the demerits of utilising OGS systems, while the right side showcases the merits per the perspectives of GA experts, OGC experts, and OGUs.

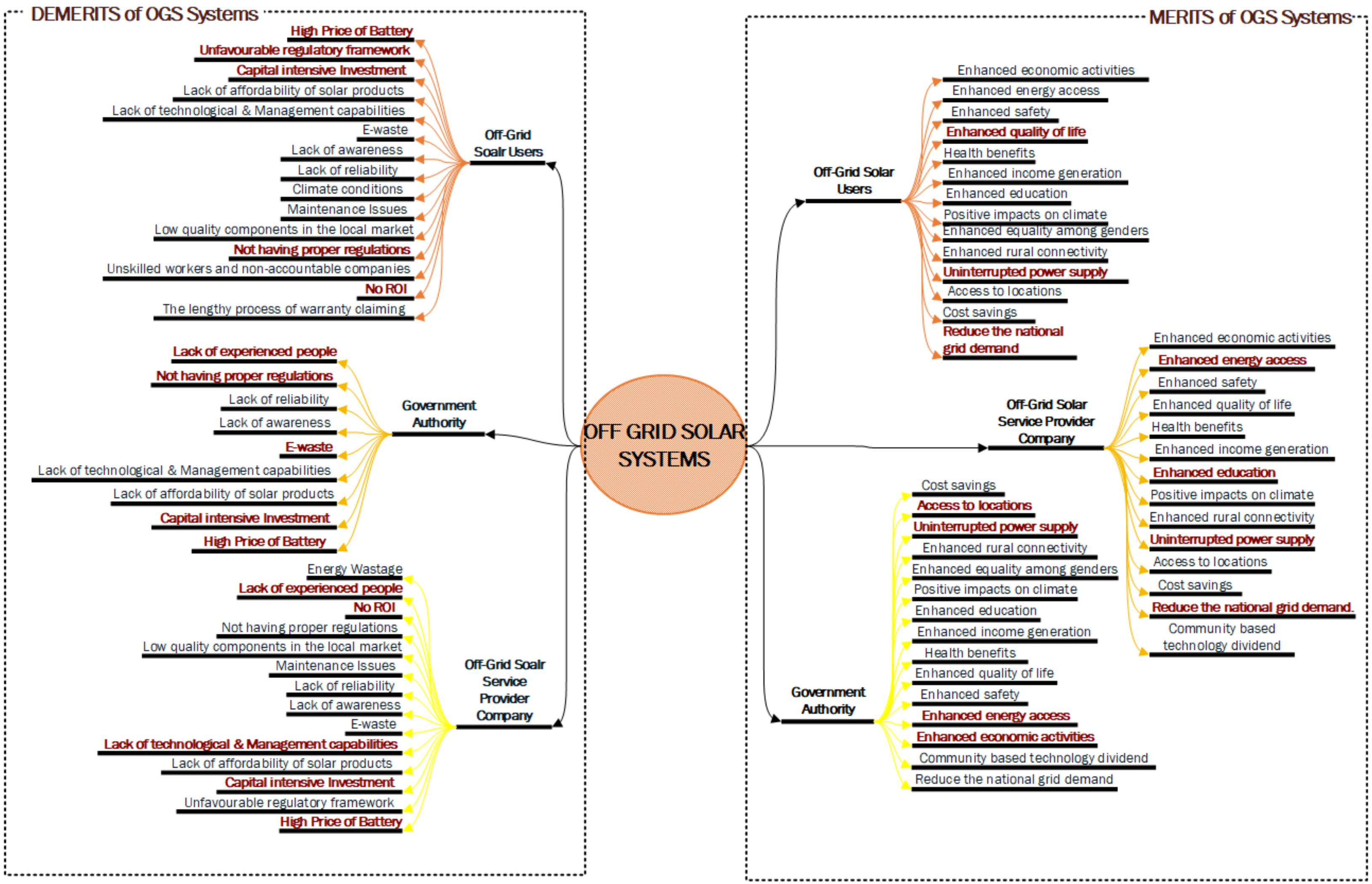

Figure 1: Summary of Merits and Demerits of OGS Systems: Key Stakeholders' Perspectives

5.1 MERITS OF UTILISING OFF-GRID SOLAR SYSTEMS

Although all respondents from OGUs and GAs agreed that using these systems **enhances economic activity**, one OGC expert (C4) had no idea, and one disagreed (C3) about this benefit. While all GA respondents agreed that **enhanced energy access** is a benefit, one from each OGU (UR4) and OGC expert (CR1) only partially agreed.

In contrast to the literature findings (GOGLA, 2019; GOGLA, 2020b; IRENA, 2022a; Wagner et al., 2021), stakeholders had conflicting opinions about the benefits of **enhanced safety** from using OGS systems. Fourteen of twenty-five respondents agreed only partially that OGS systems provide enhanced safety. Furthermore, the analysis found that this partial agreement was based on comparing kerosene lamps and other energy generation sources to using OGS systems during power outages. However, respondents pointed out that when these types of DC systems are not installed correctly according to safety procedures, they can pose a fire risk. Four out of twenty-five respondents strongly disagreed that these systems improve safety. Concerns were raised regarding the lack of safety regulations, particularly for OGS systems in the Sri Lankan context. Thus, the findings revealed that enhanced safety could only be considered a benefit in the Sri Lankan context if proper safety precautions were taken during installation. Furthermore, all respondents agreed that **enhanced quality of life is** a benefit of implementing OGS systems in Sri Lanka.

Though the literature mentioned that these systems improve community health (Hirmer & Guthrie, 2017; IRENA, 2022a; IRENA, 2022b; Mugisha et al., 2021), the study's findings indicated that this could not be directly applied to the Sri Lankan context. Six out of eight OGC respondents partially agreed, citing concerns such as the long-term release of toxic chemicals into the environment. Two GA experts agreed partially, and one had no idea about the health benefits, while four respondents agreed that there are health benefits. Seven out of ten OGUs, on the other hand, agreed that there are health benefits. Respondents who agreed there are health benefits pointed out that these systems emit no CO_2 compared to other alternatives such as kerosene lamps and diesel generators. As a whole, thirteen of twenty-five respondents agreed that these systems provide **health benefits**. Thus, in the Sri Lankan context, with some long-term concerns, health benefits can be viewed as a plus.

From the standpoint of OGCs, seven out of eight agreed that **income generation** (Meyer & Solms, 2022; Radley & Lehmann-Grube, 2022; Wagner et al., 2021) is improved. However, according to the findings, OGS systems do not have a direct Return on Investment (ROI). However, indirectly these using systems will generate income by generating solar-related jobs and allowing the community to continue working without interruptions. Eighteen out of twenty-five respondents agreed that enhanced income generation from OGS systems benefits the Sri Lankan context. Furthermore, all respondents from stakeholders agreed that these systems would **enhance education** which can benefit the Sri Lankan context.

According to the OGC experts, four out of eight only partially agreed, while others completely agreed that these systems **positively impact climate**. Only five GA experts fully agreed, one had no idea, and one partially agreed that there are positive effects. From the perspective of the OGUs, eight fully agreed, while two partially agreed. Although there are no CO_2 emissions, the partially agreed respondents are concerned that these systems will result in long-term E-waste for the environment. However, based on the overall responses, using OGSs positively impacts the Sri Lankan context. Experts from the GAs agreed that they could identify **improved gender equality** (GOGLA, 2020b; IRENA, 2019) using these systems, whereas five OGC experts had no idea, and three disagreed. From the perspective of the OGUs, seven had no idea, three disagreed, and only one agreed. According to the findings, enhanced gender equality using OGS systems cannot be viewed as a benefit in the Sri Lankan context.

Regarding **enhanced rural connectivity (**IRENA, 2019; IRENA, 2022a; Meyer & Solms, 2022;), the GA experts agreed six out of seven times, while the OGC agreed seven out of eight. According to the OGUs, one had no idea and only seven agreed. Because Sri Lanka is nearly fully electrified, respondents who disagreed or partially agreed remarked that this benefit does not apply in the Sri Lankan context. Nonetheless, GAs experts confirmed that Sri Lankan villages, such as 'Galamunduna,' generate energy through mini-grid off-grid systems. Another concern was that rural people in Sri Lanka needed these systems to be more affordable to install. However, the majority agreed that improved rural connectivity could benefit the Sri Lankan context. Overall, the study identified significant benefits of having an uninterrupted power supply and reducing the national grid demand.

5.2 DEMERITS OF UTILISING OFF-GRID SOLAR SYSTEMS

When considering the **high battery price** (Delgadillo et al., 2022; Mugisha et al., 2021; Wattana & Aungyut, 2022), all respondents from the GAs and OGUs agreed that it is a disadvantage for these systems in the current context. According to the OGCs, seven out of eight agreed, with one partially agreeing. Overall, it was discovered that the high battery price is a significant disadvantage of using these systems and that the ongoing energy crisis has caused a rapid increase in battery prices. All the GAs respondents disagreed, stating that Sri Lanka has no **unfavourable regulatory framework** (Hoeck et al., 2022; Jensen et al., 2019; Wattana & Aungyut, 2022) for these OGS systems. Furthermore, experts from the GAs have revealed that a guideline preparation for the OGS systems is underway and has yet to be published. Thus, it was determined that no regulations were imposed during the data collection period, particularly in the OGS sector.

Nonetheless, when it comes to OGUs and OGC experts, they have no information on the government's guideline preparation, and six out of eight OGCs disagreed with this as a drawback. Six out of ten OGUs, on the other hand, disagreed with this as a drawback. Overall, the study indicated that while the literature has identified an unfavourable regulatory framework as a disadvantage in the global context, there are no regulations for this sector in the Sri Lankan context at the time of data collection. As a result, the study's findings reject this as a disadvantage in the Sri Lankan context.

All stakeholders agreed that these systems are **capital-intensive**, a disadvantage for the Sri Lankan community. Furthermore, twenty-four out of twenty-five respondents cited the lack of affordability of solar products as a disadvantage in the Sri Lankan context. The next disadvantage identified in the literature was the **lack of technological and management capabilities** (Jensen et al., 2019; Mugisha et al., 2021; Samarakoon, 2020; Hoeck et al., 2022), which twenty out of twenty-five respondents identified as related to Sri Lanka. According to the findings, the government and the private sector in Sri Lanka lack technological and management capabilities for the OGS sector.

Most respondents considered **E-waste** a disadvantage but emphasised that this is not the case in the current context in Sri Lanka. However, findings revealed that E-waste could adversely affect the future due to Sri Lanka's lack of a recycling plan for solar components. On the other hand, two OGC experts and one GA expert pointed out that the OGCs could manage this E-waste in the future when they occur. The unavailability of proper regulations, no ROI, high capital-intensive investment and the lack of qualified people have been identified through findings as significant drawbacks to using OGS systems.

6. CONCLUSIONS AND RECOMMENDATIONS

Amidst the current energy crisis in Sri Lanka, many people have opted for OGS systems to fulfil their energy requirements instead of hybrid or on-grid systems. Therefore, this study aimed to investigate the merits and demerits of OGS systems from the key stakeholders' perspectives. The merits and demerits were identified in Sections 2.2 and 2.3 of the literature review and presented to the key stakeholders in semi-structured interview guidelines for comment. Enhanced gender equality was rejected from the findings from the merits in literature, but having an uninterrupted power supply and reducing the national grid demand were some of the significant benefits identified by the study. On the other hand, from the demerits in the literature, the unfavourable regulatory framework has been identified as irrelevant to the Sri Lankan context. The unavailability of proper regulations, high- capital-intensive investment, no ROI and a lack of qualified people have been identified through findings as significant drawbacks to using OGS systems. The study emphasised that it is vital to consider all stakeholders' perspectives regarding the potential merits and demerits of utilising OGS systems to have informed policy decisions for the OGS sector in Sri Lanka. It is recommended that government authorities should incorporate OGS systems to get uninterrupted power supplies and access energy where the grid system is unreliable. As a further research direction from this study, the viability of OGS systems in the Sri Lankan context using a cost-benefit analysis can be investigated.

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MINIMISING CONSTRUCTION AND DEMOLITION WASTE USING CIRCULAR ECONOMY CONCEPT TO ACHIEVE SUSTAINABLE URBAN DEVELOPMENT

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ABSTRACT

Urban development significantly increased construction activities, which led to the generation of Construction and Demolition Waste (CDW) and inefficient resource exploitation. Most of these CDWs end up in landfills, and most countries give little attention to sustainable practices in this area. "Circular Economy" (CE) is one of the best ways to reduce CDW and the use of resources. Even though CE is not a new idea, it is not fully used to reduce CDW because the construction industry is still based on a linear economy and building materials are designed to be used linearly. Hence, this paper aims to investigate how CE can contribute to minimising the CDW to achieve sustainable urban development. This study adopts a qualitative approach to examine the strategies used to minimise the CDW in Sri Lanka. Multiple holistic case studies with three large-scale construction projects in the Colombo district were selected, and semi-structured interviews were used to get first-hand information. Manual content analysis was used for data analysis. Findings noted that disposal is unavoidable for all 14 CDW types, and e-waste was counted as the 15th type. The 3Rs (reduce, reuse, and recycle) of CE are quite popular among the projects, and the other 8Rs of Cimen (2021) of the CE concept are challenging to put into practice. To increase the knowledge and application of CE principles among built environment experts, this research provides recommendations based on a desk study by gathering case studies from secondary sources where CE principles are extensively applied for CDW minimisation.

Keywords: *Circular Economy (CE); Construction and Demolition Waste (CDW); Sri Lanka; Sustainability; Urban Development.*

1. INTRODUCTION

Every day, thousands of migrants arrive in urban areas all over the world to gain opportunities for a better life (Zhang, 2015). Fifty-five percent (55%) of the world's population lives in cities right now and globally, more than two-thirds of the population will probably reside in cities by 2050 (United Nations, 2014). It has to do with changes in lifestyle, more use of natural resources, higher demand for energy, and the commercialisation of urban life (Iossifova, 2012). Urban population and urban

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development (construction industry) both are interlinked with one another (Chen, et al., 2013). Globally, the construction industry is one of the most important sectors in urban development because it consumes a high volume of natural resources and energy, produces a large amount of waste, and contributes significant amounts of toxic air emissions, thus potentially playing a key role in sustainability (Wang (2014). Moreover, massive urbanisation has boosted infinite construction, and construction and demolition waste (CDW). Which has resulted in nasty and fatal impacts on urban sustainability and survival in terms of economic values and environmental safety (Aslam, et al., 2020). Further, Aslam et al. (2020) state that urbanisation is one of the prime factors, which influenced CDW generation and Nitivattananon and Borongan (2007) mentioned that parallel to rapid urbanisation, environmental impacts from CDW increasingly become a major issue in urban waste management. Similarly, the CDW is inevitable and needs to be managed during the urban development (Dong, et al., 2019; Wu, et al., 2017). Further, CDW had several negative effects on the environment, such as land degradation, carbon and greenhouse gas emissions, landfill and resource depletion, water pollution, and high energy consumption (Akanbi, et al., 2018). In other words, the minimisation of CDW can have multiple long-term benefits including waste minimisation, cost-saving, spreading out existing landfills, safety, and support of a sustainable environment and economy (Shen, et al., 2004).

The Circular Economy (CE) concept is one of the considerable solutions to minimise CDW, as it would reduce environmental impacts while contributing to economic growth (Lieder & Rashid, 2016; United Nations, 2021). It constitutes a novel regenerative system to optimise the use of materials and their value throughout their lifecycle phases and to minimise waste (Bocken, et al., 2016). It has been developed and has gained recognition globally in Germany, Japan, China, and Europe in the field of construction (Merli, et al., 2018), but it is still not widely used. In addition, Osobajo et al. (2022) say that the construction industry is one of the key sectors with the most potential for CE adoption, and the European Commission (2015) says that CDW is a priority in CE policies. For the CE Concept to be more widely used in the industry, more knowledge and tools need to be developed (Lacy & Rutqvist, 2015). This industry takes longer to implement new ideas because buildings are unique projects with a long supply chain that makes things even more complicated (Pomponi & Moncaster, 2017). Since buildings are often torn down when they reach the end of their useful lives, it seems impossible to reuse materials in the construction industry. As a result, Smol et al. (2015) state that the construction industry should do a better job of using its resources. Due to the unique design expected in each facility, standardisation is not encouraged. When the products used for construction are circularly designed, the waste at the end of the life of the building can be minimised. Therefore, CDW is inevitable until the CE is fully incorporated within the built environment, which is not going to happen soon.

Hence, this research aims to investigate how the CE can contribute to minimising CDW to achieve sustainable urban development. The following section presents the research methodology followed by the research findings and discussion. Finally, the conclusions are provided.

2. RESEARCH METHODOLOGY

This research adopted a qualitative approach, using multiple holistic case studies as the key research strategy. Kothari (2004) explained that the qualitative research approach is subjective, exploratory, attitudinal, and involves assessing opinions and behaviours, which facilitates the collection of rich data in an in-depth manner. On the other hand, as CE is a relatively unfamiliar concept among Sri Lankan construction stakeholders, a quantitative approach that usually distances the researcher from the source of data is not preferred. The case studies were conducted in Sri Lanka, where urbanisation has been increasing since 2009 with the end of the civil war in the country (Ranagalage, et al., 2020). The urban development projects mainly consist of residential buildings along with other types such as offices, hotels, and other recreational buildings. Hence, three large-scale construction projects that are a prime part of the urban development in Colombo, Sri Lanka, were selected. Two residential projects, one to cover construction waste and the other to cover demolition waste, have been selected. In addition, a mixed-use development project comprising residential, official, hotel, and recreational facilities has also been selected as the third case study. Table 1 presents the details of the selected cases.

Table 1: Details of cases

Case	Value (LKR)	Start date	Duration	Respondents
Mixed Development Project (M)	104.0 billion	03.08.2014	96 Months	RM1: Top RM2-RM4: Middle RM5: Low
Residential Project (R)	16.2 million	01.03.2019	48 Months	RR1: Top RR2-RM4: Middle RR5: Low
Residential project with demolition (D)	197.5 million	11.04.2020	29 Months	RR1: Top RR2 - RM4: Middle RD5: Low

As Sekaran (2003) stated, when interviews are conducted in a semi-structured manner, it enables the adaptation of the questions necessary, clarifies doubts, and ensures that the respondent is properly understood by repeating the questions. Thus, semi-structured interviews of five (05) respondents from each case with more than 5 years of experience in CDW management were selected. The respondents from each case are from all three management levels as top (01), middle (03), and low (01) with designations including managing director, project manager or head, quantity surveyor, facilities manager, site engineer, material officer, technical officer, and labour.

The case study focused to collect the waste generated from the selected projects and to identify suitable strategies for minimising waste. The quantity of each type of waste generated in the projects was collected qualitatively under three scales low, medium, and high levels. The scaling given by the interviewees based on their qualitative judgement was cross-checked with the available CDW management-related documents at the case study projects. As such the collected data to measure the extent of CDW under each type of waste across three case studies were made comparable. The identified strategies were further studied to see the relationship of such strategies with CE principles. As there is limited application of CE principles in Sri Lankan urban development projects, a desk study was conducted by focusing on secondary-based case studies to identify suitable strategies that are then proposed as the recommended strategies to implement CE principles effectively in the local context. The next section presents the research findings of the research with recommendations.

3. RESEARCH FINDINGS AND DISCUSSION

This section presents the findings on the type and minimisation strategies of CDW, followed by a recommendation for CDW minimisation strategies based on a desk study to address the gaps in adopting CE principles within the local context.

3.1 TYPES AND MINIMISATION STRATEGIES OF CONSTRUCTION DEMOLITION WASTE IN SRI LANKAN URBAN DEVELOPMENT PROJECTS

Although all three cases are measuring their CDW, the method used to measure the CDW is different from case to case. Case M and Case D are more concerned with the weight of CDW waste, whereas Case R is more concerned with the CDW's financial impact. Case M is using both volume and weight to measure the CDW generated in the construction projects, and RM3 stated that "*even though both volume and weight are used to measure, mostly volume (m^3) is used and for few scenarios only weight (kg or ton) is used*". Case D measures only weight in both kilograms (kg) and tonnes. Practically, in both cases, the number of loads (truck or tipper) is used to measure the amount of waste generated in construction projects. However, Case R is using value (cost) to measure the CDW generated in their construction project. Furthermore, RM2 mentioned that the formula used to measure CDW is by deducting the actual usage and the last stock from the received materials [CDW = Received Material – (Actual usage of Material + Remaining stock of Material)]. Accordingly, it is complicated to compare and analyse the different projects because they have different methods of measuring CDW. Hence, the waste generation data across the three cases were measured under the scales of low, medium, and high levels for each level of waste based on the qualitative judgements of respondents to enable the comparison between the types of waste and between the cases. This study is bounded with the common CDW types identified by Gowsiga and Thayaparan (2020), and Table 2 shows the scaling of each of these types of waste across all of the cases so that they can be compared and contrasted. Accordingly, 70% or more of the waste type out of total waste is defined as "high", between 70% and 40% of the waste type out of total waste is outlined as "medium", and less than 40% of the waste type out of total waste is described as "low".

Table 2: The weighted average interpretation of extended CDW types across the cases

No	Waste type	Case M	Case R	Case D	Average
A	Concrete - Portland cement, asphalt, broken parts, and aggregates of concrete	H	M	H	H
B	Asphalt - Asphalt shingles asphalt concrete	L	L	L	L
C	Brick and clay tile	M	M	H	H
D	Ceramic materials (masonry)	M	L	M	M
E	Metals - steel, heavy metals, ferrous	M	M	M	M
F	Timber or wood products - trees, stumps	H	M	H	H
G	Plastics - polyvinylchloride (PVC)	M	L	L	L
H	Packaging waste - cardboard	H	M	H	M
I	Soil and earth, slurry, rocks	L	M	H	M

No	Waste type	Case M	Case R	Case D	Average
J	Gypsum wallboard and plaster/ drywall	H	L	L	M
K	Mineral waste	M	L	L	L
L	Miscellaneous /mixed waste	M	M	L	L
M	Glass	L	L	M	L
N	Paints, solvents, adhesives, caulks, pesticides, wood preservatives, oil, asbestos, polychlorinated biphenyls (PCBs)	H	M	L	M
O	E-waste	N/A	N/A	L	

According to Table 2, concrete is ranked as the major type of CDW in all three cases because it is used to make structural and non-structural panels and represents more than half of construction activity. After that, bricks, clay tiles, wood, and wood products moved up to second place because they are often used in building projects. These three materials have gained a high level of weighted average interpretation. At the medium level, ceramic, soil and earth, slurry, and rocks are listed because they are used a lot in big construction projects but produce less waste than concrete, brick, clay tile, and wood products. Moreover, packaging waste, cardboard, and metals were ranked next based on their usage in construction projects. Following that, gypsum wallboard, plaster, paints, solvents, adhesives, caulks, asbestos, and polychlorinated have been listed based on their weighted average rank. As per the data collection, low-level CDW generation has been listed as mixed waste, plastic, PVC, glass, mineral waste, and asphalts. Then, the CDW minimisation strategies were evaluated against the CE principles, which helped to detect the level of diffusion of knowledge and awareness of the CE concept in the Sri Lankan construction industry, especially in the context of CDW minimisation. Table 3 is a summary of the strategies used in the case study projects for each CDW type stated in Table 2.

Table 3: CDW waste minimisation Strategies in Sri Lankan construction projects

No	Strategies	Types of waste													
		A	B	C	D	E	F	G	H	I	J	K	L	M	N
[1]	Proper storage and handling		*	*	*	*		*		*		*	*	*	*
[2]	Use proper estimation	*		*	*	*	*	*		*	*	*			
[3]	Use the proper construction method	*				*	*	*			*	*		*	
[4]	Proper supervision			*	*	*	*				*		*	*	
[5]	Procurement of materials	*			*	*	*			*					*
[6]	Focus more on proper transportation		*	*						*				*	*
[7]	Use skilled manpower	*			*						*				*
[8]	Use substitute materials or components		*				*	*							
[9]	Proper schedule management	*	*												
[10]	Avoid or minimise later changes	*		*											
[11]	Avoid site works (work at a separate location)						*						*		
[12]	Train workers												*		
[13]	Reuse	*		*	*	*	*	*	*	*	*	*		*	*
[14]	Recycle	*			*	*		*	*		*	*		*	
[15]	Disposal	*	*	*	*	*	*	*	*	*	*	*	*	*	*

As per Table 3, a key concern has been given to the "reduce" principle, as strategies from [1] to [12] belong to the reduce principle, and strategy [1] has gained priority as RM2 says, "*it's important to store things carefully in yards without exposing them to the outside to prevent corrosion*", and RD4 said that "*they always make sure that heavy products are not placed, especially on PVC and glass*". In addition, RR2 says that "*after rebar is bound or steel is set up at the site, anticorrosive paint needs to be put on to protect against corrosion until the concrete is poured*". RR1 has pointed out under strategy [3] that, "*having a better formwork system for the structures is the most important thing to do for waste minimisation*", and RD3 has mentioned that "*while cutting metal, proper consideration should be given to the given measurement and actual condition*". Moreover, RD2 has agreed that the available panel size from a demolished building has to be considered while making walls for new buildings. According to RM2 and RD3, measurements, drawings, and the condition of the site must always come first. The actual quantity of materials must also be double-checked before materials and items are ordered. Hereafter, a key concern has to be given to transportation, for instance, wheelbarrows are used when transporting materials to a specific location; always make sure to unload the materials near the respective building, and the trucks should be properly covered while transporting the soil into the site to minimise spillages. RM3 says that "*using skilled and expert workers for installation, formwork, and fabrication will reduce CDW waste more than expected*", and RD4 mentioned that "*if there is not much material requirement, it is always a better idea to use substitutes and alternatives to minimise wastage of material by transporting, storing and handling*". Fewer people say strategy [9], although it is important in construction. This may be because, according to RR5, "*if there is too much concrete for a job, it can be used right away for something else instead of being wasted. For example, it can be used to make slabs and columns at the same time, not along with the schedule*". In contrast, RM4 has stated that "*the planning and the scheduled time should be properly managed to avoid later changes; a further example is that there will be a lot of waste when the concrete doesn't harden quickly enough. Glass and plastic materials are the best examples; it is a better option to cast them in another location and bring them to the site while installing them to minimise wastage*". According to the respondent, workers must be taught how to use materials more efficiently, how to deal with waste, and how to control quality. The major driver towards reducing waste is cost. Time-consuming process for design, drawing, measuring, and making awareness, construction staffs are more focused on achieving progress, sudden changes of plan and variations, weather issues, and time act as the major barriers to implementing the "reduce" strategy to minimise CDW. Further, the cost is the main reason to implement these strategies to "reduce" CDW waste, while the barriers to implementing these strategies are that designing, drawing, measuring, and making people aware of things take a lot of time, so construction workers are more focused on making progress. In addition, the main things that make it hard to use the "reduce" strategy to reduce CDW are sudden plan and variation changes, weather problems, and a lack of time.

"Reuse" has been identified as the next principle to minimise waste after the generation of CDW, and findings reveal that only two of the 14 CDW waste types were excluded, which are asphalt and mixed waste. Some strategies of the "reuse" principle are summed up from the cases as follows: In Case M, they either crush and sell out the collected waste material for landfilling purposes at another site, hand over the material to the approved contractors, or send the material back to the original supplier. In addition, labourers use brick-like materials to lay them under their beds in the labour camps to make even surfaces that are comfortable for sleeping on. In Case R, they always try to use additional cut-off bricks for other temporary works at the site and landfilling purposes within the site. Soil material, except for some excavated earth that can be used for backfilling and soil improvement work under the instruction and approval of the engineer. In Case D, they have a separate location for reuse materials according to their labels and categories. The drivers of implementing the strategies of reuse are cost-saving and environmental friendliness, whereas the challenges are difficulty in educating the laymen at the site level, a quality issue, not being fit for the intended purpose, proper sorting of reusable materials from the generated waste, and mainly the identification of reusable materials.

"Recycle" is the next principle to discuss. It is mostly used to minimise the disposal of waste types such as concrete, rebar, paint, bricks, steel, concrete, glass, packing waste, metal, plastic, and timber. RM3 has highlighted that "*disposing to the approved solid waste contractor will be useful to recycle the materials*", and RD4 has given a true example of their project as they discussed with the supplier about the packaging methods to focus on recycling materials. Retailing to third-party contractors is the only strategy used in all three cases. Recycling has benefits for the economy and the environment, like saving money on resources and reducing pollution. However, Sri Lankan projects do not think much about recycling because there are not many recycling plants in the country. Further, difficulty sorting it out when huge amounts of waste are generated and less technology advancement, as well as less attention to recycling, were identified as the challenges to incorporating recycling strategies for CDW minimisation in Sri Lanka. Finally, the disposal will be the last but used in all three cases for all 14 types of CDW to take away from the construction sites. Dumping and burning are widely used to get rid of trash, while some can be carried out at the same site or else in a different disposal yard. In addition, handing over to the municipal council is also one of the common practices in these cases, irrespective of CDW types.

Furthermore, when questioned, "*Are you aware of any other principles or R-imperatives (the R framework) beyond the 3 R's (reduce, reuse, and recycle)? (e.g.: refuse, repair, refurbish, remanufacture, repurpose, recover, reimagine, and replace)*", all the respondents answered "no" to this question. Most of the respondents did not even know what the term “circular economy" meant. Moreover, it is necessary for the involvement of all persons engaged with construction activities, irrespective of their level (e.g., top management or labour), and it is important to have a single responsible person to manage, ensure, and improve waste management within a construction project. However, unfortunately, in all three cases, there is no single responsible person to look after waste management or minimisation activities, which do share some professions but differ from project to project. In Case M, the Quality Control Department is responsible for the CDW waste management, and the environmental manager, engineer, and site supervisor are directly dealing with waste management. But, in Case R, the project manager is mostly focused on CDW minimisation activities, and the site engineer is in charge of supervising those activities. Case D consists of many professionals in this area as it is mainly engaged in demolition activities, making the possibility of CDW generation also high; these are the technical officer, project manager, site engineer, and site supervisor.

According to the interview findings, it is obvious that reduce, reuse, and recycle strategies are used mainly to reduce the project cost through both reducing the cost of materials that become waste and also getting income from waste materials. Also, Case M respondents said that these strategies stop 30% of the extra costs that would have been added to the project. RM4 detailed that "*cost varies with the type of material, but nearly 30% of the additional cost may be required if not using waste minimisation strategies of reduce, reuse, and recycling*". Likewise, Case R could save around 20% of the additional project cost. In the case of D, around 12% of the project cost is saved through the CDW minimisation strategies. Moreover, RD2 noticed that "*there are different types of CDW materials, among which some waste can be sold in the competitive market, including rebar scraps, H iron, sheet files, light metals, and coppers*". Similarly, sellable items are sold and returned the money to the project, which is credited to the project account.

3.2 RECOMMENDATIONS BASED ON DESK STUDY

Identifying and measuring the waste is essential to minimising whatever the waste is, which should precede the process of elimination, and this can be overcome by implementing a proper waste measurement system. Moreover, complex waste identification and quantification are the prime conditions for effective waste minimisation (Pienkowski, 2014). Accordingly, the types of waste were identified from the literature, and the primary data on the waste generated under the same types were collected using three case studies. The results (Table 2) indicate that all the CDWs identified in the literature apply to all three projects. However, even if e-waste is harmful to the environment, it was identified only in Case D, as it is a demolition project where e-waste is a common waste type. E-waste, or electronic waste, is a generic term embracing various forms of electric and electronic equipment that have ceased to be of any value to their owners (Kiddee, et al., 2013). It generates hazardous and non-hazardous materials that can adversely affect human health and the environment, and thus, it is important to pay attention to managing that properly (Chancerel & Rotter, 2009). Accordingly, e-waste was considered an additional type of waste during the data collection. According to Mallawarachchi and Karunasena (2012), the “3R” is a major concept of e-waste management adopted in developing countries.

The Sri Lankan construction industry does not know much about the CE concept, and even though the respondents know and use the 3 R's, they do not understand the clear connection between them in a circularity concept. In addition, the Sri Lankan construction industry stakeholders does not try to understand or use the other Rs of the CE concept. Further, the study reveals that a lack of knowledge and awareness is the main reason for the limited adoption of the CE concept for minimising CDW. Besides, the lack of collaboration among the supply chain stakeholders, the lack of second-hand materials or product markets, limited research and development, and cultural barriers are some of the reasons why the CE is not adopted (Charef et al., 2021). To address this gap and lack of knowledge and awareness of CE concepts beyond the basic 3R framework within the local context, the authors have further conducted a desk study to collect case studies from secondary sources where CE principles are widely adopted for CDW minimisation. Table 4 summarises the strategies used to manage CDW in a global context, and such strategies are mapped against the 11R framework of Cimen (2021), which is the latest study on CE principles for the building sector.

Table 4: Proposed strategies to minimise CDW based on desk study

CE Principles	Strategies	Sources
Refuse (Removing functions to make products redundant)	• Collaboration and communication among the stakeholders • Make emotional attachments while designing to make owner unwilling to discard it • Rejection of packaging waste and shopping bags	[1] [2] [3] [12] [14]
Rethink (Making use of product more intensive)	• Buildings for multifunctionality • Simultaneous use and sharing of product	[11] [14]
Reduce (Increasing the efficiency of natural resources to make a product)	• Adopt innovative technologies (Building Information Modelling, Internet of Things) • Design Out Waste • Encourage off-site construction (E.g., prefabrication) • Enhance supervision and management during construction • Increase the CDW treatment cost and landfilling cost • Introduction of economic incentive or awarding schemes (E.g., Construction Waste Disposal Charging Scheme or Stepwise Incentive System) • Lessen the usage of purchased products and use them with more care and longer • Making repairs for life extension, for example with consumer-to-consumer support • Material selection (E.g., Eco-labelling Products) • Periodize standardisation in building design (E.g., Modular Coordination) • Sharing economy' through pooling (simultaneous use) and sharing of product • Stricter supervision and punishment must be concurrently enforced for CDW disposal • Use modern methods of construction (E.g., Industrialised Building System)	[1] [2] [3] [4] [14] [16]
Reuse (Reusing a product discarded by another user)	• Adopt better information systems, innovative technologies and market models • Appropriate plants for demolition work / selective demolition methods • Cities could maintain their resources as material banks • Create a strong market for reused materials • Collaborating and communicating among stakeholders • Design for reuse, materials optimisation, flexibility and deconstruction • Enhancement of regulations related to CDW like Pay-As-You-Throw	[1] [2] [3] [5] [6] [7] [8] [9] [10] [13] [16]

CE Principles	Strategies	Sources
	• Enhance supervision and management • Introduction of economic incentive or awarding schemes including Construction Waste Disposal Charging Schemes or Stepwise Incentive System • Imposing standards on reused CDW materials to maintain the quality of reused material and to assure the availability • On-site sorting technique and proper guidance • Procurement Transformation (Revise Standard Form of Contract, Green Procurement) • Usage of modular buildings • Waste collection process (E.g., Appoint Waste Collector)	
Repair (Repairing a product to continue its function)	• Adopt innovative technologies and market models • Preventive maintenance • On-site sorting technique and proper guidance • Select and procure repairable materials • Waste minimal maintenance and easy repair and upgrade adaptability	[1] [2] [3] [10] [14]
Refurbish (Restoring an existing product)	• Adopt innovative technologies and market models • Design for materials optimisation, flexibility and deconstruction	[3] [10] [16]
Remanufacture (Using abandoned parts for a new product with the same function)	• Design for materials optimisation and flexibility and deconstruction	[16]
Re-purpose (Using discarded components for a different purpose)	• Design for repurpose and material optimisation • Design for flexibility and deconstruction	[11] [14] [15]
Recycling (Material is processed to obtain a new material)	• Adopt innovative technologies and market models • Appropriate Plants for demolition work / Selective demolition methods • Continuous development and integration of emerging technologies • Collaborating and communicating among stakeholders • Design for deconstruction technique • Enhance supervision and management	[1] [2] [3] [7] [13] [17]

CE Principles	Strategies	Sources
	• Enhancement of regulation related to CDW (E.g., Pay-As-You-Throw) • Eco-industrial park development • Introduction of economic incentive or awarding schemes • Manufacturing of plank products for buildings (E.g., moisture-resistant and recyclable composite material from plastic waste and wood fibers) • Open communication to assure the quality or make trust recycling • On-site sorting technique and proper guidance • Procure recyclable materials and use procurement Transformation • Use as raw material for other industries • Strong developed market for recycling to have a price advantage for recycled materials • Waste collection process (E.g., Appoint Waste Collector)	
Recover (Material is incinerated to recover energy)	• Design for recovery • Production of biomass	[14] [16]
Replace (Replacing with sustainable Material)	• Design for sustainability • Eco-design	[1] [9]

[1]- Adams et al. (2017); **[2]** – Aslam et al. (2020); **[3]**- Chang and Hsieh (2019); **[4]** - Coughlan et al. (2018); **[5]** - Esa et al. (2019); **[6]-** Huang et al. (2018); **[7]**-Leising et al. (2017); **[8]**- Manelius et al. (2019); **[9]** - Marika et al. (2021); **[10]**- Nordby (2019); **[11]**- Reike et al. (2017); **[12]**- Sanchez et al. (2020); **[13]-** Swift et al. (2017); **[14]** - Torgautov et al. (2021); **[15]**- van-Buren et al. (2016); **[16]**- Xu et al. (2021); **[17]-** Zhou et al. (2021)

This will improve the awareness of CE principles among built environment professionals, which in turn will improve the practices of construction professionals in minimising CDW by adopting them. Moreover, waste always means an additional cost to be incurred from both the client's and the contractor’s viewpoint, and the frustrations with each other can be driven by the failure of the performance of the contract as well.

Hence, minimising CDW waste leads to saving all three aspects of construction: time, cost, and quality. Further, it ensures mutual understanding and trust among the parties to the contract and the successful completion of the project for the intended purpose within the given time frame. Thus, the CE can lead to dematerialisation by reducing the waste generation and consumption of virgin materials in construction projects, which decouples economic growth from environmental impacts and also creates cost savings for construction projects.

4. CONCLUSIONS

Due to urbanisation, the growing amount of CDW is a pressing problem in many countries. There are many strategies used in different countries to minimise the CDW, such as precast construction, strategies of architects at the design stage, use of BIM, the 3 Rs, material waste minimisation strategies, and a lean approach. Although CE can be considered an appropriate solution to minimise CDW as it would reduce environmental impacts while contributing to economic growth, Thus, this research investigated how the CE can contribute to minimise the CDW to achieve sustainable urban development. Three cases were selected for the data collection and are from a mixed development project, a residential project, and a residential project with demolition. Key findings of the work include that all 14 CDW types identified in the literature appear in Sri Lankan construction projects, and e-waste was identified. Also, CDW minimisation strategies in Sri Lankan construction projects were identified, which belong to the 3 Rs of CE, such as reduce, reuse, and recycle. While the disposal is unavoidable for all 14 CDW types, adopting CE would help to minimise CDW disposal and, in turn, reduce the impact created by landfilling. 3R strategies are used mainly to reduce the project cost, both by reducing the cost of materials that become waste and also by getting income from waste materials. However, the other 8Rs of CE, i.e., refuse, rethink, repair, refurbish, remanufacture, repurpose, recover, and replace, are not understood or applied in Sri Lankan CDW minimisation. The study reveals that a lack of knowledge and awareness is the main reason for the limited adoption of the CE concept for minimising CDW. Therefore, this research recommended the strategies used to manage CDW in a global context, and such strategies are mapped against the 11R framework of Cimen (2021). These recommendations help to improve the awareness of CE principles among built environment professionals, which in turn will improve the practices of construction professionals in minimising CDW by adopting appropriate CE.

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MINIMISING LOGISTIC COST OF CONSTRUCTION MATERIALS IN THE CONSTRUCTION INDUSTRY: CONTRACTOR'S PERSPECTIVE

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ABSTRACT

Construction projects involve major resource consumption, particularly in materials which can account for up to 60% of the total construction cost. Construction logistics is the integration and collaboration of several activities to plan, execute, and control the flow of physical objects from their point of origin to their point of consumption. While logistics plays a significant role in minimising material costs, the construction industry tends to pay less attention to logistic cost minimisation. This paper aims to identify construction logistic cost components and propose strategies to minimise these components on construction material cost from a contractor's perspective. Accordingly, the literature review highlighted the significance of construction materials as a resource for construction projects and the importance of material costs in total construction costs. Moreover, semi-structured expert interviews were conducted with twelve (12) experts involved in construction logistics to gather data. Both on-site and off-site experts were included in the sample. Manual content analysis was used to analyse the collected data due to its flexibility and adaptability for small sample sizes. Thirteen (13) strategies were proposed to minimise construction logistic costs on material costs, including proper knowledge of the logistic process and its cost components and implementing proper logistic cost minimisation strategies through coordination and collaboration between the head office and the site. The findings of this study are expected to contribute to the construction industry's better understanding of the importance of logistic cost minimisation strategies and their potential benefits.

Keywords: *Construction Logistics; Construction Materials; Logistic Cost (LC); Logistic Cost Minimisation.*

1. INTRODUCTION

Construction is the second highest industry after agriculture, with colossal resource consumption (Raja & Murali, 2020). Construction projects consume significant resources such as labour, material, machinery, and equipment in permanent and temporary works. However, materials around 50-60% take a high percentage, and their impact will be 80%

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of the project budget (Caldas et al., 2015). In some underdeveloped nations, material expenditures might account for 60-65% of the total construction cost (Tserng et al., 2006). Furthermore, a loss of 30% of labour productivity could result from a lack of materials at the time they are required (Caldas et al., 2015). Material management is a necessary process that needs to be controlled conscientiously. When it explores the contractors' perspective, it is essential to manage construction materials well to prevent cost overruns. Therefore, it is likely that the cost of materials would be increased excessively if careful planning, management, and controlling of the utilisation of construction materials were not exercised (Fang & Ng, 2011). As a definition, a flow of physical objects from their point of origin to their point of consumption can be planned, executed, and controlled through the integration and collaboration of several activities known as logistics (Benotmane et al., 2018). Construction logistics support acquiring, storing, and transporting materials, labourers, and other resources needed throughout the construction process (Miashkova, 2022). It involves more than just controlling the flow of information and materials; it also entails providing quality, ensuring safety, and creating an environment that makes construction activities easier (Guffond & Leconte, 2000).

The significance of logistic construction cost is 20-30% of the material cost (Fang & Ng, 2011). Inadequate logistic process planning may cause material shortages that delay the project schedule simultaneously, and it will drive indirect costs such as material price fluctuations, penalty costs, loss of discounts, and so on (Tserng et al., 2006). Fang and Ng (2011) mentioned that transportation, storage, and procurement are major logistic cost components, which acquire a significant proportion of the material cost. Aljohani (2017) identified material cost overrun as a critical factor directly impacting project cost overruns. Nevertheless, the construction industry pays less attention to logistic cost minimisation even though it is a significant component of material cost (Raja & Murali, 2020). Since the material acquisition process involves both supplier and the contractor, there are suppliers' and contractors' side logistic activities. However, this study focuses on logistic cost minimisation from the contractors' perspective because the contractors bear most of the logistic cost components of the material logistic process (Fang & Ng, 2011). As a result, this paper aims to identify the construction logistic cost components and propose strategies to minimise those logistics cost components on construction material cost. Consequently, this study presents an adopted logistic planning model for cost minimisation.

2. RESEARCH METHODOLOGY

According to Chalakkal (2021), the research approach is an action to examine a research problem and justify using methods or strategies. Borrego et al. (2009) have stated that there are three research approaches which are quantitative, qualitative, and mixed methods. In qualitative research, textual data is gathered and analysed via surveys, interviews, focus groups, conversational analysis, observation, and ethnographies (Olds et al., 2005). Qualitative research allows for the development of details through deep involvement in experience, and the qualitative approach enables the researcher to be highly involved in the scenario to collect data (Creswell, 2014). For this study, it is required to collect data regarding the material logistic process at a typical construction site, logistics in the construction industry, logistic cost calculation, and logistic cost minimisation, which are subjective.

Moreover, the required data, such as subjective perceptions, opinions, and emotions, is difficult to quantify. Therefore, the qualitative approach is more suitable for this study. The semi-structured expert interview was selected as the data collection method since interviews are considered one of the best data collection techniques as it goes up to the depth of opinion of the interviewees (Punch & Oancea, 2014). Gathering data would be more applicable because the required data is highly dependent on professional experience, opinions, and beliefs. Table 1 shows the profile of selected respondents.

Table 1: Experts' profiles

Detail	Profession	Designation	Experience in the industry
Expert 1	Quantity Surveyor	General Manager in Estimate and Contracts	16 years
Expert 2	Quantity Surveyor	General Manager in Estimate and Contracts	15 years
Expert 3	Quantity Surveyor	Head of Procurement Division	11 years
Expert 4	Quantity Surveyor	Procurement Manager	10 years
Expert 5	Quantity Surveyor	Chief Quantity Surveyor	26 years
Expert 6	Quantity Surveyor	Chief Quantity Surveyor	25 years
Expert 7	Quantity Surveyor	Site Quantity Surveyor	5 years
Expert 8	Quantity Surveyor	Site Quantity Surveyor	7 years
Expert 9	Quantity Surveyor	Site Quantity Surveyor	7 years
Expert 10	Engineer	Project Manager	10 years
Expert 11	Engineer	Project Manager	15 years
Expert 12	Engineer	Site Engineer	12 years

Twelve experts with relevant experience in construction logistics and who are involved in the material logistics process were selected. Both head office and site-level experts were included among these experts to address on-site and off-site logistics consequences. On completion of twelve interviews, data saturation was found because no new interpretations were arising for latest three interviews. The interviewees were systematically queried regarding multiple dimensions related to the research objectives, including the significance of LC, the level of awareness among industry professionals regarding logistics, the processes involved in material logistics, the key components contributing to logistics costs, and potential strategies to mitigate these costs. The collected data were analysed using the manual content analysis method, where the researcher carefully goes over and classifies text-based data, such as written documents, interview transcripts, or focus group transcripts (Elo & Kyngäs, 2008). Since manual content analysis is more flexible and adaptable and can be used for analysing small samples of data in depth (Krippendorff,2019), it was selected as the data analysing method.

3. LOGISTICS IN THE CONSTRUCTION INDUSTRY

When it matches the concept of logistics to construction firms, construction logistics can be defined as the process of delivering materials and resources required at a construction site in a productive way (Ghanem et al., 2018). Voigtmann and Bargstadt (2010) mentioned that planning, coordinating, and monitoring the movement of construction materials within the construction site are all parts of construction logistics. According to previous studies, construction logistics can be divided into off-site and on-site material logistics.

3.1 ON-SITE LOGISTICS

The technique of allocating places for resource delivery, storage, and handling to minimise site congestion and extra material movement so that inefficiencies are kept to a minimum is known as on-site logistics (Thomas et al., 2005). In the construction industry, when materials arrive at the working site, it does not mean materials have reached their destination. Because still, crews at the site need to transport, store at the on-site warehouse, and install in the right place - these steps in site call on-site logistics (Ghanem et al., 2018). Wang et al. (2014) also highlighted that construction logistics present two potential areas for performance improvement, and the first step is to address the logistical issues at the construction site. Moreover, rearranging site logistics can result in significant improvements (Sundquist et al., 2018).

3.2 OFF-SITE LOGISTICS

Off-site construction logistics is a component of supply chain management in which numerous businesses collaborate to create a network of interconnected procedures to move goods, services, cash, and information efficiently to lower overall costs, shorten overall lead times, and increase overall profits while putting the needs of the customer above all other considerations (Hamzeh et al., 2007). Main contractors are supplied goods and services from sub-contractors and suppliers, and then those activities consider off-site logistics. This is also called supply logistics which involves construction material suppliers (Ekeskär & Rudberg, 2016). Fellows and Liu (2012) argued that supply logistics (off-site logistics) is more complex because it involves more construction processes. For efficient resource and material flow management, cooperation and coordination between supply chain participants and the utilisation of off-site logistics are other steps that should be considered (Brusselaers et al., 2022).

4. MATERIAL LOGISTIC PROCESS AT CONSTRUCTION SITE

According to Fang and Ng (2011), a logistic process in a construction site is a sum of all logistic activities involving material acquisition from suppliers to transporting to the construction site. According to Jang et al. (2003), major logistic activities are procurement, transportation, storing, and handling. The material acquisition process involves both supplier and the contractor; there are suppliers' and contractors' side logistic activities. Since this study focuses on logistic cost minimisation from a contractor's perspective, it would only consider contractors' side logistic activities. Accordingly, Figure 1 illustrates how those major logistic activities are ascertained in a construction site.

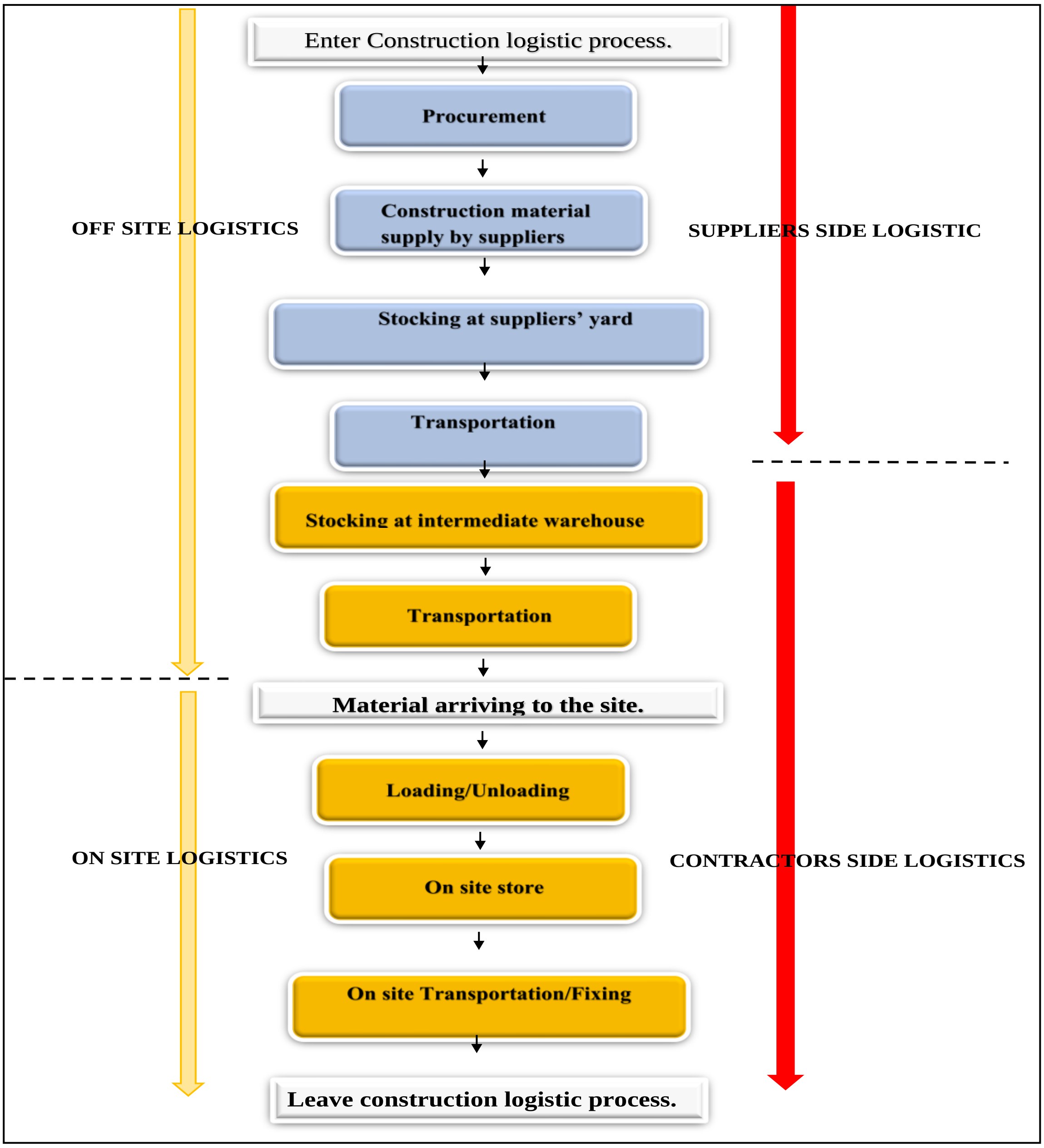

Figure 1: Material logistic process at a typical construction site

5. BASIC CONSTRUCTION LOGISTIC COST ELEMENT

Fang and Ng (2011) proposed Activity Based Cost (ABC) method to quantify the total logistic cost, which is a method for identifying cost components, determining the costs associated with each activity, and assigning those costs to cost objects, such as labour, materials, equipment, facilities, property, and capital. According to Fang and Ng (2011), the cost of each logistic activity is identified as a logistic cost element. Sobotka and Czarnowski (2005) presented a similar concept. Generally, the supplier bears the storage costs at the supplier's yard and transportation costs to the intermediate warehouse. The contractor absorbs the storage cost on site and intermediate warehouse, material handling (loading/unloading), other transport costs between the construction site, on-site transportation, and procurement cost (Fang & Ng, 2011).

5.1 PROCUREMENT COST

The word "procurement cost" refers to the costs related to finding appropriate suppliers for the project, which includes selecting the best suppliers, requesting quotes from them, negotiating the terms of the contracts with them, and ordering the material (Zeng & Rossetti, 2003). The best item must be purchased at the appropriate quality, quantity, time, and cost, according to the objectives of material procurement (Kamalaeaswari & Vedhajanani, 2015). Observing consumed resources which are working staff, office equipment, and capital cost, provide the cost of procurement (Fang & Ng, 2011).

5.2 TRANSPORT COST

Transportation is significant when considering logistic activities in the construction industry (Sobotka & Czarnigowska, 2005). Generally, suppliers are responsible for transport from their store to an intermediate warehouse or on-site storage. Meanwhile, the contractor takes care of himself with on-site and material transportation to the construction site (Fang & Ng, 2011). Rafiq et al. (2021) emphasised that the transportation cost should relate to the distance travelled between the warehouse and the destination, including the driver's salary, equipment expenses, fuel cost, and inventory costs incurred in transit. The cost of the inspector and the rental or depreciation of the vehicles should be included in the transportation cost (Fang & Ng, 2011).

5.3 COST OF SITE STORAGE

Some studies on the manufacturing sector believe that once the materials arrive at the warehouse, the logistics process is complete (Lambert et al., 1998; Ferguson, 2000). However, in the construction industry logistic process will not be ended until materials are fixed to the exact location (Fang & Ng, 2011). Thus, construction materials are often loaded into a temporary storage facility at the construction site before being fixed at the appointed place (Fang & Ng, 2011). The fundamental responsibility of material management is an in charge of the flow of materials from where they are ordered, received, and stored until they are used (Patil & Pataskar, 2013). According to Fang and Ng (2011), the cost of site storage shall include all the cost-related items, which are material costs for racks, stow woods, other relevant materials, and labour costs charged at the store. Moreover, it consists of the capital cost, which means the opportunity cost of frozen material at the site (Fang & Ng, 2011).

5.4 INVENTORY COST

Inventory control is crucial to the timely and successful execution of construction projects. The purpose of the inventory is to have the supplies on hand for when needed by storing them (Zeng & Rossetti, 2003). Inventory also keeps finished goods, spare parts, tools, and supplies needed for construction. Contractors maintain an intermediate warehouse to keep materials and supply construction sites when needed (Kumar & Malik, 2022). The same authors mentioned inventory cost consists of holding cost, storing cost, rent and electricity. The inventory holding cost is the difference between the transfer and buffer stock costs (Zeng & Rossetti, 2003).

5.5 COST OF MATERIAL HANDLING

Effective material handling is a material management objective consisting of loading, unloading, and fixing materials (Ramya & Viswanathan, 2019). Material handling is performed using machinery, mobile cranes, and other equipment or manually with human resources (Muralitharan & Elangovan, 2015). Equipment used for material handling, such as cranes, forklifts, chain hoists, and slings, should be sufficiently capable and adequately maintained. Material handling costs include labour costs, machinery costs (cranes), and equipment costs (Fang & Ng, 2011).

5.6 CUSTOM DUTY/TAXES

According to Jayasinghe et al. (2016), the tax was identified as a significant cost component of the material. The construction industry development authority in Sri Lanka and the Sri Lankan custom confirms that most of the construction materials in the local industry are imported from foreign countries, and then there are several duties and taxes charged. CESS levy, PAL, and customs duty take a significant amount on material cost (Customs, 2023). The form of the contracts stated that paying tax on materials is a contractor's responsibility.

Based on the ABC method, the Contractors' total LC can be quantified as follows:

Contractors' total LC = Procurement cost + Cost of intermediate warehouse + Cost of transportation + Cost of material handling (loading, fixing) + On site storage cost + Custom duty/taxes

Therefore, if the contractor requires to minimise total LC, they shall identify possible LC cost components to cut unnecessary costs.

6. STRATEGIES TO MINIMISE LOGISTIC COST

This research study focuses on developing strategies to minimise logistic costs from a contractor's perspective. Several researchers have endeavoured to discover suitable strategies for logistic cost minimisation. Further, strategies have been identified through expert interviews. According to expert interviews, LC comes to the arena in two major stages. They are LC estimating at the bidding stage and monitoring and calculating actual LC during construction. Therefore, LC minimisation strategies shall be developed in the bidding stage, and developed strategies will be implemented during the construction stage. It is imperative to monitor the progress after implementing strategies to ascertain the degree to which logistical activities conform to said strategies. Table 2 presents the strategies recognised through the literature review and expert interviews. If at least one expert said that a particular strategy minimises logistic cost, it has been mentioned as an identified strategy through expert interviews. If a specific strategy has been deemed effective in minimising logistic costs by at least one expert, it is considered an identified strategy through expert interviews.

Table 2: Strategies

Strategy	Literature findings	Expert interviews
Better construction site plan	X	X
Better logistic plan	X	
Identifying the most suitable material delivery schedule in line with the construction schedule	X	
Identifying the quickest route (lowest distance) with less disruptions	X	X

Strategy	Literature findings	Expert interviews
Better labour supervision and optimising construction site with less interruption	X	X
Better material management	X	
Centralised material supply centre to supply materials for each ongoing site		X
Local vendors		X
Identifying ideal storage capacity	X	X
Keeping own material plants to integrate the supply chain		X
Alternative transportation methods		X
Technological advancement		X
Ensure the quality of material		X

6.1 BETTER CONSTRUCTION SITE PLAN

According to Gustafsson and Schultz (2010), a construction site plan includes many logistic cost-related aspects such as transportation routes, lifts, cranes, crane placements and ranges, gates, passages, unloading areas, and storage areas. Experts emphasised that a better construction site plan will minimise on-site transportation and storage costs and save material handling by optimising the site space. Moreover, optimising construction site space will minimise material handling costs since it saves working hours on loading and unloading materials.

6.2 BETTER LOGISTIC PLAN

Said and El-Rayes (2011) developed a logistic planning model to assist contractors in reducing material logistics costs by utilising an integrated approach that optimises the critical planning decisions of material procurement and layout on construction sites. Figure 2 shows that the existing model in a specific construction site cannot integrate material procurement plans and storage layouts on construction sites. With that number of drawbacks which increase logistic cost more, are arising. By utilising an integrated strategy that simultaneously optimises two categories of decisions, the new model is intended to assist contractors in reducing the costs associated with material logistics: (1) material procurement decisions, which affect material inventory levels and storage requirements; and (2) dynamic layout decisions, which identify various locations of material storage areas and other temporary facilities over the course of a project. Both types of decisions directly impact the objective function created to minimise the construction logistics (Said & El-Rayes, 2011).

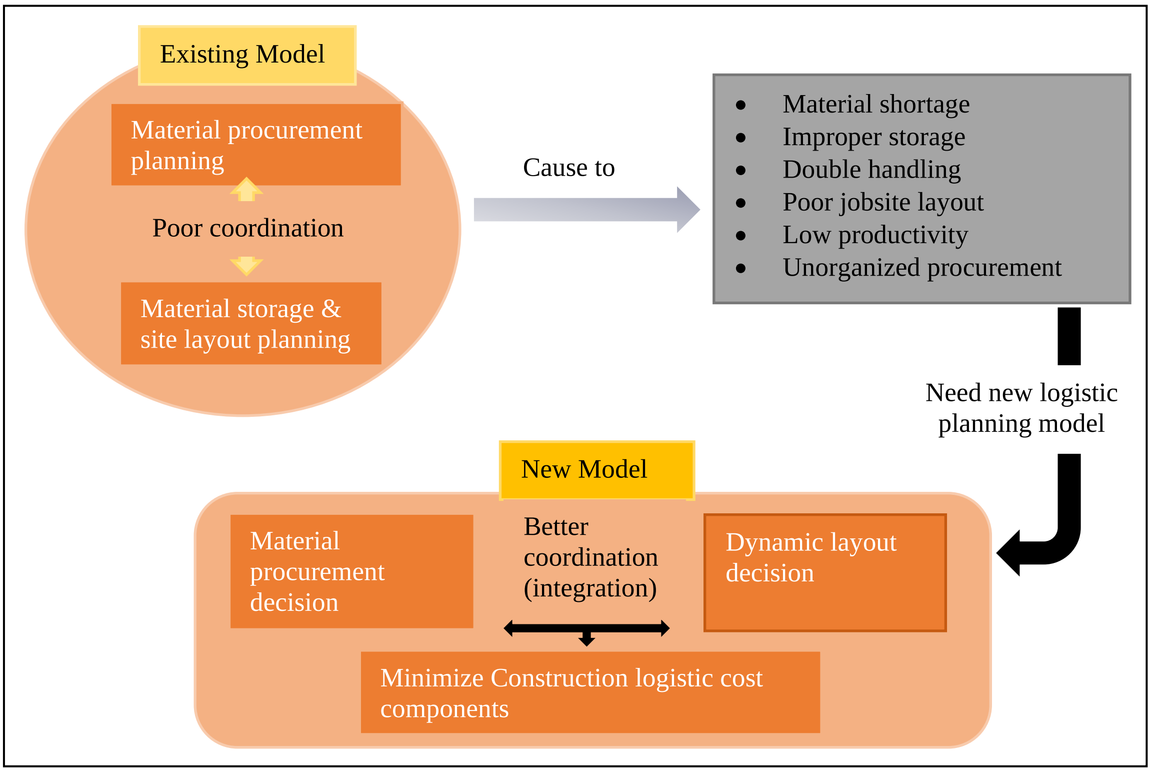

Figure 2: Construction logistic planning model (Adopted from Said & El-Rayes, 2011)

6.3 IDENTIFYING THE MOST SUITABLE MATERIAL DELIVERY SCHEDULE IN LINE WITH THE CONSTRUCTION SCHEDULE

A material delivery schedule minimises the number of orders and delivery times. According to Expert 2, the most suitable material delivery schedule can be easily implemented if a proper construction schedule is available. The construction schedule mentions resource requirements for relevant activity in line with time. This strategy can minimise procurement and transportation costs due to few material orders (Fang & Ng, 2011).

6.4 IDENTIFYING THE QUICKEST ROUTE

Identifying the quickest route with the lowest distance and fewer disruptions is crucial to minimise material transport costs (Shah et al., 2019). Expert interviews further elaborated on the quickest route strategy will be caused to minimise project delays, which saves unnecessary costs for Contractors

6.5 BETTER MATERIAL MANAGEMENT

Shah et al. (2019) have mentioned that better material management which consists of material procurement, material quality, and transportation of suitable material on-site at the right time, is another strategy for logistic cost minimisation. If the material management in construction projects is not managed correctly, it will create a significant project cost variance (Gulghane & Khandve, 2015).

6.6 CENTRALISED MATERIAL SUPPLY CENTRE TO SUPPLY MATERIALS FOR EACH ONGOING SITE

Most of the experts stated that a centralised material supply centre allows bulk purchasing, which causes a reduction in the number of orders. On the other hand, each ongoing construction site can decline logistic costs because all the materials can be delivered from one place.

6.7 LOCAL VENDORS

According to Sri Lanka customs, the construction industry spends high costs on customs duties and port/airport levies depending on imported materials and experts confirmed it is better to deal with local vendors to minimise duties, levies, and taxes as a logistic cost component (Jayasinghe et al., 2016). Experts believe the Contractors should explore alternative materials for imported materials.

6.8 IDENTIFYING IDEAL STORAGE CAPACITY

Ideal storage capacity cuts down the high initial cost of the store and maintenance costs (Fang & Ng, 2011). On the other hand, experts confirmed that ideal storage capacity minimises the number of material orders.

6.9 KEEPING OWN MATERIAL PLANTS TO INTEGRATE THE SUPPLY CHAIN

Another suggestion of the experts was keeping their material plants to integrate the supply chain that, allows the contractor not to be concerned about material transportation from suppliers' yards, taxations and material shortages.

6.10 ALTERNATIVE TRANSPORTATION METHODS

Contractors should find alternative transportation methods which spend the least transportation cost to minimise the logistic cost. Experts recommended that material transportation from railways is a cheap alternative transportation method.

6.11 TECHNOLOGICAL ADVANCEMENT & ENSURING QUALITY OF MATERIALS

Furthermore, ensuring excellent quality material and using new technologies were identified as effective strategies to minimise the logistic cost component. Poor quality materials increase material rejections, which repeat the logistic process. As suggested by Experts 1, 2, 3, 4, 8, 10 and 12, adopting new technologies improves the efficiency of the material acquisition process and minimises the logistic cost as they have practically experienced using Enterprise Resource Planning (ERP) system.

7. CONCLUSIONS

Examining logistical expenses is paramount for contractors as it facilitates the successful execution of projects within budgetary constraints while attaining anticipated profitability. The primary objective of this research endeavour was to formulate strategies that mitigate logistical costs on material expenses, achieved through a comprehensive review of existing literature and semi-structured interviews conducted with industry experts. The literature review in this study centred on elucidating the fundamental principles underlying the minimisation of logistical costs associated with construction materials, thereby underscoring the influential role construction materials play as a critical resource in construction projects. Prior scholarly investigations have unequivocally substantiated the significance of material costs within the overall framework of construction expenditure. Consequently, this study adopted a contractor-centric perspective in its examination of logistical costs, identifying a substantial portion of such costs attributable to construction material expenses. Minimising unnecessary logistic costs and observing the logistic cost component to reduce material costs is crucial. The study presented the material logistic process and identified major logistic activities that could be categorised as significant cost components. These costs related to the logistics of construction materials were delineated based on the ABC approach.

The study found that logistic costs can be controlled in both the bidding and construction stages. Accordingly, thirteen strategies were proposed to minimise logistic construction costs on material costs. It was confirmed that estimators, planners, project managers, and other industry professionals must properly know the logistic process and its cost components. Logistic costs take a considerable proportion of material costs, and a lack of planning and controlling of logistics can cause material cost overruns. Therefore, this study's outcome is beneficial for contractors to have a clear picture of logistic costs and develop a proper logistic plan to address logistic cost minimisation strategies. As both the head office and construction site are involved in the logistic process, implementing proper logistic cost minimisation strategies requires proper coordination and collaboration between the head office and the site. The introduction of technological advancements can enhance the implementation of these strategies.

Finally, in-depth investigation, proper training for staff, and identifying barriers will provide continuous development for contractors in establishing logistic cost minimisation strategies. The findings of this study are expected to contribute to the construction industry's better understanding of the importance of logistic cost minimisation strategies and their potential benefits.

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MODELLING DESIGN STAGE RISKS IN MODULAR INTEGRATED CONSTRUCTION PROJECTS IN SRI LANKA

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ABSTRACT

Modular integrated Construction (MiC) as a promising construction method has instigated significant advancements in the construction industry, especially in developed countries. However, the MiC has been becoming popular in developing countries such as Sri Lanka given its potential to improve construction efficiency, reduce cost and waste, and enhance quality. The design stage is considered critical in MiC since design errors can propagate to manufacturing and assembly issues and entire project failure. Further, as the Sri Lankan construction industry is in the preliminary stages of MiC implementation, the most risk-exposing stage is the design stage. Therefore, it is essential to explore the design stage risks (DSRs) affecting MiC in Sri Lanka to enable timely decision-making to withstand the potential risks in its implementation. Under these circumstances, this study proposed and developed a Social Network Analysis (SNA) model to identify the most critical DSRs and their co-relational impacts by probing and assessing the data collected through an industry expert survey. The findings revealed that the inaccuracy of design information, inadequate planning for design and unclear design specifications are the most critical DSRs in MiC initiation in Sri Lanka among the identified 14 total risks. Further, three significant risk categories were determined, and the co-relational impact of each risk was assessed as depicted in the SNA model. Moreover, the study findings would motivate industry professionals to appreciate and address the critical DSRs in the context of the three respective categories and thereby develop adequate measures to successfully withstand them to boost industrial performance.

Keywords: *Construction Industry; Design-Stage Risks (DSRs); Modular Integrated Construction (MiC); Social Network Analysis (SNA); Sri Lanka.*

1. INTRODUCTION

Modular integrated construction (MiC) is a distinctive offsite construction method that enables hitherto unattained innovations in highly efficient, safe, speedy, optimised, clean and advanced construction methods with reduced environmental impact in the construction industry (Chourasia et al., 2023; Ekanayake et al., 2021). Given these merits, MiC is widely applied in countries with advanced construction developments such as the

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United Kingdom, United States of America, Singapore, Hong Kong, Japan, Germany and China. Sri Lanka, which is a developing economy, is in its infancy stage of modular construction due to the shortages of expertise and experience, high initial cost, and lack of technological support (Sandamini & Waidyasekara, 2022). However, successful implementation of MiC in the construction industry would facilitate an optimal solution for the prevailing economic crisis in Sri Lanka by addressing the issues of resource scarcity, higher prices of construction materials and labour, and higher demand for lands in capital cities while facilitating many construction employment opportunities (Sandamini & Waidyasekara, 2022). That may be the reason why the leading construction companies in Sri Lanka have now started planning and initiating MiC projects.

MiC process involves designing and manufacturing the prefabricated modules in a controlled factory environment, transporting them to the site, and assembling or installation of the modules on-site (Subramanya et al., 2020). Compared to the initial generations of prefabrication, 3-dimensional volumetric units are manufactured and installed in the modular construction process and thus the entire supply chain process (manufacturing, logistics and assembly) has become much more challenging and riskier. If these challenges or so-called risks are not managed effectively and efficiently, from the beginning, i.e., the designing stage, the associated benefits realised from adopting MiC will undoubtedly wither away (Ekanayake et al., 2021). Hence, effective risk management in MiC projects is essential for successful project delivery and should begin with the identification of critical risks in MiC projects.

As the Sri Lankan construction industry is in the preliminary stages of MiC implementation, the most risk-exposing stage is the design stage. Therefore, it is vital to pay specific attention to 'design risk management' instead of following a holistic risk management strategy. Further, the design risks; known as 'wicked problems' are complex in nature, ill-defined most of the time and difficult to detect and address (Wuni et al., 2023; Buchanan, 1992). Besides, wicked problems need urgent attention in implementing MiC projects, especially in Sri Lanka as the industry is attempting to initiate the projects in the near future. Apart from the study of Wuni et al. (2023) (which attempted to identify design risk factors in MiC generally), there is no known study that attempted to explore the critical Design Stage Risks (DSRs) and their co-relational impacts in MiC in Sri Lankan context.

Given the abovementioned industry imperatives and the lack of theoretical underpinnings to explore MiC DSRs, this study was inspired and motivated to investigate and model the most critical DSRs and their co-relational impact on MiC implementation in the Sri Lankan construction industry from the viewpoint of academic and industry experts and the practitioners in Sri Lanka. By focusing on the critical DSRs identified in this study, it is expected that the MiC industry professionals will be far better informed on the appropriate DSR mitigation methods to boost industrial performance. The forthcoming sections of this paper present the research background, methods used, results and consequential discussions, practical research implications, and conclusions, including research limitations and suggested ways forward.

2. REVIEW OF DESIGN STAGE RISKS IN MIC

The history of modular construction could be found back in 1855 and MiC was used as a solution for heightened housing demand due to the rapid immigration in California

(Thurston Group, 2018). Since then, MiC has been developed up to the recent innovation of assembling prefinished volumetric flats/building units. These volumetric units can be either ‘permanent modular’ or ‘relocatable modular’. Relocatable modules can be hired or bought directly from the suppliers or leased for a short period and used for temporary purposes such as construction site offices, temporary communication rooms and temporary classrooms. The use of permanent modules is visible in long-lasting structures such as housing apartments, schools, high-rise buildings, and hotel constructions (Dharmendra & Thusyanth, 2021). Anyhow, the construction process of MiC comprises four main stages: design and planning, manufacturing of modular units/off-site assembly, transportation/logistics and on-site assembly of modular units (Sutrisna & Goulding, 2019). When it comes to the design stage, the total cost implication is lesser compared to the other three stages, but this stage is considered to be the most critical phase in MiC projects given its massive implication towards downstream supply chain processes (Andi & Minato, 2003). Further, the design stage of MiC is complex, and the design team faces significant challenges in line with design errors that contribute to aggravated manufacturing and assembly issues (Gao et al., 2019; Wuni et al., 2023). For instance, in MiC, unless a reasonable tolerance is provided, if a unit is designed and cast with even a 1 mm error, it becomes vulnerable to on-site assembly problems that cause considerable cost and time overrun (Ekanayake et al., 2021). Accordingly, design variations/changes are quite expensive and difficult to initiate after the design freeze and manufacturing of volumetric modular units. Besides, implementing the timely design freeze is essential in MiC to meet tighter manufacturing and assembly schedules to realise the allied time and cost savings in MiC (Wuni et al., 2023). However, managing the risks and complexities associated with the design stage of MiC is quite challenging and needs the special attention of the design team. In this regard, Wuni et al. (2023) attempted to identify the DSRs in the MiC implementation process. However, the study was not specific to the Sri Lankan context and generic risk constraints were discussed in the published papers. Therefore, after conducting a comprehensive literature search together with a desk study, the authors identified 14 DSRs (as shown in Table 1 with apposite references) as appropriate to the Sri Lankan construction industry where the MiC is at its primary stages of implementation.

Table 1: Design risk factors with references

Code	Risk Factor	References
DRF 1	Complicated supply chain links in MiC	[1]; [4]; [11]
DRF 2	Overestimation of design loads and materials	[2]; [4]; [8]
DRF 3	Inappropriate designing	[4]
DRF 4	Insufficient or lack of codes and standards	[4]; [5]
DRF 5	Poor response to the design changes	[2]; [4]; [11]; [12]; [13]
DRF 6	Inefficiency in design approval	[1]; [4]; [10]
DRF 7	Inadequate planning for design	[4]; [6]
DRF 8	Inaccuracy of design information	[4]; [7]; [15]; [16]
DRF 9	Incomplete design drawings	[1]; [4]; [8]
DRF 10	Frequent design changes in project scope	[1]; [9]
DRF 11	The design information gap between the designer and fabricator	[1]; [4]
DRF 12	Information gaps and leaks in the supply chain	[1]

Code	Risk Factor	References
DRF 13	Unclear design specifications	[2]; [3]; [14]
DRF 14	Late involvement of suppliers, fabricators, and contractors	[1]; [4]; [6]

Sources: [1] Li et al. (2016); [2] Lee and Kim (2017); [3] Rahman (2014); [4] Wuni et al. (2023); [5] Luo et al. (2015); [6] Nibbelink et al. (2017); [7] Sutrisna and Goulding (2019); [8] Mojtahedi et al. (2010); [9] Taylan et al. (2014); [10] Hossen et al. (2015); [11] Pervez et al. (2022); [12] Kamali et al. (2017); [13] Pan et al. (2007); [14] Gan et al. (2018); [15] Li et al. (2013); [16] Wu et al. (2018)

All these identified DSRs are threefold based on the root cause of each risk factor. The first category [DGRP1] includes the risks originating from information availability and human (design team) errors. Overestimation of design loads and materials (Lee & Kim, 2017), inappropriate designing (Wuni et al., 2023), incomplete design drawings (Li et al., 2016) and unclear design specifications (Lee & Kim., 2017) results in design failure that can be aggravated throughout the entire construction process if unattended. Inadequate planning for design (Sutrisna & Goulding, 2019) would be a serious cause of all these design team errors and data unavailability and hence, needs significant attention from the beginning.

The second category of DSRs [DGRP2] emerged from statutory and planning bodies that are responsible for MiC project implementation. The inefficiency of design approvals (Li et al., 2016) from municipal and respective city councils creates delays and causes significant impacts towards project delivery. Also, the lack of codes and standards to maintain the design quality is another challenging consideration as it generates serious negative impacts on the quality of the final product and the satisfaction of the clients.

Considering the third category of supply chain-related DSRs [DGRP3], information gaps and leaks in MiC supply chains result in serious design errors (Nibbelink et al., 2017). This is why contractors pay for additional quality inspectors assigned to oversee the component design and manufacturing at factories to avoid information gaps and design errors (Ekanayake et al., 2021). Further, it helps to eradicate the design information gap between the designer and fabricator. In addition, the contractors who use their own manufacturing plants can control their design quality better through BIM which enables a collaborative communication platform and a smooth flow of information (Ekanayake et al., 2021). Having such a collaborative communication platform would be further beneficial to enable timely decision-making as the late involvement of suppliers, fabricators, and contractors also generates a greater risk of inaccurate and late design (Nibbelink et al., 2017). Frequent design changes (Li et al., 2016) and poor responses to design changes (Lee & Kim, 2017) are two other DSRs that result in extended design completion time. Although there can be several reasons behind the late design changes, the major cause would be the information gap and the late involvement of supply chain members in design freezing and decision-making. Moreover, the complicated supply chains in MiC projects considerably affect the upstream and downstream supply chain links and make the construction process riskier (Li et al., 2016).

Although these DSRs greatly affect the overall performance of the MiC projects even in Sri Lanka, the criticality of each risk factor and their co-relational impacts have not been investigated in previous research and attempts were not focused on developing strategies to better manage them. Given the existing gap in research and the importance of proper implementation of MiC in the Sri Lankan construction industry, this study aimed to identify and model the critical DSRs and their co-relational impacts by employing an empirical research approach explicated in detail in the following section.

3. RESEARCH METHODS

A deductive quantitative research approach was mainly adopted in this study based on the positivist research philosophy as the study aimed at investigating the criticality of DSRs in MiC implementation and their co-relational impacts. Figure 1 depicts the research methods, their flow, and interactions in this study.

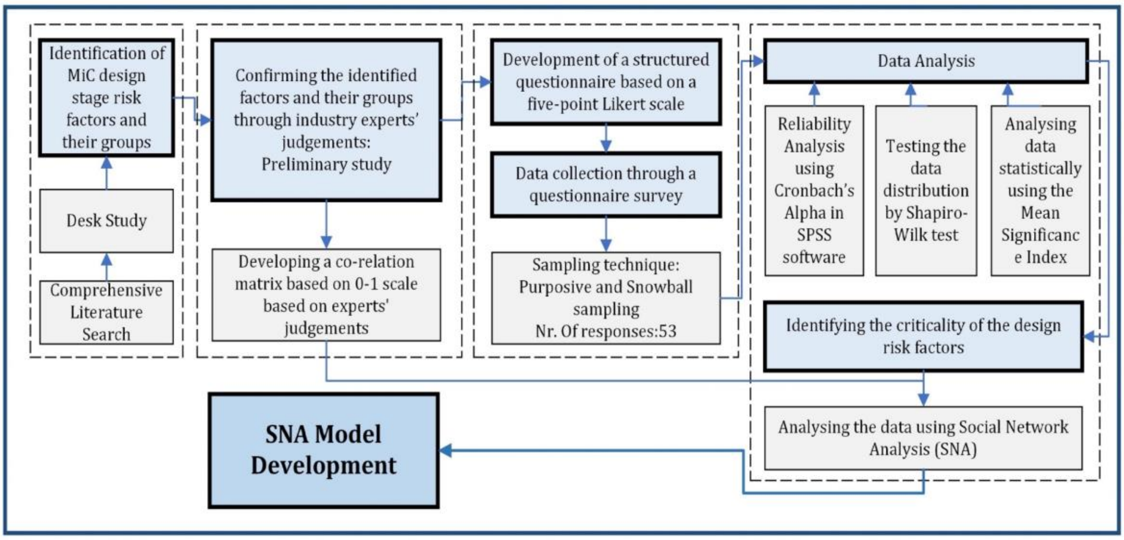

Figure 1: Research data collection, analysis and flow of this study

Accordingly, a set of 14 design stage MiC risks were first determined from a broad literature search followed by a desk study as explicated above. Then, a pilot study was conducted with a group of seven industry experts who are currently involved in modular construction projects in Sri Lanka to test the significance, applicability, and comprehensiveness of the identified DSRs in order to proceed with the main data collection through a questionnaire survey. These industry experts were from designing, engineering, architectural and quantity surveying (helps to determine economical risks in design) backgrounds and possess vast relevant knowledge and industry experience in the Sri Lankan construction industry. Further to the preliminary testing of the risk factors, the industry experts were asked to confirm the grouping of the factors and to identify each factor's significance within the respective groups and their overall significance on a 0-1 scale. The collected data was used to identify and model the degree of co-relationships of each factor towards its own group and other factor groups.

After agreeing upon the identified 14 DSRs and groupings, a structured questionnaire was designed by including the DSRs. A five-point Likert scale (5 - highest criticality, 4 - moderate criticality, 3 - slight criticality, 2 - least criticality and 1 - not at all) was used in the questionnaire to rank the risk factors based on their level of criticality in the design stage of MiC projects. A questionnaire survey was then conducted to collect the relevant data for analysis in this study. The time horizon used was cross-sectional and a purposive sampling approach was employed to arrive at the selection of suitable respondents for data collection (Ekanayake et al., 2021). In selecting the respondents, it was considered that the respondents should have adequate knowledge, industry experience or research experience and/or be involved in MiC planning or implementation. Following the purposive expert sampling, the snowball sampling technique was then used to expand the respondent 'catchment area' for this study. The questionnaire was sent to the selected professionals in the construction industry in Sri Lanka through personalised emails. A total of 53 (over 137) complete responses (with a 38.6% response rate) were received. Although the samples size was slightly small, it was considered adequate because (a) the lower number of professionals full fill the used respondents' selection criteria in Sri Lanka; (b) the number of responses exceeds the minimum requirement of the central limit theorem for valid statistical analysis (Ott & Longnecker, 2016); and (c) the responses were adequate to derive meaningful conclusions as appropriate to this study.

The data collected from the questionnaire survey was first tested for reliability and validity using Cronbach's Alpha in SPSS software (Brown, 2002) and for the data distribution type using the Shapiro-Wilk test (Razali & Wah, 2011). After that, the subsequent statistical analysis was conducted using the Mean Significance Index to identify the criticality of the DSRs (Ott & Longnecker, 2016; Wuni et al., 2023). Then, the data received from the pilot study were analysed using Social Network Analysis (SNA) to determine and model the degree of co-relational impact among the risk factors and their respective risk categories because SNA is established as an effective method to explore the influence of risk factors in construction supply chains (Gong et al., 2019) and it facilitates effective decisional and interactional analysis with a limited sample size (Tichy et al., 1979).

4. RESULTS AND DISCUSSION

4.1 PRE-TEST ANALYSIS

The result of Cronbach's Alpha Test was 0.703 and indicated that the selected MiC DSRs are internally reliable and consistent (Brown, 2002). Also, the results of the Shapiro-Wilk test indicated that the data in this study are nonnormally distributed as the test value was lesser than the stipulated p-value, at a standard significance level of 0.05 (Razali & Wah, 2011). Therefore, the study then proceeded with the statistical analysis.

4.2 SURVEY RESULTS

Accordingly, primary statistical techniques of the Mean Significance Index and the Weight Index (respectively presented in Equation 1 & Equation 2) were used to determine the most critical MiC DSRs in the Sri Lankan construction industry.

$$\mu_i = \frac{(E \times F)}{N} \qquad \textit{(Eq...1)}$$

$$W_i = \frac{\mu_i}{\sum_{i=1}^{n} \mu_i} \qquad \textit{(Eq...2)}$$

Where:

E = the number of point scale (1 - 5) for the Design Risk Factor (DRF),
F = the scores assigned to a DRF by the experts ranging from 1 to 5,
N = the total number of responses obtained by a DRF,
Wi = the weight of a DRF,
Σμi = the summation of the mean significance indices of all DRFs for MiC projects in Sri Lanka

Table 2 presents the results generated from this primary statistical analysis including the ranking of the DSRs based on their criticality.

Table 2: Table of descriptive statistics of the identified DSRs

Risk Factor	Risk Category	Standard Deviation	Mean	Weight	Rank	Score % for SNA	Co-relation matrix		
							DG RP1	DG RP2	DG RP3
DRF2	Category 1 [DGRP1]	0.98	3.92	0.07	8	7.04	1.00	0.00	0.00
DRF3		0.97	3.91	0.07	9	7.02	1.00	0.00	0.50
DRF7		0.82	4.28	0.08	2	7.68	1.00	0.30	0.30
DRF8		0.84	4.40	0.08	1	7.90	1.00	0.20	0.20
DRF9		0.70	4.08	0.07	5	7.32	1.00	0.20	0.20
DRF13		0.71	4.19	0.08	3	7.52	1.00	0.00	0.00
DRF4	Category 2 [DGRP2]	0.86	3.85	0.07	10	6.91	0.40	1.00	0.00
DRF6		0.84	3.79	0.07	12	6.80	0.50	1.00	0.50
DRF1	Category 3 [DGRP3]	0.82	4.09	0.07	4	7.34	0.00	0.00	1.00
DRF5		0.84	4.06	0.07	6	7.29	0.00	0.50	1.00
DRF10		0.81	3.96	0.07	7	7.11	0.65	0.15	1.00
DRF11		0.89	3.83	0.07	11	6.88	0.00	0.00	1.00
DRF12		0.84	3.57	0.06	14	6.41	0.00	0.00	1.00
DRF14		0.82	3.77	0.07	13	6.77	0.00	0.00	1.00

4.3 SNA MODELLING

After the primary statistical analysis, the data collected through the industry experts survey were incorporated to develop a social network analysis model as illustrated above in the research methods section. The score values and matrix values used to develop the model are shown in Table 2. As identified in the pilot study, each factor's significance within the respective groups and their overall significance on a 0-1 scale was used to create the SNA matrix. The appropriate percentage values shown in Table 2 are the total scores received for each DRF over the summation of scores received for all the DRF groups. All those values were imported into the Netminer 4 software, and a two-mode network analysis was conducted to derive the results depicted in Figure 2. The node shapes on the SNA model denote the types of DSRs (circles) and their categories (squares), respectively, whereas the arrow (link) thickness reflects the degree of influence between the nodes. In this context, this study adopted SNA to determine and model the co-relationships between DSRs and their own risk categories.

The node size reflects the level of criticality of each design risk factor. Further, 'degree' as one of the key measures in SNA was used to explain the results. By examining the immediate characteristics of node connections, this metric identifies the extent of connections to other actors within the network (Tichy et al. 1979). Hence, the measure of 'degree' enabled identifying the most critical DSRs, considering the highest degree values they received.

4.4 DISCUSSION OF THE RESULTS

As presented in Table 2, the questionnaire respondents have ranked all the risk factors as significant and more or less critical given their Mean Significance Index exceeds 3.5. The most critical DSRs are the inaccuracy of design information, inadequate planning for design and unclear design specifications. All these critical risks belonged to Category 1 and originated from the unavailability of information and human (design team) errors. As the MiC is in its preliminary stage of implementation in Sri Lanka (Sandamini & Waidayasekara, 2022), the lack of hands-on experience would be the cause behind these human and information-based risk factors. However, these risk factors could be properly managed by paying due care and attention (Luo et al., 2015). Also, the lessons learnt from other jurisdiction-based industry advancements would be greatly helpful in this respect. Besides, the results are in line with the study conducted by Wuni et al. (2023) as the most critical risk factor in general MiC implementation is the unsuitability of the design. Therefore, it is visible that even developed industries still struggle with design management in MiC.

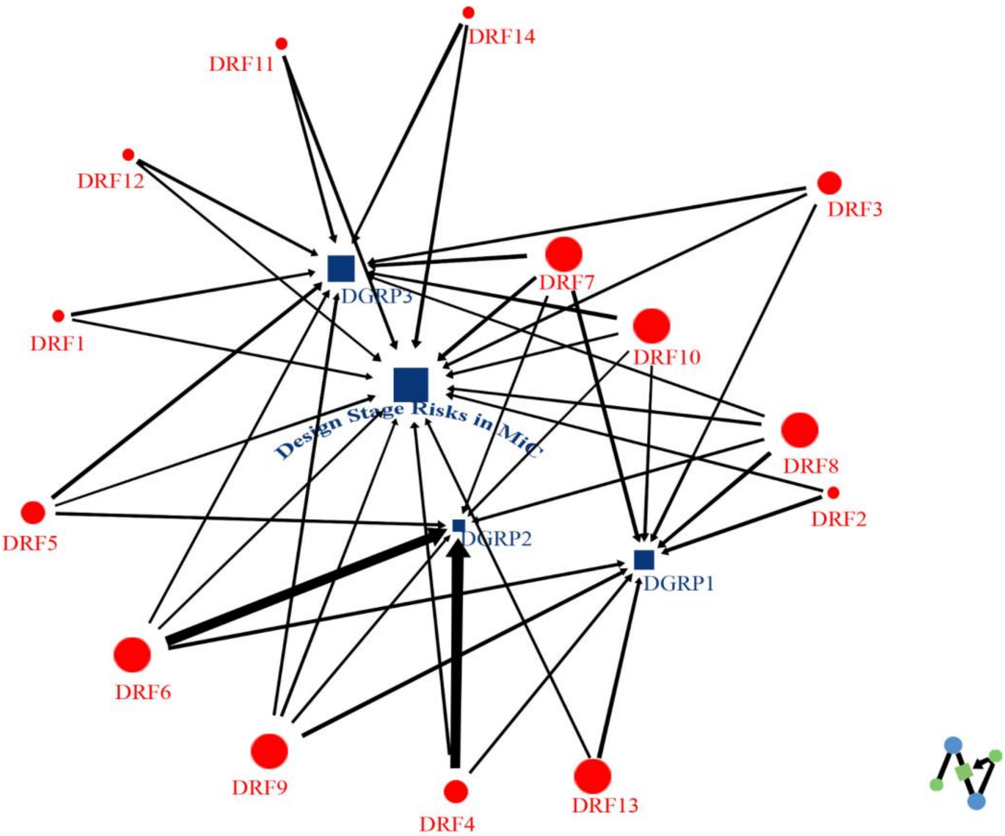

Figure 2: SNA Model for DSRs in MiC

'Complicated supply chain links in MiC' is ranked as the fourth critical risk factor. The pre-fabricators, architectural designers, structural engineers and contractors (both upstream and downstream supply chain links) should work together from the beginning of the design stage to avoid fabricating and assembly issues due to the design complexity of MiC projects. However, as observed in Wuni et al. (2023), project complexity is ranked as the 9th critical risk factor in global MiC implementation. The reason behind this difference can be due to the lack of technology and the shortage of expertise in MiC within the Sri Lankan construction industry when compared to other developed industries in the UK, USA, Hong Kong, Japan, and Australia. Therefore, the design complexity and inaccuracies would be quite significant and expected more in Sri Lanka compared to the industries with advanced technology and expertise.

Improved anticipation, collaboration and visibility would be effective in mitigating the DSRs due to supply chain complexities in MiC (Ekanayake et al., 2021). For instance, as practised in developed countries, assigning quality checkers (representing the contractor) to oversee the modular component design and manufacturing is vital to avoid design information issues and design errors while eradicating subsequent tolerance issues in assembly. BIM-integrated project management tools and collaborative communication platforms can help to trigger early warning signals before any disruptions (Luo et al., 2015) and facilitate early design risk mitigation and management. As model simulations are also possible with the techniques, all the models could be pre-tested to detect and manage design errors at the first instance.

The 10^{th}-ranked DSR of this study is the lack of codes and standards for MiC implementation. Currently, in Sri Lanka, BS Codes and EU codes are used for the design purposes of modular projects because the industry is initiating small-scale projects. Therefore, still, standardisation has not become a substantial issue for MiC delivery in Sri Lanka compared to the other DSRs. However, the lack of bespoke MiC codes has been detected as one of the topmost critical DSRs in an international survey conducted by Wuni et al. (2023). As described by Nibbelink et al. (2017), the output will be greatly defective when the accuracy of the input data is poor, especially in the MiC since the early design freeze is essential for the successful delivery of the projects. Therefore, standardisation and receiving technical guidance would play key roles in this respect and gathering industry knowledge and technology would be necessitated.

Data reported in Table 2 are confirmed to a higher extent by results achieved through the SNA model. Referring to Figure 2 released by the model, the DGRP3 category shows a higher level of direct correlational impact with different DSRs (unless DRF2, 4 and 13) in comparison to the other two categories, the same outcome is reported in Table 2 in the correlation matrix section. It is emphasising the importance of establishing efficient information workflow between different stakeholders involved in MiC from the early stages of design to avoid clashes and mistakes. Risks originating from human errors (DGRP1) demonstrated direct relation to 9 different DRFs while the level of effectiveness of each DRF in this category is almost the same (semi-similar arrow line thickness). Totally eight Risk Factors are connected directly to the DGRP2, while among them two DRF4 and DRF6 illustrated a very high level of effectiveness that both related to the lack of adequate standards and procedures defined by the government for MiC in the industry during the design stage. Based on the SNA model, every DRF suggested in this research at least has linked with two DGRP categories, while the majority of them demonstrated a connection with all DGRP groups.

The DRF6, 7, 8, 9,10 and 13 are reported with the highest level of criticality in accordance with the size of the node demonstrated in Figure 2. This agrees with values reported in Table 2 which measured the Inaccuracy of design information, Inadequate planning for the design, Incomplete design drawings, Frequent design changes in project scope and Unclear design specifications as main risk factors with a high level of effectiveness in the design stage in MiC projects. Apparently, improving mentioned factors can assist to enhance the efficiency of the design in MiC.

4.5 RESEARCH IMPLICATIONS

This research contributes to the MiC knowledge domain by first identifying the critical DSRs (within three different risk categories) affecting the MiC projects' success. And then, the study reveals the co-relational impacts of each critical risk towards the different risk categories and their overall impact towards the MiC design process. More significantly, this is the first known attempt to model DSRs in MiC implementation through the SNA approach. Besides, the model facilitates industry practitioners in Sri Lanka to determine the critical DSRs in MiC and their relational impacts while enabling them to make well-informed timely decision making to overcome these risks successfully. As the Sri Lankan construction industry is currently seeking avenues to enhance its overall performance due to the prevailing economic crisis, effective risk management is essential and inevitable to realise the expected benefits of MiC. Other developing countries will also be benefited from these research outcomes by enhancing their own practices to determine and withstand design stage risks by following the suggested research approach. Therefore, it should be noted that the novel research method employed, and the principal research outputs from this study significantly contribute to both construction research and industry development.

5. CONCLUSIONS, LIMITATIONS AND WAY FORWARD

This study revealed the critical DSRs and their co-relational impacts on MiC implementation in the Sri Lankan construction industry through an expert survey and Social Network Analysis approach. Three critical risk groups were identified based on the root cause of each risk factor including the risks originating from information unavailability and human (design team) errors, statutory and planning bodies, and supply chain-related complexities. Further, the inaccuracy of design information, inadequate planning for design and unclear design specifications were identified as the most critical DRFs among the identified 14 DSRs through the primary statistical analysis of data. Finally, an SNA model was developed by considering the criticality of the DSRs and their co-relational impacts. The developed model represents both theoretical and practical underpinnings of the DSRs' influence on MiC implementation. Hence, industry practitioners would benefit from having prior knowledge of these DSRs and their levels of criticality as well as their co-relational impacts, enabling them to prioritise addressing them, targeting successful MiC project implementation in Sri Lanka as the industry is at its primary stages of MiC initiation.

More significantly, the study unveiled that SNA is an effective method to analyse and model DSRs in construction projects by being the first known study that analyses the co-relational impacts of DSRs in MiC projects using SNA. As a way forward, the model can be further improved by reflecting 'centrality' values and more inputs from the industry to withstand these risks. Further, subsequent studies may increase the response rate for enhanced generalisation of the results. Moreover, the model could be tested through different case studies and proceed with the verification of the findings. Since these risks and their levels of criticalities are jurisdiction-specific, the developed model can be extended as appropriate to other country contexts and generalised for different industrial contexts. In addition, it is worth noting that there could be other potential risk factors that are unavoidably missed in the model development which may potentially lead to unobserved heterogeneity and biases of the estimates in the developed model. However, this novel modelling approach facilitates useful implications for construction research, and practice in the Sri Lankan construction industry given that it is high time to rethink effective measures to enhance the construction industry's performance while boosting the whole economy.

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NEED OF ESTABLISHING DESALINATION PLANTS TO MITIGATE WATER SCARCITY IN DRY ZONES OF SRI LANKA

Y.J.M. Yatawatta[1] and P. Sridarran[2]

ABSTRACT

This research study aims to explore the necessity of implementing desalination plants as a solution to address water scarcity in the dry zones of Sri Lanka. Water sustainability is crucial for ensuring the availability and preservation of water resources to meet the needs of current and future generations. Various innovative methods, including rainwater harvesting, irrigation efficiency, sewage water treatment, and desalination, have been employed to minimise water scarcity. Desalination, in particular, plays a vital role in meeting the growing water demands by removing salt and harmful elements from drinking water, making it safe for consumption. The primary objective of this research is to identify the specific need for desalination plants in the dry zones of Sri Lanka, while also examining the underlying reasons for water scarcity in the region. The methodology employed in this study involves template analysis, utilising data collected through expert surveys. Six experts were selected for semi-structured interviews, ensuring saturation in information gathering. The findings of this research reveal nine crucial factors that necessitate the implementation of desalination plants in the dry zones of Sri Lanka. These factors include irrigation inefficiency, groundwater depletion, the prevalence of waterborne diseases, insufficient rainwater harvesting systems, limitations in current water distribution methods, the impact of climate change, population growth, and challenges faced by industries operating in the region. The findings underscore the importance of implementing appropriate strategies to mitigate water scarcity and ensure a reliable and secure water supply for the region's present and future needs.

Keywords: *Desalination; Diseases; Dry Zone; Irrigation; Water Scarcity.*

1. INTRODUCTION

One of the most critical problems of the twenty-first century is water scarcity (Food and Agriculture Organisation [FAO], 2018). Water scarcity arises when the demand for fresh water in a given domain exceeds the supply (FAO, 2012). White (2014) stated that water scarcity is insufficient water availability for human and environmental uses and it is being recognised as a serious and growing problem in the world. Water scarcity currently affects more countries worldwide (Srinivasan et al., 2012). South Asia is a hotspot of water scarcity (Asia Development Bank [ADB], 2017). Abeysingha and Rajapaksha (2020) identified that water scarcity had been the most significant and natural hazard in the DZ

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of Sri Lanka in terms of the people affected. The DZ of Sri Lanka faces a range of water-related issues due to environmental and socio-economic complexities (Bandara, 2003). The authors highlight the presence of extreme water scarcity in the DZ and attribute it to various factors. Irrigation inefficiency is a major reason for water scarcity in DZ (Jayasekara, 2017). Climatic changes are one of the reasons for water scarcity in Sri Lanka (Dissanayake, 2005). Jayasekara (2017) argues that harvesting is only done seasonally, which is not a good solution for a DZ situation because water scarcity only occurs during the dry season. Moreover, consuming contaminated groundwater could cause various illnesses, some of which can be deadly, such as dental fluorosis and chorionic kidney diseases (CKD) (World Health Organisation [WHO], 2004).

Introduces large-scale, water sustainable innovative methods for minimising water scarcity (Islam et al., 2018). Rainwater harvesting systems, desalination, sewage treatment, and irrigation efficiency as currently using innovative water sustainable methods (Islam et al., 2018) However, some problems were identified related to the innovative techniques. Desalination is becoming a more efficient method of supplying fresh water in many countries where it is scarce (Islam et al., 2018). Desalination of salt water is the most practical method for solving water scarcity because seawater contains 97% of the world's water and 3% of the world's water resources are immediately accessible drinking water (Islam et al., 2018). Desalination can produce water for drinking purposes and agricultural purposes (Jayasekara, 2017). So, as a result, Sri Lanka is an island covered in oceans. Hence this study will identify the need for desalination for the DZ.

2. LITERATURE REVIEW

2.1 WATER SUSTAINABILITY

Water sustainability can be defined as the ability to manage water resources in a manner that meets the needs of present and future generations while ensuring the preservation of ecosystems (United Nations Educational, 2018). Solarimpulse Foundation, (2021) stated that water scarcity could be significantly reduced if there is a focus on making large-scale, innovative methods like rainwater harvesting systems, desalination technology, sewage treatment, and irrigation efficiency, which are discussed below.

- **Rainwater Harvesting System**

Rainwater harvesting refers to the technique of diverting, capturing, and storing precipitation that falls on a site for on-site consumption rather than allowing it to run off, evaporate, or infiltrate into the soil (Bottom, 2016). Raheem (2020) argues that rainwater harvesting is limited for the countries because of insufficient rainfall, mosquito growth and waterborne diseases.

- **Sewage Treatment**

Wastewater reuse is the process of turning wastewater into water that may be reused for various uses while removing contaminants from sewage (Kümmerer et al., 2016). Shakir et al. (2017) argue that because of health concerns, water-borne infections and skin irritations can occur in those who come into direct contact with reused wastewater. However, sewage water is not suitable for drinking purposes; that water is only suitable for agricultural and irrigation uses.

- **Irrigation Efficiency**

In the agriculture industry, simply switching from flood irrigation to sprinkler or drip irrigation could save a large amount of water (Waterlogic, 2017). When combined with improved soil management practices, which reduce evaporation from the soil, efficient irrigation systems can significantly reduce water usage (Waterlogic, 2017). Hansen (2020) argues that some health concerns developed due to irrigation efficiency technology, and water is best suited for agricultural needs, not for humans.

- **Desalination**

Desalination is a broad term for removing dissolved particles and producing freshwater from various feed fluids, including seawater (Islam et al., 2018). Seawater provides a seemingly limitless, consistent supply of high-quality water while preserving natural freshwater ecosystems (Elimelech & Phillip, 2011; Islam et al., 2018). Desalination is one of the water sustainability methods (Islam et al., 2018).

2.2 DESALINATION AS THE WATER SUSTAINABILITY

Sustainable water management refers to meeting current water needs without compromising future generation’s ability to do so (Saavedra et al., 2021). Natural and artificial activities are quickly depleting freshwater supplies; however, Desalination is becoming a more popular water sustainable method of supplying fresh water in many countries (Peñate & García-Rodríguez, 2012). Elimelech and Phillip (2011) stated that several large-scale sustainable desalination facilities had been developed in water-stressed countries in recent years to supplement limited water resources, and additional desalination plant building is likely to expand in the near future. Around the world, seawater desalination is used at 67% of the installed capacities (Islam et al., 2018). The number of desalination plants and daily water production grew by 12.4% to 41.2% between 2016 and 2019 (Saavedra et al., 2021).

2.3 NEED OF DESALINATION TO MINIMISE THE WATER SCARCITY IN THE DZ OF SRI LANKA

According to Sri Lanka, the country is divided into two principal divisions based on annual precipitation of 1,875 mm: DZs, which account for around 70% of the country, and wet zones, which account for the remaining 30% (Ichikawa, 2012). Here discussed the needs of desalination for Sri Lanka.

2.3.1 Irrigation Inefficiency

Agriculture, forestry, and fisheries produce about 8.4% of the country's GDP, with agricultural workers accounting for 58% of the workforce involved in economic activities in 2020 (World Bank [WB], 2020). The DZ’s produce around 40% or more of Sri Lanka's annual agriculture production (Ministry of Agriculture & FAO, 2017). Abeywardana et al., (2019) stated that the tank-based irrigation system is one of the world's oldest irrigation techniques used in Sri Lanka.

In 2002, there were 15,373 tanks in the DZ (Panabokke et al., 2002). By 2006, there were less than 14,950 minor tanks (Imbulana et al., 2006). In 2017, approximately 14,200 tanks were used for irrigation in agricultural areas (Ministry of Agriculture & FAO, 2017). Most of the farmers face water problems because of irrigation inefficiency (Burchfield &

Gilligan, 2016). During dry seasons, a significant number of irrigation systems experience drought conditions, resulting in inadequate water availability for daily activities and agricultural purposes (Burchfield & Gilligan, 2016). As a consequence, many individuals face numerous challenges and difficulties due to the inefficiency of irrigation systems in dry zone.

2.3.2 Rainwater Harvesting

Numerous technologies and techniques are available to help a country's water sector, such as the 3R process (Reuse, Reduce, and Recycle), including rainwater harvesting (Sayanthan et al., 2017). In 1998, Rainwater harvesting was promoted by the Sri Lankan government and non-governmental organisations, and the technology has since spread to Sri Lanka (Ariyananda et al., 2011). In 1998, the president was personally involved in rainwater collecting, and the water board built 73 rainwater collection systems in Kandy and Yatinuwara (Ariyananda et al., 2011; Jayasekara, 2017). However, there are currently 23 institutions involved in this, with nearly 32000 projects in operation (Jayasekara, 2017). Jayasekara (2017) argues that harvesting is only done seasonally, which is not a good solution for a DZ situation because water scarcity only occurs during the dry season. Further, Sayanthan et al. (2017) argue that Sri Lanka's population is growing day by day, and rainwater collecting is insufficient to meet the needs of the DZ of Sri Lanka. The harvesting water could be stagnant and infected with microbial activity, and in such instances, a preventative strategy should be implemented (Jayasekara, 2017).

2.3.3 Groundwater Depletion

Groundwater is a critical natural resource for life, and it is used extensively in the drinking, industrial, agricultural, and domestic sectors. In Sri Lanka, over 60% of the population drinks groundwater from shallow drilled wells (Mahagamage & Chinthaka, 2015). According to Sri Lanka, water pollution and overexploitation intrusion are the leading causes of groundwater depletion (Chandrajith et al., 2012). The former is highly transparent in DZ, and nitrate concentrations exceeding 200 mg per litre are reported (United Nations Educational, 2018). In the regions of Puttalam, Mannar, Kilinochchi, and Mullaithivu, overexploitation and saltwater intrusion are prevalent issues. This is because the wells in these areas are currently yielding low-quality groundwater, rendering it unsuitable for drinking and agricultural purposes (United Nations Educational, 2018). Additionally, the rapid exploitation of groundwater has exacerbated the strain on these already vulnerable water sources (Sayanthan et al., 2017).

2.3.4 Climate Change

Sri Lanka is divided into three main agro-climatic zones, namely wet zone (>2,500 mm), intermediate zone (2,500-1,750 mm), and DZ's (< 1,750mm) (Punyawardena, 2010). The amount of rain that falls varies significantly between seasons and years (Dissanayake, 2005). Climate change has a significant impact on human well-being and will continue to do so in the future (Esham & Garforth, 2013). Jayasekara (2017) identified some districts in Sri Lanka that received an annual average rainfall of less than 1,000 mm, classifying them as areas with extreme water scarcity districts in DZ. Drought has affected the DZ in years such as 2001, 2004, 2016, 2017, and 2018 (Alahacoon & Edirisinghe, 2021).

2.3.5 Diseases

Groundwater is essential for rural water supply (Chandrajith et al., 2012). However, water quality is poor in some districts, such as the DZ and near coastal areas (Jayasekara, 2017).

Because of that, calcium, fluoride, magnesium, sodium/potassium type, and non-dominant are found in Sri Lankan groundwater (Dissanayake, 2005). Consumption of contaminated water can cause various illnesses, some of which can be death (Jayasekara, 2017).

- **Dental fluorosis**

Dental fluorosis is a disorder in which the look of tooth enamel deteriorates (National Center Chronic Disease Prevention and Health Promotion [NCCDPHP], 2019). Dental fluorosis may occur if children drink fluoride regularly during their teeth-forming years, ages eight and younger (NCCDPHP, 2019). In the beginning, teethes are discolouration and even browning becomes obvious, and the enamel becomes eroded, pitted, rough, and difficult to clean (Jayasekara, 2017).

Table 1: WHO guideline for fluoride in drinking water

Concentration of fluoride (mg/L)	Impact on health
0.0 − 0.5	Limited growth and fertility, dental caries
0.5 − 1.5	Promotes dental health, prevents tooth decay
1.5 − 4.0	Dental fluorosis (mottling of teeth)
4.0 − 10.0	Dental fluorosis, skeletal fluorosis (pain in back and neck bones)
> 10.0	Crippling fluorosis

Source: (WHO, 2004)

The optimal fluoride level in Sri Lankan groundwater for caries protection is 0.6 - 0.9 mg/L (Chandrajith et al., 2012). Due to the use of high-fluoride groundwater, millions of people in Sri Lanka's DZ are at risk of developing some diseases Dental fluorosis skeletal fluorosis (Chandrajith et al., 2012; Jayasekara, 2017).

- **Chronic kidney disease (CKD)**

Around 500 people die each year in DZs of Sri Lanka from chronic kidney disease (CKD), which is thought to be caused by arsenic and cadmium contamination in groundwater due to agricultural pesticides (Jayasekara, 2017). CKD is a common serious health problem, with 3 - 4% of the population suffering in several villages (Jayasekara, 2017). In Sri Lanka, the emergence and prevalence of CKD with Unknown Aetiology among residents of North Central (Gunatilake et al., 2015).

2.3.6 Contemporary Water Distribution Methods

Some DZ areas are in the courtyards during the draught season to compete for water (Ariyananda et al., 2011). Water availability decreases due to population growth, limited water resources, and climatic changes, while water demand increases (Ariyananda et al., 2011). The National Water Supply and Drainage Board (NWSDB) developed a distributing of fresh, pure water by trucks and storing it in tanks of 100 litres capacity for common use by people in DZ districts, which is high in fluoride and suffers from Chronic Kidney Disease (Jayasekara, 2017). This is not a long-term solution for a community water supply because water distribution is uncontrollable and on a first-come, first-served basis (Jayasekara, 2017).

2.3.7 Population Growth

Between 2012 and 2016, the total population of Sri Lanka grew at an increasing rate of 0.42% (Sayanthan et al., 2017). As a result, water and food production demands are also increasing (Ministry of Agriculture & FAO, 2017). Groundwater is under additional stress due to the growing population (Sayanthan et al., 2017).

2.3.8 Industries Related Problem

The water scarcity problem in the DZ region affects various industries including hotels, commercial, manufacturing, and residential buildings (Chandrajith et al., 2012). Most sectors used ground water, which is under additional stress due to rapid exploitation and growing population (Sayanthan et al., 2017). The hotel industry is the most affected by water scarcity in DZ (International Finance Coorporation (IFC), 2013). Some hotels use bore wells and wastewater treatment plant water for gardening and laundry because that NWSDB supplied water is insufficient (IFC, 2013). However, there are health concerns associated with the reuse of wastewater (Shakir et al., 2017). The hotels also spend more money on purchasing bottled water for drinking (IFC, 2013). Therefore, plastic bottles are harmful to health, wildlife, and the environment (Mers, 2019). Some buildings have implemented rainwater harvesting (Lo & Koralegedara, 2015). During the dry season, hotels have to restrict their water consumption due to water scarcity (IFC, 2013). Desalination is a common solution for both people and industries to minimise water scarcity in the DZ region (Dasinaa & Delina, 2016)

3. METHODOLOGY

The comprehensive literature review to explore innovative water sustainable methods and propose desalination as a viable solution for addressing the water needs of the DZ. To conduct the literature review, books, journals, conference proceedings, dissertations, reports, newspapers, magazines, websites and government publications were used as sources. An expert survey was conducted to gather data from professionals with extensive experience in the field of water resource management in Sri Lanka. Six experts were chosen for the interviews, as they indicated that the information provided by additional participants would likely yield redundant findings, reaching a point of saturation. These experts collectively possessed over 20 years of experience in the field, with specific expertise in desalination spanning 5-10 years. These experts are directly involved with the Jaffna desalination plant, which is the first and only largest plant installed in Sri Lanka. Semi-structured interviews were selected as the data collection method to allow for flexibility in exploring participants' knowledge, insights, and experiences related to the need for desalination plants. A qualitative research approach was adopted to gain an in-depth understanding of the complex factors contributing to water scarcity and the need for desalination plants in Sri Lanka's dry zones. This approach enabled the exploration of participants' perspectives, experiences, and expert knowledge, providing valuable insights into the research problem. By employing qualitative methods, this study aimed to capture nuanced information that quantitative methods alone may not fully capture. Template analysis was chosen as the analytical framework for analysing the expert survey data. This method involves developing a coding template or a set of pre-established themes based on the research objectives and relevant literature. The template served as a structured guide to organise and categorise the data obtained from the interviews. Table 2 presents a profile of experts of the expert survey.

Table 2: Profile of experts

No	Interview code	Designation	Year of experience	Year of experience for the desalination
1	R1	Assistant General Manager	21	10
2	R2	Water Treatment Specialist	29	9
3	R3	Water Treatment Specialist	23	9
4	R4	Engineer	25	10
5	R5	Engineer	24	9
6	R6	Engineer	26	10

4. DATA ANALYSIS AND FINDINGS

4.1 IDENTIFY THE NEED OF IMPLEMENTING DESALINATION FOR THE DZ OF SRI LANKA

The need for implementing desalination was first identified from the literature (Section 2.4) and then refined based on the expert's opinions. Water scarcity is a growing problem in the DZ of Sri Lanka. Interviewee R1 stated, "*Most North and North-Central provinces face huge effects because of water scarcity"*. Currently, on top of a breakdown at the Norochcholai coal power plant, there are insufficient water levels in reservoirs for hydropower generation because of water scarcity (Jayasinghe, 2022). Interviewee R2 identified DZ districts with extreme seasonal or year-round water scarcity, such as Ampara, Anuradhapura, Batticaloa, Kurunagala, Hambantota, Jaffna, Killinochchi, Kurunegala, Mullaitivu, Polonnaruwa, Puttalam, Trincomalee, Mannar and Vavunia. According to experts, DZ currently has a water scarcity problem. In the future, it will be badly impacted to Sri Lanka. Interviewee R5 suggested, "*If the government wants to minimise water scarcity, Government should consider new technologies like desalination"*. Currently, Sri Lanka needs more alternative methods to minimise water scarcity. Interviewee R4 stated, "*Desalination is most suitable for Sri Lanka because of the location*". Sri Lanka is an island and Sri Lanka has open access to seawater. Hence, desalination is one of the best solutions to minimise the water scarcity of DZ. Through a comprehensive literature review, the criteria necessitating the implementation of desalination in the dry zone of Sri Lanka have been identified. This section examines the expert opinions and ideas concerning the identified needs outlined in the literature.

4.1.1 Irrigation Inefficiency

In ancient times, irrigation systems were designed to save rainwater collected during the short rainy seasons to maintain water supplies for human needs. Interviewee R2 identified, "*In 2007; there were 33,000 tanks in Sri Lanka's DZ; by 2021, the remaining tanks would be less than 10,000"*. According to that, most of the irrigations were left. Interviewee R5 stated "*The reason for the irrigation inefficiency is the government's poor water storage, poor maintenance, and poor water management"*. The interviewee R5 identified, most of the tanks in DZ are mostly maintained by village-level farmer organisations, not the government. The government implements several projects to increase irrigation efficiencies, such as the Mahaweli Authority of Sri Lanka, Malwathuoya, Daduru Oya, Manik Ganga and Rambukanaoya projects. Further, Interviewee R6 mentioned that "*The government started several projects to cover several* *areas of the DZ, but until any projects are not completed. The previous government started some projects, but projects were not complete until then*". MASL is the largest irrigation project in Sri Lanka. Currently, MASL project's primary purpose is the provide water for the hydropower plant. Interviewee R3 mention that "*If government improve the MASL project and Malwathu Oya project can minimise the water scarcity of Anuradhapura, Polonnaruwa and Mannar districts"*. The Asian Development Bank (ADB) is assisting Sri Lanka with a large government water resources project to redirect untapped water from the Mahaweli River. This is the country's largest river basin, with headwaters in the southern wet zone. The government hopes to finish the MASL project in 2024. Interviewee R6 specified that "*If the government increased the efficiency of Manik gaga project, can be covered some districts of the southern province which faced water scarcity"*. According to the interviewees, when developing the irrigation system of Sri Lanka, the government can minimise the inside of the country's water scarcity.

4.1.2 Rainwater Harvesting

The government established the rainwater harvesting project in 1998. Rainwater harvesting is collecting and storing rainwater rather than letting it flow off. Interviewee R6 explained, "*The NWSDB is responsible for over 32,000 rainwater collection systems in the DZ of Sri Lanka"*. Interviewee R1 mentioned that "*Rainwater harvesting plants are established in the wet zone. It pumps to the DZ for consumption"*. Interviewee R2 argues that *"It is not 100% acceptable for minimising water scarcity for the DZ"*. Further, Interviewee R3 specified that "*Most people in DZ establishing domestic rainwater plant to fulfil their requirements"*. Rainwater harvesting is not the 100% supportive method for the DZ of Sri Lanka. The interviewees R1 and R2 argue that Rainwater harvesting is insufficient for living in one year because the rainy season is coming in once a year for the DZ. According to the DZ, the rainy season is coming from December to March. Interviewees R1, R2, and R6 stated that rainwater harvesting could cover basic human needs and is insufficient to do agriculture. Additionally, Interviewee R6 stated that "*When using the rainwater harvesting method needs to be a supporting method like developing irrigation"*. As a result of the final discussion, rainwater harvesting is not a 100% possible solution for minimising the water scarcity in DZ.

4.1.3 Groundwater Depletion

Groundwater is used for drinking, industrial, agricultural, and domestic purposes in the DZ. Over 60% of Sri Lanka's population drinks groundwater from the wells. Interviewee R6 mentioned that "*Water quality is considerably low in the DZ and coastal areas"*. All interviewees identified that salinity, hardness, fluoride, and agricultural pesticides lead to poor groundwater quality in the DZ of Sri Lanka. Interviewee R5 confirmed that "*There would be groundwater depletion in the future"*. Interviewee R1 identified "*Population growth and the complexity of human needs"* as reasons for groundwater depletion. Interviewee R2 identified, *"Deforestation is the main reason for groundwater depletion in Sri Lanka"*. Interviewee R3 stated "*Most industries discharge their wastewater into water sources"*. Groundwater is water that seeps into the earth and collects. The leading cause of ground depletion is water pollution. According to the final discussion, there will be groundwater depletion in the future because of deforestation, population growth, increasing human needs and water pollution.

4.1.4 Diseases

Many people have faced some diseases because of the lack of pure groundwater. Most people in DZ consume groundwater for drinking purposes. Interviewee R3 stated "*Kidney illness is frequent in many Sri Lanka's DZ regions, particularly in the North Central Province. Recently, chronic renal failure has risen in Anuradhapura and Polonnaruwa districts".* Interviewees R1, R2, R4 and R5 indicated that most people are affected by Dental fluorosis, skeleton fluorosis and skin allergies because of the lack of pure water. Interviewee R3 stated, *"CKD has affected around 150,000 people in Sri Lanka".* Interviewees R2, R3 and R6 identified one of the reasons for the diseases is the high Total Dissolved Solids (TDS) rate of the groundwater and drinking fluoride water without filtration. Calcium, fluoride, magnesium, sodium, potassium type, and nondominant are all present in Sri Lankan groundwater; as a result of this, contaminated water can induce a variety of illnesses, some of which can be dangerous.

4.1.5 Current Distribution Methods

Interviewee R3 stated that "*Some people walk too far to find pure water".* People are time-consuming to find pure water sources in DZ. Currently, the NWSDB uses several methods to fulfil human needs. Interviewee R6 stated, *"The NWSDB supplies fresh water to villagers via trucks, which were then stored in tanks with a capacity of 100 litres".* Interviewee R5 argues that *"NWSDB supplying water is insufficient to fulfil all needs of the people and it was just temporary solution".*

4.1.6 Population Growth

The population growth rate of Sri Lanka is 0.39%. Interviewee R1 identified that *"Population growth and the complexity of human needs are reasons for water scarcity in DZ of Sri Lanka".* According to the interviewees, population growth is increasing day by day. As a result, basic human needs will increase. Due to groundwater depletion, deforestation, and water pollution, water demand will increase in Sri Lanka.

4.1.7 Climate Change

Climate change is the main reason for the water scarcity in Sri Lanka. Interviewee R3 identified that *"The DZ got the rain from December to March".* That water is insufficient to fulfil their human needs. Most of the people do agriculture in the DZ. Interviewee R6 mentioned that "*The Mannar district and a part of the Hambanthota district receive less than 1000 mm of rainfall on average, and are classified as places of severe water scarcity".* According to the interviewees, the main reason for water scarcity is climate change.

4.1.8 Water Problem in Industries

The water scarcity affected the industries which are situated at the DZ. Interviewee R6 stated, "*Most hotels, hospitals, and manufacturing companies are affected by water scarcity".* However, interviewees R1, R2, R5 and R6 explained most industries were affected by water scarcity in the past, but nowadays, many industries established minor BWRO (Brine Water Reverse Osmosis) or SWRO (Sea Water Reverse Osmosis) to supply their water requirements in the dry season. According to the discussion, several issues are identified regarding the water scarcity of the DZ of Sri Lanka. Interviewee R5 mentioned that "*The government should need to follow new technology to minimise water scarcity".* When considering the new technologies, desalination is the most upcoming method globally. Interviewee R6 confirmed that "*Desalination is one of the best methods to minimise the water scarcity of Sri Lanka"*.

5. DISCUSSION

One of the most significant worldwide challenges is water scarcity. By 2025, nearly two-thirds of the world population may face water scarcity (Gao et al., 2018). With the increase in the population, the scarcity of water resources to meet food production demands is a significant issue that will increase in the future (Porkka et al., 2016). Water scarcity currently affects more countries worldwide (Srinivasan et al., 2012). Currently used innovative methods to mitigate water scarcity, including rainwater harvesting, irrigation efficiency, sewage water treatment, and desalination have been identified in the literature. Desalination is widely used as it is seen as a sustainable, cost-efficient and energy-efficient method (Islam et al., 2018).

Abeysingha and Rajapaksha (2020) identified that water scarcity had been the most significant and natural hazard in the DZ of Sri Lanka in terms of the people affected. The Interviewee R2 identified some districts experiencing extreme seasonal or year-round water scarcity in the DZ, such as Ampara, Anuradhapura, Batticaloa, Kurunagala, Hambantota, Jaffna, Killinochchi, Kurunegala, Mullaitivu, Polonnaruwa, Puttalam, Trincomalee, Mannar and Vavunia. The literature, identified the need of desalination for DZ of Sri Lanka such as irrigation inefficiency, insufficient rainwater harvesting, groundwater depletion, climate change, population growth, and industries-related issues. According to the irrigation efficiency, Interviewee R5 stated "*The reason for the irrigation inefficiency is the government's poor water storage, poor maintenance, and poor water management"*. All interviewees mentioned that when developing the irrigation system of Sri Lanka, the government can minimise the inside of the country's water scarcity. The Literature review identified rainwater harvesting in Sri Lanka. Interviewee R1 mentioned that "*Rainwater harvesting plants are established in the wet zone. It pumps to the DZ for consumption".* Interviewee R2 argues that *"It is not 100% acceptable for minimising water scarcity for the DZ".* The interviewees R1 and R2 argue that Rainwater harvesting is insufficient for living in one year because the rainy season is coming in once a year for the DZ. Groundwater depletion is another reason for water scarcity in Sri Lanka. According to the interviewees, there will be groundwater depletion in the future because of deforestation, population growth, increasing human needs and water pollution. Many people have faced some diseases because of the lack of pure groundwater. Most people in DZ consume groundwater for drinking purposes. According to the interviewees, some diseases arise in the DZ, such as dental fluoride, skin allergies, chronic kidney diseases (CKD), renal failure, and skeleton fluorosis. Interviewee R3 stated, *"CKD has affected around 150,000 people in Sri Lanka".* When discussing about the current distribution methods, Interviewee R6 stated, *"The NWSDB supplies fresh water to villagers via trucks, which were then stored in tanks with a capacity of 100 litres".* Interviewee R5 argues that *"NWSDB supplying water is insufficient to fulfil all needs of the people and it was just temporary solution."* Interviewee R1 identified that *"Population growth and the complexity of human needs are reasons for water scarcity"*. Climate change is the main reason for the water scarcity in Sri Lanka. Interviewee R3 identified that *"The DZ got the rain from December to March"*. That water is insufficient to fulfil their human needs. Interviewee R6 stated, "*Most hotels, hospitals, and manufacturing companies affected water scarcity"*. R1, R2, R5 and R6 explained most industries affected water scarcity in the past, but nowadays, many industries established minor BWRO or SWRO to supply their water requirements in the dry season. According to the discussion, several issues are identified regarding the water scarcity of the DZ of Sri Lanka. Interviewee R5 mentioned that "*The government should need to follow new technology to minimise the water scarcity*". Additionally, all interviewees highlighted the significant challenge faced by Sri Lanka in establishing desalination plants, which is the high cost involved. The economic crisis further exacerbates the difficulty for the government in establishing such plants. However, it is important to note that the establishment of desalination plants has the potential to generate future income for the government.

Table 3 summarises the factors that have been identified through the data analysis and findings.

Table 3: Summary of research findings

Literature Findings	**Data Collections Findings**
Irrigation inefficiency	▪ The reason for the irrigation inefficiency is the government's poor water storage, poor maintenance, and poor water management. ▪ Most of the tanks in DZ are mostly maintained by village-level farmer organisations, not the government. ▪ The government started several projects to cover several areas of the DZ, but until any projects are not completed. The previous government started some projects, but projects were not complete until then. ▪ If government improves the MASL project and Malwathu Oya project can minimise the water scarcity of Anuradhapura, Polonnaruwa and the Mannar districts. ▪ If the government increased the efficiency of Manik ganga project, can be covered some districts of the southern province which faced water scarcity.
Rainwater Harvesting	▪ Rainwater harvesting is not 100% acceptable for minimising water scarcity for the DZ. ▪ Most people in DZ establish domestic rainwater plants to fulfil their requirements. ▪ Rainwater harvesting is insufficient for living in one year because that rainy season is coming in once a year for the DZ. ▪ rainwater harvesting could cover basic human needs and is insufficient to do agriculture. ▪ When using the rainwater harvesting method needs to be a supporting method like developing irrigation
Groundwater depletion	▪ Water quality is considerably low in the DZ and coastal areas ▪ salinity, hardness, fluoride, and agricultural pesticides lead to poor groundwater quality in the DZ of Sri Lanka ▪ salinity, hardness, fluoride, and agricultural pesticides lead to poor groundwater quality in the DZ of Sri Lanka. ▪ There would be groundwater depletion in the future. Because of Population growth and the complexity of human needs, Deforestation and water pollution
Current distribution methods	▪ The NWSDB supplies fresh water to villagers via trucks, which were then stored in tanks with a capacity of 100 litres. ▪ NWSDB supplying water is insufficient to fulfil all needs of the people and it was just a temporary solution."

Literature Findings	Data Collections Findings
Population Growth	▪ Population growth and the complexity of human needs are reasons for water scarcity in DZ of Sri Lanka
Climate change	▪ The DZ got rain from December to March. That water is insufficient to fulfil their human needs ▪ The Mannar district and a part of the Hambanthota district receive less than 1000 mm of rainfall on average and are classified as places of severe water scarcity. ▪ Identified DZ districts with extreme seasonal or year-round water scarcity, such as Ampara, Anuradhapura, Batticaloa, Kurunagala, Hambantota, Jaffna, Killinochchi, Kurunegala, Mullaitivu, Polonnaruwa, Puttalam, Trincomalee, Mannar and Vavunia.
Water problems in (industries)	▪ Most hotels, hospitals, and manufacturing companies are affected water scarcity. ▪ most industries affected water scarcity in the past, but nowadays, many industries established minor BWRO (Brine Water Reverse Osmosis) or SWRO (Sea Water Reverse Osmosis) to supply their water requirements in the dry season.

6. CONCLUSIONS

Water scarcity is insufficient water for human and environmental uses. It is increasingly recognised as a serious and growing problem in many countries (White, 2014). Through the literature reviewed identified rainwater harvesting, desalination, sewage treatment, and improving irrigation efficiency as a current innovative method used for minimise the water scarcity. Desalination is a most sustainable innovative method used in all over the world. Desalination is becoming a more efficient method of supplying fresh water in many countries where it is scarce. Currently, seawater desalination is deployed at 67% of the existing capacity around the world. Through the literature identified, water scarcity is a growing problem in Sri Lanka. The need for establishing desalination plants in the DZ was identified due to various factors (09) such as irrigation inefficiency, insufficient rainwater harvesting, groundwater problems, climate change, population growth, and industries related issues. These nine factors are discussed with the experts. According to an interviewee R5, identified the reason for irrigation inefficiency in Sri Lanka is due to poor water storage, maintenance, and management by the government. All interviewees agreed that by improving the irrigation system, the government could minimise the inside of the country's water scarcity. Rainwater harvesting has been identified in literature review, but interviewee mentioned it is not considered a complete solution to water scarcity due to the limited rainy season. Identified the depletion of groundwater another reason for water scarcity. The interviewees are identified, Groundwater depletion in the future is a concern due to factors such as deforestation, population growth, increasing human needs, and water pollution. Lack of pure groundwater has resulted in health issues, including dental fluoride, skin allergies, chronic kidney diseases, renal failure, and skeleton fluorosis, with CKD affecting around 150,000 people in Sri Lanka. The current supply of fresh water from NWSDB is considered insufficient. Population growth, complexity of human needs, and climate change are also contributing to water scarcity. The government is advised to adopt new technology and desalination is seen as the best method to minimise water scarcity.

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OUTSOURCING CONSULTANT QUANTITY SURVEYING ACTIVITIES DURING THE POST-PANDEMIC ERA

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ABSTRACT

The COVID-19 pandemic has left a significant impact on the survival of the global construction industry and its stakeholders including quantity surveyors. Outsourcing is recognised as a business strategy which can be tried for consultants quantity surveying organisations for surviving in the construction industry during a pandemic period. Due to the absence of previous studies that evaluated the effectiveness of outsourcing consultants quantity surveying activities in the Sri Lankan context following the pandemic, this study intends to fill the aforementioned research gap. As a result, the research was aimed at examining the feasibility of outsourcing key consultants' quantity surveying activities in the Sri Lankan context following the pandemic. A thorough literature review was carried out in order to investigate the possibility of outsourcing key consultant quantity surveying activities in Sri Lanka during the post-pandemic era. To achieve the goal of this research, a mixed-method approach with structured expert interviews and a questionnaire survey was used. Thematic analysis using QSR Nvivo version 12 software and the RII method was used to analyse the data. The most suitable activities for outsourcing in Sri Lanka during the post-pandemic era were identified as BIM model creation, BOQ preparation, and BOQ verification. The study's findings revealed the possibility of outsourcing the quantity surveying activities of consultants in Sri Lanka during the post-pandemic era. Furthermore, the findings of this study can be used to identify prevalent motivating factors for introducing or improving the outsourcing concept as well as to put into practice within consultant quantity surveying organisations.

Keywords: *Consultant Quantity Surveying Activities; Outsourcing; Post-Pandemic Era.*

1. INTRODUCTION

A high degree of risk is common in the construction industry due to its nature, work processes, construction environment and organisational culture (Goh & Abdul-Rahman, 2013). Furthermore, the construction industry is facing different types of risks such as technical, construction, physical, organisational, financial, environmental and socio-political (Mhetre et al., 2016). The COVID-19 pandemic, which just hit the world, has

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altered every aspect of the regular system and it can be identified as a risk to construction projects (Ogunnusi et al., 2020). Alsharef et al. (2021) mentioned that the construction industry was also impacted as a result of the high economic impact generated through COVID–19 pandemic. Consequently, quantity surveyors too faced some negative impacts due to COVID-19 (Ogunnusi et al., 2021).

Several surviving strategies used by the firms in the post-pandemic situation can be identified as outsourcing, improved service delivery, reduction of company overheads and workforce training (Jayalath & Gamage, 2021). Outsourcing has emerged as a strategic decision in the industry when achieving the required quality and reducing the cost and time duration of the project in the post-pandemic period (Erickson & Norlander, 2021). Furthermore, it is supported by Aburumman (2020), who elaborated that outsourcing is the optimal solution for recovering and surviving. Though the term "outsourcing" is the most famous concept in the industries, it is not much popular in the construction industry in past (Ranasinghe et al., 2019).

Being an important stakeholder in the construction industry by managing the project's cost components, quantity surveying firms are facing the same issues as other industries as a result of the pandemic (Badu & Amoah, 2004). Most of the quantity surveying jobs have been outsourced due to the common advantages identified such as time and cost-savings (Beaumont & Sohal, 2004). Moreover, according to researchers, outsourcing has been identified as the third-best survival strategy after the COVID-19 pandemic in quantity surveying firms in the Gulf region (Jayalath & Gamage, 2021).

Though there are studies on the effectiveness of outsourcing in other industries such as information technology, no previous studies evaluated the effectiveness of outsourcing consultants quantity surveying activities in the Sri Lankan context during the post-pandemic era as the industry recovers from the critical period. Thus, this study intended to fill the said research gap in the industry.

Accordingly, the aim was set as to investigate the possibility of outsourcing key consultants quantity surveying activities in Sri Lanka during the post-pandemic era. Reviewing the concept of outsourcing related to the construction industry, identifying the key drivers for outsourcing consultant quantity surveying activities during the post-pandemic era and investigating the activities that can be effectively outsourced within the context of consultancy quantity surveying firms in Sri Lanka during the post-pandemic era were the three objectives that formed to achieve the research aim.

2. LITERATURE REVIEW

2.1 ROLE OF QUANTITY SURVEYORS IN THE CONSTRUCTION INDUSTRY

Olanrewaju (2016) mentioned that a construction project is a team and several professionals are involved with a single project such as the client, construction professionals, design professionals and operational team. Olanrewaju (2016) further identified those professionals as key stakeholders in the construction industry.

The quantity surveyor plays a vital role in construction projects providing value for money (Olanrewaju, 2016). Providing preliminary cost advice, preliminary cost planning, risk analysing services, provide value engineering, value planning and value management services were revealed as quantity surveying activities by Cartlidge (2018). In addition to that, the role of quantity surveyors is involved in the whole life cycle of the project in the stages of design, construction, maintenance, refurbishment, extension and demolition (Olanrewaju, 2016).

2.2 SURVIVAL STRATEGIES DURING THE POST-PANDEMIC ERA

This pandemic impacted many industries in Sri Lanka, including the construction industry. Pathirana (2020) stated that the construction industry in Sri Lanka was completely shut down after March 23rd, 2020, due to health regulations to control the situation COVID-19 has a significant impact on the construction industry, including material damage, high rental costs for offices spaces, idle plant and machinery, the risk of bankruptcy, the risk of contract termination, and the risk of employee termination (Vithana et al., 2020).

Despite the fact that all industries have been affected by the Covid-19 pandemic, they must find a way to continue operations while minimising the impact without going bankrupt (Gamil & Alhagar, 2020). In line with that, Haynes et al. (2019) mentioned that innovations and inventions have a greater contribution to surviving during a crisis period. According to Alves et al. (2020), entering into new markets, learning new things and product diversification can be identified as business survival strategies in a crisis period.

Among the limited literature on business survival during the pandemic era (Abubakar, 2020), more researchers are concerned about survival through innovation and inventions (Jayalath & Gamage, 2021). In addition to that, it has recommended some flexible human resource strategies (Abed, 2022). Besides, Olufemi (2020) has highlighted that government can help industries to survive this situation by easing credit terms and reducing interest rates and tax payments.

New infrastructure investment and other economic recovery stimulus policies, internet and instant communication technology eased communication barriers caused by the epidemic, government tax relief and subsidies from the government were identified as strategies to mitigate the impact of COVID-19 on the construction industry (Wang et al., 2022). Construction companies also moved to remote work policies for professional activities through digital platforms such as Zoom (Butterick & Charlwood, 2021). Furthermore, Jayalath and Gamage (2021) stated that those methods are more effective from the consultant perspective which is done based on computer aid software and the work-from-home concept.

According to Jayalath and Gamage (2021), the major survival strategies that are practised in quantity surveying forms within the gulf region are working from home, decentralised decision-making, improving networking, retaining existing staff and outsourcing. In addition, according to Aburumman (2020), the optimal solution for survival has been identified as outsourcing.

Table 1 presents the summary of survival strategies that can be used during the post-pandemic era.

Table 1: Summary of survival strategies for the post-pandemic era

Rank	Strategy	References
1.	Work from home	(2)
2.	Decentralised decision making	(2)
3.	Improving networking	(2), (3)
4.	Retaining existing staff	(2),

Rank	Strategy	References
5.	Outsourcing	(2), (1)
6.	Reducing the costs of transactions	(2), (3)
7.	Minimising overhead cost	(2), (3)
8.	Using virtual technology	(2)
9.	Improving service delivery	(2)
10.	Improving organisational structure	(2)
11.	Using social media platforms	(2)
12.	Use innovative ideas	(2)
13.	Going after work in new areas	(2)
14.	Obtaining loan and tax concessions	(2)
15.	Provide training to the workforce	(2)
16.	Diversifying the competing areas	(2)
17.	Mergers, acquisitions, and joint ventures	(2)
18.	Staff layoff	(2), (3)
19.	Fewer service charges	(2), (3)
20.	Provide discounts to customers	(2), (3)
21.	Effective knowledge management	(2)
22.	Family involvement	(2)
23.	Coopetition	(2)
24.	Evaluation and accounting of the existing projects	(3)
25.	Changing distribution channels	(3)
26.	Stop hiring temporary employees,	(3)
27.	Reduce bonuses and rewards to existing employees	(3)

(1)- (Aburumman, 2020)/ (2)- (Jayalath & Gamage, 2021)/ (3)- (Namarathna & Gunarathna, 2022)

2.3 CONCEPT OF OUTSOURCING

The concept of outsourcing was born in 1950 in America (Verroiopoulos & Sfakianaki , 2015) but it was formally initiated as a strategy in 1989 (Kalinzi, 2016). Outsourcing is distinguished from contracting and subcontracting because outsourcing refers to the long-term relationship including the high degree of sharing risk while contracting and subcontracting refer to providing a task job on a job basis to an outside party (Baatartogtokh et al., 2018).

According to Oshri et al. (2015), the main three types of outsourcing methods can be identified as total outsourcing, selective outsourcing and transitional outsourcing. Furthermore, outsourcing can be divided into two major types: temporary and permanent. Based on requirements temporary outsourcing is used to fulfil the short-term requirement of staff while permanent outsourcing is used to fulfil the long-term strategies of the organisation (Ketler & Willems, 1999). In addition to that, it can be simply categorised as domestic and international outsourcing based on the method of work carried out whether it is locally or internationally (Chongvilaivan et al., 2009).

2.4 APPLICABILITY OF OUTSOURCING TO THE CONSTRUCTION INDUSTRY

Outsourcing become the most common practice in many industries in the past decade (Sattineni, 2008). Sattineni (2008) further stated that the construction industry involves with this outsourcing concept for the past ten years. Nowadays, outsourcing is an efficient and economical method for the complex nature of construction projects (Arditi & Chotibhongs, 2005). However, it can lead to additional costs, delays, less quality and project failure with inappropriate methods (Lee et al., 2009).

When considering the profession of a quantity surveyor, the quantity surveyor works under both client and the contractor in providing expert advice (Badu & Amoah, 2004). The consultant group has more options for quantity surveying activities such as in-housing, outsourcing, out-tasking and partnerships (Beaumont & Sohal, 2004). Moreover, Assaf et al. (2011) revealed that outsourcing is the best option for non-core business activities in consultant quantity surveying activities.

2.5 KEY DRIVERS TO IMPLEMENT OUTSOURCING IN THE CONSTRUCTION INDUSTRY

The outsourcing process should be well planned because it is a risky decision (Blumberg, 1998). According to Hassananin et al. (2011), it is important to identify the key drivers affecting outsourcing decisions. According to Pratap (2014), drivers for outsourcing are access to innovation, cost benefits and expertise capabilities. Assaf et al. (2011) further categorised the drivers for outsourcing decisions into six categories as strategic, economic, management, technological, quality and functional factors.

Kremic et al. (2006) highlighted that access to world-class capabilities, risk sharing with contractors and freeing resources for core activities are the strategic factors to utilise outsourcing. Saving the overall cost is the key economic driver behind the outsourcing decision because that is the major goal of the organization (Assaf et al., 2011; Kremic et al., 2006). According to Cronin et al. (2004), Djavanshir (2005) and Assaf et al. (2011), the overall cost can be reduced by reducing the labour cost, material cost and management cost. Kremic et al. (2006) mentioned that the cost of in-house services is higher than outsourcing because outsourcing is not comprised of fixed costs. Assaf et al. (2011) and Jain and Natarajan (2011) reported that saving management time is a key management factor in outsourcing. Furthermore, Assaf et al. (2011) revealed that service quality is the key quality driver for outsourcing decisions where the lack of equipment, tools and technology to carry out the tasks is the key technological driver in moving towards outsourcing.

2.6 CONSULTANT QUANTITY SURVEYING ACTIVITIES THAT CAN BE OUTSOURCED

As per Chong et al. (2012), the majority of traditional and non-traditional quantity surveying activities can be outsourced. Furthermore, Abdul-Aziz and Ali (2004) mentioned that frequently outsourced consultant quantity surveying activities include the preparation of preliminary cost plans, preparation of BOQ, preparation of tender estimate, tender evaluation, preparation of contract documents, providing cost advice, providing advice on contracts, preparation of work progress evaluation, evaluating work variation and completing final accounts.

Ranasinghe et al. (2019) identified nine (9) key quantity surveying activities that can be outsourced as preparation of BOQ, preparation of cost plans, preparation of tender documents, preparation of contract documents, preparation of interim payment certificate (IPC), preparation of final accounts, providing advice on alternative dispute resolution (ADR) methods, value engineering services, claims management, providing tax advice and insurance, advising on environmental and safety aspects, preparation of maintenance user manuals. When outsourcing the dispute resolution process, according to the nature of the dispute the relevant specialists can be used to improve the quality of the ADR process. Organisations can outsource the preparation of BOQ as a profitable method as the key quantity surveying activity because the pre-contract documents such as the standard method of measurement, method statement, type of contract, tender drawings and specifications are readily available (Ranasinghe et al., 2019). Moreover, there were very few studies to identify the consultant quantity surveying activities that can be outsourced. Hence, it is required to identify the activities to fulfil the research gap.

3. METHODOLOGY

A mixed approach was selected to carry out this study while using a qualitative approach to validate the literature findings in the Sri Lankan context followed by a quantitative approach to generate the final outcome. Expert interviews were conducted with industry experts in order to do the affirmation of literature findings in the post-pandemic era in Sri Lanka.

Non-random sampling is better suited to a qualitative approach with a pre-selected list of respondents from the research area (Brahme et al., 2006). Quantity surveyors, project managers, and CEOs of organisations involved in outsourcing activities from a consultant perspective were invited to participate in the interviews as experts in this study. The interviews were conducted with ten (10) experts. Thematic analysis was used to analyse the data collected through expert interviews using the NVivo 12 software. Details of interviewees involved in expert interviews are given in table 2.

Table 2: Details of interviewees for expert interviews

Respondent Coding	Profession	Designation	Years of experience
R01	Chartered QS	Managing Director	35 years
R02	Chartered QS	Director	18 years
R03	Chartered QS.	Director	30 years
R04	Chartered QS	Director	19 years
R05	Chartered QS.	Director	05 years
R06	Chartered QS	Operation Director	26 years
R07	Chartered QS	Commercial Manager	15 years
R08	Chartered QS	Director	22 years
R09	Chartered QS	Managing Director	20 years
R10	Chartered QS.	Quantity Surveyor	7 years

Following the expert interviews, a questionnaire survey was used to identify the most effective quantity surveying activities that could be outsourced in the post-pandemic Sri Lankan context. Given that a certain number of respondents is required for a questionnaire survey, the purposive sampling method was chosen when the population and the objective of the research are considered. This method is also a nonprobability sampling method, and experts such as quantity surveyors and CEOs with experience in construction outsourcing decisions were chosen to collect data. Fifty (50) quantity surveying experts with construction industry experience in Sri Lanka were chosen to distribute the questionnaire, and thirty (30) respondents responded. Each activity was quantified on a 1-5 Likert scale based on its suitability for outsourcing. Finally, the relative importance of quantity surveying activities that can be outsourced was determined.

4. ANALYSIS AND RESEARCH FINDINGS

4.1 EXPERT INTERVIEWS

Fourteen (14) numbers of consultants' quantity surveying activities that can be outsourced during the post-pandemic era were identified through the literature review and those were customised to the Sri Lankan context during the expert interviews.

The customised list of consultants' quantity surveying activities that can be outsourced in the Sri Lankan context can be identified as follows. The new activities that are identified through the expert interviews are highlighted and the number of respondents who validated the activities is represented in the chart.

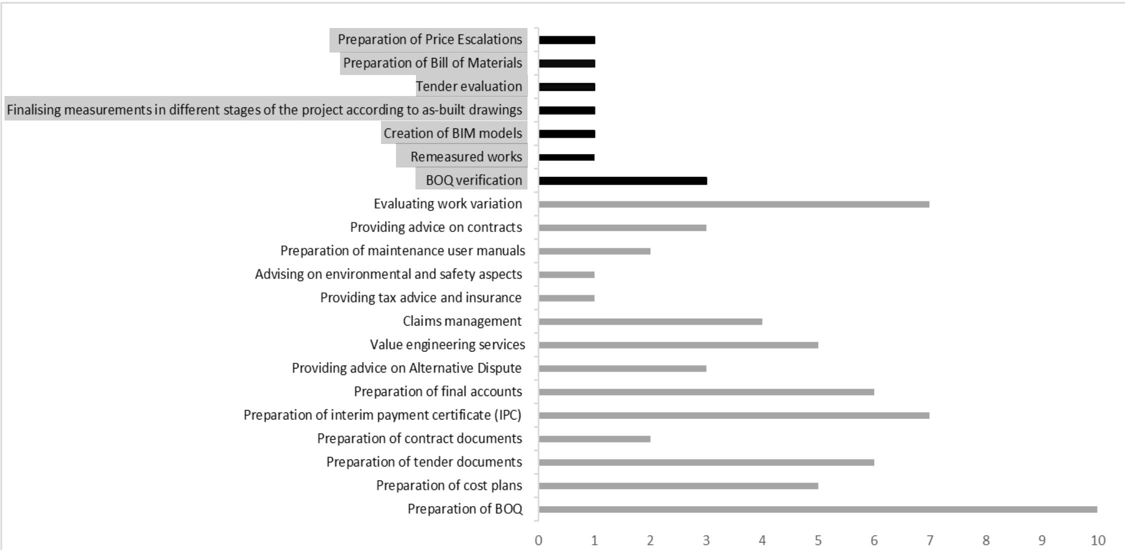

Figure 1: Consultant quantity surveying activities suitable for outsourcing

Most of the activities identified through the literature survey were validated by the respondents. In addition, a few new activities were introduced by the respondents such as BOQ verification, remeasured works, creation of BIM models, finalising measurements in different stages of the project according to the as-built drawings, tender evaluation, preparation of bills of materials and preparation of price escalations.

All the respondents have stated that the preparation of bills of quantities can be outsourced while R05 stated that the reason for outsourcing is *"limited time and resources available within the organisation"*. Evaluating work variation and preparation of cost plans were also validated by seven respondents out of ten as outsourcing activity while the R07 stated that *"the pricing part cannot be done through outsourcing, but the measurement part can be done"*.

R01, R05 R06 and R07 stated that the preparation of cost plans, preparation of tender documents, preparation of contract documents, preparation of IPC and preparation of final accounts cannot be fully outsourced and only the measurement part can be outsourced because those are confidential information and client is not willing to reveal those to an external party.

Though most of the respondents described that the value engineering can be outsourced, R01 did not agree with that opinion and elaborated the reason as *"value engineering is done in two stages (concept design stage and just before the tender documents are* *floated) and after the Issued for Construction (IFC) drawings are issued, value engineering is not done because it creates a huge impact to redesign, redo and come up with variations"*. R07 further confirmed the above statement by giving the reason as *"value engineering is a continuous and subjective process"*. Therefore, according to practical situations, it was difficult to outsource within Sri Lanka.

R01 further insisted that outsourcing tax advice and insurance is not a proper idea because "that task is related to auditors but not a responsibility of a quantity surveyor". According to R01's opinion "advising on environmental and safety aspects are not the responsibility of the quantity surveyor and the professionals in Green Building Council Sri Lanka can be used for this purpose". R01 further mentioned that "preparation of maintenance user manuals is the responsibility of the facilities manager". According to R05 opinion, claims management cannot be outsourced because "more details are required for this process".

The respondents believed that the consultant quantity surveying activities with the greatest potential for outsourcing were BOQ and tender document preparation. Further, the measurement part of the activities such as evaluating work variation, preparation of final accounts, preparation of cost plans, value engineering works, preparation of bills of materials and preparation of price escalations can be outsourced effectively in Sri Lanka during the post-pandemic era.

4.2 QUESTIONNAIRE SURVEY

In the second stage of data collection, a questionnaire survey was carried out among quantity surveying professionals who are experts in the field of knowledge in Sri Lanka. The questionnaire was developed based on the findings of the literature review and expert interviews.

Level of suitability was tested through a five-point Likert scale (1- The activity never can be outsourced, 2 – The activity is not suitable to outsource, 3 – The activity can be outsourced but it will not much effective, 4 – The activity can be outsourced, 5 – It is more effective to outsource the activity). Responses were analysed using RII.

Furthermore, Zulu et al. (2022) have used a scale with five categories to determine the importance level of drivers and barriers ranked using RII. According to Zulu et al. (2002), table 3 illustrated the interpretation of suitability levels for outsourcing each activity based on their respective RII values.

Table 3: Interpretation of RII values

RII Value	Interpretation
0.000 – 0.200	Not suitable at all
0.200 – 0.400	Slightly suitable
0.400 – 0.600	Moderately suitable
0.600 – 0.800	Highly suitable
0.800 – 1.000	Extremely suitable

The results of the questionnaire survey are summarised in table 4.

Table 4: Ranking the activities based on RII Values

Activity	RII	Rank	Suitability of outsourcing the activity
Creation of BIM models	0.87	1	Extremely suitable
Preparation of BOQ	0.83	2	Extremely suitable
BOQ Verification	0.79	3	Highly suitable
Finalising measurements in different stages of the project according to as-built drawings	0.79	3	Highly suitable
Remeasured Works	0.77	5	Highly suitable
Preparation of Bills of Materials	0.75	6	Highly suitable
Value engineering services	0.73	7	Highly suitable
Preparation of tender documents	0.71	8	Highly suitable
Providing advice on contracts	0.71	8	Highly suitable
Evaluating work variation	0.71	8	Highly suitable
Preparation of price escalations	0.71	8	Highly suitable
Providing advice on Alternative Dispute	0.70	12	Highly suitable
Preparation of cost plans	0.69	13	Highly suitable
Claims management	0.67	14	Highly suitable
Providing tax advice and insurance	0.67	14	Highly suitable
Preparation of contract documents	0.64	16	Highly suitable
Preparation of interim payment certificate	0.63	17	Highly suitable
Preparation of final accounts	0.63	17	Highly suitable
Tender evaluation	0.61	19	Highly suitable
Advising on environmental and safety aspects	0.59	20	Moderately suitable
Preparation of maintenance user manuals	0.58	21	Moderately suitable

The top activity, with a 0.87 RII score, was the creation of BIM models. This activity was not detected through literature synthesis because it is based on new technology utilised in the industry. The second task that was deemed to be extremely suitable for outsourcing was BOQ preparation. During the initial interviews, the majority of respondents positively identified the same activity.

Several tasks fall into the category of highly suitable for outsourcing. Accordingly, finalising measurements in different stages of the project according to as-built drawings, and BOQ verification is found to be equally critical with finalising measurements at different stages of the project and achieved a 0.79 RII value while ranking as the third most suitable activity. Remeasured works were discovered to be the fifth most suitable activity, ranking next with an RII score of 0.77. In addition to that, preparation of Bills of Materials, value engineering services, preparation of tender documents, providing advice on contracts, evaluating work variation, preparation of price escalations, providing advice on an alternative dispute, preparation of cost plans, claims management, providing tax advice and insurance, preparation of contract documents, preparation of interim payment certificate (IPC), preparation of final accounts and tender evaluation were identified as highly suitable activities for outsourcing based on RII values.

Advising on environmental and safety aspects and preparation of maintenance user manuals was identified as moderately suitable activities for outsourcing with the lowest

RII value. In addition, some respondents acknowledged during the expert interviews that those tasks are not quantity surveying operations.

Creation of BIM models, preparation of BOQ, BOQ verification, finalising measurements in various stages of the project according to as-built drawings, remeasured works, and the preparation of Bills of Materials was ranked as the top activities in Sri Lanka during the post-pandemic era that has the greatest potential for outsourcing. This ranking was consistent with the interviewers' responses in the previous stage.

5. CONCLUSIONS AND RECOMMENDATIONS

Though most industries have been affected by the COVID-19 pandemic, industries found a mechanism to continue business activities minimising the effect without bankruptcy. During this period, though the construction is comprised of on-site activities, remote work policies were used for professional activities. Apart from the general survival strategies in the industry, the major survival strategies that can be used in quantity surveying firms are working from home, decentralised decision-making, improving networking, retaining existing staff and outsourcing. Among them, outsourcing was identified as one of the most suitable strategies for consultant quantity surveying in firms. Strategic drivers, technological drivers, management drivers and functional drivers can be identified as the key drivers for outsourcing decisions. Quality factors were not much considerable driver because the quality of the output is depended on the outsourcing team. Subsequently, economic factors and management factors also have less priority because when outsourcing cost was not much considerable factor.

According to the results of the study, it can be concluded that measurement-related activities have more potential to outsource among consultants' quantity surveying activities since the amount of information that has to reveal to an outside party is limited. Accordingly, the creation of BIM models, preparation of BOQ, BOQ verification, finalising measurements in different stages of the project according to as-built drawings, remeasured works and preparation of Bills of Materials were identified as the activities that have more potential to outsource in Sri Lanka during the post-pandemic era.

The results of this study will aid quantity surveying professionals, particularly those who work for consultancy organisations to push for outsourcing possibilities for consultant quantity surveying activities in Sri Lanka during the post-pandemic period in order to improve the corporate image. The study's findings can be used as a guide to determine the driving forces for introducing or enhancing the outsourcing concept inside firms and putting into practice the identified potential consultant quantity surveying activities.

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POTENTIAL IMPACTS OF BLOCKCHAIN TECHNOLOGY IMPLEMENTATION ON CONSTRUCTION CONTRACT MANAGEMENT IN SRI LANKA

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ABSTRACT

The construction contract is the mainstay for the ascendancy of the construction project requiring proper contract management. The Sri Lankan construction industry has many complications associated with contract management. Blockchain, as a decentralised transaction and data management technology, can potentially address the issues related to contract management amidst the impediments to effective implementation. However, blockchain technology adaptation in the Sri Lankan construction industry lacks evidence, even though other sectors, for example, banking and agriculture, are with the initial implementation. Hence, this research aimed to identify the potential impacts of implementing blockchain technology in construction contract management in Sri Lanka. A literature review was conducted to identify the concept of blockchain technology, its applications and its benefits. A qualitative survey strategy was adopted, and data were collected via semi-structured interviews in two phases; Phase I with ICT and finance industry experts and Phase II with construction contract experts. Samples were selected purposively through snowball sampling. The data analysis revealed that the awareness and use of blockchain technology in Sri Lanka are relatively low. However, Sri Lanka has the potential to adopt Blockchain in different fields, depending on their capabilities. Furthermore, the study found associated positive impacts of Blockchain, e.g., avoiding complex procedures, providing transparency, no ambiguities, no human errors and reducing political influence to mitigate contract management issues. Besides, Blockchain may negatively impact due to, e.g., high initial and maintenance costs, lack of knowledge and expertise, unavailability of rules and regulations, and reluctance to change those need mitigations.

Keywords: *Blockchain Technology; Construction Contract Management; Smart Contracts; Sri Lanka.*

1. INTRODUCTION

Construction is a dynamic industry with complicated and distinctive nature having many constraints and stakeholders. One of the specific requirements of the construction industry is to adjust quickly to new circumstances within the fast-changing environment (Hanisch et al., 2009, as cited in Mesaroš et al., 2018). Innovative tools and applications

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such as the Internet of Things (IoT), Building Information Modelling (BIM), and general digitalisation help achieve construction project goals more effectively (Mesaroš et al., 2018). Even though there is a significant opportunity and possibility for enhancing the process of construction projects through digitalisation, it is one of the last industries to go digital (Mesaroš et al., 2018). Recently, the construction industry tried improving its procedures while mitigating their challenges, e.g. lean construction and BIM. However, still, there are issues in supply chain management in the construction industry due to a lack of trust and transparency (Hamma-Adama et al., 2020). Hence, the construction industry faces several challenges regarding information sharing, trust and process automation (Wang et al., 2017).

Blockchain is one of the most significant technological breakthroughs in recent years, influencing the productivity of construction projects and possessing a key feature of enabling trust (Sarmah, 2018). Hence, participants do not need pre-existing trust relationships if the construction business or activities are carried out on a blockchain system. In addition, Blockchain can be used in various ways due to its unrivalled security and ability to provide a comprehensive solution to digital identity issues (Sarmah, 2018). There are several domains where blockchain-based applications are emerging, including reputation systems, financial services, the IoT (Zheng et al., 2017), smart property, cybersecurity, cloud storage and provenance, blockchain healthcare, intellectual property and smart contracts (Rawat et al., 2020). Blockchain-enabled applications can also assist contract administration by using smart contracts, financial management without the involvement of third parties, subcontractor management by linking payment schemes, asset management by tracking movements of materials and purchase control by linking key stakeholders in supply chains (Hewavitharana et al., 2019). Furthermore, due to the immutable data record, Blockchain can reduce the risk of disputes and litigation compared to conventional methods (Wang et al., 2017).

Some Sri Lankan organisations are currently at the testing, initial implementation, or use stage of blockchain technology only for a few products/services. For instance, the Central Bank of Sri Lanka has completed the Proof-of-Concept project enabling efficient and secure sharing of Know-Your-Customer (KYC) information between banks (Central Bank of Sri Lanka [CBSL], 2021). Although foreign banks currently use blockchain-based cryptocurrencies for transactions, Sri Lankan banks have little trust in the technology's ability to execute payments (Gunasekara & Sridarran, 2021). However, no organisation has completely adopted Blockchain due to several reasons, e.g. the lack of understanding, unavailability of technological facilities, organisational and environmental barriers, a lack of isomorphic pressures, and a lack of trust among stakeholders, etc. (Gunasekara & Sridarran, 2021). Moreover, due to potential issues and a lack of proven models, blockchain adoption in the supply chain and logistics in Sri Lanka is also slow (Madhunamali & Jayasena, 2020).

On the other hand, with a young workforce and an expanding population, Sri Lanka, as a developing country, has much to gain from the Blockchain (Madhunamali & Jayasena, 2020). Even though other sectors in Sri Lanka, e.g. banking and agriculture, have begun adopting blockchain technology, the construction industry lacks evidence. Hence, the Sri Lankan construction industry is identified as an industry with less adaptation to new technologies (Weerakoon & Chandanie, 2021). According to Nitharsan and Francis (2022), the urge to adopt blockchain applications outweighs their readiness in the Sri Lankan construction industry. However, as discussed, blockchain-based contract management is a disruptive innovation that can transform how the construction sector does business. Hence, this research aims to identify the potential impacts of implementing blockchain technology in construction contract management in Sri Lanka.

2. LITERATURE REVIEW

2.1 BLOCKCHAIN TECHNOLOGY AND ITS APPLICATIONS

Blockchain can be defined as a distributed database of transaction records that are checked and updated by a worldwide network of computers (Sarmah, 2018). It also refers to a distributed data storing method for synchronising, sharing, and replicating data dispersed over numerous places, nations, or organisations (Perera et al., 2020).

There are many common advantages of blockchain technology. E.g. hacking threats will be reduced to a greater extent (Geroni, 2021), audibility is high (Makadia, 2022), supports the creation of new classes of applications and business models (Kriptomat, 2022), and democratising (Bertagnoli, 2022). Further, there are disadvantages such as. high implementation costs (Budhi, 2022), high energy consumption (Song et al., 2016), slower than centralised databases (Song et al., 2016), and speculative markets (Fauvel, 2017).

Blockchain has several applications for a transparent, verifiable register of transaction data, mainly on a decentralised platform with no need for centralised control and is, therefore, resistant to fraud (Martin, 2018). Blockchain-based solutions are being developed and commercialised by numerous organisations from various industries to upend current business procedures or practices (Martin, 2018). Table 1 summarises how the researchers discussed the application of blockchain technology in different fields and related areas.

Table 1: Fields and areas of blockchain technology application

Reference	Construction	Finance	Supply Chain	Health Care	Legal Applications	Manufacturing	Transportation	Food & Agriculture	Insurance	Real estate	Advertising, media and entertainment
Nofer et al. (2017)		✓			✓				✓		
Balint (2018)		✓		✓			✓		✓		
Makridakis & Christodoulou (2019)			✓	✓							✓
George et al. (2019)		✓	✓		✓						
San et al. (2019)	✓										
Bodkhe et al. (2020)		✓	✓	✓		✓		✓			
Rawat et al. (2020)		✓	✓	✓				✓		✓	✓
Perera et al. (2020)		✓		✓			✓	✓			
Baiod et al. (2021)		✓	✓	✓	✓				✓	✓	✓
Javaid et al. (2021)				✓		✓		✓			
Kosala et al. (2021)	✓										
Nitharsan & Francis (2022)	✓										

2.2 BLOCKCHAIN IN THE CONSTRUCTION INDUSTRY

The construction sector has constantly been challenged to increase productivity and efficiency while embracing opportunities brought by disruptive technologies. Blockchain is the most recent technology that has started the construction industry's digital transformation (Hewavitharana et al., 2019). Blockchain application is projected to enhance the accuracy of the construction project data and their management through the concepts such as 'peer-to-peer networks, public-key cryptography, consensus algorithm, and hashing algorithm, establishing a transparent and high-security data storage platform throughout the lifecycle of construction projects (Gamage et al., 2020).

Perera et al. (2020) identified that many possible blockchain applications exist for the construction industry in supply chain management, building information modelling, payment management, document management, stakeholder management, waste management, and contract management.

2.3 CHALLENGES IN CONSTRUCTION CONTRACT MANAGEMENT

Contracts are extremely vital in construction projects with big targets, extended implementation times, and complex coordination relations (Zheng, 2018). Construction contracts are agreements, either oral or written, between owners and contractors for construction and/or maintenance work performed for remuneration, consisting of five stages: proposal, design, award, construction, and completion (Phillips, 2009). Further, construction contracts are required to control and manage the project design, bid package preparation, contract award, compliance, progress, spending, timetables, inspection, completion, and acceptance in a standard, orderly, and effective manner (Phillips, 2009). Therefore, managing construction contracts has a high standing in construction projects with high technical requirements, complex construction, enormous investments, a significant social impact, and a long life cycle (Wang, 2020). Further, construction contract management should also consider being implemented in compliance with the appropriate laws and rules in the contract. However, construction contract management also involves several challenges identified in the literature as shown in Table 2.

Table 2: Challenges in construction contract management

Challenges	Ref.
Lack of supporting laws and policies and lack of legal awareness of parties to the contract	[1] [5]
Inadequate supervision	[2] [5]
Poor planning	[2] [4]
Delay in approvals	[2] [4]
Delayed payments	[2] [3]
Lack of skilled and trained professionals	[3] [6]
Insufficient use of technology	[3]
Poor communication across parties	[5]
Misunderstanding of roles and responsibilities by professionals	[6]

Sources: [1] Zheng (2018), [2] Memon and Rahman (2013), [3] Ahmed (2015), [4] Alzara et al. (2016), [5] Surajbali (2016), [6] Gunduz and Elsherbeny (2020)

2.4 THE NECESSITY OF BLOCKCHAIN FOR CONSTRUCTION MANAGEMENT

Technology has advanced to help construction projects lessen their associated problems through applications like Blockchain. According to Kosala et al. (2021), traceability, accountability, transparency, fast transactions, and trust are the main benefits of implementing blockchain technology in the Sri Lankan construction industry. Blockchain technology can help contract execution by optimising and ensuring a transparent information flow during the various stages of the construction process (Pattini et al., 2020).

Blockchain technology introduced the ‘smart contract’, a digital contract that can be automatically carried out when certain circumstances are satisfied (Balint, 2018). Smart contracts refer to transactions beyond the basic buy/sell currency transactions and may have more detailed instructions (Swan, 2015).

Table 3: Benefits of using smart contracts

Benefits	**Szabo (1994)**	**Swan (2015)**	**Pattini et al. (2020)**	**Alzara et al. (2016)**	**Hughes (2017)**	**Hewavitharana et al. (2019)**	**J. Wang et al. (2017)**
Reduces the need for trusted intermediaries	✓	✓					
Minimises malicious and unintentional exceptions	✓			✓			
Forms automatically and without human intervention		✓					✓
Funds can be embedded into the contract, and payments can be automatically released at the end of each project verification cycle			✓	✓			
Ensuring participants’ maximum fairness in the tender stage			✓			✓	
Transform contractual clauses into computational language expressions		✓	✓				
Tenders can process immutably and transparently			✓				
Save significant time for contract registration, monitoring, and updating				✓			
Reduce the inherent risks under contract administration planning and data hoarding					✓		
Avoid unnecessary costs for written text, legal consultation, and contract document drafting						✓	

Table 3 summarises the benefits of blockchain technology applications, e.g. smart contracts for construction contract management. Accordingly, a smart contract is an automated transaction mechanism that carries out a contract’s provisions in a way that satisfies standard contractual requirements (Szabo, 1994), abandoning opportunistic behaviour due to the free interpretation of clauses in a traditional contract (Pattini et al., 2020). It saves contract registration, monitoring, and updating time as a tamper-proof system (Wang et al., 2017). With smart contracts, various contractual terms can be rendered entirely or partially self-executing and self-enforcing (Nitharsan & Francis, 2022).

Accordingly, the inherent properties of blockchain-based smart contracts, such as traceability, immutability, and security, create greater cooperation and transparency between project stakeholders (Ernst & Young Global Limited, 2018). Hence, blockchain technology provides several benefits and helps mitigate issues in construction contract management if adequately implemented. Therefore, this study aims to identify the potential impacts of implementing blockchain technology in construction contract management in Sri Lanka.

3. RESEARCH METHODOLOGY

A literature review investigated current knowledge of Blockchain and its implementation in the construction industry. Since Blockchain is a new concept and its inside is lacking among Sri Lankan construction industry experts, finding a reliable large sample was difficult for quantitative data collection. Hence qualitative data were collected using semi-structured interviews with experts. Due to the nonuse of Blockchain in the Sri Lankan construction industry, finding two or more independent sources for data collection was difficult. Hence, a mono-method qualitative choice was adopted. Figure 1 shows the research process of the study.

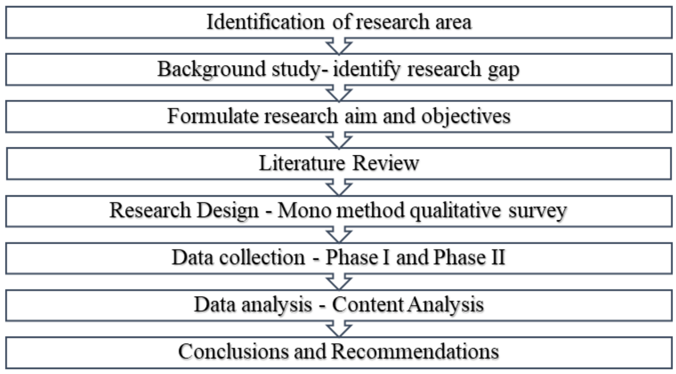

Figure 1: Research Process of the Study

Data were collected in two phases; Phase I focused on other industries those already initiated blockchain technology to find the awareness, features and use of Blockchain in Sri Lanka and to get opinions on blockchain adoption in the Sri Lankan construction industry. Phase II interviews were with construction industry experts to investigate the issues in construction contract management and to identify the potential impacts of Blockchain in construction contract management in Sri Lanka.

The non-probability purposive sampling method is used to select the interviewees for Phases I and II interviews and further used snowball sampling. Pre-defined criteria were also used when selecting samples of both phases, as shown in Table 4.

Table 4: Selection Criteria for Interviewees

	Phase I	Phase II
Education qualification	A bachelor's degree	A bachelor's degree
Industry Experience	5 years or more	10 years or more
Knowledge on	ICT (Blockchain)	Construction administration and ICT
Socioeconomic status	Professional	Professional

Table 5 presents the coding and profile of Phase I and Phase II interviewees used for data analysis.

Table 5: Codings and Profile of Interviewees

	Interviewee ID	Organisation	Designation	Area of expertise
Phase I	BE1	Consultancy	Managing director	Software development and digital marketing
	BE2	Consultancy	Director	Technology and resource planning

	Interviewee ID	Organisation	Designation	Area of expertise
	BE3	Banking	Senior assistant director	Software engineering and finance
	BE4	Trading	Software quality engineer	Software development
Phase II	CE1	Contractor	Deputy general manager	Project management
	CE2	Contractor	Quantity surveyor	Quantity Surveying
	CE3	Consultancy	Senior quantity surveyor	Construction Administration
	CE4	Consultancy	Director	Civil engineering
	CE5	Consultancy	Assistant director	Project management

All the interviews were audio recorded with the interviewees' permission and transcribed for data analysis. This study has employed a manual content analysis method to analyse qualitative data collected from interviews, as per Krippendorff (2004).

4. DATA ANALYSIS AND DISCUSSION

4.1 AWARENESS AND THE CURRENT USE OF BLOCKCHAIN IN SRI LANKA

The awareness of Blockchain in Sri Lanka is low. Interviewees disclosed the lack of awareness. For instance, BE1 stated, *"in Sri Lanka, there are professionals who have never heard of the word blockchain*". The awareness is not up to the required level to effectively apply Blockchain in Sri Lanka, as highlighted by BE2 saying, *"there should be great awareness of blockchain to apply in Sri Lanka"*. According to BE4, *"Sri Lanka is prevented from taking full advantage of the new technology due to not keeping pace with digital advancements and continuing to require paper-based documentation*". Therefore, *"it will be good to have some plans from the government to initiate the technology first"* [BE4].

Although the awareness of blockchain technology in Sri Lanka is minimal, according to BE4, *"the awareness is yet to gain momentum, and few organisations have considered adopting initial-level implementations*". BE4 pointed out, *"some banks are doing proof of concept to understand how they can leverage blockchain"*. For instance, *"blockchain technology has been introduced to payments and banking through 'Know Your Customer' projects"* [BE3].

It was also suggested that Sri Lanka has the potential to adopt Blockchain in construction. For example, "*Blockchain can be applied to the construction industry due to the benefits to contract management and supply chain*" [BE3]. BE1, BE3, and BE4 identified "Smart Contracts" as one of the blockchain-based applications that can create a boom in the construction industry. BE4 stated that blockchain technology is good for the construction industry because the transactions of construction projects are massive amounts.

There are requirements to fulfil when properly implementing Blockchain in any industry in Sri Lanka. For instance, BE3 warned about government initiation and support conditions since specific organisations cannot easily implement them independently. Further, BE 1 stated, *"Sri Lanka will benefit from blockchain if there is a proper governance model"*. Sri Lanka can benefit from Blockchain in several ways. E.g. *"Blockchain is great because records and transactions cannot be changed, only updated so that it can reduce corruption and fraud*" [BE1].

Figure 2 summarises the findings from Phase I.

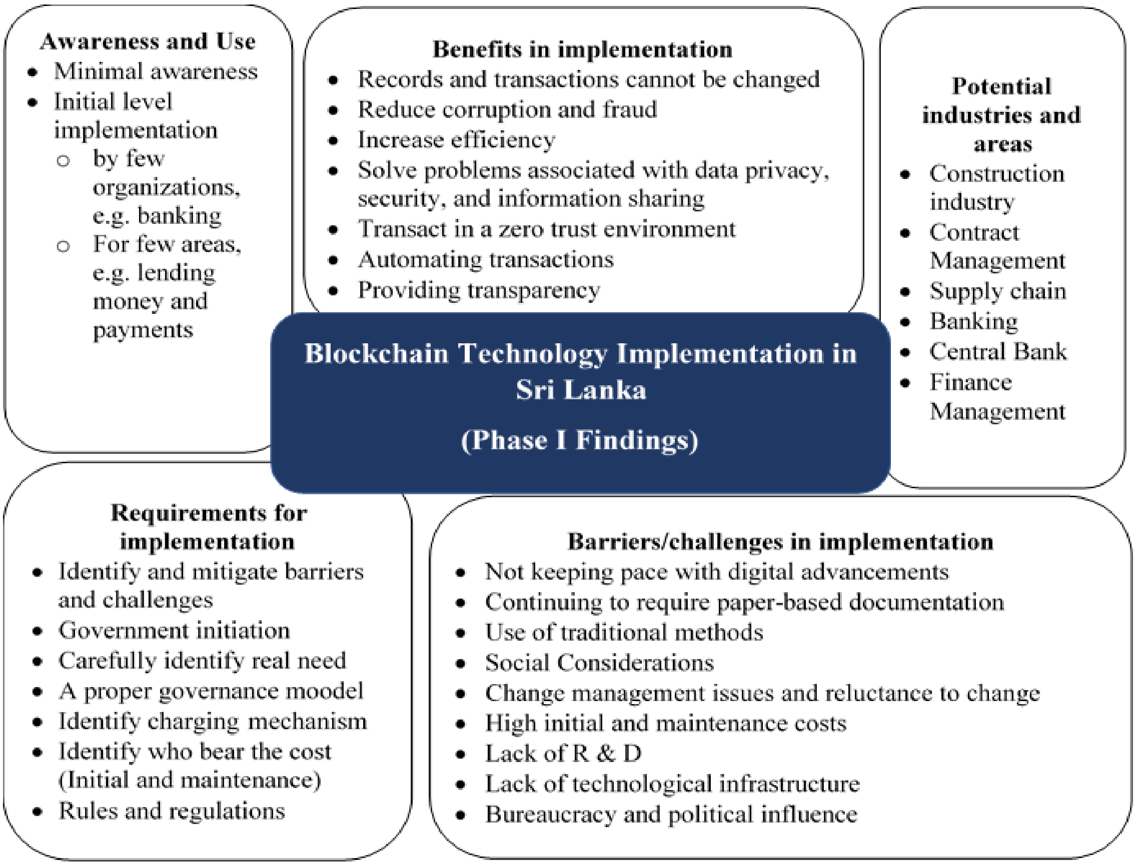

Figure 2: Summary of Phase I findings

As per Figure 2, there are barriers to implementing Blockchain in Sri Lanka. E.g. lack of research and proper investigations [BE1, BE2] and lack of technological infrastructure [all Phase I interviewees], social barriers [BE4], Bureaucracy and political influence [BE1, BE3], use of traditional methods and lack of technological knowledge [all Phase I interviewees], and reluctance to change [BE3, BE4].

All Phase I interviewees suggested that the construction industry has the potential to use blockchain technology for managing financial activities and contracts since it is currently suffering from numerous issues. Moreover, Phase I findings provided different aspects to be considered when implementing Blockchain in any industry (Figure 2). E.g. the requirements to be fulfilled to successfully implement Blockchain and challenges to implementing Blockchain.

4.2 CONSTRUCTION CONTRACT MANAGEMENT IN SRI LANKA

As per findings, contract management is one of the most important areas of a construction project. CE2 stated, *"Contract gives the basis for all the phases of a construction project, preconstruction, construction and post-construction stages"*. The contract ensures legal enforceability, providing vital protection for all stakeholders in a construction project. *"The most important part of contract management is the legal relationship between the parties to the contract"* [CE2, CE3, CE5].

Contract management handles parties' obligations to the contract as per all Phase II interviewees. According to CE1, *"Contract management prevents conflicts and resolves many more disputes"*. CE4 expressed, *"Contract management provides a clear line of* *accountability, decisions and its impact".* Subsequently, as per Phase II interviewees, contract management ensures value for money and maintains a project's time, cost and quality. As per the findings, some issues related to construction contract management in Sri Lanka are listed in Table 6.

Table 6: Issues related to construction contract management in Sri Lanka

Construction contract management issue	CE1	CE2	CE3	CE4	CE5
Complex procedures	✓	✓			✓
Lack of structure	✓	✓			✓
Excessive documentation	✓	✓	✓	✓	✓
Poor Communication	✓	✓		✓	✓
Unethical acts like fraud and bribery	✓	✓		✓	✓
Defining and tracking contract costs					✓
Maintaining unwritten contracts	✓				✓
Outdated boilerplate language and ambiguities in the contract	✓			✓	✓
Poor handling of contract stakeholders		✓		✓	✓
Errors in decision-making ability				✓	
Requirement of legal assistance		✓	✓		
Issues in payment (e.g. payment delays)			✓	✓	

4.3 POTENTIAL POSITIVE IMPACTS OF BLOCKCHAIN ON CONSTRUCTION CONTRACT MANAGEMENT IN SRI LANKA

As per Phase II findings, blockchain-based smart contracts ensure the time-saving of a project in many ways. E.g. CE2 stated that the traditional use of documents could be reduced via blockchain technology. In addition, CE4 mentioned, *"Through smart contract physical presence can be minimised which saves time and money".*

According to CE1, CE2 and CE5, smart contracts can contain functions that trigger conditional actions. CE5 gave an example, *"if one party clears their payments, the contract can self-close or inform all the parties involved in the smart contract".* In addition, CE3 stated, *"Blockchain will prevent overpayments and repetitions, and thus avoid financial issues".* All Phase II interviewees accepted that Blockchain restricts unethical acts and corruption. CE3 confirmed, *"corruptions and frauds in the construction can be minimised with the adoption of blockchain".*

Finally, the solutions from blockchain technology for the identified issues of construction contract management were analysed from Phases I and II and presented in Table 7.

Table 7: Solutions to construction contract management issues in Sri Lanka

Construction contract management issue	Solutions from blockchain technology As per Phase I and Phase II findings
Complex procedures	The use of smart contracts will avoid complex procedures
Lack of structure	Use of smart contracts which automate procedures
Excessive documentation	Use of smart contracts which does not comprise complicated documentation
Poor Communication	Use of Blockchain, which shares data in a distributed and transparent way
Unethical acts like fraud and bribery	Solve problems associated with data privacy and security Provide transparency

Construction contract management issue	Solutions from blockchain technology As per Phase I and Phase II findings
Defining and tracking contract costs	Use of Blockchain, which keeps track of all transactions among network participants
Maintaining unwritten contracts	Use of smart contracts which only allow digitalised data
Outdated boilerplate language and ambiguities in the contract	Use of smart contracts which does not comprise ambiguities
Poor handling of contract stakeholders	Use of smart contracts which automate procedures and build trust among stakeholders
Errors in decision-making ability	Use of smart contracts which does not comprise human errors
Requirement of legal assistance	Use of smart contracts which does not comprise third-party involvement (e.g. political influence)
Issues in Payment	Use of Blockchain, which allows peer to Peer transactions and does not comprise third-party finance institutes Reduce corruption and fraud Increase efficiency and transparency

Accordingly, blockchain technology implementation impacts construction contract management positively in several ways by providing solutions for the issues and problems in construction contract management in Sri Lanka (Table 7). Further, it offers benefits like time-savings, reduced physical presence and avoiding corruption.

On the other hand, Phase II findings explored some negative impacts of implementing blockchain technology in construction contract management in Sri Lanka due to several barriers. All Phase II interviewees stated that the lack of technological infrastructure is one of the barriers. For example, CE1 stated, *"Practising blockchain in construction contract management in Sri Lanka is questionable due to lack of required facilities."* Further, it was emphasised that a lack of expertise also would be a barrier to implementing Blockchain. CE4 expressed, *"It will be difficult for construction companies to handle blockchain-based applications due to skill and education gap"*. CE4 highlighted their experience *"when implementing Enterprise Resource Planning; we were struggling to find experts in IT and related fields*".

Difficulties in integrating the Blockchain into the existing systems, being expensive, time-consuming [all interviewees], lack of awareness among stakeholders [CE2, CE4, CE5] and unavailability of rules and regulations [CE1, CE3, CE5] were also identified as barriers. CE3 pointed out, *"Although blockchain can be used for financial transactions, digital currencies are still legally unregulated in Sri Lanka"*. CE1 stressed, *"lack of awareness and experience to handle these technologies may create even more disputes"*. However, CE5 stated, *"conducting awareness programs will be an additional cost"*.

Therefore, CE2 mentioned, "*We have to think separately about how this technology will affect our time and cost management"*. According to all the interviewees, the Sri Lankan construction industry still has to become competent to adopt blockchain technology. Thus, CE4 suggested the need for comprehensive research studies on blockchain implementation in the Sri Lankan construction industry. CE2 emphasised the requirement of including blockchain technology in the higher education system.

5. CONCLUSIONS

This study aimed to identify the potential impacts of implementing blockchain technology in construction contract management in Sri Lanka by collecting qualitative data via interviews in two phases.

Accordingly, blockchain technology is an emerging technology possessing prominent characteristics such as immutability, transparency, improved security and privacy, and traceability. Hence it provides several benefits and allows many applications. Literature review and empirical findings identified that blockchain technology use and awareness are minimal in Sri Lanka, with few initial implementations in, e.g. banking, finance and ICT industries. Moreover, Phase I data analysis provided details on current awareness and use, barriers/challenges, benefits and requirements for implementing blockchain technology in Sri Lanka (Figure 1). These aspects of Blockchain can be used by academia to gain further knowledge of Blockchain concerning different industries.

Phase II identified the current issues related to construction contract management in Sri Lanka, e.g., complex procedures, excessive documentation, unethical acts and maintaining unwritten contracts. Implementing blockchain technology would positively affect construction contract management by mitigating its issues through, e.g. maximised transparency, eliminated ambiguities, no human errors, minimised corruption and increased efficiency. On the other hand, barriers such as lack of technological infrastructure, lack of awareness and absence of rules and regulations will negatively affect the implementation of blockchain technology in construction contract management in Sri Lanka. Accordingly, construction industry practitioners can identify benefits and barriers when implementing Blockchain. This study suggested enhancing blockchain technology awareness in Sri Lanka by including it in Sri Lanka's higher education system. The qualitative findings of this study require validation through quantitative results in future. Further research is necessary to find strategies to mitigate the negative impacts of implementing Blockchain in the Sri Lankan construction industry.

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POTENTIAL USE OF DIGITAL TWIN FOR CONSTRUCTION PROGRESS MONITORING

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ABSTRACT

The digital twin (DT) presents an opportunity for the integration of the physical world into the digital world. DT technology has the potential to transform the construction industry and respond to some of its challenges. In conventional construction projects, progress is largely monitored by direct observation and measurement which suffers from numerous challenges, including low productivity, blunders, and poor technology advancements. Concerns are now being raised about integrating technology for autonomously monitoring building activity. In other sectors, DT technology has been responsible for saving product development time and costs by up to 50%. However, DT is still lagging the adoption of new technologies in the construction industry. The overarching aim of this study was to explore the adaptability of DT in construction site progress monitoring. This study comprehensively reviews and analyses DT concepts, technologies, and applications in the construction industry, parameters of applications of DT in construction site progress monitoring, how DT could be used for site progress monitoring in construction, common challenges in the implementation of DT in site progress monitoring, and strategies such as barriers related to DT in site progress monitoring, using literature findings while incorporating qualitative analysis of semi-structured interviews. This research shows that DT has a high potential to solve the numerous challenges in construction site progress monitoring, rather than other current technologies in use. Thus, this study raises awareness and the need for the application of DT in construction site progress monitoring.

Keywords: *Automation; Construction Industry; Digital Twin; Site Progress Monitoring.*

1. INTRODUCTION

The construction industry is infamous for the long-standing issue of poor performance and has been criticised for resistance to adopting technological advancements (Akanmu et al., 2021). However, evidence from the manufacturing sector and other industrial sectors has sparked an interest in construction to adopt technological advancements (Fischer et al., 2023). The exponential growth of data-acquisition systems, information technology, and networking technologies has enabled the synergistic integration with building lifecycle providing real-time monitoring and more control over project outcomes (Akanmu & Anumba, 2015). These technologies have fostered some of the emerging fields such as Virtual Design and Construction (VDC), Cyber-Physical Systems (CPS)

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and Digital Twins (DTs) which facilitate the automation of construction processes worldwide (Akanmu et al., 2021; Rafsanjani & Nabizadeh, 2023).

The applications of these new developments share many similarities, VDC is a broad area which focuses on using multidisciplinary performance models of construction projects to support various project objectives (Rafsanjani & Nabizadeh, 2023). On the other hand, DTs seek to enable two-way dynamic mapping between virtual models and physical components (Tao et al., 2019) while CPS focus on providing real-time monitoring and active control via communication and computing (Liu et al., 2018). Akanmu et al., (2021) identified DT as a prerequisite for the development of a CPS.

Despite being a 20-year-old concept, the notion of a Digital Twin was first introduced in 2003 in a Product Lifecycle Management course (Grieves, 2014). DT was first characterised as "a reengineering of structural life pre-diction and management" (Tuegel, 2012), before moving on to product manufacturing (Boschert et al., 2016) and more recently, smart cities (Howell et al., 2017). DT has been successfully used in several fields, including product design, production, prognostics, and health management (Tao et al., 2019). It expands on the foundations of computing in construction, construction monitoring technologies and methodologies, and lean planning and control. Digital twins provide a conceptual link between these strands for a closed-loop production control system (Sacks et al., 2020).

Rafsanjani and Nabizadeh (2023) state that the construction sector often has bottlenecks, slowing operations without supervisors' knowledge. In traditional construction, progress is monitored mainly by direct observation, and measurement consumes considerable time and produces errors (Costin et al., 2012; Zhao et al., 2019). Many technology methods for autonomously monitoring building activity have lately been available and widely implemented (Sacks et al., 2020). Many authors including Akanmu et al., (2021) and Fischer et al., (2023) have identified these technological advancements as the solution for the long-standing poor performance of construction industry based on the success they have had on other industries. Engineers can use real-time mirroring to forecast and avoid mechanical failures, and it helps manufacturers make better forecasts, choices, and strategies (Guo et al., 2022). Therefore, this research attempts to study the potential of using DT technology to facilitate construction progress monitoring. This paper initially reviews the concept of DT and determines its application of DT in the construction industry. Subsequently, semi-structured interviews were conducted among industry professionals and research scholars to identify how DT can be adopted for construction progress monitoring and potential barriers to its adoption.

2. LITERATURE REVIEW

The DT is such a new technology, that its definitions and abilities are not yet well understood on a systematic level. Consequently, standards and best practices for applications have not yet been clearly defined (Ibrahim, 2019). According to Glaessgen and Stargel (2012) and Negri et al. (2017), NASA had initially defined DT as a probabilistic simulation of a system that employs the physical models. A more common definition was brought by Kritzinger et. al., (2018) who defined DT as the virtual and computerised counterpart of a physical system. Reifsnider and Majumdar (2013) defined DT as Physical simulations of the materials and structures considering the engineering sector while Lee, et. al., (2013) defined DT as models of the process's current state and behaviour. Therefore, being a relatively new concept, definitions and applications of DT had been industry-specific. However, all definitions refer to a digital counterpart of a physical system as explained by Kritzinger et. al., (2018).

DTs have a brief history, which is mostly due to technological constraints during their early development. The first occurrence of DTs may date back to Grieves' 2003 presentation, which was regarded to be the origin of DTs (Grieves, 2014). Theoretically, DTs developed in three stages: formation, incubation, and growth (Tao et al., 2019). From the inception of the DT concept in 2003 to 2011 is identified as the formation stage where a rapid advancement of communication technology was observed. In 2011, NASA established the description of DTs and discussed its potential use in the aviation industry making the beginning of the incubation period (Glaessgen & Stargel, 2012). From 2014, DT has experienced rapid growth with increased attention from academics (Tao et al., 2019).

2.1 ARCHITECTURE OF DIGITAL TWIN

Sensor and measurement technologies, the Internet of Things, and machine learning provide the foundation of the digital twin's architecture (Liu et al., 2018). The primary purpose of implementing a digital twin using physics-based models and data-driven analytics is to offer realistic operational representations of the assets (Farsi et al., 2019). The technology enables simulations on the digital twin to anticipate the actual product's behaviour. The accuracy of the digital twin grows as the number of simulations and equipment linked to the network increases (Boschert, et, al., 2016).

2.2 CHARACTERISTICS OF DIGITAL TWIN

Depending on the type of DT, it can possess distinctive properties from others, but regardless, all DTs have a few characteristics in common as presented in the table below.

Table 1 Characteristics of digital twin

Characteristics	Description
High-fidelity	A DT must be an almost replica of its physical counterpart in terms of look, content, functioning, and so on. Computer models with extremely high fidelity are regarded as the DT's backbone (Reifsnider & Majumdar, 2013).
Dynamic	Create connection and interchange between the physical and virtual worlds. The data transferred may be dynamic, historical static, or descriptive static (Barricelli et al., 2019).
Self-evolving	A DT self-adapts and self-optimises based on the data acquired in real-time by its physical twin (Barricelli et al., 2019).
Identifiable	DT could be uniquely recognised from its physical twin or vice versa everywhere in the world and throughout its lifespan (Tao et al., 2019).
Multiscale and Multi physical	The virtual model in DT is based on the physical twin's macroscopic geometric features, such as shape, size, tolerance, and so on, as well as microscopic properties, such as surface roughness (Singh et. al, 2021).
Multidisciplinary	DT serves as the pillar of Industry 4.0, bringing together computer science, information technology, and communications; mechanical, electrical, electronic, and mechatronic engineering; automation and industrial engineering; and system integration physics, to name a few (Bajaj et al., 2016).

Hierachy	The hierarchical aspect of DT stems from the fact that each of the various components and elements that constitute the final product has its own DT model (Tuegel, 2012).

2.3 BENEFITS OF DIGITAL TWIN

The primary advantages of DT technology are its ability to reduce mistakes, uncertainty, inefficiencies, and costs in any system or process. Additionally, it dismantles the silos that exist inside typical industrial compartmentalised and divided systems. Numerous purported advantages of DT are presented in the table 2.

Table 2 Benefits of digital twin

Benefit	Description	Source
Predicting Problems/ System planning	Real-time data exchange between the physical asset and its DT is capable of anticipating issues at various phases of the product's lifespan.	(Tao, et al., 2019), (Guo et al., 2022)
Prototyping	Resulting in faster and more efficient prototyping and re-design.	(Liu et al., 2019).
Cost-effective	The overall cost of prototyping is reduced over time with extensive use of virtual resources.	(Grieves, 2014).
Accessibility	Remote monitoring and management of equipment and systems where local access is restricted.	(Shen et al., 2020)
Improved Maintenance	Traditional maintenance relies on heuristics and worst-case scenarios rather than specific materials, structural configurations, and usages.	(Singh et al. 2021), (Guo et al., 2022)
Documentation and Communication	DT enables a deeper understanding of system responses, it may be used to document and convey the physical twin's behavior	(LaGrange, 2019)
Safer than the Physical Counterpart	The potential of DT to remotely access its physical counterpart, along with its predictive capabilities, can help minimize the possibility of accidents and hazardous breakdowns.	(Goasduff, 2021), (Fischer et al., 2023)
Training	DT could be utilized to create more effective and illustrative safety training programs than conventional methods.	(Kaarlela et al., 2020).
Waste Reduction	Using DT to virtualize and test prototypes minimizes waste, costs, and time spent on developing a product before it is ready for market.	(Singh et al. 2021).

2.4 DIGITAL TWIN IN CONSTRUCTION

The definition of Digital Twin might seem similar to BIM, construction researchers highlighted the differences between these two concepts. As mentioned by Khajavi et al. (2019), the objective, technology, end-users, and facility life stage of BIM and Digital Twin are all unique. While architects/engineers use BIM to do conflict detection and material take-off during the design phase of a project, contractors utilize it for production control, constructability analysis, and site and safety management (Volk et al., 2014). It is incompatible with real-time data (Khajavi et al., 2019). However, the digital twin is used to monitor the physical asset and optimize its operating efficiency through the analysis of real-time information (Khajavi et al., 2019). The data acquired through the deployment of a Digital Twin throughout the facility's operation and maintenance phase could be kept in a database for future projects by architects (Qi and Tao, 2018). The existing literature on Digital Twins in construction is difficult to find since the phrase "Digital Twin" is rarely used directly and is frequently referred to as BIM or BIM-FM (BIM based Facility Management System) (Jazzar et al., 2020).

2.5 AUTOMATION IN PROGRESS MONITORING

Progress Monitoring involves periodic measurement of the actual progress of a project and its comparison with expected progress (Hwang et al., 2013). Successful project progress monitoring requires accurate and efficient capture, analysis, and visualization of project as-built status. Due to the complexity of goals and interdependency of activities, progress monitoring is regarded as one of the most challenging tasks (Alizadehsalehi & Yitmen, 2019). According to Navon and Sacks (2007), the most cost-effective and efficient method of monitoring the progress and performance of building projects is to automate the process. Until now, academics have examined a variety of developing field data gathering technologies for automating project inspections, either through the use of a single technology or through the integration of many technologies (Alizadehsalehi & Yitmen, 2016; Asadi et al., 2021; Rasoolinejad et al., 2020). However, collecting, storing, analyzing, and managing this massive and complex data in order to generate simple, accurate, fast, and real-time progress monitoring reports requires a smart/intelligent system that can incessantly learn and update itself from numerous sources (Boje et al., 2020).

2.6 DIGITAL TWIN IN CONSTRUCTION PROGRESS MONITORING

DT is used to create the optimum solution from detailed simulations and rich data that specify the best architecture, configuration, materials, and cost (Kan & Anumba, 2019). A DT can be used in the build phase to provide the construction specifications or parametric estimates to different providers (Shirowzhan et al., 2020). With enough sensors, the virtual twin is providing all relevant data about the state of the physical twin. During operations, an abundance of data is gathered and transmitted to the DT through a digital thread. DT can discover and even forecast maintenance difficulties in advance (Boje et al., 2020).

2.7 THE NOVELTY OF THIS RESEARCH

DT being a novel approach, there is a lack of clarity on the value that it may offer to individuals, businesses, and industries. Inadequate technical and practical understanding also impedes the advancement of technology (Singh et. al., 2021). Additionally, there is a dearth of case studies illustrating successful practices or business models for integrating DT into company activities (Simchenko *et al.*, 2019). Hence, there is a necessity to investigate the potential of the Digital Twin in the construction industry to assist the project monitoring and controlling process. Finding suitable solutions and potential challenges is also essential to ensuring the better adoption of the DT. Consequently, the need for such an investigation is duly recognized in construction site progress monitoring.

3. RESEARCH METHODOLOGY

Being a novel concept of technology, to explore the potential of DT in construction progress monitoring a qualitative approach was adopted. Hence, the data collection has been done by taking semi-structured interviews with industry practitioners and research scholars who are familiar with the applications of DT. A heterogeneous purposive sampling method was used to select respondents having more than 2 years of working experience in SMART construction from Australia, Singapore, Ghana, China, and UAE. The sample selected includes participants from different age categories. It was also possible to get ideas based on their various experience levels. Face-to-face semi-structured interviews were conducted on online platforms for 30-45 minutes. Collected data were analysed with manual content analysis as the responses varied depending on the scope of involvement with the technology. The profile of the interviewees is presented in table 3 below.

Table 3 Profile of the interviewees

No	Details				
	Designation	**Type of Organization**	**Country**	**Experience**	**Key Expertise Areas Related**
I.01	PhD Researcher	Educational	Australia	4 years	Computer vision, Machine Learning, Image Processing, Deep Learning
I.02	PHD Researcher & Chartered QS	Educational (Currently)	Australia	5 years	Construction Performance measurement, Efficiency and effectiveness in construction
I.03	PHD Researcher	Educational	Australia	4 years	SMART Construction, Construction Industry Skills Research and development in construction
I.04	PHD Researcher & Lecturer	Educational	Australia	6 years	Blockchain, Carbon Emission, Sustainability
I.05	PHD Researcher	Educational	Australia	2 Years	Digital Twin and DT Cities AR, BIM, SMART buildings
I.06	Engineer and Digital Transformer of FM	IT Company	Singapore	2 Years	Digitalizing the typical buildings, BIM
I.07	Facility Engineer	IT Company	UAE	5 years	Digitalizing buildings, BIM
I.08	PHD Researcher	Educational	China	3 Years	Prefabricated Construction, Digitalization Technologies

I.09	PHD Researcher	Educational	Ghana	4 Years	Digital Twin, BIM & SMART buildings
I.10	Professor	Educational	Australia	More than 30 years	Construction Informatics, Construction Data Analytics, Disaster Management,
I.11	Facility Engineer	IT Company	UAE	2 Years	Digitalizing buildings, BIM

Most of the interviewees were from educational organizations because the real-life practitioners of DT in the construction industry are very few. The relevant data is collected from consultancy, facility management, and educational organizations. The type of sample, therefore, provides the research gap with viral information and experience-based and theoretical-based answers.

4. RESEARCH FINDINGS

4.1 AWARENESS OF DT IN CONSTRUCTION SITE PROGRESS MONITORING

Regarding the current level DT application, I.01 held that awareness of the potential use was very low. Respondent further explained that the necessity for the DT is currently used for maintenance work and renovation activities. I.06, I.08, I.09, and I.11 also agreed with this view. All respondents claimed that there is significant potential for DT on the construction industry. According to the interviewees, the industry is trying to visualize and monitor progress through BIM models which have certain limitations with regard to capturing data. I.07 and I.11 stated that partial applications of DT are being used in infrastructure projects and renovation projects where a digital representation of onsite data grant access to areas that would be hard to access.

4.2 ADVANCEMENTS IN DT FOR PROGRESS MONITORING

This section initially aims to distinguish the advancements of DT rather than the current technologies. According to the literature review, there is already discussion about current technologies which are being used in construction site progress monitoring.

The semi-structured interview identified how the DT concept in site progress monitoring differed from the current advanced technologies and the potential of the DT concept in site progress monitoring. The following routine parameters of current automated and semi-automated progress monitoring are identified and suggested.

4.2.1 Project Status Tracking

According to I.04, I.05 and I.10, DT can be used for component tracking, performance monitoring, equipment collaboration tracking and greenhouse gas emission tracking on-site. I.03 explained that *"DT can also help monitor energy consumption and provide strategies to optimize energy usage in building projects"*. Monitoring and tracking other construction activities at the site by avoiding paper-based documentation can be done. Similar observations had been made by Guo et al., (2022) and Fischer et al., (2023).

4.2.2 Site Performance

I.05 stated that *"DT can be used for evaluating the site performance in real-time with the use of previously stored data"*. As the DT gathers information on current progress the data can be compared with previous data to reveal the performance status. According to I.10, *"analysing such data would help take corrective actions to improve the site's current performance"*. These observations further emphasised the findings of Akanmu et al., (2021).

4.2.3 Construction Safety and Health

DT can be used for preventive maintenance and monitored to probably identify any health and safety issues. According to I.04, *"scaffolding erection work can be simulated using the DT before physical erection to ensure the safety of the workers"*. I.05 mentioned that training could be provided for different situations involving augmented and virtual reality with the help of the DT. Hence the interview findings resonated with the concepts brought forward by Akanmu et al., (2021).

4.2.4 Facility Management and Building Performance

I.10 pointed out, *"Facility management has enormous potential, where we have the digital twin of the physical object"*. In I.03's words, A facilities manager's maintenance tasks can be automated in a digital twin model. The system itself, the building, can talk with the digital twin model and give the digital twin model information. Buildings can communicate with actual physical structures.

4.3 CHALLENGES FOR ADOPTION OF DT FOR PROGRESS MONITORING

When considering challenges to adopting DT in site progress monitoring, table 4 lists the challenges identified from the literature along with the interviewees' responses illustrated with shaded background.

Table 4 Identified challenges for the adoption of DT for progress monitoring

Challenges and Factors	I.01	I.02	I.03	I.04	I.05	I.06	I.07	I.08	I.09	I.10	I.11
Investment costs for DT	√	√	√	√	√	√	√	√	√	√	√
System maintenance costs	√	√	√	√	√	√	√	√			√
The need for recruiting IT staff		√	√	√	√	√	√	√	√	√	√
Compatibility of software	√	√	√	√	√			√	√	√	√
Functional possibilities of the system/ Knowledge of the use of DT in the field		√	√	√	√	√			√	√	√
Ability for future upgrading	√		√	√	√			√			
User Experience Readiness and disinterest of users	√	√	√	√	√			√	√	√	
Ability to embrace innovation and change	√	√	√	√	√			√	√	√	
Lack of management support	√	√	√	√	√	√				√	√
Fragmentation of the sector and integration among participants in construction projects	√		√	√	√			√	√	√	√
Time-consuming	√										

Lack of training material, lack of resources for training			√	√					

All interviewees identified the high investment cost as the main barrier to DT technology adoption. I.05 highlights low-cost data collection methods such as drones, photography, and GIS applications, but developing software systems and implementing AR and VR technologies can be expensive. Uncertainty surrounds system maintenance costs due to the evolving nature of DT technology and the lack of standardization. Compatibility issues with other technologies are recognized by I.03 and I.02. DT is a new technology that requires training for staff and faces resistance to change, which I.01, I.02, I.04, and I.09 agreed on. Training, research, and development investments are suggested as solutions. The construction industry is among the least digitized and hesitant to adopt new technologies, but leaders and investors will embrace DT if it improves profitability and efficiency, as stated by I.02, I.08, and I.05. Management support is considered crucial by all respondents, and I.04 emphasized the need for top management support, training, and R&D investments. Due to the industry's fragmentation, digital twin technology can be highly effective and productive. The construction process involves architects, quantity surveyors, civil engineers, and contractors. Simchenko *et al.,* (2019) found time-consuming to be a barrier, which I.03 supports, stating that stakeholders need time to learn about the digital twin concept due to its steep learning curve.

5. CONCLUSIONS AND RECOMMENDATIONS

The main focus of the research was to identify the potential DT technology to improve the progress monitoring of construction projects. The literature findings identified that DT can be considered as a virtual entity, relying on the sensed and transmitted data of the IoT infrastructure with the purpose of allowing optimizations and decision-making. Further, the primary purpose of implementing a DT using physics-based models and data-driven analytics is to offer realistic operational representations of the assets. The literature revealed that there had been promising results with the adaption of DT in sectors other than construction. Common challenges that had influenced the implementation of DT were also identified from the literature. The applicability of these findings to the project progress monitoring was identified through semi-structured interviews. It was revealed that DT can track project status by monitoring component tracking, performance, equipment collaboration, and greenhouse gas emissions on-site. It can also monitor energy consumption and optimize energy usage in building projects. Further, DT enables real-time evaluation of site performance by comparing current progress with stored data, allowing for corrective actions to improve performance. DT also contributes to construction safety and health by simulating and ensuring the safety of workers during activities like scaffolding erection. Lastly, DT facilitates facility management by automating maintenance tasks and allowing buildings to communicate with their digital twin models. Hence, DT technology provides advantages such as risk assessment, predictive maintenance, remote monitoring, improved teamwork, and better decision-making through data analysis and integration. Interviews also revealed fragmented nature, lack of training, time constraints and lack of support from the organization management critical factors in addition to the literature findings. Some of the barriers identified in the literature were rejected by respondents and new barriers were added. ‘Cost’ is identified as a major barrier when it comes to developing countries. It could be noted that the industry does not have a good idea about the barriers due to technology.

Presently, research in the area of DT is at an embryonic stage of development but will be the futuristic option. The research outcomes are contributed to knowledge to understand the DT concepts, developments, and applications of DT in the construction industry. In addition to that the findings also enable comprehension of the barriers for the DT adoption in construction Site progress monitoring. The current study can provide practitioners with a readily accessible point of reference that captures the state-of-the-art of research on the use of digital twins in construction site progress monitoring, as well as the concept, stakeholders, and technologies. In such a context, practitioners can employ the findings of this study as a prior introductory guide. Since construction projects are heterogeneous, more concern needs to be taken on the cost and security of system adoption. Moreover, practitioners should develop innovative attitudes and flexibility to adopt new practices such as the identification of inefficiencies with real-time data, proactive maintenance, and prediction of resilience with futureproofing. These studies can achieve maximum benefit.

However, it shall be noted that given the embryonic stage of development of the DT in construction majority of the interviewees selected for the study had an academic background therefore future research can focus on exploring the practical applications of DT in construction project progress management. Additionally, the newly identified competencies highlighted in this study, as well as any future competencies, need to be firmly established within the construction industry.

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PRINCIPLES OF CIRCULAR ECONOMY FOR BUILDING SECTOR: A SYSTEMATIC REVIEW

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ABSTRACT

Globally, the building sector accounts for almost 40% of resource use and waste production and nearly 33% of greenhouse gas emissions. The Circular Economy (CE) and the adoption of its principles are currently recognised as one of the options to address these unsustainable issues. Despite, these principles are represented differently within three main domains: (1) collections of R-imperatives or R-framework, (2) CE loops, and (3) the ReSOLVE model, makes it a challenge for embracing CE principles in the building sector. A systematic literature review was carried out to respond to the research question "What are the R-imperatives that are applicable for the building sector as CE principles?", using Preferred Reporting Items for Systematic Reviews (PRISMA). It yielded a total of 23 papers to analyse. This review confirms that although alternative domains exist, the most practical CE principles seem to be confined to R-imperatives. The study provides 17 R-imperatives in the descending order of their circularity, along with their definitions. Finally, these R-imperatives are logically linked with principles of other two CE domains. This would provide a clear understanding of CE principles and thereby enable CE applications in the building sector.

Keywords: *Building Sector; Circular Economy (CE); Literature Review; Principles; Preferred Reporting Items for Systematic Reviews (PRISMA).*

1. INTRODUCTION

The building lifecycle yet based a linear economic model with high natural resource consumption and little resource recovery (Guerra & Leite, 2021; Anastasiades *et al.*, 2020). Buildings account for almost 40% of energy use and solid waste production, 30% of raw material use and nearly 33% of greenhouse gas emissions globally (Eberhardt *et al.*, 2019; Bolier, 2018). The concept of circular economy (CE) is a set of principles that collect a large variety of practices under the same objective of cutting the production of waste and consumption of resources by retaining the value of resources as long as possible while improving efficiency of material and energy, using renewable energy and using environmentally low-impact and toxic-free materials (Joensuu, *et al.*, 2020). Lindgreen *et al.* (2020) emphasised that CE must address the linear economy challenges, and it has grown in significance as a practical alternative for the shift to sustainable development

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(Kuzma *et al.*, 2022). This circular way of using materials can also reduce waste, the quantity of new materials used, and carbon emissions (Minunno, *et al.*, 2018). Accordingly, this concept should be used in buildings and building materials to keep materials sustainable and lower their embodied energy and carbon (Akhimien, *et al.*, 2022). It is important and desirable to put CE principles into practice to reduce adverse effects on the environment (Eberhardt *et al.*, 2019). Further, adopting CE principles has the potential to generate a net economic benefit while simultaneously benefiting the environment and society at large (Mhatre *et al.*, 2020). Principles of CE is crucial in the building sector to address the unsustainable effect of the industry and to achieve a resource-efficient society (Benachio, *et al.*, 2020; Osobajo, *et al.*, 2020). Cimen (2021) highlighted that this industry has been struggling to embrace CE principles.

However, CE has been viewed differently in different fields and from different perspectives, based on the representation of its principles. Amongst, primarily, R-framework or R-imperatives can be noted. The roots of CE lie in many schools of thoughts and scientific concepts such as industrial ecology, industrial symbiosis, performance economy, R-framework, blue economy, biomimicry, cradle-to-cradle, that have the closed-loop approach (Lieder & Rashid, 2016). However, the implementation of CE is being pursued through the use of the R-imperatives (or framework), which vary in quantity, and order and also have changed over time (Reike *et al.,* 2018). Amongst, 3R principles (OR framework), Reduce, Reuse, and Recycle are considered as the basis of CE and it summarises CE's primary methodology (De Pascale *et al.*, 2020; Aarikka-Stenroos, 2021). Similarly, Barreiro-Gen and Lozano (2020) indicated that CE encompasses four Rs: Reduce, Repair, Remanufacture, and Recycle. Although there exists several other R-imperatives such as 5Rs, 6Rs, etc, from a broader perspective, Reike *et al.* (2018) and Potting *et al.* (2017) concluded that there are 10Rs value retention options that can be implemented by consumers and enterprises along the whole value chain of a product while Sarfraz *et al.* (2021) highlighted a framework with 11 CE principles for improving the level of compatibility and organisational performance. Moving from the above general perspectives, in a subsequent instance, Cimen (2021) proposed 11Rs, particularly for the built environment by adding the new R principle of "Replace" to the existing 10 "R" principles of Potting *et al.* (2017).

The Ellen MacArthur Foundation's ReSOLVE Model is another domain representing CE where it incorporates six principles (Regenerate, Share, Optimise, Loop, Virtualise, and Exchange) that guide the transition to circular business paradigm (EMF et al., 2015). In addition, it is recognised as the most comprehensive and well-succeeded CE principles or frameworks for businesses (Williams, 2019). There were instances where ReSOLVE model was used as CE principles. For example, Kouhizadeh *et al.* (2019) examined the likely use of blockchain technology to transform and advance CE realisation. Similarly, Williams (2021) and Prendeville *et al.* (2018) explored the ways to adapt ReSOLVE to urban environments.

Apart from R-frameworks and ReSOLVE model, CE loops is another popular domain to represent the principles of CE. There were three different types of loops: closing, narrowing, and slowing loops (Akhimien, 2020; Gallego-Schmid *et al.*, 2020). Later, a regenerative loop was identified as the 4th loop (Cetin *et al.*, 2021). Few studies which used loops as the CE principles include Bocken *et al.* (2016) who developed a framework of strategies to guide designers and business strategists in the move from a linear to a CE, while Gallego-Schmid *et al.* (2020) demonstrated the links between CE and climate change mitigation by increasing resource efficiency through slowing, closing, and narrowing CE loops for material and energy. As foregoing review evidenced, although CE principles are applied and investigated in different fields from the perspective of different domains, a gap exists in applicable CE principles to building sector. To this end, this study aims to explore the CE principles applicable to building sector, and the relationship between the main three domains of CE principles.

The remainder of the paper is organised as follows. Section 2 discusses the study methodology adopted for the study while section 3 presents the literature findings, analysis, and the summed-up principles of CE for the building sector. Finally, section 4 presents the conclusions of this study.

2. RESEARCH METHODOLOGY

To achieve the aim of this study, a systematic literature review was carried out as it enables map, evaluate, and put together different pieces of literature to learn more about a field (Tranfield *et al.,* 2003). Initially, the research question was formulated as "What are the R-imperatives are available for the building sector as CE principles?". Then, appropriate search terms were identified and the final search string was developed as; *(builing?sector OR building? OR construction? OR "building design?" OR "building operation*" OR "building maintenance" OR "facilit* management" OR "building life?cycle" OR sustainability OR "sustainable development?" OR "sustainable building?" OR "adaptable design?" OR "architectural design?" OR "construction and demolition waste" OR whole?life?cycle) AND ("circular economy" OR circularity OR "circular concept") AND (principle?)*

Only peer-reviewed articles pertaining to the principles of CE and the building sector, published in English, between 2010 and 2022 were considered as filters. The said year of publications were considered due to the contemporary nature of the research, the diffusion of research on subject area. The TITLE-ABS-KEY was used as the search field. For the literature search, the Web of Science, Scopus, and Science Direct databases were chosen as they contain academic papers with high rankings and indexes. Google Scholar was also looked at to see if there were any other papers that might have been around and answered the study's research question. The PRISMA statement served as the guide for the systematic review (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). Accordingly, Figure 1 depicts the PRISMA flow diagram used in the study.

Figure 1 shows that a total of 265 records were found, including 118 Web of Science, 141 Scopus, and 6 Science Direct records. Out of them, 187 records were selected for the title and abstract screening process after 78 duplicate records were eliminated. 134 of them were found to be unrelated to the research question of the study during the preliminary screening, which resulted in 53 records. The full-text review of 36 records was continued after 17 records were unable to extract the entire article, and finally, 21 research contributions were selected for in-depth analysis. Another couple of records were manually added using Google Scholar Search, bringing the total number of records examined in this study to 23.

Following the systematic review, a further review into available literature was carried out to identify the definitions for particular CE principles which were not defined in the selected studies and to establish the link between main CE domains.

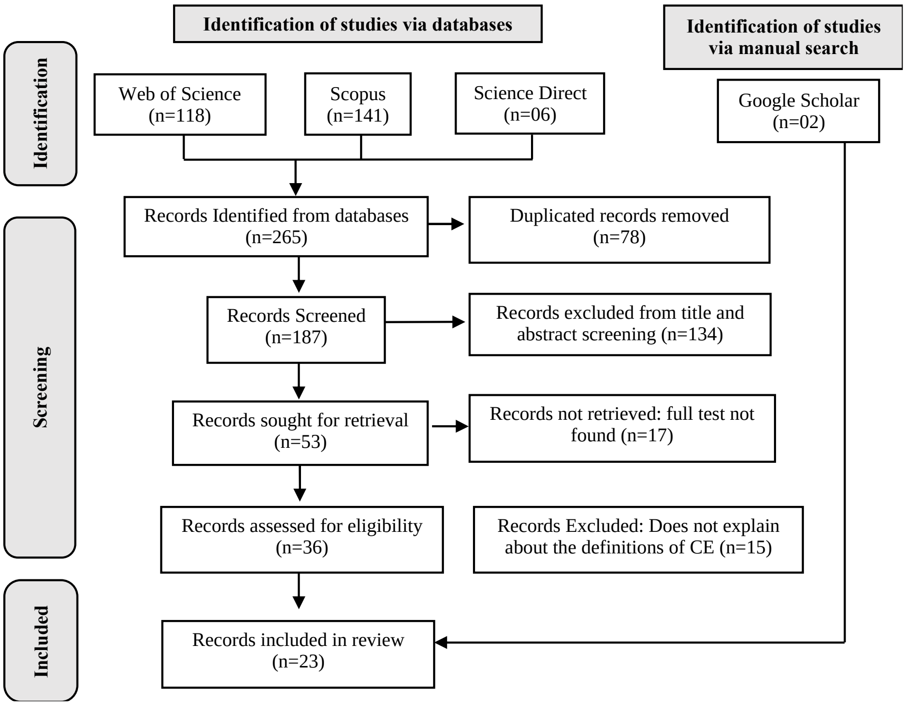

Figure 1: PRISMA flow diagram

3. RESULTS AND DISCUSSION

The results of this research are presented in two parts: (1) a descriptive analysis of the selected articles and (2) an analysis of the content of the articles in relation to CE principles applicable to building sector.

3.1 DESCRIPTIVE ANALYSIS

The number of publications found during the period considered for search is shown in Figure 2. With a steep increase from 2019 to 2020, the number of articles related to subject area published has been on upward trend, indicating the uptake of CE applications. Then, the selected articles were further scrutinised to identify the main domains of CE principles and building lifestyle stages covered in the previous scholarly works. In terms of main domains, most of the studies (17 out of 23) have considered the CE principles in R-frameworks while only few articles covered CE loops and the CE ReSOLVE model. This indicates that R-imperatives have received significant focus in terms of CE principles applicable to building sector. Figure 3 presents the number of articles that discussed the different CE domains.

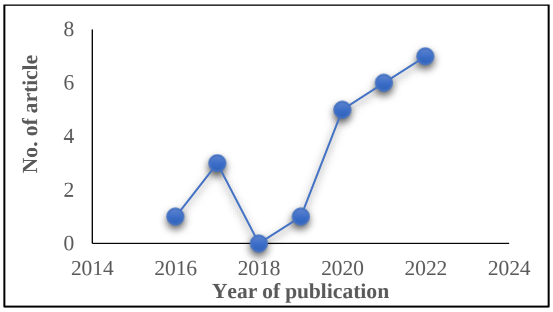

Figure 2: Number of publications

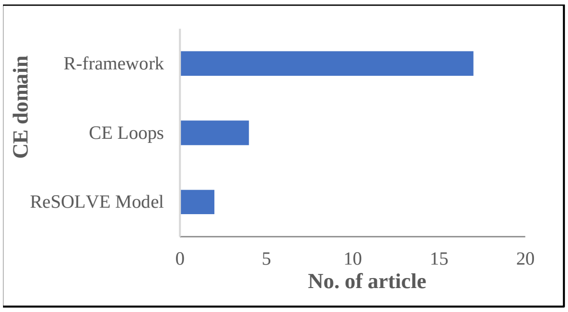

Figure 3: Articles distribution in different CE domains

Figure 4 displays the distribution of building lifecycle stages considered in the selected articles. As seen from Figure 4, generally, studies have considered CE principles applicable to all stages of the life cycle, commencing from design, construction, operation, and end of life. 4 out of 23 studies considered the whole life cycle stages of the building, and 3 out of 23 studies discussed the design stage and end-of-life stage. While 5 out of 23 studies do not specify any building lifecycle stages, they are discussing the CE indicators, stakeholder perspectives, and management of CE application.

Following the above descriptive analysis, Figure 5 displays the distribution of focus of the articles in terms of different building types considered. Mostly, 11 out of 23 articles have not focused specifically on whether existing or new buildings while 2 articles focused on both existing and new buildings. Another 6 and 4 articles considered CE applications in the new buildings and existing buildings, respectively. Accordingly, both new as well as existing buildings are considered almost equally in terms of CE applications. Further, Figure 5 depicts the stages of existing buildings discussed in the articles. Accordingly, the operational stage and the end-of-life stage are covered in most of the studies considered, and there was only one study that focused on both the operational and end-of-life stages.

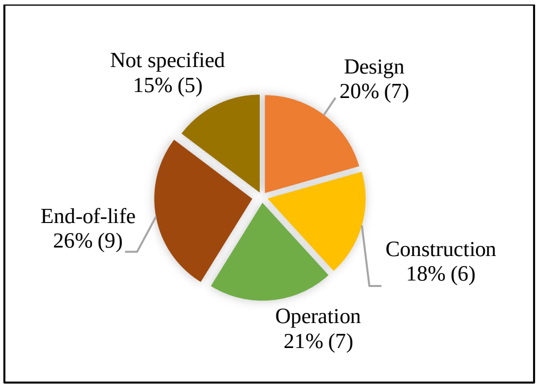

Figure 4: Building lifecycle stages

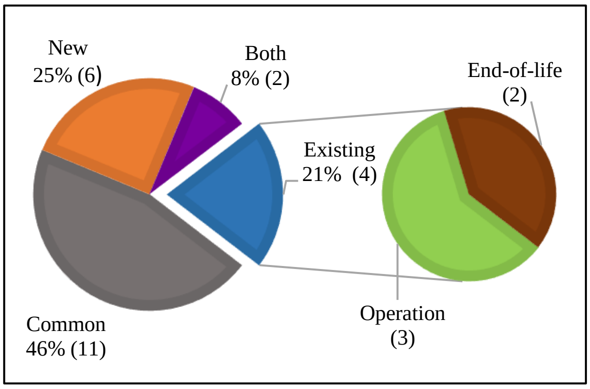

Figure 5: Types of building focused in articles

3.2 Circular Economy Principles Applicable to the Building Sector

The extensive literature analysis resulted in the identification of a total of 26 CE principles which can be used to represent the building sector, shown in Table 1. As commonly available in the literature as the 3R-framework, the top three CE principles **R**euse, **R**ecycle, and **R**educe have been referred to in the majority of the studies, respectively, 22, 19, and 12 out of 23 in the reviews.

Table 1: Summary of CE principles applicable to building sector

No	CE Principles	Sources																							Total
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	
1	Reuse	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*		21
2	Recycle	*	*		*	*	*	*	*	*	*	*	*			*	*	*	*	*	*		*	*	19
3	Reduce	*	*					*			*	*	*		*	*	*		*	*	*		*		13
4	Repair		*		*				*				*		*	*			*	*					08
5	Refurbish/ Reprocess /Requalification			*	*			*				*	*						*	*					07
6	Remanufacture	*		*	*							*				*				*	*				07
7	Recover									*	*		*		*	*		*							06
8	Replace						*				*	*	*												04
9	Disposal									*			*											*	03
10	Reclaim				*										*					*					03
11	Adaptive reuse															*				*					02
12	Return				*							*													02
13	Reverse						*					*													02
14	Renew																		*	*					02
15	Remarket/ Resell														*			*							02
16	Refuse									*									*						02
17	Upgrade								*						*										02
18	Selective Demolition		*																						01
19	Retain				*																				01

No	CE Principles	Sources																							Total
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	
20	Relocate												*												01
21	Refit				*																				01
22	Recondition																			*					01
23	Repurpose																			*					01
24	Redesign																		*						01
25	Rehabilitation																			*					01
26	Retrofit				*																				01

Sources: [A] - Nasir *et al*. (2016); [B] - Adams *et al.* (2017); [C] - Cayzer *et al.* (2017); [D] - Mangialardo & Micelli (2017); [E] - Akanbi *et al.* (2019); [F] - Anastasiades *et al.* (2020); [G] - Gallego-schmid *et al*. (2020); [H] - Jansen *et al*. (2020); [I] - Kanters (2020); [J] - Mercader-moyano & Esquivias (2020); [K] - Antonini *et al.* (2021); [L] - Bertino *et al.* (2021); [M] - Dams *et al*. (2021); [N] - Kosanovic *et al.* (2021); [O] - Marika *et al.* (2021); [P] - Torgautov *et al*. (2021); [Q] - Al-Obaidy *et al.* (2022); [R] - Arauzo-Carod *et al.* (2022); [S] - Dabaieh *et al.* (2022); [T] - Huang *et al*. (2022); [U] - Liu *et al.* (2022); [V] - Ruiter *et al.* (2022); [W] - Spisakova *et al.* (2022).

Despite the differences in terminologies, some of these 26 CE principles have some similarities in their meaning. At first, **A**daptive **R**euse is defined as "a process that changes a disused or ineffective item into a new item that can be used for a different purpose" (Department of Environment and Heritage, 2004). It is comparable to the **R**econdition principle, which is defined as restoring an old product and turning it into a new one (Sarfraz *et al.,* 2020). Further, there are similarities between **A**daptive **R**euse and **R**ehabilitation, where **R**ehabilitation is defined as "the process of making a building work again" ([S]; Foster & Kreinin, 2020) or "the process of making something good again" (Cambridge Dictionary, 2022b). Next, the concepts of **R**esell, **R**emarket, and **R**elocation are all included in the **R**euse principle, because **R**euse refers to continuing to use any material, component, or product in its current state for the same function after another consumer no longer finds it useful (Sarfraz *et al.,* 2020; Reike *et al.,* 2018). **R**esell or **R**emarket means selling the material, component, or product to another user for the same function, whereas **R**elocate means that when a building is demolished, its components are taken out and moved to new locations where they are placed for use in different lifecycles ([L]; Reike *et al.,* 2018). Then, **R**eclaim was referenced in three articles, but only one of them [S] used it as a principle of CE, whereas the other two [D; N] used the terms "reclaimed/secondary materials and components" and "reclaim materials for reuse" as strategies to attain CE principles. According to Cambridge Dictionary (2022a), the term **R**eclaim refers to "treat waste materials to get useful materials again or to get useful materials from waste". Accordingly, it can be concluded that it is a component of **R**epurpose or **R**econdition principles. Following that, **R**etrofit and **R**everse principles can also be added to CE principles. The term **R**etrofit is derived from the concept of "adaptation" and refers to significant physical alterations to buildings (Dixon & Eames, 2013; Wilkinson, 2012). It is defined as "any work done to a building that goes beyond maintenance to change its capacity, function, or performance" or "any action to change, reuse, or upgrade a building to fit new conditions or needs" (Douglas, 2006).

Similarly, Saffari and Beagon (2022) denoted that **R**etrofit entails changes to the building sector's fabric, shape, and systems. that go beyond the frequently invisible maintenance and repair. It can happen to entire building or portions of building, for instance one or more floors of a high-rise building (Wilkinson, 2012). Accordingly, **R**etrofit can take a position between the principles of **R**epair and **R**efurbishment. Other one is **R**everse, which is described as "the use of reversible connections is advocated" ([F]; Kozminska, 2020) or "implementing reverse logistics to optimise the system performance" [K]. For example, steel and wood may permit reversibility (Rahla *et al.,* 2021); dismantlable steel connections may be reversible for prefabricated concrete elements, and wooden column-slab systems may be reversible with cross-laminated timber cassettes (Kozminska, 2020). As seen from Table 1, **R**efit principle identified by [D] and placed it between **R**etain and **R**efurbish. **R**efit is defined as "to make repairs or changes to a building, factory, or store to improve it or change its purpose" (Cambridge dictionary, 2022c). It can therefore be incorporated into both **R**epair and **R**etrofit. Further, **R**eplace and **R**edesign principles are mentioned in four [F; J; K; L] and one [R] articles respectively. **R**edesign can be included within **R**eplace principle as it is defined as a more sustainable material, designed and manufactured as an alternative to replace existing material (Cimen 2021; Sarfraz *et al.* 2021).

Afterward, **U**pgrade is defined as the ability of a product to continue being useful under changing conditions by improving the quality, value, and effectiveness or performance

(Linton & Jayaraman, 2005, p. 1814), whereas [L] described **R**efurbishment as the set of interventions aimed at transforming the building through a systematic set of works that can lead to a building that is totally or partially different from the previous one. In addition, Ghisellini *et al.* (2017) noted that refurbishing has the potential to increase a building's lifespan, adapt to new requirements, and/or improve its energy and environmental performance instead of adopting new construction plans. As a result, upgrading can be referred to as "refurbishment of a building or "a component of refurbishment".

The principles of **D**isposal and **S**elective **D**emolition can be taken out of the CE principles for the building sector because they could form part of either **R**euse, **R**ecycle, **R**ecover or **R**eturn. For instance, **R**euse or **R**ecycling can be used as an alternative to incineration or waste disposal to keep building materials and components inside the production cycle [L]. Despite **D**isposal being mentioned in three articles [I; L; W], it cannot be considered a CE principle as it contradicts the idea of circularity. Given that it hurts the environment, it is the least sustainable waste management strategy, including for construction and demolition waste [W; I]. Then, **S**elective **D**emolition was listed only by [B] in the circular aspects of end-of-life. Although **S**elective **D**emolition is preferable to demolition since it can contribute to starting a new lifecycle of materials, components, and parts of buildings through a closed loop [W], these are mostly used in reuse and recycling. In addition, [L] specified that consideration must be given to potential strategies to avoid demolition and disposal of existing buildings as the majority of them were not designed for deconstruction.

Finally, 16 out of the 26 listed principles of CE have been summarised from the discussion. As discussed previously, Cimen (2021), Sarfraz et al. (2021), and Reike et al. (2018) developed different R-frameworks of CE, and summing them gives 15 R-imperatives as depicted in Figure 6. Of them, three principles of Reimagine, Rethink, and Remine are not identified in the list of 26 CE principles applicable to the building sector, shown in Table 1. Out of these three principles, the Rethink principle must be added as it entails intensifying product use as well as rethinking existing strategies and objectives, while principles of Re-mine and Re-imagine can be omitted as they seem to have less potential for application in building sector and due to time consuming process.

This eventually results in a list of 17 CE principles applicable to building sector, as depicted in Figure 6. The CE principles and their descriptions are shown in Figure 6 in the sequence in which they should be applied to a given building sector context. Further, the figure gives an indication on principles that are new additions and which are already available in other less popular R-frameworks of CE (Cimen, 2021; Sarfraz *et al.*, 2021; Reike *et al.*, 2018).

Figure 6: Summary of CE principles applicable to building sector

Considering the other two domains of CE principles, CE Loops and the ReSOLVE model, all these 17 R-imperatives can be logically linked with any one of the four loops and also in any one of the six actions of ReSOLVE model, by referring to addition sources such as Caldas *et al.* (2022); Kennedy and Linnenluecke (2022); Cetin *et al.* (2021); Akhimien, (2020); Gallego-Schmid *et al.* (2020), Hopkinson *et al*. (2020); Mendoza *et al*. (2019); Antikainen *et al.* (2018) and Bocken *et al*. (2016).

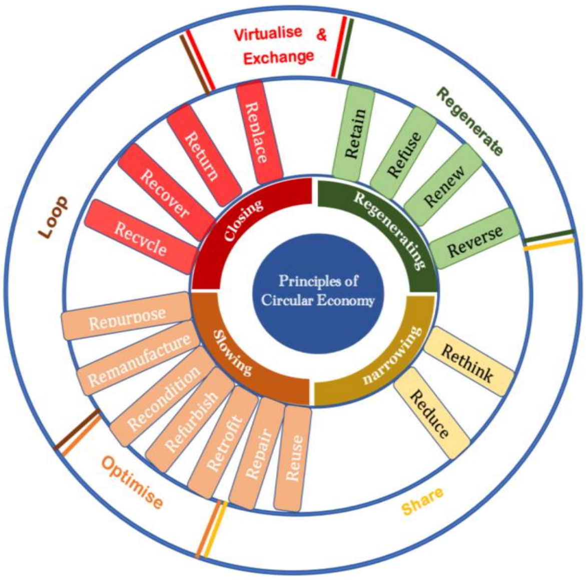

Figure 7: Logical link between R-imperatives and other domains

Figure 7 displays three levels of circles to depict the logical connection between R-imperatives and other CE domains. The inner circle represents the CE loops, while the middle and outer layer represents the R-imperatives that are presented in Figure 6, and the ReSOLVE model, respectively. Additionally, the level of circularity for each principle is expressed using a color-coding where green indicates more circularity whilered represents less circularity.

4. CONCLUSIONS

In this study, CE principles were viewed within the most popular three main domains of R-imperatives, CE Loops, and the ReSOLVE model. A critical review carried out on 23 peer-reviewed scholarly articles retrieved through systematic review using the PRISMA tool indicated that most of the studies (18 out of 23) represented the CE principles within the domain of R-imperatives. The review provided altogether a list of 26 R-imperatives as CE principles applicable to building sector. Of the 26 principles, most of the study contexts (over 12 out of 23) have identified the common 3Rs of Reuse, Recycle, and Reduce. Although some of these principles were referred to by different terminologies, they represented similar concepts or meanings. Upgrade, Reclaim, Rehabilitation, Adaptive Reuse, Refit, Resell/Remarket, Redesign, and Relocate are the concepts which refer to similar meanings of some other concepts in the list of 26 principles. Further, the principles of Disposal and Selective Demolition were excluded from the list of CE principles for building sector as they can be represented to some extent under the principles of Reuse, Recycling, Recovery, and Return. Further, these principles seem to contradict the concept of CE as well. Accordingly, a condensed list of 16 CE principles was derived. When these principles were further compared with previous well-known studies relating to R-frameworks by Cimen (2021), Sarfraz et al. (2021), and Reike et al. (2018), it was identified that three principles of Re-imagine, Remine and Rethink are missing from the list of 16 principles. However, of them, Rethink is taken into account when building sector principles, while the remaining two are eliminated. This adds the seventeenth principle to the list of CE principles applicable to the building sector. Moreover, Retain, Renew, Reverse, Retrofit, and Return are the five principles added as CE principles that are applicable to the building sector in this study compared to previous studies. The current study also establishes a link between the three popular domains for understanding CE principles, including CE loops, the ReSOLVE model, and the R-framework. These models are continuing to evolve, and at this point in time, this logical connection model encompasses all aspects of the various domains of CE principles. This makes it possible to understand the CE principles clearly and thereby enhances their application in the building sector. These review findings can be applied to real life buildings of different types to validate. Further, these principles seem to require appropriate strategies for their adoption. Hence, the current study is extended to explore these aspects.

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QUANTITATIVE ANALYSIS OF CONSTRUCTION-RELATED LEGAL CASES IN NEW ZEALAND

Pramod Malaka Silva[1], Niluka Domingo[2] and Noushad Ali Naseem Ameer Ali[3]

ABSTRACT

The construction industry in New Zealand (NZ) plays a significant role in the country's economy. Similar to many other countries around the world, the construction industry in NZ is also prone to many disputes, which sometimes end up in courts. To investigate comprehensively about the disputes in the construction industry, several researchers have analysed court cases internationally. There is only a limited number of studies in NZ construction industry that followed court case analysis. This study has been carried out in search of quantitative aspects of 35 construction industry-related court cases in NZ. Based on the studied 35 court cases in NZ, majority of them has fallen into the area of payment issues, quality of works and variation entitlements. Poor contract understanding and administration, contractor's quality of work and poor contract arrangement have been identified as the most recurring primary causes of disputes. Further, the majority of cases that were heard before NZ courts had followed lumpsum contracts and traditional procurement route. The findings of this study is beneficial to the construction industry practitioners to avoid disputes by early identification of common issues in the industry.

Keywords: *Causes of Disputes; Court Case Analysis; Disputes in NZ.*

1. INTRODUCTION

Kumaraswamy (1997) has defined a dispute as a "situation in which a claim or assertion made by one party is rejected by the other party and the rejection is not accepted in return". Disputes in construction projects hinder the project's success as they largely impact the time, cost and quality objectives of its parties (Naji et al., 2020).

1.1 STUDIES ON COURT CASES RELATED TO THE CONSTRUCTION INDUSTRY

Given the importance of investigating disputes in the construction industry, many researchers have focused on this area. One of the main data collection methods for those studies related to disputes in the construction industry were "court case analysis". Court

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case analysis provides an in-depth understanding of how judges make decisions and examines factors such as policy considerations and different viewpoints on past cases (Sunstein, 2005).

Davenport and Brand (2013) investigated how Australian high courts have relied on the effectiveness of the time bar clause in the case Andrews v. Australia and New Zealand (NZ) Banking Group case. To investigate the reasons for escalating the disputes from the arbitration and adjudication to litigation in England and Wales, a review of 48 legal cases were conducted by Barman and Charoenngam (2017). Arditi and Pulket (2005) gathered information from 114 construction related court cases in USA to develop a decision making tool based on a boosted decision tree system capable of forecasting the result of construction litigation.

1.2 STUDIES ON NZ COURT CASES RELATED TO CONSTRUCTION INDUSTRY

Jelodar et al. (2016) reviewed court cases in NZ from 2009 to 2014 and revealed:

- Opportunistic behaviour, breach of contract, poor workmanship and contract and documentation problems, are the most common causes of disputes,
- How relationships among the parties get impacted by a dispute, and
- The importance of proper contractual provisions, evidence and reasoning to manage a dispute smoothly.

Amongst the studied cases, 70% of the total court cases were triggered by multiple causes, hence the complexity of the causes was highlighted. Further, their study identified, disputes between client and the Contractor as the most frequent type of dispute to proceed to the courts while disputes between the Contractor and the sub-contractor being the second largest. Similarly, Ramachandra and Rotimi (2011) also ascertained amongst the cases studied, the majority (82%) were between the clients and contractors followed by cases between contractors and sub-contractors (10%) and between clients and sub-contractors (8%). This study examined the nature of payment problems in NZ by analysing 40 court cases (by identifying the parties, nature of the payment dispute, claimed amount and status of the final judgement) and liquidator's report. Moreover, 80% of the cases which were examined in this study were related to progress and final payment disputes.

1.3 NZ LEGAL SYSTEM

NZ legal system has diverged from the traditional English legal system in many aspects and it protects the customary or indigenous rights (Penk & Russell, 2018). In 1840, British Crown and Māori chiefs entered into an agreement called, “Treaty of Waitangi”, which emphasises the relationship between the Crown in NZ and Māori (Ministry of justice, 2020). Similar to England, NZ's constitution remains unwritten, but the parliament has passed many statues namely Constitution Act 1986, the State Sector Act 1988, the NZ Bill of Rights Act 1990. The sources of NZ law are mainly the parliament, where statues are originated and the courts, where case laws being initiated (Penk & Russell, 2018). Matters related to construction industry are often governed by the Construction Contracts Amendment Act 2015 passed by Parliament on 20 October 2015.

The court system, which belongs to the government and few private sector entities involve in dispute resolution process in NZ. The hierarchy of court system in NZ follows common law jurisdictions similar to United Kingdom and Australia which allows to appeal the decisions of lower courts in higher courts. The court hierarchy is basically consisted of three levels namely: (a) Higher Courts, (b) Lower Courts, and (c) Tribunals and Authorities as illustrated in Figure 1.

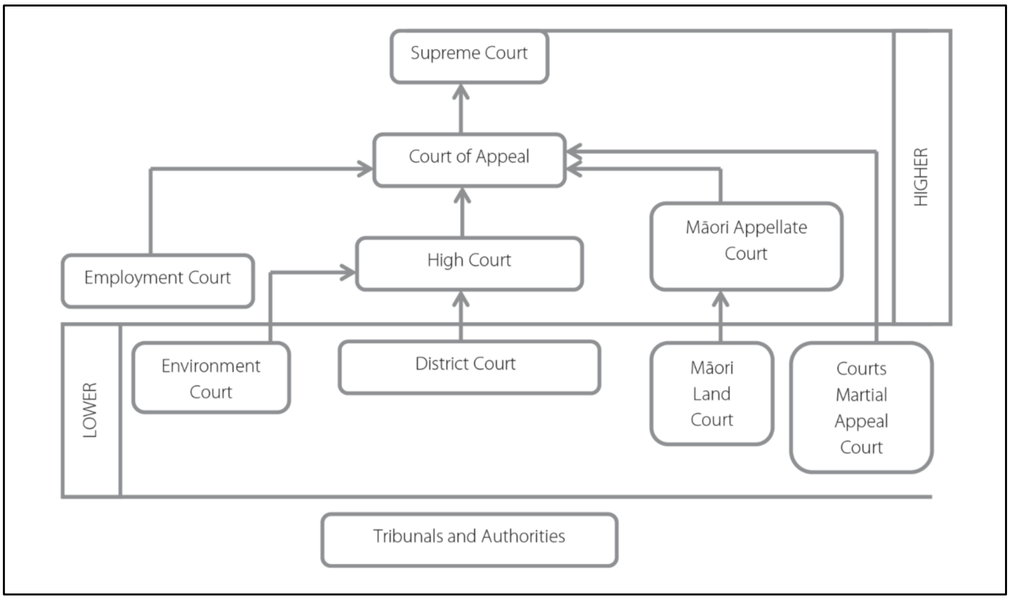

Figure 1 : Hierarchy of court system in NZ
(Source: Penk and Russell, 2018)

In summary, several studies around the world preferred court case analysis as their data collection method to achieve various research objectives such as investigating the usage of contractual provisions and developing decision-making tools to predict judges' decisions. However, in NZ, there are very limited number of studies regarding the construction related disputes such as the (a) study by Jelodar et al. (2016), which focused on how the relationship among parties gets impacted by a disputed environment, and (b) study by Ramachandra and Rotimi (2011), which focused on the payment related dispute. This study mainly aims to identify frequent causes of disputes and common types of disputes in the NZ construction industry. Additionally, it attempts to recognise what procurement and contract types have mainly contributed to disputes. The said aims were expected to be achieved using quantitative analysis of court cases in NZ construction industry.

2. RESEARCH METHODOLOGY

This paper presents the findings of only a part of a more extensive study. Researchers have already identified 28 causes of construction-related disputes under four main categories by conducting a systematic literature review. An in-detail court case analysis on the cases which were heard before the courts in NZ was carried out to study their causes more comprehensively. A simple methodology from the selection of cases step to the reporting step was followed as depicted in Figure 2.

“Lexis Nexis – NZ” is a powerful and user-friendly online database that has the ability to search cases and legal information effectively and accurately. Therefore, it has been used as the database to review the cases. Lexis Nexis - NZ contains number of varieties of cases and does not limit to construction cases. Users of Lexis Nexis have the ability to filter cases which were categorised based on “catchwords”. Hence, firstly the main category, “Building and construction” was selected, secondly under that main category, only three sub-categories namely “Building Contracts”, “Construction” and “Subcontractors” were selected leaving four other sub-categories unselected as they were irrelevant to the focus of this study. Seventy cases were reviewed initially and almost half of them were not further considered as they were related to condominium property, building consent or litigation procedure-related disputes.

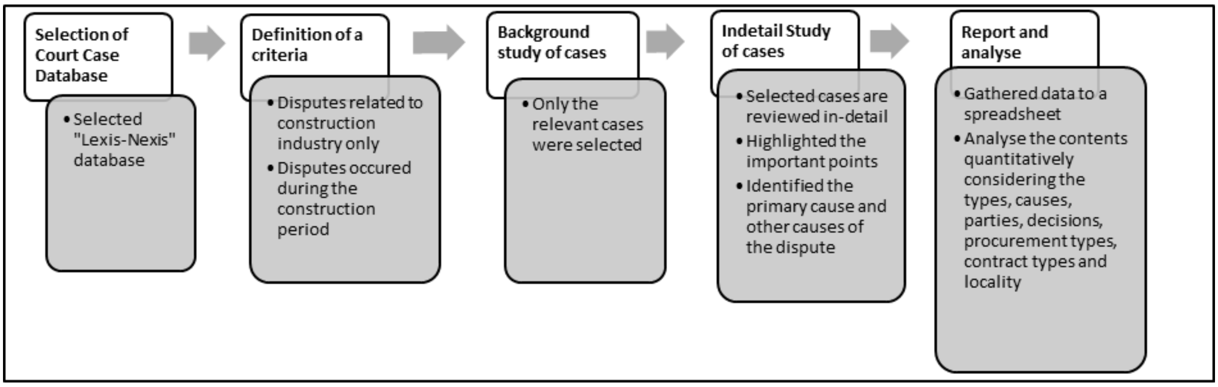

Figure 2 : Research methodology

The detailed study on the cases were carried for the selected 35 court cases. In each selected case, background information, location, year, primary cause of dispute, other causes and type of dispute were the main aspects recorded in the spreadsheet database. The cases were categorised mainly under eleven causes and analysed qualitatively and quantitatively. However, this paper only presents the quantitative findings. It is possible to bring quantitative aspects even for qualitative data by employing approaches such as frequency counts (by summarising the occurrence of different themes) and descriptive statistics (by calculating measures such as mean, mode and median) (Bryman, 2016; Saldaña, 2015). The reviewed cases were categorised and coded into eleven causes of disputes and 16 types/areas of disputes. Further, those cases were also categorised considering their procurement methods, contract types and locations. Under each category, the frequencies of occurrences of the selected cases were calculated to determine the most common/significant causes, types, procurement types, contract types and locations of construction-related disputes in NZ.

3. FINDINGS AND ANALYSIS

Within the selected 35 court cases, eleven “primary causes” of disputes have been identified. The number of cases identified against each of the primary causes is listed in Table 1.

Table 1 : Primary causes of court cases

Primary Cause	Total
Poor contract understanding and administration	10
Poor contractual arrangements	7
Contractor's quality of works	5
Unrealistic Expectations of Employer	4
Non or delayed payments	3

Primary Cause	Total
Unrealistic Expectations of Contractor	1
Employer-initiated scope changes	1
Weather and Environmental Issues	1
Engineer's faults	1
Financial Failure of Contractor	1
Other sub-contractors' conducts	1

Most of the cases (10 out of 35) were related to "poor contract understanding and administration", which can be considered as a broad "primary cause" with several sub causes such as the party's unilateral decisions, poor instructions, improper reasoning and non-compliance to the contract document. Poor contractual arrangements and quality of the CContractor's work have also caused many construction disputes that have gone up to NZ courts. A previous study by Jelodar et al. (2016) reviewed court cases in NZ from 2009 to 2014 and revealed 26 causes of disputes and amongt those causes, opportunistic behaviour, breach of contract, poor workmanship and contract and documentation problems were identified as the most common. The study by Jelodar et al. (2016) have identified causes of disputes in more narrower manner whereas this study identifies causes in a more broad manner.

Several uncommon causes were also identified namely the Engineer's faults, the financial failure of the Contractor, and other sub-contractors' conducts. Even though a primary cause of each case was identified, several cases were triggered due to multiple reasons; for instance, in "Andrews Property Services Ltd v Body Corporate" (2017), the defendant decided to depart from one of its liabilities unilaterally and on the other hand appellant had not clarified design details during pre-contract stage, therefore this particular case was triggered by multiple causes. Moreover, in a case heard before the High Courts, NZ; "HSU v MAHONEY" (2021) was caused by lack of supervision by Employer and non-compliance to the construction Standards by the Contractor. Similarly, Jelodar et al. (2016) have also emphasised the fact that many of disputes (70% of cases studied by the author in NZ) were triggered due to several distinct causes.

Authors have further attempted to identify common areas of disputes among the selected 35 cases. Figure 3 depicts the areas and causes that led to a particular dispute area. Disputes related to payment issues were found on most of the cases (12 out of 35 cases) and causes for that dispute area were poor contract understanding and administration, poor contractual arrangements, non/delayed payments, Contractor's quality of works and weather and environment issues.

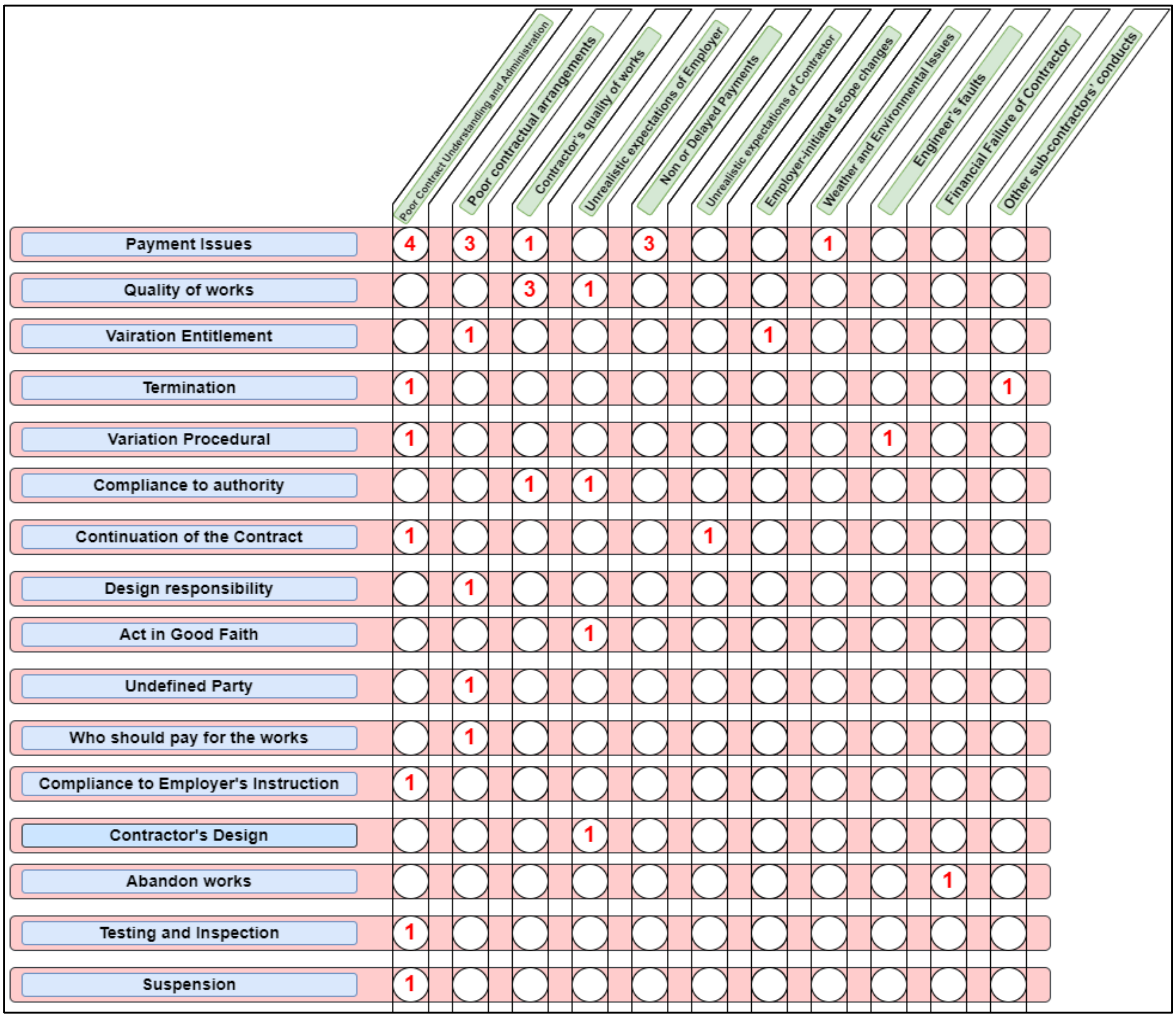

Figure 3 : Primary causes and common areas of disputes

Though many stakeholders are involved in construction projects, disputes between the Contractor and the Employer are identified as the most common, accounting for 26 out of 35 cases. It re-confirms two previous studies in NZ by: (1) Ramachandra and Rotimi (2011a), which revealed that four-fifths of the cases in NZ were between the employers and contractors, and (2) Jelodar et al. (2016), which again found that disputes between client and the Contractor as the most frequent type of dispute to proceed to the courts. Amongst the cases between employer and Contractor (27), 15 were claimed/appealed by Contractor, and eight cases were decided in favour of Contractor. The rest of the 12 cases were claimed/appealed by employer, and employer managed to obtain a decision for their side in 7 cases. A total of 4 cases were identified between the Contractor and the sub-contractor in which majority of them were claimed/appealed by the sub-contractor (3 cases out of 4) who managed to win two of them. Overall, the claimed/appellant party were only successful in 15 cases. Table 2 shows the summary of court cases based on parties and their decisions.

Table 2 : Disputant parties in cases

Parties	Claimed / Appealed by	Decision in Favour of				
		Contractor	**Employer**	**Sub-Contractor**	**Consultant**	**Authority**
Employer VS Contractor (26)	Contractor (16)	8	8			
	Employer (10)	7	3			
Contractor VS Sub-Contractor (4)	Contractor (1)			1		
	Sub-Contractor (3)	2		1		
Contractor VS Consultant (2)	Contractor (1)				1	
	Employer (1)		1			
Authority VS Contractor (1)	Authority (1)					1
Employer VS Sub-Contractor (1)	Sub-Contractor (1)		1			
Employer VS Consultant (1)	Employer (1)		1			
		17	**14**	**2**	**1**	**1**

Traditional procurement, in which the Contractor only involves to the construction relying on the design provided by the employer, is identified in 70% of the cases as shown in figure 4. Importantly, findings show that extremely low number of cases (3%) were reported with regard to "design and built procurement" method. Some cases were raised from labour only (7%) and material only (7%) procurement settings. Besides the cases between employer and Contractor, few cases were reported between employers and consultants and contractors and authorities as well.

Cases were reported in various contract types. More than one third of cases (39%) were raised from lumpsum contracts whereas cost reimbursement contracts and measure and value contracts were highlighted in 13% and 9%, respectively. Noticeably, the parties of one out of ten cases have not agreed to a type of their contract at all. In some instances, parties had entered into very specific contracts such as "Working together agreements" and mixed type of contracts but could not resist carrying their disputes to the courts.

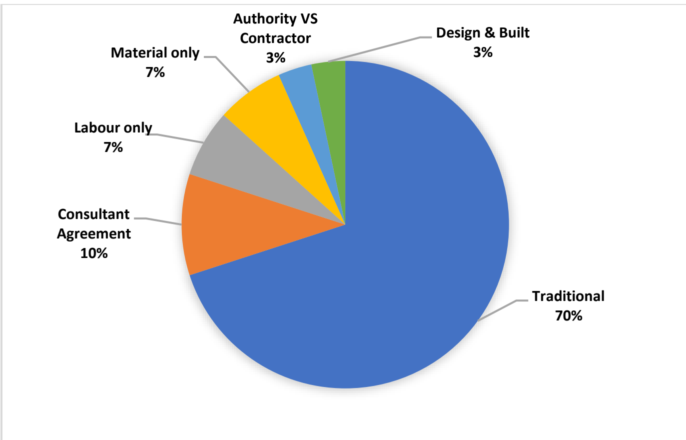

Figure 4 : Distribution of cases based on procurement type

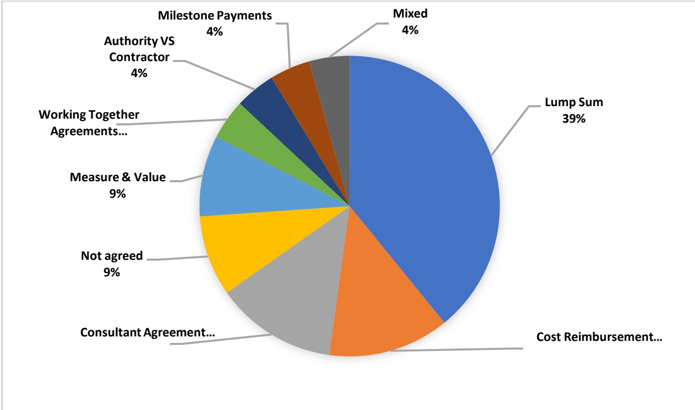

Figure 5 : Distribution of cases based on Contract Type

Amongst the studied cases, 23 of them had written contracts. Out of those 23 cases, 10 of them have clearly mentioned that parties had followed a standard form of contract such as NZS 3910:2003. However three cases had not had a written contract at all.

As shown in figure 6 below, court cases were reported across the two islands of NZ. However, the majority of them were reported in Auckland (16 cases) and Wellington (12 cases).

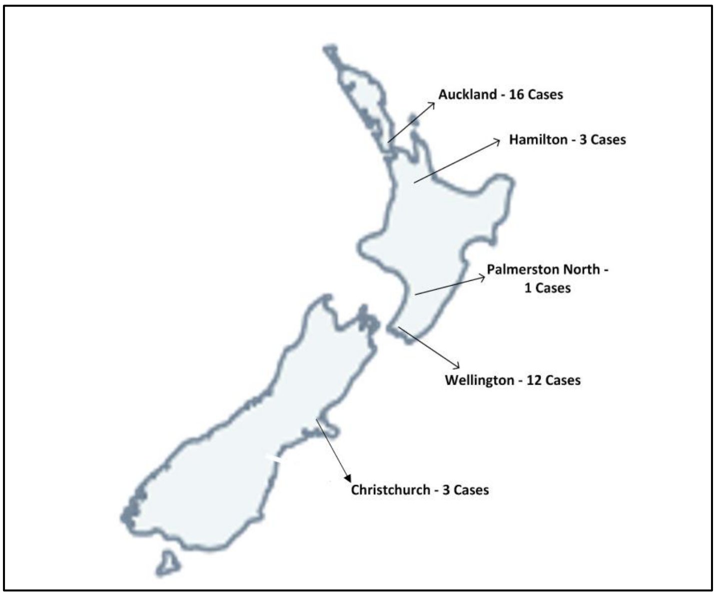

Figure 6 : Distribution of cases across NZ

4. CONCLUSIONS

Analysing court cases has been a popular research method for many studies related to disputes and law. As a part of a larger study, this paper has presented only quantitative findings of 35 court cases in the construction industry of NZ. The most significant cause of a particular court case has been considered as "primary cause" and eleven "primary causes" of disputes were identified. Poor contract understanding and administration, poor contractual arrangements, CContractor's quality of work and unrealistic expectations of employer were identified as the most frequent "primary causes" of disputes. Similar to few previous studies in NZ, payment issues were highlighted in most of the cases followed by disputes related to quality of works, variation entitlement and termination. Most of the cases were between contractors and employers in which Contractor claimed/appealed often. Traditional procurement route and lumpsum contracts were reported in most of the cases. The findings of this quantitative study pave the path for an in-depth study investigating the reasons and avoidance strategies for the disputes which arise out of traditional procurement route and lumpsum contracts in NZ. Industry practitioners can also be aware of more common types of disputes and causes that mostly contributed to each type of disputes in NZ.

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QUANTITY SURVEYOR'S PERSPECTIVE ON DOCUMENT MANAGEMENT IN CONSTRUCTION PROJECTS: AN EXPLORATORY STUDY IN SRI LANKA

L.S.D. Rathnayaka[1], B.K.M. Nadeetharu[2] and U. Kulatunga[3]

ABSTRACT

Electronic Document Management Systems (EDMS) have become increasingly popular in recent years as construction organisations seek to improve document management efficiency, productivity, and security. However, the Quantity Surveyor (QS), a key stakeholder responsible for construction documentation management, has less adapted to it in the Sri Lankan context. Accordingly, this study used twelve expert interviews to identify the status of documentation management in the Sri Lankan construction industry from a QS perspective. Manual content analysis was used to analyse the findings. Despite the disadvantages, the conventional DMS approach is still prevalent in the Sri Lankan context. Despite the QSs having a basic understanding of the EDMS approach and being willing to transit to EDMS, they are less familiar with EDMS software. In addition, project size, limited availability of technical facilities, and the reluctance of government and professionals cause to continue this adaptation are still a barrier. The findings of this research can be based on future studies on different stakeholder perspectives. Since conventional DMS is proved to be a less efficient solution for the document management of construction projects and EDMS is also difficult to be initiated, these findings can be benchmarked by policymakers to address the identified causes of the issue.

Keywords: *Barriers; Document; Electronic Document Management System (EDMS); Quantity Surveyors (QS); Sri Lanka.*

1. INTRODUCTION

Effective and efficient management of documents is essential to ensure the successful completion of a construction project (Ahmad et al., 2019). Specifically, as Gerardi (2022) stated, document management in construction refers to organising, regulating, storing, sharing, and editing drawings, specifications, estimates and other construction-related documents. Specifically, the construction industry uses many documentation techniques and profusely adapts conventional document management for their projects (Ahmad et al., 2015). This conventional approach of record keeping refers to a conventional

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document management system (DMS) where records are kept in hand-written or printed hard copies with or without soft copies. However, this conventional approach of DMS exhibits several disadvantages, including less flexibility in inserting comments and revisions, difficulty searching for the correct document, high maintenance costs and time wastage (Jane, 2020). Consequently, limitations of the conventional DMS intensify the importance of an electronic document management system (EDMS) to construction projects, which can be identified as an approach with high operational efficiency and effectiveness (Abdulkadhim et al., 2015).

As revealed in the recent study of Chandramohan et al. (2020) documentation is the most important competency for a quantity surveyor (QS). Despite QSs play a significant role in managing construction project documents, they hesitate to adopt this technology for several reasons, such as lack of awareness, resistance to change, and limited technological infrastructure (Haupt & Naidoo, 2016). Sri Lanka is a developing country with a high tendency of reluctance to technology, especially in quantity surveying (Edirisinghe & Bandara, 2022). Henceforth, Sri Lankan QSs are biased to practice traditional documentation methods in their projects, which is less advantageous in the present context as the global construction industry and professionals are eagerly embracing new technologies. Accordingly, this study aims to investigate the perspectives of QSs, who play a significant role in managing construction project documents, regarding the DMSs used in the Sri Lankan context. Following the aim, the main DMSs used in Sri Lanka, their limitations, awareness about EDMSs and their tools by Sri Lankan QSs, and barriers to the adaptation of EDMSs have been presented in this paper.

2. LITERATURE REVIEW

2.1 TRENDS IN DOCUMENT MANAGEMENT IN CONSTRUCTION INDUSTRY

Most professionals have personal computers today, and the Internet's "information superhighway" provides the essential infrastructure for effective computer-assisted document management. A considerably advanced approach is that documents are digitally generated and conveyed as email attachments. This approach facilitates a rapid transfer of documents (Björk, 2003). Further, Samuelson and Bjork (2013) reported the findings of an IT barometer study performed in 2000, 2007, and 2022, suggesting that EDMS usage in construction companies is rising year after year. Similarly, this concept has been strengthened in a recent study by Oral and Aydinli (2017). In the last few years, the use of EDMS has been the fastest-growing IT application in construction (Fernando et al., 2019; Hjelt & Björk, 2006). Moreover, the findings of the Fernando et al. (2019)expressed that the current scenario in the construction sector is that papers are managed using a combination of different generating processes like manual and electronic. Overall, Figure 1 describes the evolution of construction document management methods.

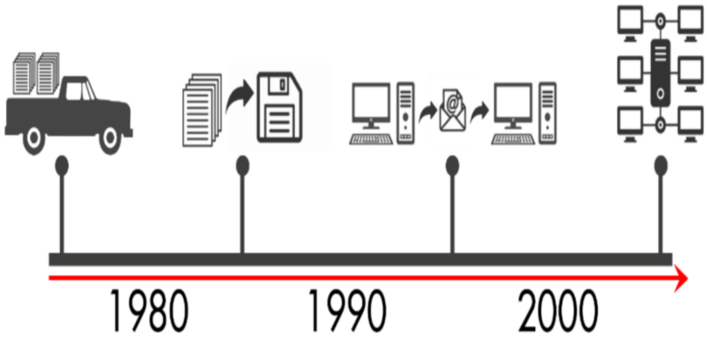

Figure 1: The evolution of construction document management methods over the last decades
Source: (Jordan et al., 2022; Sprague, 1995)

According to Figure 1, sharing of documents has evolved with time, and in the earliest stages, documents themselves have to be transported from place to place. After, documents were stored in a portable data transfer media and exchanged. The next stage was considered sharing documents through computers using an electronic transferring medium (Jordan et al., 2022), and finally, the computers were connected within and across organisations to transfer the documents (Samuelson & Bjork, 2013). This opens the potential for application of the digital technologies like BIM and blockchain to construction documentation (Mandicak et al., 2022). Overall, in the present context, the construction industry utilises four main documentation trends, hardcopies, a combination of hardcopies and softcopies, softcopies, and electronic documents. The first three approaches can be referred to as conventional DMS; the last approach is the emerging trend in the construction industry, referred to as EDMS.

2.2 CONVENTIONAL DOCUMENT MANAGEMENT SYSTEMS

A conventional document management system (DMS) is a system that manages documents in a physical or paper-based format or saves all the documents in one location and is difficult to retrieve and use on an urgent occasion (Jane, 2020). Further, McHugh (2021) explains conventional DMS as a practice of keeping paper-based records, which are stored physically as hardcopies and maintained. It is a common record-keeping procedure used in present business organisations (McHugh, 2021), which has the benefits of easy handling and less technical knowledge requirements. However, it processed a variety of drawbacks, including security issues, a requirement for high storage space, the difficulty of editing, collaboration and transportation and can be easily damaged (Melo, 2019). The findings of this study present the barriers to using conventional DMS for QSs for construction document management.

2.3 ELECTRONIC DOCUMENT MANAGEMENT SYSTEMS

EDMS tend to treat the documents they shuffle around as black boxes, just like the post office has little interest in what is inside the envelopes they keep shuffling around as long as the mail gets to the s recipient in time (Björk, 2003). Furthermore, according to Accruent (2023), most EDMSs let users alter and administer the system and various physical filings methods, such as storage location, security, access control, and version or revision control, are often included.

Đokić et al. (2012) define EDMS as a process of selecting the evidentiary documents relating to the institution's actions from all of the documents the institution prepares throughout its daily operations and managing them from production to final destruction while protecting their format and characteristics.

2.3.1 Electronic Documentation Process

According to Oral and Aydinli (2017), every document utilised in the company has a life cycle. This life cycle includes operations that begin with the document's creation and finish with its destruction. The above view strengthens the findings of Johnston and Bowen (2005) and Yusof and Chell (2000). Figure 2 exhibits the critical processes in the life cycle of an electronic document, which the stakeholders' access through an EDMS.

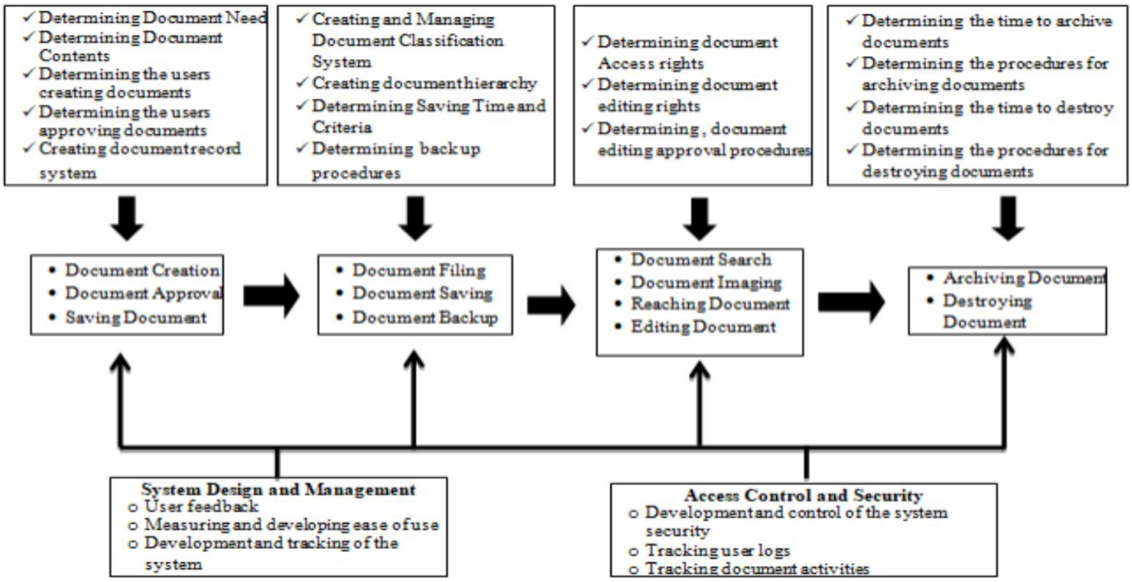

Figure 2: Key processes in the life cycle of an electronic document
Source: (Oral & Aydinli, 2017)

Accordingly, EDMS can manage the documents in these vital life stages by quickly upgrading revisions.

2.3.2 Electronic Document Management Software Used in the Construction Industry

There are several software brands available now for electronic document management. Software-suggest (2023) provides a list of well-known document management tools. Aconex, FileHold, Efilecabinet, dMACQ DMS, Skysite, and Procore are some brand names used globally. The majority of firms in the world currently uses those systems.

2.3.3 Impacts of Electronic Document Management Systems (EDMS) on the Construction Industry

According to Mandicak et al. (2022), EDMS provides a comprehensive, effective system to electronically collect, manage, and secure critical data in a flexible yet regulated manner, allowing to keep everything in one place, waste less time and save money while work from anywhere, simplify compliance, and guarantee security by eliminating lost or misfiled construction documents. Furthermore, they highlighted that automating superfluous procedures, controlling access and tracking building documents, saving money and space, fast-tracking the completion of construction papers, performance maximisation, expanding the building company, processing bidding paperwork, building financing, and more can be easily achieved through the implementation of EDMS.

Moreover, an EDMS simplifies users' jobs and provides the organisation with security, data dependability, and work process management (Forcada, 2005; Mandicak et al., 2022). These characteristics ultimately reduce time, facilitate work, secure investment in document creation, enforce quality standards, allow an audit trail, and assure accountability. Moreover, the initialisation of EDMS in construction projects expands advanced opportunities and effective technologies in future including BIM and blockchain (Kiu et al., 2022).

However, Fernando et al. (2019) stated that in developing nations such as Sri Lanka, no significant efforts have been made to implement electronic document management technologies, nor attempts have been made to comprehend documentation needs appropriately.

3. RESEARCH METHODOLOGY

This study followed a qualitative research approach with a survey strategy and utilised expert interviews as the data collection technique. This approach was led by the researcher's requirement to collect broad and subjective data about attitudes, views and behaviours through the participants, where Kothari (2004) identified the qualitative approach as appropriate. Accordingly, to identify the insights of the QS experts of the construction industry regarding the current DMSs used in construction projects, their limitations, suitability, awareness, and limitations of EDMS and its tools, 12 semi-structured expert interviews were conducted with QSs in the construction industry, with the knowledge and experience on different DMSs. Here, the professional QSs in the construction industry was selected as the population, and the experts were identified using judgemental sampling, where the experts have knowledge and experiences on different DMSs, making them suitable to be participated as an expert. This sampling technique has been recognised for studies where the researcher defines the purpose and involves their knowledge in the determination of participants (Andrade, 2021). Table 1 provides the details of the respondents who participated in the study.

Table 1: Respondent Profile

Expert Code	Designation	Industry experience
R1	Senior Quantity Surveyor	08 years
R2	Quantity Surveyor	05 years
R3	Quantity Surveyor	03 years
R4	Quantity Surveyor	04 years
R5	Senior Quantity Surveyor	11 years
R6	Quantity Surveyor	06 years
R7	Consultant Quantity Surveyor	04 years
R8	Senior Quantity Surveyor	22 years
R9	Senior Quantity Surveyor	09 years
R10	Senior Quantity Surveyor	06 years
R11	Senior Quantity Surveyor	07 years
R12	Senior Quantity Surveyor	10 years

4. DATA ANALYSIS AND DISCUSSION

4.1 DOCUMENT MANAGEMENT SYSTEMS USED IN SRI LANKAN FIRMS

Experts validate the less use of EDMS in Sri Lanka, and five (05) respondents (out of 12) confirm their current experience with EDMS but in partial. Specifically, R2 emphasised that "*firms will find it challenging to adopt EDMS for QS-related activities entirely*". This view has been emphasised by R1, explaining the mixed use of conventional and electronic DMS in their firms and claiming that "*ERP and Aconex systems are employed, and ERP handles pre-contract process documenting while Aconex addresses post-contract phase documenting but, in some instances, conventional document management systems are also employed in the company*". Moreover, R10 and R11 similarly explained the mixed use of DMS in their organisations. According to their views, conventional DMS are highly weighted (with more than 50% of use), and EDMS are less commonly used, primarily in the pre-contract stages.

Seven (07) experts ascertained their entire experience with conventional DMS, and R6 highlighted that *"all papers are filed as hard copies, with multiple copies generated for the Employer, Engineer, and Contractor reference copies. Soft copies are also stored as working documents, and a scanned signed copy serves as the final draft"*. Furthermore, R7 mentioned the use of electronic devices in the generation and exchange of documents; however not entirely electronic because *"all letters are sent with signed physical copies, as well as a scanned copy of the signed letter and attachments delivered through email. Working copies of letters are also maintained, organised by the person to which the letter is sent and the reference number "*.

According to the information above, QSs have basic knowledge about EDMS and are also curious about adapting EDMS. However, it portrays minimal use in Sri Lankan firms as a hybrid approach and conventional DMS. Furthermore, firms that use EDMS are designated explicitly as international firms or any local firm that has a link with a foreign firm highlighting that Sri Lankan firms are still reluctant to adopt EDMS for the cost management of megaprojects.

4.2 LIMITATIONS OF CONVENTIONAL DOCUMENT MANAGEMENT SYSTEMS

Despite being the abundant DMS in Sri Lanka, conventional DMS instigates a variety of difficulties and limitations for the users. The experts illustrate the limitations of conventional DMS, as shown in Table 2.

Table 2: Limitations of conventional DMS

Limitation	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12
Delivery Speed is slow	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
A tremendous amount of waste is created		✓			✓	✓				✓	✓	
It needs more storage space	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
The documents' durability is poor	✓				✓		✓					✓
The procedure of delivery has become more challenging			✓			✓				✓		

Limitation	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12
Finding paperwork in an emergency is difficult	✓	✓			✓		✓				✓	✓
It is tough to locate old records		✓		✓				✓	✓			
When sending documents, agents provide private data to external parties			✓				✓	✓				
During a lockdown in a pandemic crisis, there is no access to papers	✓					✓				✓		
If there are a large number of users, need to print a large number of hard copies		✓							✓		✓	

Given the preceding opinions of each expert, it is evident that most of them have raised similar issues about the conventional document management system. As a result of the concerns mentioned above, it is clear that everyone agrees that the most prevalent difficulty with conventional DMS is the necessity of high storage and poor delivery speed. Similarly, R6 stated, "*the most significant difficulty with the conventional document method is storage and time."* Apart from the two primary concerns described above, most experts cited issues such as increased waste generation, complex delivery procedures, difficulty finding papers in an emergency, and poor durability as other critical issues with the conventional document management system. "*If there are a significant number of users*," R5 stated, "*we must print many hard copies*." The time spent collecting and submitting hardcopy papers was unnecessary, and it was also demonstrated that the conventional document management procedure is far more complicated.

According to the information mentioned earlier, conventional DMSs use in Sri Lanka has several challenges, which are impacted by the firm's status. Due to the aforementioned issues faced by conventional systems firms, it has become a driving force to switch from conventional document management to electronic document management systems (EDMS). Overall, limitations of conventional DMS have strengthened the focus of Sri Lankan construction firms to utilise EDMS.

4.3 SUITABILITY OF ELECTRONIC DOCUMENT MANAGEMENT SYSTEM TO SRI LANKAN CONSTRUCTION INDUSTRY

All the respondents positively accepted EDMS to the construction sector in Sri Lanka and explained its benefits and challenges. When evaluating the opinions of interviewees on EDMS, R1, R10, and R11 stated that EDMS is a superior option for document management as maintaining and managing documents using EDMS is effective and efficient. In addition, R3 stated, "*It is a superior solution for large-scale projects.*" Furthermore, R2 emphasised the suitability of EDMS with a current example and highlighted that EDMS is more advantageous in pandemic situations, particularly for megaprojects to carry out work in a "work from home" approach, since time management is critical in megaprojects owing to their high time consumption. On the other hand, R6 noted, "*For small-size projects, it could be a pricey option*", while R9 and R12 expressed similar sentiments about its applicability for small-scale projects.

Nonetheless, this suitability is subjected to some limitations. Specifically, R4 claimed that "*Benefits should be considered and a cost analysis should be conducted to assess the viability, prior to implementing EDMS*," whilst R6, R9, and R12 indicated that EDMS is not a simple mechanism. It requires an adequate technical understanding to get the best results accordingly. Furthermore, the experts representing government organisations R6, R8, R9, and R12 stated that the Sri Lankan government sector is still not ready to embrace EDMS in their construction firms.

4.4 AWARENESS OF ELECTRONIC DOCUMENT MANAGEMENT SYSTEMS IN SRI LANKA

As per the data gathered through expert interviews, experts that have already used EDMS in their firms have a greater level of understanding, which is to be expected. However, the significant takeaway from the given information is that the experts with conventional document management systems in their firms are also aware of the EDMS to a decent degree. Accordingly, all the experts have an acquaintance with the meaning, purpose, and concepts of EDMS. Hence, the results provoke low utilisation despite the considerable knowledge and awareness of EDMS in the Sri Lankan context.

4.5 AWARENESS OF EXISTING ELECTRONIC DOCUMENT MANAGEMENT SYSTEM SOFTWARE IN THE SRI LANKAN CONSTRUCTION INDUSTRY

Although most respondents are aware of the concept of an EDMS, they are less familiar with the electronic document management tools that most organisations now utilise. *"In Sri Lankan firms that have already switched to EDMS, Aconex is the frequently utilised Electronic Document Management System,"* R1 stated. The concept conveyed by the R1 was supported, according to the interpretation of the R2, R3, R10, and R11, since they had the same motive about the existing EDMS in the local context. Furthermore, R1, R2, R3, R5, R7, and R8 stated that ERP is an EDMS utilised in the local context, but R4, R6, R9, and R12 had no idea about the current electronic document management tools in the local context despite being familiar with the concept of EDMS. Nonetheless, the experts' awareness of EDM tools used globally was far lower since they only knew of Aconex. As a result, their comprehension of EDM tools in a global context was inadequate, even though a few other tools are utilised in a global setting, as evidenced by the literature findings in Subsection 2.3.1.

4.6 BARRIERS TO THE USE OF ELECTRONIC DOCUMENT MANAGEMENT SYSTEMS IN THE SRI LANKAN CONSTRUCTION INDUSTRY

Even with the fact that the construction industry is willing to incorporate EDMS, a variety of barriers hinder the use of EDMS. First, the system's complexity, which is not supported by the available facilities of the construction industry, can be identified. This opinion has been confirmed by R3 and R11 and indicated that the project's magnitude is one of the main concerns which hinders the use of EDMS. Further, small projects are having a problem when comparing their project costs to the EDMS as it requires a high initial cost and ongoing maintenance cost. Accordingly, the size of the project acts as a barrier to initiating EDMS in the Sri Lankan construction industry, consequent to the difficulty of managing finance.

Further, R6 and R9 emphasised that the Sri Lankan government did not participate in or do a study on EDMS to modernise its systems. Also, according to E12, "*most of the* *employees lack the proper technical knowledge and apprehension about implementing new systems*". This knowledge deficiency is a severe concern that limits the use of EDMS in the Sri Lankan construction industry, which is further validated by E8, which states that some professionals are hesitant to rely entirely on electronic documents as they are unfamiliar with them. Overall, based on the information acquired from the interviews and the literature, it is evident that EDMS is the new worldwide trend in construction documentation. However, as stated in the preceding section, the Sri Lankan construction sector is experiencing difficulties adopting EDMS.

5. DISCUSSION

The empirical findings of this study convey the limitations of conventional methods for document management, which illustrates similar views to the findings of Jane (2020) and Melo (2019). However, damages that occurred during the transportation, which was identified as an issue by (Melo, 2019), were not revealed as an issue in Sri Lankan context. Nonetheless, the QSs' level of awareness of electronic document management tools in a global context was far lower since they only knew of Aconex. It contradicts the view of Software-suggest (2023), which highlights the great use of EDMS in the global context. Further, Sri Lankan QS considers time-saving and multiple editing as the pros of EDMS and recognised technology and cost as the significant cons. Henceforth, despite Accruent's (2023) findings, Sri Lankan QSs must be more aware of EDMS's benefits. As a result, comprehension of Sri Lankan QSs regarding the electronic document management tools used in a global context was inadequate.

Moreover, findings of the empirical study emerge the benefit of EDMS in work-from-home concepts and crises. Concerning the application of EDMS to the Sri Lankan construction industry, this study contradicts the findings of Fernando et al. (2019) and mentions that Sri Lankan industry efforts to adopt EDMS, especially for mega construction projects and however, the efforts of expanding are in vain consequent to the identified barriers. Barriers to adopting the EDMS in Sri Lanka from the QSs perspective disclose similar findings to the study of Haupt and Naidoo (2016). In addition, less support from the government, project size and less familiarity with electronic documentation have been revealed as current barriers for Sri Lankan QSs.

6. CONCLUSIONS

Sri Lanka prominently practises conventional documentation, basically hardcopies and/or softcopies stored in a computer folder. Even though storing data in softcopies has taken attention, professionals rarely agree to maintain only softcopy documents. This documentation process highly impacts the successful completion of construction projects and creates various time, cost, quality, and storage issues. Following this, Sri Lankan QSs are ready to welcome EDMS positively but not ready to practically implement it in their projects, consequent to various barriers within and beyond their control. Accordingly, the current barriers are the complexity of EDMS technology, unavailability of adequate training facilities, compatibility issues, absence of a standardised procedure, attitudes and perceptions. Moreover, the QSs generally understand the EDMS concept but are less familiar with the tools.

Various circumstances limit the use of EDMS in construction projects, including project size, hesitation of government and professionals, and incompatibility with the current practices of construction projects. To sum up, conventional DMS is proved to be a less efficient solution for the document management of construction projects, and EDMS is also difficult to be initiated. Accordingly, future studies can focus on the different stakeholders who are less responsible for less incorporation of EDMS to identify feasible solutions to normalise it in construction projects.

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REVIEW ON THE IMPORTANCE OF CAPACITY BUILDING FOR ENHANCING DISASTER RESILIENCE THROUGH THE EFFECTIVE UTILISATION OF RESOURCES

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ABSTRACT

Considering the increase in catastrophic events, resilience is now a widely accepted concept. Building resilience among the physical structures, infrastructure, and communities has become a necessity to improve the capacity to face future disasters. Effective utilisation of resources is one of the possible ways of building capacity within communities with the perception of enhancing resilience to future disasters. Therefore, identifying the correlation between resilience, capacity building, and resource utilisation is highly important to face future calamities. The resources required for enhancing disaster resilience vary depending on the type of disaster and the area affected by the disaster. Hence, resource constraints have been acknowledged as a factor in the ongoing failure of numerous recovery efforts. As such, capacity must be developed by utilising the resources effectively to address the deficiencies in resilience levels. Thus, a narrative literature review was carried out to establish the resource requirement in terms of capacity building to form disaster resilience. As the outcome of this comprehensive review, a conceptual framework was developed to support future decision-making processes with regard to disaster resilience. As per the findings, resource requirements exist in different forms such as infrastructure, institutional, economic, social, and environmental, and addressing them collectively, one after the other will enhance the resilience to future disasters in a considerable manner.

Keywords: *Capacity Build-Up; Disaster Resilience; Resource Utilisation.*

1. INTRODUCTION

A disaster is a phenomenon that can cause damage not only to life and property, but also can destroy the economic, social, and cultural well-being of a community (Perera, 2018). Disasters are widely defined as sudden events that cause significant damage to society with major losses of human beings, properties, economy, industry, and the environment that exceed the capacity of the affected society to cope with its resources (Ayataç, 2021;

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Keraminiyage & Piyatadsananon, 2013; Wang et al., 2020). According to data from the CRED International Disasters Database (EM-DAT), in the year 2021, the number of disaster events and extensive economic losses increased worldwide by recording 432 disastrous events related to natural hazards worldwide, 10,492 deaths, affected 101.8 million people and caused approximately USD 252.1 billion of economic losses. When a disaster occurs, the environment changes drastically, which increases physical and mental stress to people (Tamura & Rafliana, 2018). Some individuals may suffer from post-traumatic stress disorder, anxiety, depression, and other mental health conditions in the long term due to the adverse conditions of a disaster (Gil-Rivas & Kilmer, 2016). While disaster risks can hardly be eliminated, it is possible to mitigate risks by minimising the adverse impacts they bring (Tay et al., 2022).

Thus, to mitigate the risks from disasters, the resilience of the communities needs to be improved (Deng et al., 2022). The widely accepted definition of "resilience" is resistance to an external shock and the ability to recover quickly (Lu et al., 2020). Nowadays the term 'Resilience' is widely used by disaster researchers, which can be identified as capacities that need to be improved to deal with adversities (Tanvir et al., 2022). Identification of those capacities and mitigating the existing gaps are extremely essential for the resilience enhancement of both communities and infrastructure (Mukherjee & Hastak, 2016). Even though there are more empirical research has been conducted related to capacity building in disaster mitigation and recovery, less attention has been paid to developing capacities in terms of resources with the perspective of enhancing resilience to an expected level. In case of a disaster, communities combine existing resources to cope with an emergency event (Odiase et al., 2020). Further, resilient communities often demonstrate a greater reliance on their resources to recover from a disaster (Albright & Crow, 2021). However, as highlighted by Deria et al. (2020a) the lack of required resources has become one of the prominent issues for the failures in disaster mitigation and recovery efforts. Further, Freeman (2004) shows that the success of the post-disaster environment will depend on how efficiently and adequately government can allocate resources for disaster recovery. This study, therefore, provides an answer to the question, "How the disaster resilience can be improved through resource utilisation as a mode of capacity building?"

2. METHODOLOGY

This paper is based on a narrative literature review to give an illustration of capacities and capacity gaps in the built environment concerning disaster mitigation and reconstruction and to define different forms of resources required to improve resilience in disaster-prone areas. Possible means for bridging the identified capacity gaps are also examined in the paper through various sources of literature. Accordingly, books, journal publications, conference proceedings, and electronic articles were referred, to extract information and to familiarise with the definitions, concepts, and other principles.

3. LITERATURE REVIEW

3.1 DISASTER RESILIENCE

With the increase in occurrences of high-impact disasters, the concept of risk reduction and resilience is widely recognised (Tanvir et al., 2022). In the disaster context, the word resilience can simply be explained as the ability of people to recover within the shortest possible time with minimal or no assistance (Malalgoda et al., 2014). Disaster resilience will be defined as the capacity of a city to be able to absorb, bounce back and recover from the stress and shock it received (Sulaiman et al., 2019). Moreover, UNISDR (2012) defined resilience as the "ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including the preservation and restoration of its essential basic structures and functions".

Disaster resilience is further defined as "the capacity to adapt existing resources and skills to new situations and operating conditions" (Lee, 2020; Tanvir et al., 2022). Improving resilience includes building capacities, redundancies, robustness (pre-disaster), and rapid recovery of systems (post-disaster) (Mukherjee & Hastak, 2016). According to Tanvir et al. (2022), typical properties of resilience are as follows:

- **Robustness**: strength or the ability to withstand stress or demand without loss of function
- **Redundancy**: availability of alternative elements, systems, or units that can fulfil the same functional requirements in case of a disruption, degradation, or loss of functionality of the primary unit.
- **Resourcefulness**: the capacity to identify problems, prioritise tasks, and effectively utilise available resources to mitigate potential disruptions to a system or unit of analysis. Resourcefulness can be further conceptualised as consisting of the ability to apply material (i.e., monetary, physical, technological, and informational) and human resources to meet established priorities and achieve goals; and
- **Rapidity**: the capacity to meet priorities and achieve goals promptly to minimise losses and avoid future disruption.

3.2 CAPACITY BUILDING

Capacity building is one of the important pillars of resilience enhancement (Mukherjee & Hastak, 2016). According to UNISDR (2009) capacity is the combination of all the strengths, attributes and resources available within a community, society or an organisation that can be used to achieve agreed goals and they can exist in the forms of infrastructure and physical means, institutions, societal coping abilities, human knowledge, skills, and collective attributes such as social relationships, leadership and management. Further, Capacity is the ability to absorb any type of disruption and it also includes a margin of ability to resist, absorb or recover rapidly from disruptions that are more severe than anticipated (Mukherjee & Hastak, 2021). Therefore, Ginige et al. (2010) highlighted that identifying capacity gaps in the built environment and enhancing the necessary capacities are essential to reduce vulnerability to the impact of disasters. According to Ginige et al. (2010) capacities exist in different forms in the world such as knowledge, skills, technology, and resources. Disaster coping capacity reflects the ability of people, organisations, and systems, to manage adverse conditions, risks, or disasters using available skills and resources (Wang et al., 2021).

3.3 NEED OF CAPACITY BUILDING FOR RESILIENCE ENHANCEMENT

United Nations International Strategy for Disaster Reduction (UNISDR, 2012) defines major challenges forming disaster resilience. Those are increased density which put pressure on land and services, settlements in hazard-prone areas, lack of capacities and unclear mandates for DRR at local levels, weak local governance, inadequate water resource management, the decline of ecosystems, decaying infrastructure, and unsafe building stocks, uncoordinated emergency services and adverse effects of climate change. According to Malalgoda et al. (2014), most of the drainage systems and protective and servicing infrastructure are not sufficient to serve the increasing population, and many dwelling houses and other buildings are built without adequate consideration of disaster risks and vulnerabilities. Hence, it is apparent that the importance of resilience and capacity building is well-established to enhance the security of communities, infrastructure, and associated critical facilities in face of such extreme events (Mukherjee & Hastak, 2016). As elaborated by Dharmasena et al. (2020), disasters cannot be avoided and what we can do is mitigate disasters and build resilience in the community. Therefore, the assessment of resiliency is not only crucial for planning and decision-making, but it also helps to identify the vulnerable population in the society that is usually most affected when a disaster strikes (Deria et al., 2020b).

Moreover, past events have proven that obtaining adequate funding, and high-quality physical and technical assistance is a primary issue for achieving a resilient post-disaster built environment (Malalgoda & Amaratunga, 2015). The repeated failure of many projects can be attributed to the shortage and unavailability of resources required for reconstruction (Chang et al., 2010). Problems in the regulatory structure, deficiencies in necessary laws and regulations including problems in their implementation, and lack of required resources and skills are prominent issues to improve disaster resilience (Ginige et al., 2010). According to Malalgoda et al. (2016), local government in Sri Lanka faces several constraints such as a lack of proper legal framework, lack of adequate tools, techniques, & guidelines, human resource constraints, funding constraints, weaknesses in the internal systems and processes, weaknesses in the external systems, and lack of community engagement, which results in disrupting resilience to future disasters. This implies the need of capacity building in terms of utilising resources effectively when improving resilience level to future disasters.

3.4 IDENTIFICATION OF DIFFERENT TYPES OF RESOURCES REQUIRED FOR RESILIENCE ENHANCEMENT

The resilience to disasters depends on the severity of the antecedent calamity, as well as the resources available for and the efficiency of the recovery process (Wickramaratne et al., 2012). Further, Dharmasena et al. (2020) highlighted that communities needed to have resources that extend beyond the very basics of life to make it resilient. According to Deria et al. (2020a) the poor suffer disproportionately from natural disasters because of their inability in terms of lack of resources in the response, recovery, and reconstruction phases that leads to more fatalities and psychological trauma among the lower-income groups. As Cutter et al. (2008) highlighted key assessment factors for disaster resilience are Social, Economic, Institutional, Infrastructure, Community competence (health, understanding risk, quality of life, etc.), and Environmental. Further, Ayataç (2021) defines four different ways of achieving urban disaster resilience such as infrastructure resilience, Institutional resilience, economic resilience, and social resilience.

3.4.1 Resources for Economic Resilience

According to Ayataç (2021), economic resilience illustrates the employment diversity in communities, and it refers to the capability to do work in the aftermath of a disaster. As per the empirical findings of Tanvir et al. (2022), socio-economic resilience indicators are education and knowledge about natural disaster health, food consumption, income, and use of savings. Moreover to Gil-Rivas and Kilmer (2016), stable employment, adequate income, housing, access to clean water and sanitation, availability and access to health and social services, and a strong and diverse financial system are the economic resources that are important for reducing vulnerability. According to Ekanayake et al. (2018) easy access to the livelihoods of disaster victims is critical for economic resilience.

3.4.2 Resources for Social Resilience

Human and social aspects of communities are also key resources in the face of disaster (Gil-Rivas & Kilmer, 2016). Social resilience indicates the demographic profile of communities, and it refers to the aspects of the social capital including age, gender, disability, and ethnic background (Tanvir et al., 2022). The utilisation of the human population as a resource is a very important concept for mitigating the threat of any disaster (Ranwella, 2021). Since reconstruction is about building back homes and infrastructure to become more resilient to the next disaster and fit for purpose for the community, local community participation is vital for the disaster reconstruction process (Mannakkara & Wilkinson, 2015). Complement to that Norris et al. (2019) stated that affected community members must be empowered to be part of the recovery and planning process. In this context, Knowledge and experience of a local community can input some important information for the construction process such as locations that are less vulnerable to potential disasters, locally available material that can be used for construction, and special community needs that are necessary to be integrated into reconstruction (Ginige et al., 2010). Also, according to El-Masri and Tipple (2010), the supportive role of international communities can be used to assist developing countries in disaster mitigation and reconstruction by applying their existing knowledge and resources. In this context, education and training are vital in developing necessary human resources (Ginige et al., 2010).

3.4.3 Resources for Institutional Resilience

As stated by Malalgoda and Amaratunga (2015) a well-structured institutional framework is a pre-requisite for a city's sound resilience initiatives. Institutional resilience refers to the capacity of those who are in charge of managing communities, such as governments and non-governmental bodies (Ayataç, 2021). Further institutional capacity encompasses the interdependent fiscal, technical, and human resource dimensions that enable proper functionality during disasters (Albright & Crow, 2021). When referring to the empirical findings of Malalgoda and Amaratunga (2015) institutional resources consist of sufficient funding, adequately qualified and skilled human resources, training and capacity-building programs for technical staff engaged in regulating a disaster-resilient built environment and leadership skills of councillors and administrators.

3.4.4 Resources for Infrastructure Resilience

As stated by Ayataç (2021) resilience of the infrastructure refers to eliminating the vulnerabilities of the built environment including buildings and transportation systems. It also indicates the housing capacity in cities, healthcare facilities, vulnerabilities of buildings to disasters, and the availability of evacuation routes and supply lines after disasters. Tanvir et al. (2022) define in their study the physical resilience indicators as electricity supply, water bodies, early warning systems, and housing patterns. According to Deria et al. (2020a) often delivering accurate information is difficult for communities living in rural areas as they may not possess telephone and internet services. Further, unequal access to transportation alternatives during natural disasters also increases the vulnerability of the exposed communities (Deria et al., 2020a). Ginige et al. (2010) emphasise that critical infrastructure systems should be restored in a manner that is consistent with such vulnerability reduction and resiliency standards in the recovery process. A quality infrastructure would help in reducing disaster risks, improving health care, increasing productivity in manufacturing and productivity in service delivery, distributing national wealth more equally, to name a few (Palliyaguru & Amaratunga, 2008). Hence, the capacity is frequently reduced during a disaster. Amaratunga et al. (2017) stated that strengthening such vulnerable infrastructure is critical to enhance the resilience of disaster-prone communities.

3.4.5 Resources for Environmental Resilience

Environmental Resilience is a critical dimension of measuring community resilience to disasters (Tariq et al., 2022). As per the empirical findings of Tariq et al. (2022), environmental resilience includes ecological resilience, biodiversity, and protection of natural resources at the local level. Accordingly, environmental resources that influence resilience to disasters are flora and fauna, biodiversity, and natural resources (pre, during, and after the disaster event) such as land use, water bodies, buffer zones, raw materials, etc (Tariq et al., 2022).

4. DISCUSSION

As per the literature findings, there is an explicit interconnection between disaster resilience, capacity build-up, and resource requirement. In terms of achieving disaster resilience, capacity enhancement can be done through the means of economic, institutional, infrastructure, social/community, and environmental resources. A recent study carried out by Mukherjee and Hastak (2021) has developed a conceptual framework to select capacity-building strategies by integrating the sustainability aspect into the decision-making process. In this paper, we have identified different resources required for capacity building under key disaster resilience boundaries and developed the same framework accordingly. Figure 1 shows a framework for the conceptual decision support system to identify disaster resilience enhancing strategies based on:

- Setting a resilience goal,
- Identifying the existing resources gap, and
- Develop capacity-building/resilience enhancement strategies.

As soon as identifying the resources required under each resilience boundary the framework suggests to implement a capacity assessment to define the existing resource gap to achieve the expected resilience level by selecting a specific resilience boundary at a time. Repetition of the same process to other boundaries would assist in understanding and developing strategies to enhance overall resilience to disasters by overcoming the resource constraints.

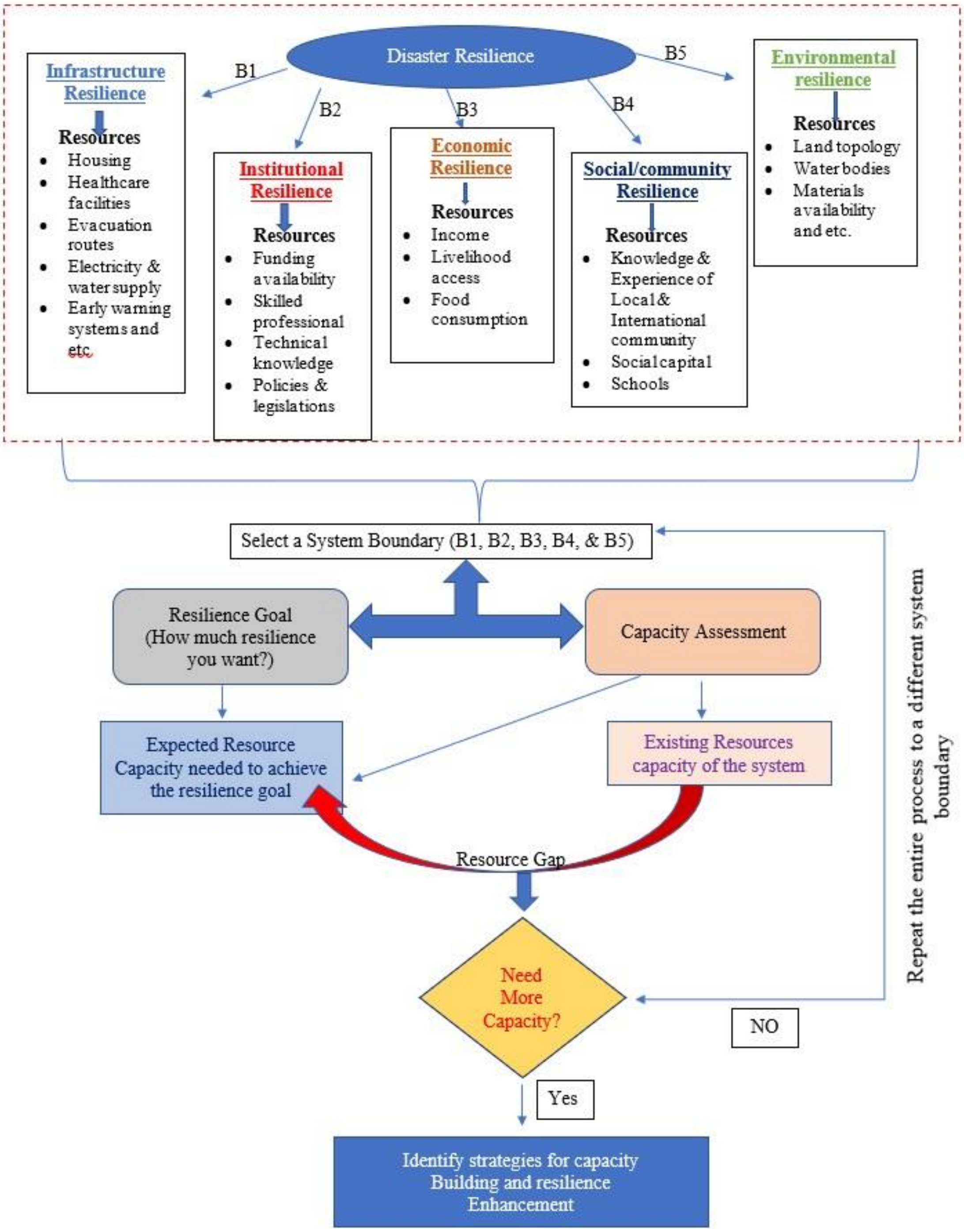

Figure 1: Conceptual decision support system to achieve disaster resilience

5. CONCLUSIONS

Resilience is an important and highly recognised concept within modern-day disaster management initiatives. When improving resilience against future disasters, it focuses on addressing capacity gaps within structures, communities, and other facilities. Capacities exist in different forms such as knowledge, skill, and resources. As per the findings of the research resource requirement can be defined under five resilience boundaries namely infrastructure, social, economic, institutional, and environmental. The accepted and proven failure of most of the disaster recovery projects was the limitations in the proper utilisation of existing resources. In this research, we have proposed a decision support system for assessing capacity needs in terms of resources to achieve a pre-defined resilience goal. Therefore, this study will be helpful when addressing forthcoming disaster-resilience research problems.

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SMART VILLAGE CONCEPT FOR RURAL AREA DEVELOPMENT IN SRI LANKA: A STUDY ON IMPLEMENTATION, BENEFITS, AND CHALLENGES

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ABSTRACT

The Smart Village (SV) concept can be mentioned as a potential enabler for rural area development by integrating smart technologies. Many developed countries adopted the Smart Village concept to develop their countryside for example "Digital Village" in Germany, the "Cowocat rural" project in Catalonia, etc. This has brought a key advantage called improved quality of rural life and public services. But in the Sri Lankan context, the evidence of the successful implementation of Smart Village for the development of rural areas is almost nil in parallel there is no significant development seen in rural areas. Thus, the study aimed to investigate the implementation, benefits, and challenges of using the Smart Village concept for rural area development in Sri Lanka. The mixed research approach was undertaken to accomplish the aim. A comprehensive literature review followed by semi-structured interviews was carried out with 07 experts knowledgeable in the Smart Village concept. The data were analyzed through the RII method and the manual content analysis. The results demonstrate, that the most implemented Smart Village feature in Sri Lanka is smart education, however, the most required Smart Village features are listed as smart connectivity and smart agriculture. Further, the technologies like ICT, AI, IoT, GIS, 5G, and smart grid can be adapted to raise the Smart Village concept covering agriculture, education, transportation, health, and infrastructure was presented. However, lack of network cooperation, difficulties in raising funds, and transitioning to low-carbon economies, were found to be the top key challenges in implementing Smart Village in Sri Lanka.

Keywords: *Rural Area Development; Smart Village; Smart Village Features.*

1. INTRODUCTION

Nowadays, cities are with an additional burden to provide essential infrastructures such as transportation, healthcare, housing, and utilities due to the uncontrolled migration from rural to urban, this uncontrolled migration happened due to the unavailability of basic services, limited economic growth and fewer job opportunities in villages (Singh & Patel, 2018). Therefore, the initiation of rural development allows a country to provide equal

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facilities for all the residents; timely it can progress to districts, provinces, or federal units before reaching the entire country (Jabbar & Sajeetha, 2015). Further, it was revealed that, if a country fails to develop its rural areas, it will not be considered as developed because the growth of the country is dependent on the development of its communities.

The balanced development of the world in the era of the 4th industrial revolution called Industry 4.0, promotes smart cities and Smart Village (SV) concepts in different countries to narrow the gap between city and village (Park & Cha, 2019). As an approach to rural development, the concept of SV has emerged as a way to improve people's quality of life in rural areas (Aziiza & Susanto, 2020). Although it was revealed, two Indian researchers called Viswanadham and Vedula created the SV concept in 2010 by describing the ecosystem for a village and mapping integrated design procedures for developing SV. In addition to that, the concept of SV was presented by European institutions as one of the most recent approaches to rural development (European Commission, 2018).

SV is an ecosystem compromise with various features to enhance the quality of community life and the village environment by connecting different stakeholders such as government, private, academics, and elements of village communities (Syaodih, 2018). As Somwanshi et al., (2016) raised the features of the SV are,

> "Smart security, efficient public transportation system, improving sanitation conditions, solid and liquid waste management, rain harvesting, safe drinking water facilities, use of renewable energy, energy conservation, functional bank account, facilities regarding the agriculture, latest and affordable medical facilities, e-governance, use of modern technologies for improvement of locality, an improvement on women empowerment, educational facilities" (p.397).

In terms of the Sri Lankan context, there are some SV features appeared in several ICT-based projects conducted in Sri Lanka namely, the "E- Sri Lanka program" which executes "Nenasala" centres in all districts by facilitating ICT services for the rural community to provide access internet as well as information technology education and English literacy for rural area students (Madhubhashini et al., 2013). In addition to those features, the existing research concludes that smart and climate-smart agriculture (CSA) have significant value in developing SV projects (Adesipo et al., 2020). Because climate-smart practices on the cluster village development project could be identified as one of the SV features, which is implemented across 11 districts to increase farmers' income, the climate-SV area farmers are cultivating the same crop or combination by using climate-smart practices and also provide technical inputs for the project beneficiaries (Climate Smart Irrigated Agriculture Project [CSIAP], n.d.).

The concept of SV is more complicated, it encompasses a more extensive range of opportunities (Chetty, 2016). And the objective behind developing "smart villages" is to offer rural communities access to clean water, sanitation, nutrition, modern information, and communication technologies, sustainable energy, good education, and health care, as well as the development of social and industrial enterprises to increase incomes (Holmes & Thomas, 2015). Mishbah et al., (2018) mentioned 7 areas that should focus on SV development including economy, ICT, people, governance, environment, living, and energy. Even though as identified above the existing research provide evidence mostly on agricultural and education features development project in Sri Lanka. Therefore, this study focuses on the current implementation of the SV concept in the Sri Lankan context, discovering the benefits and possible challenges.

2. LITERATURE REVIEW

2.1 CONCEPT OF SMART VILLAGE

The term SV holds the rural areas and rural communities development strategy, which is based on new digital technologies, networks, and services, In addition to that it improves the use of knowledge and creative solutions of individuals for their businesses, and society (Adamowicz & Zwolinska-Ligaj, 2020). The SV concept defines as a bundle of services delivered to its residents and businesses effectively and efficiently (Viswanadham & Vedula, 2010). Further, it was revealed, Dozens of services including construction, farming, electricity, health care, water, retail, manufacturing, and logistics are included in SV.

2.2 TECHNOLOGIES USE IN SMART VILLAGES

The concept of SV was primarily based on social innovation, later on, technological innovation was raised due to the community becoming more familiar with the technology (Guzal-Dec, 2018). Digital technologies are the most considered tools for SV (European Commission, 2018). Accordingly, digital technologies will be used in many cases to achieve the goals of SV efficiently and effectively (Ecorys & Origin For Sustainability, 2019). The key technologies of the SV concept are IoT, AI, cloud, blockchain, GIS, computing, smart grid, 5G, and ICT (Wang et al., 2022). A variety of technology tools, such as sensors, actuators, cameras, drones, robots, medical devices, and agro-devices, can be used to automate decision-making in SV components such as smart energy, smart agriculture, and smart healthcare (Ram et al., 2021). In particular, SV must undergo a digital transformation that brings out the distinct potential of a specific area, and the entire digital ecosystem should include several cloud-hosted solutions that connect devices and collect, combine, or manage data for various rural services like mobility, health, care, and education (European Network for Rural Development [ENRD], 2018).

2.3 SMART FEATURES IN SMART VILLAGE DEVELOPMENT

SV refers to a bundle of features such as smart education, smart infrastructure, smart environment, smart agriculture, smart health, smart connectivity, and smart security that are delivered effectively and efficiently to its residents and businesses (Gangani et al., 2018). Numerous identified features in SV are listed in table 1.

Table 1: Smart Features of a Smart Village

Smart feature	Reference			Frequency
	1	2	3	
Organized settlement	x		x	II
Smart agriculture	x	x	x	III
Smart infrastructure (Road, Water, Sanitization	x	x	x	III
Smart Education	x	x	x	III
Disaster Management	x			I
Smart energy		x	x	II
Smart connectivity		x		I

Smart health	**x**	**x**	II
Smart environment	**x**		I
Smart security		**x**	I
Management of solid and liquid waste.		**x**	I
Rain Harvesting		**x**	I
References: [1] (Ranade et al., 2015), [2] (Sahu & Ghosh, 2018), [3] (Somwanshi et al., 2016)			

According to the above table smart agriculture, smart infrastructure, and smart education were found to be the most listed features under the SV concept. Moreover, organized settlement, smart energy, and smart health also have a significant impact. When considering the Sri Lankan context, smart agriculture also should be prioritized due to the agricultural economy.

2.4 NEED OF A SMART VILLAGE FOR SRI LANKAN RURAL AREA

Karunanayake & Abhayaratna, (2002) state that, the regional development of Sri Lanka has two perspectives called political and developmental that operated simultaneously. As further pointed out by the above author, the areas of the developmental process are infrastructure development, land settlement, irrigation development, village settlement expansion, and district-integrated rural development, and the political process includes decentralization of centre functions, which was followed by devolution aimed at greater regional power-sharing. Additionally, the authors have highlighted, the two systems' main weakness in regional development is the two processes operated as separate processes without proper integration. Therefore to revitalize rural areas, rural area issues must be addressed within the concept of SVs (Jezic et al., 2021). Especially the idea of smart development is implemented based on the social and economic characteristics of a specific geographic location (Wolski & Wójcik, 2019). The authors further mentioned that, addressing the issues in the relevant area while changing stakeholders' perspectives on the implementation of ideas that could improve the quality of rural life.

2.5 BENEFITS OF A SMART VILLAGE FOR SRI LANKAN RURAL AREA

SV is a rural development approach that demonstrates the direction of the development processes (Naldi et al., 2015). The civilizational challenges can be mitigated by implementing tailored solutions to its economic, social, cultural, and natural conditions (Satoła & Milewska, 2022). In SV, the networks and services are enhanced through the use of digitalization, telecommunication, innovation, and knowledge utilization (Szpor, 2021). Further, it was revealed, the benefit of SV can be highlighted as improving the quality of life, raising the standard of living, providing improved public services to citizens, making better use of resources, having a lower environmental impact, and providing new opportunities for rural value chains in terms of products and improved processes. As stated by Aditya A. et al., (2016), benefits the SV will lead to achieving smart infrastructure, smart service delivery, smart technology and innovation, smart institutions, and optimal mobilization and utilization of available resources, resulting in faster and more inclusive growth.

2.6 CHALLENGES OF IMPLEMENTING SMART VILLAGE

The implementation of the SV concept has the greatest challenges due to the inadequacy of supportive background (Satoła & Milewska, 2022). The literature-based challenges to implementing SV are listed in table 2.

Table 2: Challenges to implementing smart village

Challenges	Reference			Frequency
	1	2	3	
Less access to resources and market	x	x	x	III
Significant differences exist in terms of social structures and socioeconomic characteristics and the low communication accessibility	x		x	II
Residents with low educational levels	x			I
Negative migration balance	x	x		II
Depopulation		x		I
Lack of funding		x	x	II
Transitioning to low-carbon circular economies		x		I
Promoting digital transformation of rural areas		x		I
Low engagement or awareness of inhabitants impeding the creation of smart communities			x	I
Low level of openness to change in rural communities			x	I
Lack of network cooperation and transfer of innovation from scientific research institutions to practical practices			x	I

Reference: [1] (Satoła & Milewska, 2022), [2] (Jezic et al., 2021), [3] (Gosnell & Abrams, 2011, as cited in Satoła & Milewska, 2022)

As per table 2, less access to resources and the market is the most listed challenge for the smart village implementation. Apart from that, significant differences exist in terms of social structures and socioeconomic characteristics, negative migration balance and lack of funding also can be identified as the most frequent challenges for SV implementation.

3. RESEARCH METHODOLOGY

A comprehensive literature review was conducted to achieve in-depth knowledge about the research area. The literature review assisted in identifying the concept of SV, possible technologies, features, benefits, and challenges in common. In terms of that to achieve the research aim, the researcher has to evaluate experts' opinions and perceptions about SV in Sri Lankan context. Accordingly, the mixed approach was preferred for this study to achieve a more comprehensive examination of the research problem. Because of the most appropriate method for obtaining a multi-dimensional understanding of the research area and validating both internal and external attributes is a mixed approach (Fellows & Liu, 2015). According to Jentoft & Olsen, (2019), Interviews are commonly used as a primary data collection method to learn about other people's opinions, descriptions, and perspectives on the problems under consideration. Moreover, the semi-structured interview is typically conducted face-to-face, allowing the researcher to ask questions, seek out additional information, and evaluate phenomena from various perspectives (Sileyew, 2020). And snowball sampling under non-probability sampling was selected for this research study. Hence SV is a novel concept, it is difficult to identify resource persons, therefore through snowball sampling seven experts are identified for the data collection. Accordingly, semi-structured expert interviews were utilised with the 7 experts who have at least 5 years of experience in smart-related projects in both global and Sri Lankan contexts to proceed deeply into a topic and fully comprehend the responses provided. Since the current applications of the SV concept are relatively low in Sri Lanka, drawing a large sample of respondents is challenging. The profiles of experts are given in table 3.

Table 3: Profile of Experts

Expert	Designation	Working experience	Working experience in smart village concepts
E1	Senior lecturer - Town and country planning	15 years	5 years
E2	Senior lecturer - Town and country planning	10 years	5 years
E3	Senior lecturer - Town and country planning	8 years	5 years
E4	Senior lecturer- Town and country planning	7 years	5 years
E5	Senior lecturer - Town and country planning	7 years	5 years
E6	Senior Lecturer – Dean	17 years	6 years
E7	Director – ICT department	23 years	10 years

Manual content analysis and the Relative Importance Index (RII) were utilised to illustrate and analyse the data acquired through expert interviews. RII can be used to rank attributes and results from a 5-point Likert scale were converted to prioritised lists using RII (Hisham & Yahaya, 2007).further to the author, RII was calculated using the following equation

$$\text{Relative Importance Index (RII)} = \frac{\sum w}{A \times N}$$

Where W = Weighting given for each factor by respondents
A = Highest weight on the scale
N = Total number of respondents

According to Akadiri (2011) and Hamdoun (2021), five impact and importance levels are identified from the RII value as given in Table 4.

Table 4: RII Value for impact level

Value	Impact/Importance
$0.8 \leq RII \leq 1$	High
$0.6 \leq RII < 0.8$	High-Medium
$0.4 \leq RII < 0.6$	Medium
$0.2 \leq RII < 0.4$	Medium- Low

Considering identified features, benefits and barriers in SV, the above-mentioned scale in Table 4 was used for ranking the responses of experts.

4. RESEARCH FINDINGS

4.1 PROJECTS AND IMPLEMENTATION UPDATES OF THE SMART VILLAGE CONCEPT IN SRI LANKA

All the experts agreed that the whole concept of SV is not implemented in Sri Lanka. But some projects for rural development consist of smart features and could be used when developing smart villages.

Table 5: Projects and implementation updates of the smart village concept in Sri Lanka

Experts	Relevant projects and implementation updates	Year implemented
E1	• Mahaveli settlements for rural agriculture	Initiated in 1961
E2	• Batticaloa farming	2018-2024
E3	• Nanasala projects	2004
E4 E5 E6 E7	• In 2014 there is a research project for a weather station to identify the water issues related to the agriculture sector such as water releasing time with the contribution of an international water management institute, however, it was not successful or not complete.	2014
	• Smart city project for Gampaha district (not complete due to financial issues)	2022
	• GIS-related projects (projects of the world food organisation)	2002
	• UNDP project for smart agriculture in Polonnaruwa, Maderigriya, and Walapane areas.	2017

The Mahaveli development project aims to produce a network of facilities such as roads, schools, hospitals, townships, and other amenities. The CSA project is designed to address climate changes, especially drought and floods. Nenasala implemented the E-Sri Lanka initiatives to spread ICT services among rural and semi-urban populations. The "4 times open and non-conventional technology for sensing the environment" project was carried out based on open source technologies and to develop an experimental low-budget weather station to measure rainfall, temperature, atmospheric pressure, humidity, solar radiation, wind direction, and soil radiation. The smart city Gampaha project aims to meet environmental sustainability, net zero, and socially inclusive technology governance. UNDP project included climate smart and non-chemical agriculture practices for farmers. Sri Lanka uses GIS for the planning and management of irrigation systems through this project. The Department of agrarian development of Sri Lanka implemented GIS to select a tank that will be renovated in the future and to evaluate how renovated small irrigation system impacts low-income farmer families and also GIS used to monitor the sustainability of the rehabilitation process and measure the changes in agriculture patterns.

4.2 THE EXISTENCE OF SMART VILLAGE FEATURES IN SRI LANKAN RURAL AREA DEVELOPMENT

The existing level of the smart village features in Sri Lanka is measured based on the identified smart village features through literature findings. RII analysis is used to rank the existence of those features based on the experts' opinions, as shown in table 6.

Table 6: Existence level of the smart village features in the Sri Lankan context.

Smart village feature	RII	Rank
Smart Education	0.771	1
Smart connectivity	0.743	2
Smart energy	0.714	3
Organised settlements	0.686	4
Smart health	0.600	6
Smart agriculture	0.543	7
Smart infrastructure	0.371	8

Most of the interviewees (6 out of 7) raised smart education is implanted to some extent in Sri Lankan rural areas. Further, they have elaborated that, the reasons for the existence of smart education are the "work from home" and "online education" concepts raised during the COVID-19 outbreak. Moreover, the interviewees' pointed out that, there is a considerable level of existence in smart connectivity, due to the increment in internet usage and mobile device usage in day-to-day activities like education, shopping, and so on within the past two years.

4.3 THE SIGNIFICANCE OF SMART VILLAGE FEATURES FOR THE SRI LANKAN RURAL AREA DEVELOPMENT

The significance of smart village features to the Sri Lankan context was evaluated using RII analysis, based on experts' opinions as shown in table 7.

Table 7: Significance level of the smart village features in the Sri Lankan context.

Smart village feature	RII	Rank
Smart connectivity	1.000	1
Smart agriculture	1.000	1
Smart energy	0.971	2
Smart Education	0.943	3
Smart infrastructure	0.943	3
Organized settlements	0.943	3
Smart health	0.886	4

As per the results, smart connectivity and smart agriculture are the most significant smart village features in Sri Lanka. In terms of connectivity, it should be there to adapt to technological upgrades. On the other hand, agriculture should be prioritized when developing rural areas of the country, because the economy of the Sri Lankan rural community highly depends on agriculture. Further advancements which will be adapted to agriculture can raise more harvesting and income.

4.4 THE POSSIBLE SUPPORTING TECHNOLOGIES TO IMPLEMENT THE SMART VILLAGE CONCEPT IN THE SRI LANKAN CONTEXT

The experts' opinion on possible supporting technologies for the proper implementation of SV was collected under several sectors such as agriculture, education, public transportation, public health, and infrastructure. The results are presented in tables 8 to 12.

- Agriculture sector

Table 8: Supportive technologies for creating smart agriculture

Technology	Possible Applications
AI	Forecasting yield, Control pests, and diseases, Monitoring the environmental conditions, Identify soil conditions and decide the suitable crops for the land
IoT	Gather real-time climate data and make decisions based on that, Smart watering system (automated irrigation system), Remote Monitoring (crop monitoring)
ICT	E-marketing

- Education sector

Table 9: Supportive technologies for creating smart education

Technology	Possible Applications
IoT	Smartboard, Monitoring, and controlling facilities within the educational institutions
ICT	E-learning platforms (including online and distance learning) using ICT tools to improve the productivity of both teaching and learning procedures
5G	Reduce low latency of internet connectivity, Use AR/VR tools for education purposes

- Transportation

Table 10: Supportive technologies for creating smart transportation

Technology	Possible Applications
GIS	Road maintenance, Accident analysis, Planning new routes

- Health

Table 11: Supportive technology for creating smart health

Technology	Possible Applications
IoT	Remote patient monitoring
ICT	E-health services, Telemedicine

- Infrastructure

Table 12: Supportive technologies for creating smart infrastructure

Technology	Possible Applications
IoT	Smart meters, Real-time data about the asset
ICT	Powerful internet connectivity
Smart Grid	Street lighting system, Energy conservation

4.5 THE KEY BENEFITS OF IMPLEMENTING THE SMART VILLAGE CONCEPT IN THE SRI LANKAN CONTEXT

Seven possible benefits of implementing SV were identified through the literature related to the global context and experts were requested to give their opinion on the relevancy of those benefits to the Sri Lankan context. The analyzed experts' opinions on the relevancy of those benefits to the Sri Lankan context are shown in table 13.

Table 13: Benefits of implementing smart village in Sri Lanka

Benefits	RII	Rank
Improve the quality of life	0.971	1
Expand access the public services	0.971	1
Make better use of resources	0.943	2
Provide new opportunities for rural value chains	0.914	3
Provide long-term social, economic, and environmental welfare	0.886	4
Address to unplanned urbanization, village underdevelopment, migration for economic pursuits, higher standard of living,	0.829	5
Reduce the negative impact on the environment	0.686	6

Through the results, the RII value of all identified benefits of SV implementation fell within the range of 0.972 to 0.686, indicating that all the benefits identified through the literature review create a significant influence on the Sri Lankan context.

4.6 CHALLENGES IN IMPLEMENTING THE SMART VILLAGE CONCEPT IN SRI LANKA

Eleven possible challenges of implementing SV were identified through the literature related to the global context and experts were requested to give their opinion on those challenges, and how they affect the Sri Lankan context. Table 14 shows the result of the impact level of the challenges.

Table 14: Challenges in implementing smart village in Sri Lanka

Challenges	RII	Rank
Lack of network cooperation and transfer of innovations from scientific research institutions to practical practice.	0.943	1
Difficulties in developing innovative projects and raising funds for these projects	0.886	2
Transitioning to low-carbon circular economies	0.800	3
Poorly developed transportation and communication networks	0.771	4
Depopulation/migration of the young population	0.743	5

Promoting digital transformation of rural areas	0.714	6
Exploiting connections with cities in all ways,	0.686	7
Less access to resources and markets compared to suburban areas	0.657	8
Significant differences in social structures and socioeconomic characteristics (low communication accessibility, negative migration balance, residents with low educational levels)	0.629	9
Low engagement or awareness of inhabitants impeding the creation of smart communities	0.572	10
Low level of openness to change in rural communities	0.543	11

Through the result of the collected data "lack of network cooperation and transfer of innovations from scientific and research institutions to business practice" was ranked as the highest impact challenge. It is also revealed by experts when discussing the smart village's current implementation. ID stated that "most of the projects were under the research, not complete successfully". And the second challenge is "Difficulties in developing innovative projects and raising funds for these projects". IE revealed that most of the smart-related development projects were unable to complete due to financial issues. Therefore, this result indicated transfer of innovations from practice and funding for the development projects will be the most difficult challenge to face when implementing smart villages in Sri Lanka. On the other hand, "Low engagement or awareness of inhabitants impeding the creation of smart communities" and "Low level of openness to change in rural communities" have the lowest RII values and are ranked as the lowest impact challenges. It could be supported by the present situation in the country, for example, when QR codes (National fuel passes) were introduced as a solution for fuel queues, people had some concerns with it at first, but after a short time, people adjusted to it, and the same experience was had when initiating online education and work from home concepts. Therefore, compared to other difficulties, these two have a lower level of impact and can be easily mitigated. Experts have pointed out some additional challenges. IE recognized administrative difficulties, including a preference not to change institutional setup practices like manual working processes and a top-to-bottom workflow for the development plan without considering the needs of communities. Additionally, IG provided some other challenges, the authorities' tendency to operate in silos and not consider facts and figures when identifying development opportunities.

5. CONCLUSIONS

As observed, the majority of the Sri Lankan population still lives in rural areas with significant development imbalances compared to urban areas. SV is an effective approach for rural area development, that provides solutions for the issues faced by rural communities. It utilizes modern digitalized technologies and services to enhance rural inhabitants' lives by considering the characteristics of a village. Therefore, informative research is required to reveal the implementation of the SV concept for Sri Lankan rural areas to revitalize the rural community. As an initial step, this research focuses on the current implementation of the SV concept in the Sri Lankan context, discovering the benefits and possible challenges. The key findings revealed that the highly existence smart village feature in Sri Lanka is smart education, while smart connectivity is highlighted as the most significantly required smart village feature because when applying smart technologies to develop SV stable connectivity is a key factor. Moreover, supportive technologies such as AI, IoT, ICT, 5G, GIS, and smart grid play a major role in creating smartness in different sectors such as agriculture, education, transportation, health, and infrastructure. In terms of the major benefits of implementing the SV concept in Sri Lanka, it will enhance the quality of life in rural areas while providing expanded access to public services. The most considerable challenge attached to the SV implementation in the local context is the lack of network cooperation in the transfer of innovations from scientific research institutions to practical practice. As per the findings, the concept of SV is not implemented successfully in Sri Lankan context. In contrast, there are some smart concept-related projects available in Sri Lanka for example, the Mahaweli settlement project, Smart city projects, Smart agriculture projects, and so on. But those projects were not recorded with positive progress. Hence the identified benefits of implementing SV will encourage the implementation of the SV concept in the Sri Lankan context. Further, knowing the possible challenges priory will ensure the smooth implementation of the SV concept. Although the scope of this research is limited to only for few features of the SV that could be implemented in SV projects in Sri Lanka. Since the "SV" is a new concept for the Sri Lankan context, the data collection and resource persons could be limited and most of the literature findings which were related to the global context were used to analyze the suitability of the SV concept in Sri Lanka. Furthermore, data collection is only based on expertise rather than on rural inhabitants, so could be quite a difference between the expert and rural communities' ideas that would not be analyzed in this research. Accordingly, this study will be an eye-opener to enhance the consideration of implementing the concept of SV for rural area development in Sri Lanka.

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STATUS QUO OF DIGITALISATION IN THE SRI LANKAN CONSTRUCTION INDUSTRY

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ABSTRACT

The construction industry faces various issues in completing the project effectively. Numerous studies have found that the construction sector has experienced a rapid and continuous digital transformation to tackle these issues. As a result, to successfully implement Industry 4.0 applications in the Sri Lankan construction industry, it is necessary to identify the status quo of digitalisation in the Sri Lankan construction industry. Therefore, the research aims to analyse the status quo of digitalisation in the Sri Lankan construction industry. The study employs a mixed-method approach consisting of two phases. In phase one, a questionnaire survey was conducted for 50 respondents selected through snowball sampling. The collected data were analysed using SPSS. In phase two, semi-structured interviews were conducted with 11 experts who had knowledge of Industry 4.0 and lean construction, selected through purposive sampling. Data analysis was conducted through code-based content analysis using NVivo 10. The study indicated that the overall level of digitalisation of the construction industry is lower, while BIM (Building Information Modelling), 3D printing, and Drones/Unmanned Aerial Vehicles (UAV) are the most often implemented applications. Research has made significant contributions to knowledge in identifying issues in the current construction industry in Sri Lanka and the level of implementations of Industry 4.0 applications in the construction industry to measure digital disruption in the industry. Accordingly, the research provides a path to investigate the barriers to implementing these industry 4.0 applications and strategies to eliminate those barriers to raise the construction sector's overall digitalization level.

Keywords: *Construction industry; Digitalisation; Industry 4.0; Issues; Sri Lanka.*

1. INTRODUCTION

Construction output represents half of the gross capital and 3 to 8% of the Gross Domestic Product (GDP) in most countries (Alaloul et al., 2021; Berk & Biçen, 2018; Chiang et al., 2015; Saka & Adegbembo, 2022). Therefore, failure to utilise innovative productive plans and lack of collaboration will lead to collapse and under-developing of the construction sector, which will reduce the GDP in the national economy and the need for

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adequate infrastructure for the economy as well (Alaloul et al., 2021). Thus, proper construction management should be followed in every construction project to eliminate such consequences. According to Erdogan et al. (2019), the two most important factors influencing the construction sector are technology and construction management. Although the construction industry is achieving rapid progress while gradually expanding, there are still some problems in the construction management and sustainable delivery of the project (Fu, 2019). There are communication problems and uncertainties in the process with an increasing number of disciplines (Biçer et al., 2020). Furthermore, a study conducted by Pakhale and Pal (2020) showed that the traditional approach usually fails to execute projects on time and within budget in the construction industry. As discussed by Tzortzopoulos et al. (2020), The findings of a few researchers further discussed endemic management issues in design management, client decision-making, and construction management (Koskela, 2000; Talebi et al., 2016). Poor construction management has also been identified throughout the past as one of the main barriers to the development of the construction industry (Gamil & Abdul Rahman, 2020; Odeh & Battaineh, 2002; Potts & Ankrah, 2008; Walker, 2015). Many researchers have highlighted the causes of problems in the construction sector. Among them, poor construction projects, taking into account costs and planning, are one of the common causes (Erdogan et al., 2019). Besides design and execution issues, budget limitations (Chin-Keng & Shahdan, 2015), contractual scheduling constraints (Liu et al., 2020), quality requirements (Wawak et al., 2020), safety and environmental concerns (H. Guo et al., 2017), issues with material logistics, sustainability rating system requirements, and stakeholder dissatisfaction with project delays are also can be taken into account as causes (Alothaimeen & Arditi, 2019). In recent decades, the construction industry has undergone a gradual and accelerated digital transformation to address these issues.

Digitization, automation, and integration provide opportunities for productivity improvement as well as design and construction quality. Certainly, the construction industry is becoming more digitalised, as it is difficult to imagine the modern construction sector without the use of specific information technology, and the importance of these technologies is growing every day (Nataliia & Oleksii, 2019). Level of implementation of Industry 4.0 applications in the Sri Lankan construction industry. Although the implementation of the digitalising construction industry has been discussed in many research. However, there is a lack of research on the level of implementation of Industry 4.0 applications in the Sri Lankan construction industry. Therefore, the research aims to investigate the status quo of digitalisation in the Sri Lankan construction industry. Further, the objective can be obtained through the current level of implementation of Industry 4.0 applications in the Sri Lankan construction industry. First, a review of the literature on issues in the construction industry and the benefits of Industry 4.0 for the construction industry. The methodology used is explained in the following section. Thereafter, the findings of the research on issues in the construction industry, the current digitalization level, and knowledge of Industry 4.0 applications in the Sri Lankan construction industry.

2. LITERATURE REVIEW

2.1 ISSUES IN THE CONSTRUCTION INDUSTRY

Most economies place a high value on the construction industry. It influences and is influenced by the GDP of any nation (Debelo & Weldegebriel, 2022; Erdogan et al., 2019; Hughes & Thorpe, 2014). According to the reports, the efficiency and productivity of the construction industry have been one of the major considerations among countries over the past 40 years (Teicholz, 2013) and was caused by several challenges, as well as needs to be improved in efficiency and productivity (Prabhu & Nagarajan, 2013). The scale of construction projects is expanding due to the growing human requirements, and construction projects are becoming more challenging in tandem with technological advancements (Biçer et al., 2020). Hence, addressing the issues within the industry is a highly concerning topic worldwide. As many researchers identify, there are common issues in construction such as poor execution of construction projects (Erdogan et al., 2019), budget limitations (Chin-Keng & Shahdan, 2015), contractual scheduling constraints (Liu et al., 2020), quality requirements (Wawak et al., 2020), safety and environmental concerns (Guo et al., 2017), issues with material logistics, sustainability rating system requirements, and stakeholder dissatisfaction with project delays (Alothaimeen & Arditi, 2019), poor communication (Makulsawatudom et al., 2004; Thorpe, 2003), poor site conditions, and poor site layout (Lim & Alum, 1995; Makulsawatudom et al., 2004). Adekunle et al. (2021) highlighted that technological growth offers solutions to the aforementioned problems, in the construction sector.

2.2 INDUSTRY 4.0

Industry 4.0 can be stated as the fourth industrial revolution which can deliver more intelligent processes in the manufacturing industry as well as in the construction arena (Zhou et al., 2015). Through this development, major problems such as lack of interoperability & automation, information transparency, and technical assistance can be addressed. BIM, drones, robotics, 3D printing, and virtual and augmented reality are some of the applications utilized to assist construction projects (Zhou et al., 2015). Building information modelling (BIM) is a digital representation of a building's geometric and non-geometric data that is used to make decisions on a facility throughout its existence (Guerriero et al., 2018; Hasan & Rasheed, 2019; Leite et al., 2011). One of the technical tools utilized by the construction business is virtual reality (VR), which allows a person to explore and interact with a three-dimensional, computer-generated environment. Augmented reality (AR) uses the same concept as virtual reality (VR), but instead of interacting in a non-existent environment (digital reality), AR uses the current environment while including virtual aspects to appear as though both are there at the same time (Dunleavy & Dede, 2013). 3D printing is a type of additive manufacturing that creates objects layer by layer. There are several forms of 3D printing, including those that use thermoplastic or polymeric materials (Chong et al., 2018) or the process known as contour crafting (Khoshnevis, 2004; Khoshnevis et al., 2006). Drones, also known as Unmanned Aerial Vehicles (UAV), have long been studied for their potential application in construction (Irizarry et al., 2012; Siebert & Teizer, 2014). Given that construction and maintenance projects frequently span large areas that can be more comprehensively and easily scanned from the air by drones, the use of drones in conjunction with 3D models and BIM systems for visual progress monitoring, site survey, safety, and quality analysis appear promising. Therefore, there are lots of benefits that can be gained through digitalisation via Industry 4.0 in the construction industry.

2.3 BENEFITS OF DIGITALISATION

Digitalization offers numerous opportunities for the advancement of the AEC business. For example, digital solutions facilitate data-driven decision-making through visualizations and simulations (World Economic Forum, 2016). Digitalization also lay the groundwork for collaborative value creation through new types of interaction, improved information exchange, and stakeholder openness (Schober & Hoff, 2016). According to (Bock, 2015), construction automation technology, such as robots, is gradually ingrained in buildings and building components. However, digitalization poses dangers to the AEC industry's future. Start-ups with digital innovations can threaten existing AEC industries, resulting in lower revenue for current players (Christensen, 2016). Over the last five years, more than 80 start-ups based on digital technologies have emerged and begun to operate in the AEC industry in Finland (Lehtinen et al., 2017). Social media, cloud computing, sensors, big data, and wireless networks are no longer buzzwords in technology. They have the potential to disrupt traditional enterprises (Porter & Heppelmann, 2014). In the media, commerce, and music sectors, incumbents have been subjected to enormous forces generated by new business models based on digital technology and data. Uber, Airbnb, and the App Store are all instances of platform-based digital services (Gawer, 2014). The conservative AEC industry has begun to feel the effects of digitalisation. BIM and other similar systems, as well as wireless sensors and data analytics, have the potential to revolutionize infrastructure construction and maintenance (World Economic Forum, 2016). Decision makers in the AEC have highlighted concerns about which digital technologies, important trends, and uncertainties will have an impact on the industry (Jacobsson et al., 2017; Linderoth, 2017). A recent study by Schober and Hoff (2016) found that decision-makers in the AEC are uncertain about realizing the benefits of digitization. In other words, business leaders are grappling with how to manage the transition from traditional construction practises to digitalized construction supply chains. Table 1 presents the benefits of digitalization for the construction industry identified throughout the existing literature.

Table 1: Benefits of industry 4.0 for the construction industry

Benefit	Descriptions	Reference
Cost savings	Labour expenses are reduced when labour-intensive operations are mechanized, such as through the use of robotics or automated workflows. Furthermore, integrating embedded sensors to automate the tracking of equipment and materials might help to cut material costs.	[1], [2], [3], [4]
Time savings	Innovative manufacturing technologies and concepts such as prefabrication and additive manufacturing allow structures to be built in a matter of days, much faster than traditional construction processes.	[5], [6], [7]
On-time and on-budget delivery	Historically, completing building projects on time and under budget has proven to be a difficult task. BIM can help to reduce project delivery time and keep projects on budget.	[8], [9]
Improving quality	The use of BIM and other simulation technologies has been suggested to improve building quality since errors can be eliminated in the early stages by replicating the entire construction process. Furthermore, based on previous data, Big Data analytics can assist project managers in making more effective and well-informed decisions.	[10], [11]

Improving collaboration and communication	Because each construction project involves a large number of project participants, cloud- and BIM-based platforms or social media apps can effectively boost collaboration and communication even beyond corporate borders.	[12], [13]
Improving customer relationship	Construction companies can provide project owners with more insights into the features and design of a building before it is created by combining simulation technologies such as Augmented Reality, Virtual Reality, and Mixed Reality with mobile devices or wearable computers. Customers can thus be included in the design process for better building customization.	[14]
Enhancing safety	The abundance of literature on safety management demonstrates that safety is one of the most critical issues in construction. The construction industry is well known for its high rate of work injuries and accidents due to its hazardous work environment. As a result, many different approaches are presented by researchers and practitioners to improve construction safety, such as virtual safety training, using risk maps to avoid work accidents, or using wearable technologies such as Smart Glasses or Smart Helmets.	[15]. [16], [17]
Improving the image of the industry	The construction industry is notorious for its tough working conditions and poor level of digitalization. As a result, it has a terrible employer image and frequently struggles to attract talented people to its team. The entire industry's digital revolution can help to boost its image.	[18]
Improving sustainability	The building and construction industry contributes significantly to CO_2 emissions due to high energy consumption and trash generation during the construction process. Several ways have been offered to address these environmental issues, such as minimizing project emissions through strategic project management or using BIM to create design alternatives.	[19], [20], [21], [22]

[1] (Barro-Torres et al., 2012), [2] (Bello et al., 2021), [3] (Bruemmer, 2016), [4] (Valente et al., 2019), [5] (Baynes & Steele, 2015), [6] (McGraw Hill Construction, 2011), [7] (Valente et al., 2019), [8] (Jones, 2014), [9] (Teisserenc & Sepasgozar, 2021), [10] (Allison, 2015), [11] (McMalcolm, 2015), [12] (Groves-Delphos, 2014), [13] (Merschbrock & Munkvold, 2015), [14] (Jones, 2014), [15] (Chun et al., 2012), [16] (H. L. Guo et al., 2013), [17] (Vahdatikhaki & Hammad, 2015), [18] (Slowey, 2015), [19] (Chou & Yeh, 2015), [20] (Davies et al., 2014), [21] (Tang et al., 2013), [22] (Yuan & Wang, 2014)

Table 1 summarises various benefits that can be achieved using innovative technologies and concepts in the construction industry. These benefits include cost and time savings, on-time and on-budget delivery, improved quality, collaboration, customer relationships, safety, industry image, and sustainability. The descriptions of each benefit are supported by references to relevant research studies. In general, Table 1 provides a concise and informative overview of how the construction industry can leverage technology to improve various aspects of its operations and results.

2.4 TECHNOLOGIES AND APPLICATIONS USED IN DIGITALIZED CONSTRUCTION INDUSTRY

Among numerous technologies that are trending, the followings are the most discussed Industry 4.0 applications in the construction industry (El Jazzar et al., 2021). Although several technologies are emerging in the construction industry, Virtual Reality (VR) and Augmented Reality (AR), BIM, robotics, AI (Artificial Intelligence), 3D printing, IoT, and drones or UAVs can be identified as the most commonly employed (El Jazzar et al., 2021). Major problems such as lack of interoperability & automation, information transparency, and technical assistance can be addressed through Industry 4.0 (Zhou et al., 2015). Furthermore, the author stated that mostly BIM and related technologies rectify these issues while enhancing communication and collaboration. Moreover, the latest technologies, such as drones, robotics, 3D printing, and virtual and augmented reality, are also assisted during construction projects and improve information transparency. Even though the applications are advantageous to the industry, the level of implementation has to be properly identified before proceeding further (Sony & Naik, 2019). The gap in properly identifying the level of implementation level has been addressed through this paper to find the readiness of Industry 4.0 in the construction industry (Mansour et al., 2023). According to that, there is a need to determine the current state of digitalization in the Sri Lankan construction industry to successfully adopt Industry 4.0 applications in the Sri Lankan construction sector.

3. RESEARCH METHODOLOGY

This research was carried out using a mixed research approach to analyse the status quo of digitalisation in the Sri Lankan construction industry. Therefore, a comprehensive literature review was conducted to review the issues in the construction industry and the benefits of digitalization. Mixed-method research is a kind of investigation that involves gathering both quantitative and qualitative data, combining the two types of data, and employing distinct designs that may include philosophical assumptions and theoretical frameworks. The key assumption of this type of investigation is that combining qualitative and quantitative data offers additional knowledge beyond what quantitative or qualitative data alone can provide (Creswell, 2014). The benefits of using this specific strategy are the ability to look at the quantitative and qualitative data to reflect the perspectives of participants, provide methodological adaptability, and gather rich, comprehensive data (Johnson & Onwuegbuzie, 2004). Thus, it is important to select the best method to carry out comprehensive research. Considering the merits and demerits of the research approaches, both the qualitative and quantitative approaches were selected. Accordingly, a mixed approach was adopted to achieve the research aim.

The data was collected in two phases. Phase one: questionnaire survey carried out among the construction industry professionals. Consequently, Phase Two: semi-structured interviews with industry experts were conducted to identify the status quo of digitalization in the Sri Lankan construction industry. The methodology employed for sampling in this dissertation involved the utilization of two distinct techniques. Firstly, the snowball sampling method was utilized to gather responses for the questionnaire and was analysed using descriptive analysis. This method involves the use of referrals by participants to recruit additional individuals who meet the study criteria. The survey was carried out via Google® Forms among 50 industry professionals who are working in the Sri Lankan construction industry and are aware of the industry 4.0 applications/technologies and digitalization in the construction industry. 50 number of participant sample size was chosen as statistically at least there should be 30 participants (Aithal & Aithal, 2020). Second, eleven expert interviews were conducted using the purposive sampling technique, a subjective sampling method that involves selecting individuals based on their expertise and relevance to the research topic, and data was analysed using code-based content analysis using NVivo 10. The number of experts was restricted to 11 as the data saturation was there with repetitive information (Fusch & Ness, 2015).

4. RESEARCH FINDINGS AND ANALYSIS

4.1 ISSUES IN THE CURRENT CONSTRUCTION INDUSTRY

Construction projects often face various challenges that can impact their success. To overcome these challenges, it is crucial to identify and prioritize the issues that are most likely to occur during a project's lifecycle. **Error! Reference source not found.** presents a list of common issues in construction projects gathered through phase I: questionnaire survey, along with their RII, and ranks based on those RII scores. The RII scores reflect the level of importance assigned to each issue.

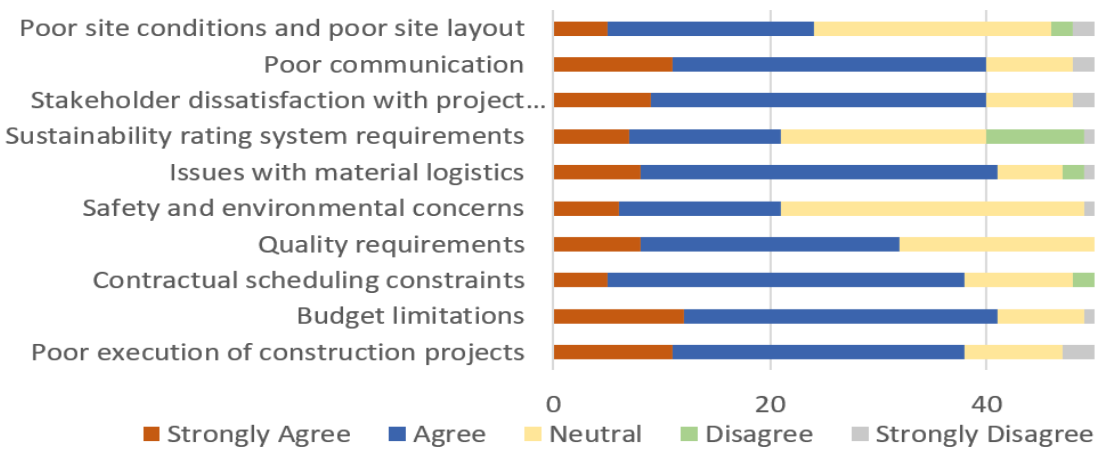


Figure 1: Issues in the current construction industry

According to the questionnaire survey, ‘Budget limitations’ was marked as the most critical issue in the current construction industry, gaining relative importance of 80%. Furthermore, ‘poor communication’, ‘problems with material logistics’, and “Stakeholder dissatisfaction with project delays’ were also ranked higher in the issues. As all the issues have more than 60% RII value, it can be identified that all the issues as described in the literature review exists in the real-world scenario. The 60% RII value is taken as the benchmark and the issues that have less than that value cannot be taken as applicable for the Sri Lankan construction industry. The RII scores represent the level of importance assigned to each issue by a group of stakeholders, such as project managers, contractors, and clients. At the top of the list are "Budget limitations" with an RII of 0.80, indicating that it is the most important issue identified by the stakeholders. This is followed closely by "Poor communication" (RII = 0.79) and "Issues with material logistics" (RII = 0.78). These three issues are all related to project management and coordination, suggesting that effective planning and communication are critical for successful construction projects. Other important issues identified include "Stakeholder dissatisfaction with project delays" and "Poor execution of construction projects", which both received an RII of 0.78, as well as "Contractual scheduling constraints" (RII = 0.76) and "Quality requirements" (RII = 0.76).

In addition to that, issues in the construction industry were validated through phase II: expert interview. Accordingly, in Section 02 of the interview guideline, the respondents were asked to give their opinion on current issues in the construction industry in Sri Lanka. Among all the issues mentioned, the limited use of digitalized applications and technology has been identified by most as a prominent issue in the construction industry.

Other than that, financing and cash flow issues, less skill and competency level of labourers, and import restrictions are also highlighted by more than two respondents.

4.2 LEVEL OF IMPLEMENTATION OF INDUSTRY 4.0 APPLICATIONS IN THE SRI LANKAN CONSTRUCTION INDUSTRY.

The list of 5 Industry 4.0 applications/technologies in the construction industry extracted from the literature review were rated for the implementation level in Sri Lanka by the respondents through phase I: a questionnaire survey. Those applications with their Relative Importance and ranks are tabulated in Table. The most implemented Industry 4.0 applications are respectively BIM, 3D printing, and Drones/UAVs. Since all applications have equal or less than 61% of the RII value, the implementation level of all the applications is considerably low.

Table 2: Level of implementation of Industry 4.0 applications in the Sri Lankan construction industry

Application/Technology	**Scale percentage (%)**					**RII**	**Rank**
	1	**2**	**3**	**4**	**5**		
BIM	3	14	17	9	7	0.61	1
VR and AR	21	12	11	4	2	0.42	5
Robotics	33	8	5	2	2	0.33	7
3D Printing	12	12	14	9	3	0.52	2
AI	31	10	2	6	1	0.34	6
Drones or UAV	7	15	22	5	1	0.51	3
IoT Solutions	12	17	15	4	2	0.47	4

[1] Very poor, [2] Poor, [3] Moderate, [4] Good, [5] Very good

According to Table 2, BIM is the mostly implemented technology, with an RII of 0.61 and a rank of 1. This is followed by 3D Printing with an RII of 0.52 and a rank of 2, and Drones or UAVs with an RII of 0.51 and a rank of 3. On the other hand, Robotics has the lowest RII value of 0.33 and a rank of 7, indicating that it is considered to be the least implemented technology among the surveyed group. Table 2 provides useful insight into the perceived implementation of different technologies in the construction industry.

Near the middle of the vortex, the effect of digital disruption is greater for anyone working in that sector. In other words, those sectors are highly digitalised. According to previous research the position of the construction industry in the vortex is far away from the eye (Keast, 2016). According to that, the level of digitization of the construction sector was further examined and validated during phase II: expert interviews. All the respondents said the construction industry in Sri Lanka has been digitalized in a percentage between 5%-50%. **Error! Reference source not found.** illustrates the level of digitalization of the construction industry according to respondents' views by positioning each respondent's views in a vortex model.

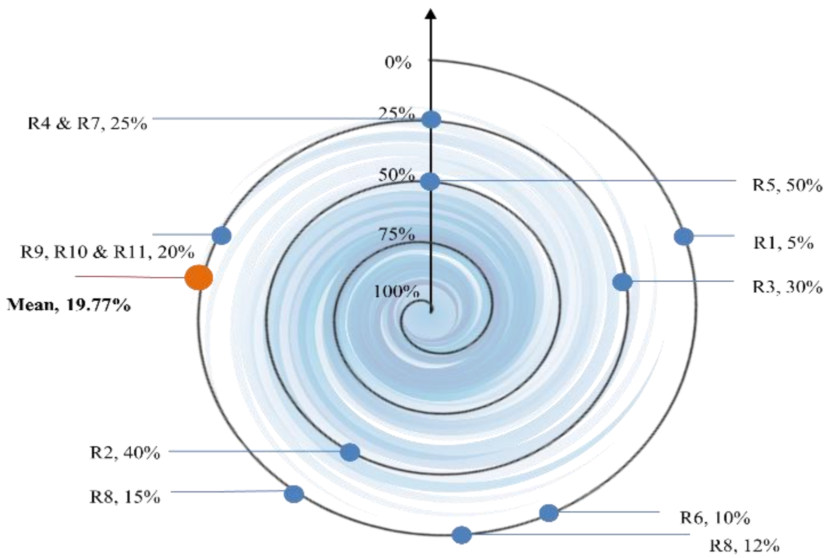


Figure 2: Level of digitalisation of the construction industry according to respondents' view

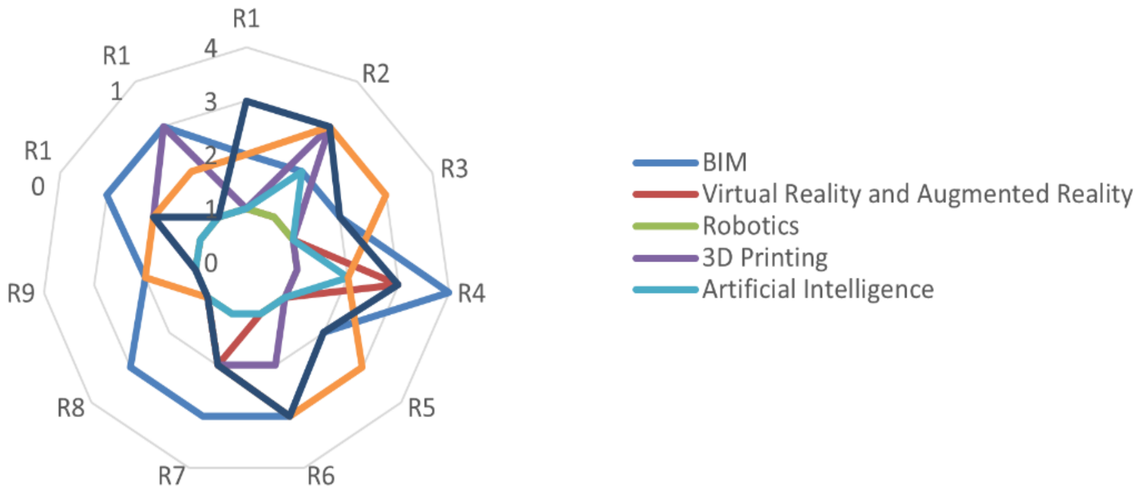
According to the data, the geometric mean value of the given percentages is 19.77%. Therefore, the level of overall responses proves that the digitalisation of the construction industry in Sri Lanka is almost below 20% compared to other industries. R4 specifically said that 'when *considering textile, manufactories industries, they are now mostly automated. For example, the Rhino roofing sheets factory is also highly automated. They use highly digitalised machines. Therefore, compared to other industries, the construction industry has only 25% digitalisation in Sri Lanka. China is very far ahead of Sri Lanka*.". R4 also stated that now some companies are taking action to digitalise the industry by implementing ERP systems, BIM, and others. In other developed countries like China, they use highly automated technologies in the construction industry like counting labourers when they entering to the site through sensors fixed in their helmets. Some construction companies in Sri Lanka also tried to implement those but due to the country's problems, all such efforts have been stopped. R9 stated: "*I think according to the research, the construction industry is the lowest digitalised industry in the world. In the Sri Lankan industry, it is not digitalised at all. We don't use advanced software for take-off and pricing, and we don't use modular building, 3D printing, VR, AR, or digital twin, we don't use those currently in Sri Lanka. I can rate very lower level*." R11 argued that currently, the Sri Lankan construction industry is experiencing technologies like BIM and IoT. Other than that, the industry is using various software for project management and BOQ preparation. Therefore, currently, the door for digitalization is open in the Sri Lankan construction industry.

4.3 KNOWLEDGE OF INDUSTRY 4.0 APPLICATIONS

As Industry 4.0 technologies continue to transform the construction industry, it is important to understand the level of knowledge and awareness that industry professionals have of these technologies. BIM, VR and AR, drones, robotics, and other advanced technologies are revolutionizing the way that construction projects are designed, planned, and executed. To explore the degree of knowledge and awareness of industry professionals about these technologies, this research conducted interviews with a group of experts in the construction industry. The interviews aimed to measure the level of knowledge of each respondent regarding various Industry 4.0 applications and to map the results in a graphical figure that provides insights into the current state of knowledge in the industry. Almost all the respondents except one have sufficient knowledge of BIM. Other than that, many of them also had the knowledge and understanding of VR & AR, 3D printing, and drones. But only 2 respondents have heard of robotics in the construction industry. All respondents have participated in at least one seminar/workshop related to any type of Industry 4.0 technologies. But many of them mentioned that they used self-learning methods to gain knowledge about many types of Industry 4.0 technologies.

4.4 IMPLEMENTATION LEVEL OF EACH INDUSTRY 4.0 APPLICATION

In the interview, the experts were asked to rank the implementation level of each Industry 4.0 application. **Error! Reference source not found.** graphically demonstrates the



results.

Figure 3: Implementation level of each Industry 4.0 application

When analysing the responses of the experts, same as the questionnaire survey, BIM was identified as the technology most widely implemented in the construction industry. Next, respectively, Drones or UAVs, IoT solutions, and 3D Printing can be ranked at the implementation level. According to their views, robotics and AI are the least implemented applications in the industry.

5. DISCUSSION

When focusing on the issues in the construction industry, research findings validate that budget limitations (Chin-Keng & Shahdan, 2015) was the most critical issue found in the industry. Other than that, issues which are found in literature such as poor communication (Makulsawatudom et al., 2004; Thorpe, 2003), stakeholder dissatisfaction with project delays (Alothaimeen & Arditi, 2019), and issues with material logistics were also accepted by the respondents. Not limited to that, expert interviews revealed that there were issues due to less digitalisation, less skill level of labourers, financing and cashflow issues, import restrictions, and so on. As discussed by Guo et al. (2017), the existence of safety and environmental concerns was again revalidated by experts in interviews.

When comparing the results of both questionnaire and expert interviews, among all the major Industry 4.0 applications which were identified by El Jazzar et al. (2021), BIM was identified as the technology most widely implemented in the construction industry with an RII of 0.61 in the questionnaire survey results. Drones or UAVs, IoT solutions, and 3D printing were also at higher implementation levels. The findings of both the questionnaire and the expert interview show that robotics and IoT were less implemented technologies in the industry. As a result of expert interviews, the overall level of digitalisation of the construction industry was less than 20%. The results of the interviews conducted with construction industry professionals provide valuable insight into the level of knowledge and awareness of Industry 4.0 technologies. While almost all respondents had sufficient knowledge of BIM, there was a significant knowledge gap in robotics. This highlights the need for more awareness and education about these advanced technologies in the industry. It is encouraging to note that many of the respondents had knowledge and understanding of VR & AR, 3D printing, and drones. This suggests that these technologies are gaining wider acceptance and adoption in the construction industry. Furthermore, the fact that all respondents had participated in at least one seminar/workshop related to any type of Industry 4.0 technologies indicates that industry professionals are actively seeking out opportunities to learn and stay up-to-date with the latest developments in the field. However, the finding that many of the respondents used self-learning methods to gain knowledge about Industry 4.0 technologies also highlights the need for more accessible and user-friendly educational resources. Overall, the insights gained from this research can inform the development of targeted educational programmes and initiatives aimed at improving knowledge and awareness of Industry 4.0 technologies in the construction industry.

6. CONCLUSIONS

The research's aim was met by conducting a systematic literature review and conducting a questionnaire survey and expert interviews of construction industry professionals. The digitalisation of the construction industry is based on the status of Industry 4.0 technologies/applications in the industry. Through the literature review, several industry 4.0 applications have been identified which are considerably used in the industry, such as BIM, VR & AR, 3D Printing, robotics, AI, Drones, and UAV and IoT solutions. The survey data indicated that the overall implementation and usage levels of these applications were lower in Sri Lanka compared to other countries. Among the selected applications, BIM was found to be the most commonly used one in the industry. Subsequently, the expert responses were analysed and BIM was identified as the technology most widely used in the construction sector, similar to the questionnaire survey. Subsequently, 3D Printing Drones or UAV and IoT solutions can be prioritized in terms of implementation. Furthermore, among them, Robotics and AI are the least implemented applications in the construction sector. However, it is important to note that these findings are limited to the context of Sri Lanka and may differ in other countries. This study recommends that industrial practitioners determine the level of implementation of Industry 4.0 applications in the Sri Lankan construction industry to effectively implement Industry 4.0 applications in the Sri Lankan construction industry and overcome the various issues in the construction industry. The findings will also pave the way for further research on the successful implementation of Industry 4.0 applications in the Sri Lankan construction industry. The results of this research will allow construction practitioners to investigate solutions to problems in the Sri Lankan construction industry. Further research is required to understand the factors that may be hindering the adoption of these technologies in Sri Lanka and to explore ways to increase their implementation and usage in the construction industry.

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STRATEGIC IMPLEMENTATION OF PPP FOR SMALL-SCALE INFRASTRUCTURE IN SRI LANKA: A COMPARATIVE ANALYSIS OF ALTERNATIVE PPP MODELS

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ABSTRACT

This study aims to provide a thorough comparison of Private Finance Initiative (PFI), Build-Operate-Transfer (BOT), and Joint Venture (JV) models for Small-Scale Infrastructure Development (SSID) in Sri Lanka and devise innovative, tailored recommendations to maximise efficiency, effectiveness, and compatibility. Employing a mixed-methods approach, the research systematically examines the key features, benefits, and limitations of PFI, BOT, and JV models in the context of SSID. A compatibility assessment is conducted, focusing on financing approaches, stakeholder engagement, and other critical success factors. The findings reveal that the BOT and JV models are superior to the PFI model due to their balanced stakeholder engagement, risk sharing, and alignment with critical success factors. Based on these insights, the study formulates novel, customised recommendations for optimising the selected model's efficiency, effectiveness, and compatibility with SSID in Sri Lanka, with the aim of informing policy and practice. Furthermore, the study highlights the need for future research exploring alternative financing models and emerging technologies in SSID, opening new avenues for innovative approaches to infrastructure development in Sri Lanka. In conclusion, this comprehensive comparison offers valuable guidance for academics, industry professionals, and policymakers seeking to enhance small-scale infrastructure development in Sri Lanka, emphasising the importance of selecting the most suitable financing model.

Keywords: *Procurement Perspective; Public-Private Partnerships; Small-Scale Infrastructure Projects; Sri Lanka; Stakeholder Engagement.*

1. INTRODUCTION

1.1 CONTEXT AND BACKGROUND

Sri Lanka's growing economy heavily relies on infrastructure development to drive growth and development, particularly through small-scale infrastructure development (SSID) projects aimed at providing essential services to rural and urban populations

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(Appuhami & Perera, 2016; Ranjith Bala, 2011). However, the successful implementation of SSID projects faces challenges such as inadequate financing, limited technical expertise, and insufficient stakeholder engagement (Akomea-Frimpong et al., 2021). Public-Private Partnerships (PPPs) have emerged as a potential solution to these issues, allowing for a collaborative effort between the public and private sectors in financing, designing, constructing, operating, and maintaining infrastructure projects (Miranda-Poggys & Morena, 2023). While PPPs have been widely used around the world and have been shown to improve project efficiency, reduce costs, and provide better services to communities, selecting the most suitable PPP model for SSID projects in Sri Lanka is challenging due to the unique economic, social, and political context of the country (Dabarera et al., 2019).

1.2 PROBLEM OF RESEARCH AND MOTIVATION

Although PPPs offer potential benefits for SSID projects in Sri Lanka, the most suitable model for the country's unique context remains unclear (Chan et al., 2010; Kandawinna et al., 2022). Traditional public procurement models have shown inefficiencies, delays, and suboptimal outcomes (Jamali, 2004; Wang et al., 2018). Inappropriate PPP model selection can result in financing challenges, insufficient stakeholder engagement, and poor project outcomes (Muhammad & Foziah, 2017; Opawole & Jagboro, 2018). This research aims to compare three PPP models (PFI, BOT, and JV) to identify the best option for Sri Lanka's SSID projects, providing tailored recommendations to maximise efficiency, effectiveness, and compatibility, and ultimately enable innovative PPP model implementation.

1.3 IMPORTANCE AND INNOVATION

The study's importance lies in offering empirical evidence to support the selection of the most suitable PPP model for SSID projects in Sri Lanka, informing policy and practice in the infrastructure sector for more efficient, effective, and sustainable projects. The research's innovation stems from its focus on tailoring recommendations to Sri Lanka's specific context, considering unique political, economic, and social factors affecting PPP implementation in SSID.

1.4 RESEARCH AIM AND OBJECTIVES

The aim of this research is to provide a comprehensive comparison of Private Finance Initiative (PFI), Build-Operate-Transfer (BOT), and Joint Venture (JV) models for Small-Scale Infrastructure Development (SSID) in Sri Lanka and devise innovative, tailored recommendations to maximise efficiency, effectiveness, and compatibility.

To achieve this aim, the following objectives was pursued: [1] To systematically examine the key features, benefits, and limitations of PFI, BOT, and JV models in the context of SSID, [2] To assess the compatibility of PFI, BOT, and JV models with SSID in Sri Lanka, focusing on financing approaches, stakeholder engagement, and other critical success factors, [3] To identify the most appropriate model among PFI, BOT, and JV for SSID in Sri Lanka by considering empirical evidence and contextual factors and [4] To formulate novel, customised recommendations for optimising the selected model's efficiency, effectiveness, and compatibility with SSID in Sri Lanka, with the aim of informing policy and practice.

Through these objectives, this research will contribute to the understanding of PPP models and their suitability for SSID projects in Sri Lanka and provide practical recommendations for policymakers and stakeholders to enhance the effectiveness of these models.

2. LITERATURE REVIEW

2.1 PUBLIC-PRIVATE PARTNERSHIPS (PPP) IN INFRASTRUCTURE DEVELOPMENT

PPP models have gained popularity as an alternative to traditional public procurement methods for global infrastructure development (Akomea-Frimpong et al., 2021; Almeile et al., 2022b). Involving public and private sectors, PPPs collaborate on financing, designing, constructing, operating, and maintaining infrastructure projects (Debela, 2021; Natalia et al., 2021). Characterised by risk-sharing arrangements, PPPs allocate risks and rewards to the party best equipped to manage them (Buzzetto & Monteiro de Carvalho, 2022; Osei-Kyei et al., 2022), differentiating them from traditional public procurement models (Deng et al., 2021).

2.2 DEFINITION, PRINCIPLES, AND RATIONALE

PPPs are contractual agreements between public and private entities, detailing their roles and responsibilities in infrastructure asset development (Opawole & Jagboro, 2018). Key principles include clear risk allocation, private sector incentives for efficiency and cost-effectiveness, and long-term value for money for the public sector (Chou & Pramudawardhani, 2015; Osei-Kyei & Chan, 2015). Preferred for infrastructure development, PPPs leverage private sector expertise, innovation, and resources for higher quality, cost-effective, and efficiently managed assets compared to traditional public procurement models (Kandawinna et al., 2022; Li et al., 2005a). PPPs can also reduce the burden on public finances by having the private sector contribute significantly to capital investment (Akomea-Frimpong et al., 2021; Kim et al., 2021; Li et al., 2005b).

2.3 DIFFERENT TYPES OF PUBLIC-PRIVATE PARTNERSHIPS AND THEIR FUNCTION IN INFRASTRUCTURE DEVELOPMENT

Public-Private Partnerships (PPPs) encompass various models that facilitate collaboration between the public and private sectors in infrastructure development (Kwak et al., 2009; Osei-Kyei & Chan, 2018; Robert & Albert, 2021; Rohman, 2021). Understanding the different types of PPPs and their functions is crucial for effective decision-making in project selection and implementation (Ametepey et al., 2020; Dabarera et al., 2019; Opawole & Jagboro, 2018; Yuan et al., 2009). Table 1 provides a summary of the PPP types, and detailed descriptions, enabling a clearer understanding of their respective roles and characteristics.

Table 1: Different types of PPP and their functions in infrastructure development

Source	PPP type and function
Opawole and Jagboro (2018); Kumaraswamy and Zhang (2001); Ranjith Bala (2011)	BOT (Build-Operate-Transfer) - The private partner is primarily responsible for designing and constructing the infrastructure. After completion, they operate and maintain it for a specified period before transferring ownership to the public sector. The BOT model allows private sector efficiency and innovation in both construction and operation phases.

Grimsey and Lewis (2002); Higgins and Huque (2015)	JV (Joint Venture) - The public and private sectors form a partnership to finance, design, and build the infrastructure. This model combines the expertise and resources of both sectors, allowing for shared ownership, decision-making, and risk management. Joint ventures promote collaboration and mutual benefit between the public and private sectors.
Akomea-Frimpong et al. (2021); Fleta-Asín et al. (2019); Song et al. (2019)	BOO (Build-Own-Operate) - The private partner designs, constructs, owns, and operates the infrastructure. They assume responsibility for the entire life cycle of the asset, including financing, operation, and maintenance. The BOO model offers the private sector the opportunity for long-term revenue generation and asset ownership.
Almeile et al. (2022b); Debela (2021); Robert and Albert (2017)	LDO (Lease-Develop-Operate) - The private partner leases the land, develops the infrastructure, and operates it for a specific period. This model allows the private sector to utilise public land and resources while assuming responsibility for the development, operation, and maintenance of the infrastructure.
Deng et al. (2021); Froud (2003); Li et al. (2005a)	PFI (Private Finance Initiative) - The private sector provides funding for the project and assumes responsibility for designing, building, financing, and operating the infrastructure. The public sector makes payments to the private partner over the project's lifecycle.
Babatunde et al. (2015); McCarthy and Robert (1991); Rohman (2021)	Concession - The private sector receives the right to finance, construct, and operate the infrastructure for a specific period in exchange for user fees or other revenue streams. Concessions transfer both the financial and operational risks to the private sector.
Almeile et al. (2022a); Dabarera et al. (2019); Robert and Albert (2021)	DBFO (Design-Build-Finance-Operate) - The private partner is responsible for designing, building, financing, and operating the infrastructure. They undertake the project's entire life cycle and are reimbursed through user fees or other revenue streams. This model provides the private sector with control over all project stages and financial returns.
Higgins and Huque (2015); Kim et al. (2021); Xiaohua and Hemanta (2008)	O&M Contracts (Operation and Maintenance Contracts) - The private sector is contracted to manage and maintain the infrastructure, ensuring its effective operation. O&M contracts typically cover a specific period and require the private partner to meet performance targets and service level agreements. This model allows the public sector to leverage the private sector's expertise in infrastructure management.
Dykes et al. (2020); Manik (2021); Wang et al. (2020)	PBC (Performance-Based Contracts) - The private sector is engaged to deliver specified performance outcomes, with payments based on meeting predefined performance targets. PBCs incentivise the private partner to achieve optimal performance, quality, and efficiency in delivering infrastructure services. This model aligns the private partner's compensation with the desired project outcomes and performance levels.

Table 1 provides a comprehensive overview of various PPP models and their roles in infrastructure development. Through the examination of relevant PPP types and descriptions, valuable insights are gained regarding the unique characteristics and responsibilities of each model. The diverse range of PPP models, including Design & Construction, Ownership & Operation, Financing, and Performance & Management, cater to specific project needs and facilitate private sector involvement throughout the infrastructure life cycle. The selection of the PFI, BOT, and JV models in this study is based on their prominence, relevance, and potential to address the specific challenges and requirements of SSID projects in Sri Lanka. These models offer a comprehensive representation of different PPP approaches, enabling a thorough comparative analysis within the scope of this research.

2.4 COMPARATIVE ANALYSIS OF PFI, BOT, AND JV MODELS

Public-Private Partnerships (PPPs) play a crucial role in facilitating collaboration between the public and private sectors for infrastructure development (Kwak et al., 2009; Osei-Kyei & Chan, 2018; Robert & Albert, 2021; Rohman, 2021). By examining the financing approach, stakeholder engagement, risk allocation, decision-making, and critical success factors, stakeholders can effectively assess and select the most suitable model for their specific projects (Fleta-Asín et al., 2019; Appuhami & Perera, 2016; Ranjith Bala, 2011). Table 2 provides a comparative analysis of the PFI, BOT, and JV models in the context of small-scale infrastructure development.

Table 2: Comparative analysis of PFI, BOT, and JV models for SSID

Features	PFI	BOT	JV
Financing Approach	Private sector financing (Almeile et al., 2022b).	Combination of public and private sector financing (Gross, 2010).	Combination of public and private sector financing (Jokar et al., 2021).
Stakeholder Engagement	Limited stakeholder engagement (Osei-Kyei & Chan, 2018).	Moderate stakeholder engagement (Almeile et al., 2022a).	High stakeholder engagement (Almeile et al., 2022b).
Risk Allocation	Reduced risk to the public sector (Babatunde et al., 2015).	Risk transfer to the private sector (Babatunde et al., 2015).	Shared ownership and risk allocation (Babatunde et al., 2015).
Decision-making	Limited involvement of stakeholders (Ametepey et al., 2020).	Moderate involvement of stakeholders (Gross, 2010).	Shared decision-making and collaboration (Osei-Kyei & Chan, 2018).
Critical Success Factors	Long-term funding and reduced risk (Fleta-Asín et al., 2019).	Balanced risk sharing and financing (Appuhami & Perera, 2016).	Shared ownership, risk management, and decision-making (Ranjith Bala, 2011).

The evaluation highlights the distinguishing features of each model, including financing approaches, stakeholder engagement, risk allocation, decision-making, and critical success factors. The PFI model offers private sector financing with reduced risk to the public sector, albeit with limited stakeholder engagement. The BOT model involves a combination of public and private sector financing, with moderate stakeholder engagement and shared risk allocation. The JV model emphasises shared ownership, decision-making, and risk management, presenting a higher potential for stakeholder engagement.

2.5 COMPARISON OF THE PFI, BOT, AND JV MODELS FOR SSID IN SRI LANKA

When considering the suitability of the PFI, BOT, and JV models for SSID in Sri Lanka, several factors need to be taken into account, including financing approaches, stakeholder engagement, and critical success factors and challenges (Akomea-Frimpong et al., 2021; Dabarera et al., 2019; Kandawinna et al., 2022). The table 3 summarises the key aspects of comparison:

Table 3: A comparison of the PFI, BOT, and JV models for SSID in Sri Lanka

Aspect	PFI	BOT	JV
Financing Approach & Flexibility	Relies heavily on private sector financing. Limited flexibility in financing (Dabarera et al., 2019).	Involves a combination of private and public sector financing. Greater flexibility in financing arrangements (Weththasinghe et al., 2016).	Can involve shared financing from both the public and private sectors. Greater flexibility in financing arrangements (Dabarera et al., 2019).
Stakeholder Engagement	Limited stakeholder engagement and accessibility (Deepika et al., 2018).	Moderate stakeholder engagement and involvement (Appuhami et al., 2011).	Potential for enhanced stakeholder engagement and collaboration (Kim et al., 2019).
Risk Allocation	Provides reduced risk to the public sector (Ranjith Bala, 2011).	Involves risk transfer to the private sector (Ranjith Bala, 2011).	Shared ownership and risk allocation (Dabarera et al., 2019).
Critical Success Factors	Long-term funding and reduced risk for the public sector (Fernando & Nanayakkara, 2020).	Balanced risk sharing, financing, and decision-making (Appuhami et al., 2011).	Shared ownership, decision-making, and risk management (Dabarera et al., 2019).

The evaluation encompasses financing, stakeholder engagement, risk allocation, and critical success factors. PFI utilises private sector financing with limited flexibility, while BOT combines private and public sector financing for greater flexibility. The JV model involves shared financing and offers flexibility. PFI demonstrates limited stakeholder engagement, while BOT exhibits moderate engagement. The JV model enhances stakeholder engagement and collaboration. PFI reduces risk for the public sector, BOT transfers risk to the private sector, and JV emphasises shared ownership and risk allocation. Critical success factors differ across the PFI, BOT, and JV models. PFI prioritises long-term funding and reduced risk, BOT emphasises balanced risk sharing and financing, and JV highlights shared ownership, decision-making, and risk management.

3. METHODOLOGY

3.1 RESEARCH PARADIGM, PHILOSOPHY, STRATEGY AND DESIGN

This study adopts a pragmatic research paradigm, which allows for the use of various research methodologies and methods to effectively address the research question. The research philosophy guiding this study is pragmatism, emphasising the practical application of knowledge and problem-solving. A mixed-methods approach is employed, combining both qualitative and quantitative research methods. The study utilises a sequential explanatory design, where quantitative data is collected and analysed first through questionnaires, followed by qualitative data collection and analysis using semi-structured interviews to provide an in-depth understanding of the research problem.

3.2 POPULATION, SAMPLING, AND DATA COLLECTION

The population of this study includes infrastructure projects in Sri Lanka that have adopted PPP models. A purposive sampling technique is employed to select a representative sample of projects involving PFI, BOT, and JV models. Questionnaires are administered to key stakeholders, including government officials, private sector representatives, and local community members. Semi-structured interviews are conducted with senior industry professionals to validate questionnaire outcomes and gain additional insights. Secondary data is sourced from project documents, government reports, academic literature, and relevant databases.

3.3 DATA ANALYSIS

Data analysis involves both qualitative and quantitative methods. Descriptive and inferential statistics are used for quantitative analysis to identify patterns and relationships between PPP model variables. Qualitative analysis includes thematic coding and content analysis to uncover themes, patterns, and insights from interview transcripts and secondary data sources. The triangulation of qualitative and quantitative findings ensures a comprehensive understanding of the research problem.

3.4 ETHICAL CONSIDERATIONS AND TRUSTWORTHINESS OF THE STUDY

Ethical considerations are addressed throughout the research process. Informed consent forms are provided to participants, and necessary ethical approvals are obtained from the relevant institutional review board before data collection. By incorporating these changes, the methodology section provides a concise overview of the research paradigm, philosophy, strategy, design, sampling, data collection, data analysis, and ethical considerations, while maintaining clarity and coherence.

4. RESULTS AND ANALYSIS

This section provides an analysis of the study's results, including the demographic profile of the sample, the key features, benefits, and limitations of PFI, BOT, and JV models, and their compatibility with SSID in Sri Lanka. The section concludes with recommendations for optimising the selected model's efficiency, effectiveness, and compatibility with SSID in Sri Lanka.

4.1 DEMOGRAPHIC PROFILE OF THE SAMPLE

The study's sample of 100 diverse participants was primarily aged 35-44 (50%), with a moderately positive skew (coefficient of skewness: 0.648). The gender distribution was balanced (40% male, 58% female), and most participants held a bachelor's degree (34%). They were affiliated with professions in infrastructure development, project management, and finance, with common affiliations being the Institute of Quantity Surveyors Sri Lanka (31%) and the Institute of Engineers Sri Lanka (21%). Respondents were primarily full-time employees in government/public administration (30%) or the private sector (45%), with top professions being quantity surveyor (25%) and government official (22%). Participants represented all Sri Lankan provinces, predominantly Eastern (18%) and Western (19%) Provinces.

4.2 KEY FEATURES, BENEFITS, AND LIMITATIONS OF PFI, BOT, AND JV MODELS

Regarding the key features, benefits, and limitations of PFI, BOT, and JV models, the study found that: [1] PFI: Key features include off-balance-sheet financing and long-term contracts. Benefits include lower initial public investment and reduced public sector risk. Limitations include less public control and less risk-sharing between the public and private sectors. [2] BOT: Key features include a time-bound concession and risk sharing between the public and private sectors. Benefits include lower public sector risk and better cost control. Limitations include the possibility of higher project costs and a focus on short-term returns. [3] JV: Key features include shared ownership and decision-making. Benefits include stronger collaboration, resource pooling, and shared risks. Limitations include potential conflicts of interest and higher complexity in management.

Qualitative outcome: The qualitative outcomes are consistent with the quantitative outcomes in identifying the key features, benefits, and limitations of PFI, BOT, and JV models. Specifically: [1] PFI: Key features include long-term contracts and private sector involvement. Benefits include reduced public sector risk and improved project delivery. Limitations include limited risk sharing and higher reliance on the private sector. [2] BOT: Key features include long-term contracts and balanced risk sharing. Benefits include lower public sector risk and better cost control. Limitations include possible higher project costs and a focus on short-term returns. [3] JV: Key features include shared ownership and synergistic collaboration. Benefits include resource pooling, shared risks, and benefits. Limitations include potential conflicts of interest and higher complexity in management.

Overall, the key features, benefits, and limitations of PFI, BOT, and JV models highlight the differences among the models in terms of risk sharing, collaboration, and management complexity, which are important factors to consider when examining their suitability for SSID projects.

4.3 COMPATIBILITY OF PFI, BOT, AND JV MODELS WITH SSID IN SRI LANKA

Quantitative outcomes reveal uneven age group distribution, potentially affecting result generalisability. The study found: [1] PFI is moderately compatible with SSID due to long-term financing and risk management needs, but limited stakeholder engagement and lower priority for local capacity building. [2] BOT is highly compatible with SSID, balancing risk sharing, long-term financing, and addressing critical success factors like local capacity building and technology transfer. [3] JV is highly compatible with SSID, enabling shared financing, risk management, strong stakeholder engagement, and prioritising critical success factors.

Qualitative outcomes support quantitative findings, showing PFI's moderate compatibility, and BOT and JV's high compatibility with SSID in Sri Lanka due to financing approaches, stakeholder engagement, and prioritisation of critical success factors.

The analysis suggests BOT and JV models are better suited for Sri Lanka's SSID than PFI, considering empirical evidence and contextual factors, as they promote balanced stakeholder engagement, risk sharing, and address critical success factors.

4.4 MOST APPROPRIATE MODEL FOR SSID IN SRI LANKA

Regarding the most appropriate model for SSID in Sri Lanka, the study found that: [1] PFI: Based on empirical evidence and contextual factors, PFI may not be the most appropriate model for SSID in Sri Lanka, as it has limited stakeholder engagement, and may not prioritise other critical success factors. [2] BOT: Empirical evidence and contextual factors suggest that the BOT model may be suitable for SSID in Sri Lanka, given its balanced risk sharing, long-term financing, and inclusion of both public and private sectors in decision-making processes. [3] JV: The JV model may also be an appropriate model for SSID in Sri Lanka, considering empirical evidence and contextual factors. It encourages shared financing, risk management, and strong stakeholder engagement due to shared ownership and decision-making.

Qualitative outcome: The qualitative outcomes align with the quantitative outcomes in evaluating the most appropriate model for SSID in Sri Lanka. Specifically: [1] PFI: Considering the empirical evidence and contextual factors, PFI may not be the most suitable model for SSID in Sri Lanka, as it has limited stakeholder engagement and may not prioritise other critical success factors. [2] BOT: Empirical evidence and contextual factors suggest that the BOT model could be an appropriate option for SSID in Sri Lanka, with balanced risk sharing, long-term financing, and involvement of both public and private sectors in the decision-making process. [3] JV: The JV model may also be a suitable choice for SSID in Sri Lanka, based on empirical evidence and contextual factors. It enables shared financing, risk management, and robust stakeholder engagement due to shared ownership and decision-making.

Based on the analysis, the BOT and JV models appear to be more appropriate for SSID in Sri Lanka than the PFI model. Both models promote balanced stakeholder engagement, risk sharing, and address critical success factors.

4.5 RECOMMENDATIONS FOR OPTIMISING THE SELECTED MODEL

Regarding recommendations for optimising the selected model, the study suggests the following: [1] PFI: If PFI were selected, recommendations could include improving stakeholder engagement and prioritising critical success factors in decision-making processes to enhance its compatibility with SSID in Sri Lanka. [2] BOT: If the BOT model were selected, recommendations might focus on strengthening public-private collaboration, ensuring transparent and fair risk allocation, and promoting long-term financing for SSID projects in Sri Lanka. [3] JV: If the JV model were selected, recommendations could include fostering a collaborative environment for shared ownership, decision-making, and risk management, as well as facilitating stakeholder engagement to optimise SSID in Sri Lanka.

The recommendations aim to inform policy and practice, ensuring that the selected model aligns with the unique needs and conditions of SSID projects in the country.

5. DISCUSSION AND RECOMMENDATIONS

5.1 INTERPRETATION AND IMPLICATIONS FOR POLICY & PRACTICE

Section 4 demonstrates that BOT and JV approaches are superior to PFI for Sri Lankan SSID projects. BOT and JV models strike a balance between stakeholder participation, risk allocation, and crucial success factors. PFI provides long-term funding and reduced risk to the public sector, but it fails to engage stakeholders and prioritise essential success criteria. Thus, SSID policymakers and practitioners in Sri Lanka should favour BOT and JV models. These solutions accomplish risk sharing, long-term financing, and stakeholder participation, all of which are necessary for successful infrastructure development. Notwithstanding its strengths, the PFI model's limited stakeholder engagement and neglect of other crucial success factors may render it inappropriate.

5.2 RECOMMENDATIONS FOR ENHANCING THE SELECTED MODELS FOR SSID IN SRI LANKA

BOT Model: [1] Boost public-private collaboration for inclusive decision-making and improved outcomes. [2] Establish transparent, fair risk allocation framework with equitable sharing of responsibilities. [3] Promote long-term financing options, such as low-interest loans or development bank assistance.

JV Model: [1] Encourage shared ownership, decision-making, and risk management in a collaborative environment. [2] Facilitate stakeholder engagement, including local communities, to meet needs and expectations. [3] Build local capacity in infrastructure development, project management, and finance to enhance SSID project success.

5.3 LIMITATIONS OF THE STUDY AND FUTURE RESEARCH DIRECTIONS

The study has some limitations, primarily in the demographic profile of the sample, which may affect the generalisability of the results. Further research is needed to validate these findings with a more diverse and representative sample. Additionally, future studies can explore alternative financing models, such as crowdfunding and green bonds, and investigate the role of emerging technologies, like blockchain and artificial intelligence, in SSID in Sri Lanka.

6. CONCLUSIONS

6.1 SYNTHESIS OF KEY FINDINGS AND CONTRIBUTIONS

The study reveals that BOT and JV models are better suited for SSID in Sri Lanka compared to the PFI model, offering improved stakeholder engagement, balanced risk sharing, and long-term financing. Key findings: [1] PFI has limitations in engagement and risk sharing; [2] BOT and JV are highly compatible with SSID, while PFI is moderately compatible; [3] The BOT model is the most appropriate for SSID due to its balanced risk sharing, financing, and decision-making inclusivity; [4] The BOT model aligns with critical success factors, optimising efficiency and compatibility of SSID projects in Sri Lanka when combined with proposed recommendations.

The findings contribute to the understanding of infrastructure financing models and their suitability for SSID in Sri Lanka. By providing evidence-based recommendations, the study informs policy and practice, ensuring that SSID projects align with the unique needs and conditions of the country.

6.2 FUTURE RESEARCH OPPORTUNITIES AND FINAL REMARKS

Future research can explore alternative financing models and the role of emerging technologies in SSID in Sri Lanka. As the country's infrastructure needs continue to evolve, innovative approaches and models will be essential for sustainable and inclusive development.

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STRATEGIES TO CREATE AN ENABLING ENVIRONMENT FOR PUBLIC PRIVATE PARTNERSHIP (PPP) PROJECTS IN SRI LANKA

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ABSTRACT

Public Private Partnership (PPP) projects have become a proven method of infrastructure procurement to achieve higher rate of economic growth in the most developing countries. However, researches carried out in similar fields have identified that lack of enabling environments hinder implementation of PPPs. Thus, the purpose of this paper is to propose strategies to create enabling environments for PPP projects in Sri Lanka. Nineteen semi-structured interviews were conducted to ascertain viewpoints of experienced professionals in fields of strategic planning and PPPs. The collected data was analysed using content analysis techniques. It was revealed that creation of a national PPP policy, establishment of a national PPP unit, creation of a private sector infrastructure development fund and making necessary legislative amendments as key strategies to create an enabling environment for PPPs in any developing nation. This research gives a significant basis of long term and short-term strategies that have to be made in five fronts of policy, legal, institutional, financial and communication frameworks for enabling PPPs. The proposed strategic outline is probable to implement, however, it requires a detailed study and further validation prior implementation.

Keywords: *Enabling Environment; Infrastructure Procurement; Public Private Partnerships; Sri Lanka.*

1. INTRODUCTION

Public Private Partnership (PPP) implies a course of action between government and private sector to deliver high quality projects with an effective risk transferring mechanism to overcome budgetary constraints (Debela, 2022; Yuan et al., 2010). PPPs present a framework that, while engaging the private sector, acknowledge and structure the role for government in ensuring that social obligations are met and successful sector reforms and public investments achieved (Asian Development Bank, [ADB], 2008). It

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was confirmed that PPPs can deliver better value for money than other alternatives, where it was applied for an appropriate project (Alshahrani et al., 2023; Edwards & Shaul, 2003; Spiering & Dewulf, 2006). Moreover, PPPs practically provides a collaboration of different entities as shareholders with different interests and expectations (Grimsey & Lewis, 2004). Therefore, the Ministry of Finance-Singapore (2012) has confirmed that PPPs provide numerous advantages for different shareholders, namely, the government, public sector and the general public.

In that perspective, PPP projects have become a proven method of infrastructure procurement. Hence, most developing countries are seeking to adopt PPPs specially to facilitate development of public infrastructure (Ke et al., 2009). However, literature findings revealed many issues in the current practices that could limit the use of PPPs and could also lead to inefficient and unsuccessful projects. Implementing PPPs in Sri Lanka has a long history in its development of infrastructure. Central Bank of Sri Lanka (2011) stated that "State Owned Enterprises (SOEs) were expected to explore innovative PPP strategies and attract private investment to catalyse infrastructure development process" (p.60). Nevertheless, Sri Lanka had tried to establish PPP projects since early 1990's, yet did not receive effective results (Shanika, 2012). As Kelegama (1999) further stated, a majority of developing countries have discouraged PPP experiences after having embarked on ambitious PPP projects without initially having a proper legal and regulatory framework in place. As mentioned by Madawala (2006), absence of a stable political and macro-economic environment, lack of basic legal structure, poor institutional and regulatory framework and weak risk management strategies can be identified as most important aspects hindering PPP implementation in most of the developing countries. Hence, establishing a strategic outline for PPPs is vital to encourage private equity holders and to effectively execute PPP projects (Borgstrom, 2008). Thus, this study is intended to propose strategic outline to create an enabling environment for PPP projects in Sri Lanka. Accordingly, as the initial step, this study identified impediments for PPPs in Sri Lanka. Then, the strategic measures that have to be taken in order to mainstream PPPs as a viable procurement method were identified and proposed a strategic outline to setup an enabling environment for PPPs in Sri Lanka. The scope of study was limited to strategic level changes that have to be made in five fronts of policy, legal, fiscal, institutional and communication frameworks of PPP implementation.

2. LITERTAURE REVIEW

2.1 ENABLING SUCCESSFUL IMPLEMENTATION OF PPPS

Worldwide experience has demonstrated that successful implementation of a PPP program requires an enabling environment to be in place in order that PPP projects may be implemented effectively and with maximum benefits to the public sector. In the opinion of Cloverson and Perera (2012), global approach to PPP is driven by contextual differences and priorities at national level, which contribute to divergence on institutional structures and legislative approaches across jurisdictions. Accordingly, there is no exact formula to establish a proper enabling environment for PPPs, hence, countries will have to observe capacities and constraints appropriately to check whether existing legislations, bureaucracy, institutional frameworks and public attitude is favourable for PPPs. On the contrary, ADB (2008) identified five requirements to be fulfilled in order to successfully execute PPP projects. Accordingly, a legal framework complimentary on PPPs, supportive political leadership, a dedicated national PPP unit, public and environmental preparation and a well proven risk allocation method were prerequisites of effective PPP projects. A review of literature by several other academics and institutions (Cheung et al, 2010; Li et al, 2005; Ministry of Finance-India, 2012) also indicate that similar requirements shall be met before PPPs can be implemented successfully.

Research on critical factors affecting implementation of PPPs in Hong Kong, Australia and United Kingdom by Cheung et al. (2010) revealed that PPP practitioners of Hong Kong highly value existence of a good legal framework, while PPP practitioners of other two countries considered it as a criterion with medium importance. Accordingly, if a country is not matured in PPP context, it is important to establish a PPP complementary legal framework to achieve success. Further, establishment of a dedicated PPP unit is seen as one such important mechanism by which governments can define, regulate and build public sector capacity with regards to PPPs (Cloverson & Perera, 2012; Kukah et al., 2023). Organisation for Economic Co-operation and Development (2010) identified that the dedicated PPP units as institutions set up with full or partial aid of government with all skills required. Further to the organisation, financial model must be flexible enough to accommodate a range of variables, allowing for an iterative process between financial modelling and PPP design. A key objective will be to ensure financial sustainability of a utility through efficiency gains and balancing of income and expenses (Zhang, 2005). Although they are methodologically sound; privatisation, PPP or private sector involvement in infrastructure programmes might fail if implementing agency does not pay much attention on trends of socio-economic environment and importance of public awareness. Moreover, policy and economic reforms succeed if stakeholders understand the necessity and effects of such initiatives.

2.2 OUTLINING ASPECTS FOR ENABLING PPP PROJECTS IN SRI LANKA

In Sri Lanka, as stated by Appuhami et al. (2011), adoption of PPP policy in Sri Lanka had been lagging due to various issues, such as lack of effective institutional structures, lack of political support, financial constraints etc. As Kelegama (1999) stated, Sri Lanka has a discouraging PPP experience after having embarked on ambitious PPP projects, without first having a proper legal and regulatory framework in place. As mentioned by Madawala (2006), absence of a stable political and macro-economic environment, lack of basic legal structures, poor institutional and regulatory framework, and weak risk management strategies were identified as most important factors hindering PPP implementation in Sri Lanka. Further, the public opposition, lack of confidence and distrust in the private sector and the higher charges to the end user has been influenced on the PPP implementation in Sri Lanka (Weththasinghe et al., 2016). As Weththasinghe et al., (2016) further found in their recent study, absence of proper PPP legal regime/ institutional framework and weakness in enabling policy and regulatory frameworks has become also become a critical issue in the Sri Lankan industry. Hence, lack of public sector project development funds, difficulties in obtaining long-term finance, conflicts of interest, corruption, unfavourable economic, and commercial conditions and constraints of local finance markets were identified as the economic barriers restricting the proper implementation of PPP in Sri Lanka. However, establishing a National Agency for Public Private Partnership and implementing a National Procurement guide for infrastructure projects in Sri Lanka has been identified as key initiatives in recent past (Ministry of Finance - Sri Lanka, 2017). Indeed, initiating strategic level changes which were proposed in line with the status of PPPs in Sri Lanka may create an enabling environment for PPPs in developing countries, especially to encourage private equity holders and to effectively execute PPP projects.

3. RESEARCH METHODOLOGY

The selection of relevant research approach is based on the type of research problem or problem being addressed (Creswell, 2014). The aim of this study is to identify measures that can be taken to prepare an enabling environment for public private partnership projects in Sri Lanka, thus qualitative research approach was selected. Accordingly, a comprehensive literature review was carried out to find out impediments for PPPs in Sri Lanka as well as to identify measures taken globally to overcome similar impediments. The qualitative approach focuses on interpretation and description which might lead to developing novel theories or concepts to evaluate an organisational process (Hancock et al., 2009). Under the qualitative approach, semi-structured interviews were conducted to collect the data. As Yin (2009) pointed out that, there are six sources of data collection can be identified under qualitative research, namely documents, archival records, interviews, direct observations, participant observation and physical artifacts. Among these techniques, interview was selected as the most reasonable data collection technique because it appears to be guided conversations rather than structured queries. Noor (2008) further stated that, semi-structured interview rather than structured interview enables sufficient flexibility to approach different respondents differently while still covering the same areas of data collection. Further, it enables to adapt the questions necessary, clarify doubts and ensure that the response is properly understood by repeating and rephrasing the questions. Proving appropriateness of collecting data on strategic measures related to PPPs, nineteen (19) semi structured interviews were conducted with experts of PPPs in Sri Lanka. Consequently, managerial level personnel of those institutions who have involved in delivering PPPs, such as policy makers, project financing officials and legal experts. The profile of interviews is given in Table 1.

Table 1: Profile of the interviewees

Sector	Expert Code	Years of Experience	Brief of Experience (Project Involved/Roles & Duties)
Government	GE1	8 years	Involved in Colombo Katunayake Expressway project
	GE2	15 years	Involved in Norochcholai Coal Power Plant
	GE3	9 years	Deputy Secretary
	GE4	10 years	Director
	GE5	10 years	Involved in Colombo Katunayake Expressway project
Private investor	PE6	30 years	Involved in Colombo Katunayake Expressway project
	PE7	15 years	Involved in Colombo Katunayake Expressway project
	PE8	15 years	Insurance company
	PE9	8 years	Private investor
	PE10	7 years	Insurance company
	PE11	12 years	Private investor

Sector	Expert Code	Years of Experience	Brief of Experience (Project Involved/Roles & Duties)
	PE12	15 years	Private investor
Donor agency	DE13	20 years	Fund officer
	DE14	25 years	Evaluator
	DE15	6 years	Coordinator
Banking sector	BE16	8 years	Manager
	BE17	12 years	Bank Officer
	BE18	7 years	Bank Officer
	BE19	8 years	Officer

The interview guideline was developed incorporating five major requirements of PPPs identified by literature survey. With the consent of interviewees, interviews were audio-recorded to secure an accurate account of conversations and avoid losing data since everything cannot be written down during an interview. The content analysis technique was adapted to analyse the data. Code-based content analysis technique was used to analyse the data using QSR.NVivo. Version 7 (Copyright © 2007 QSR International Pty Ltd) software. Coding structure was prepared focusing mainly on five fronts namely; policy framework, legal framework, institutional framework, financial framework and communication framework. The analysis was done by identifying probable strategies under each front.

This research was limited to PPP projects implemented in Sri Lanka during the last 35 years. Further, a strategic outline was developed to create an enabling environment for PPPs, which may need further justification through a detailed study prior to implementation in Sri Lanka.

4. RESULTS AND DISCUSSION

This section presents the key research findings of different strategic measures justifying with related literature. Section 4.1 presents specific implications for enabling PPP projects in Sri Lanka.

4.1 STRATEGIC OUTLINE FOR CREATING AN ENABLING ENVIRONMENT FOR PPPS

Through the findings of data analysis, it was identified that strategic outline should be formulated in five fronts, namely: policy, legal, institutional, financial and communication frameworks as presented in Table 2.

Table 2: Proposed strategies

Aspect	Term	Strategy	Sector			
			Government	Private	Donor	Banking
Policy framework	Short-term	The requirement of private sector involvement in infrastructure projects	x			
		Establishing a national policy for PPPs			x	
		Having a political will or committed national leadership is a prerequisite to establish an effective policy framework			x	
	Long-term	Fiscal policy changes to encourage PPPs, such as tax structure, minimum revenue guarantee, debt guarantee and exchange rate guarantee	x			
		Create a contingent liability fund	x			
Legal	Short-term	Making amendments to existing legislations to cater PPP requirements	x	x		
		Eliminating ambiguities of various legislations and make them coherent	x		x	
		Making expressed provisions for tiered dispute resolution process in Board of Investment (BOI) Act			x	x
	Long-term	Enacting a separate PPP Act	x		x	
Institutional	Short-term	Establishing a National PPP unit in Ministry of Finance	x			
		Bringing in qualified staff and remunerate them above normal public employee pay scale	x			
		Identifying the functions of National PPP unit	x	x	x	
	Long-term	Establishing PPP cells in line ministries, provincial councils etc	x	x	x	x
Finance	Short-term	Establishing a private sector infrastructure development fund	x		x	
		Establishing a viability gap fund, such as a form of capital grant, annuity payment or a combination of both forms etc	x		x	
	Long-term	National PPP unit in collaboration with multilateral donor agencies	x	x		x
		Training for banking professionals conversant about PPPs	x	x		x
Communication	Short-term	Improving public perception immensely influences the success of a PPP project	x			
		Maintaining communication amongst project stakeholders	x		x	
	Long-term	Inter department communication channel shall be established to disseminate the knowledge and gain efficiency	x			x

4.1.1 Policy Framework

As a short-term measure to create an enabling policy environment for PPPs, the research identified that Sri Lanka should create a PPP policy. Identification of the objectives of using PPPs as a procurement system is equally important. DE14 in Donor agency expressed his view on PPP policy of Sri Lanka as: *"If you take India, they have done many successful projects with PPPs. The main reason for success is that they have a clear policy to attract private companies in infrastructure development through PPPs. Sri Lanka does not have such a policy, but in its report the Central Bank has mentioned that they encourage state owned enterprises like water board and electricity board to get private sector involved in their projects"*. However, a relatively different judgment was offered by DE13 in Donor agency; *"Policy is not the most important factor here; political willpower is the most important. What is the use of a policy if there is no support from the leadership? If the political will is there, policymaking is not a question"*.

Accordingly, enforcement of a policy is always tied to political support; hence, a PPP policy is not necessary if there is a committed leadership. In the long term, Sri Lanka requires fiscal policy changes to encourage PPPs. The research identified that application of an arbitrary fiscal policy from one project to another is viewed as a discouraging factor by PPP stakeholders. GE2 in government sector revealed his opinion on necessary fiscal policy changes to accommodate minimum revenue guarantee funds in following manner; "*commissioning a PPP will have a strain on fiscal policy; primarily because the government will have to provide a minimum revenue guarantee to the investors. A fund has to be set aside to be used if such guarantees become due"*. In that regard, the country will have to establish a contingency fund by the budget, from which unexpected payments such as lower revenue, debt default and exchange rate risks can be met with. As identified in data analysis, there should be a coherent fiscal policy which shows aspects, such as tax structure, minimum revenue guarantee, debt guarantee and exchange rate guarantee at least for solicited proposals.

4.1.2 Legal Framework

The prevalence of legislation on PPP can help attract financiers to a country by improving or clarifying legal aspects related to PPPs. The research identified that in the short term it is impractical and unnecessary to enact a separate PPP legislation. Most interviewees opine that this is not the prime opportunity to bring in a new law; however, in the long run a requirement of a specific PPP law might arise. This opinion was supported by PE7 who expressed his dissatisfaction on provisions of current legislation related to PPPs. *"If you look at Electricity Act it says that if the capacity of a private power plant is more than 25Mega Watts; more than 50% of the shares of Project Company shall be invested with the government. Then the private investor becomes a minor shareholder of the project company. With that we have to face many regulations"*. In line with majority of interviewees, the researcher believes that amendments to existing legislation will be sufficient to address short term legal barriers on PPPs. Further, due to complexity of PPP agreements and involvement of plethora of parties, disputes are inevitable. As long-term strategies, DE15 highlighted that Sri Lanka may require a separate PPP Act to integrate fragmented provisions in different legislations related to PPPs. A separate PPP legislation will demonstrate clear guidelines on public procurement, implementation and further steps of project life cycle. The study conducted by Kosycarz et al. (2019) in Poland have expressed that a special team in the Ministry of Development has been established for the development of PPPs and legislative changes have been introduced. As stated by interviewees, PPP legislation can be introduced with provisions for procurement of PPPs, risk sharing among parties, grant of concessions, ownership and transfer of project assets after concession period and dispute management. Accordingly, various short term and long-term strategies, such as making amendments to existing legislations to cater PPP requirements, eliminating ambiguities of various legislation and make them coherent, making expressed provisions for tiered dispute resolution process in Board of Investment (BOI) Act and enacting a separate PPP Act, can be elaborated as stated in Table 2. As stated in key literature findings, legal framework should be given a high consideration when creating a suitable environment to PPPs. According to a study conducted by Cheung et al. (2010), the implementation of PPPs in Hong Kong, Australia, and the United Kingdom is influenced by several critical factors. The research found that PPP practitioners in Hong Kong place a high level of importance on having a strong legal framework in place, whereas practitioners in the other two countries view it as a moderately important criterion. However, the study pointed out that developing countries such as Sri Lanka should not go for new separate legislation only for PPPs due to lack of experienced and knowledgeable legislators.

4.1.3 Institutional Framework

As expressed by GE2 in government sector, identifying right functions and providing necessary authority to act on them is highly important for success of a PPP unit. *"When forming a national PPP unit, we must assign tasks that are achievable and must provide powers to work on them. If functions of such unit are to merely provide guidance, advice and knowledge dissemination, it won't be effective in Sri Lanka. PPP unit shall actively participate in promoting PPPs, rather than being just a consultant".* As a short-term strategic measure, it was identified that it is important to establish a national PPP unit under an authorised ministry. The study conducted by Neto et al. (2020) have focused on increase the efficiency of PPP units in Brazil which explains the existence for PPP units for the proper implementation of PPP projects. The functions of such unit shall be to develop a PPP policy, identify potential PPP projects, funding/managing feasibility studies, preparation of solicited proposals, marketing proposals, calling for bids, negotiation with private partner and concluding the deal and to act as a resource centre for PPPs. Accordingly, four proposals were developed to locate the national PPP unit and locating it within the Ministry of Finance was identified as the best way by majority of experts. Additionally, this research identified that proposed national PPP unit shall be staffed with people experienced in PPPs. As long-term measures, when experience is gathered and potential of PPP projects increase; in compliance with PPP policy, the national PPP unit shall help the government agencies to establish PPP cells within them. It will enable to make a web of PPP nodes that will help each other in capacity building, knowledge sharing, and ultimately will provide synergy in overall PPP programme. As stated by Cloverson and Perera (2012), establishment of a dedicated PPP unit has been seen as one such important mechanism by which governments can define, regulate and build public sector capacity with regards to PPPs.

4.1.4 Financial Framework

This research identified that Sri Lanka lacks a financial institution that can stimulate PPP projects take-off. Although project financing is done by local banks; they are not really encouraging private sectors to invest in infrastructure. Bank loans are the most common and the main source of funds for PPP projects in China (Ngoc Linh et al., 2018). The PE7, a private investor expressed his dissatisfaction on the local commercial banks as follows; *"To do project financing for PPPs you need to do a lot of preparatory works. And it requires considerable amount of time, money and human resources. I wonder whether banks have people who can carry out risk assessment, cash flow calculation and all. You need to have specialised banks or any other kind of funding institutions to do those works. Our banks are not accustomed to do them. In my opinion the lending rates of the commercial banks are not favourable for investors. They are too high*". Thus, the researcher suggests that as a short-term strategy Sri Lanka should establish a private sector infrastructure development fund. However, it should initiate concurrently with the short-term strategies of other PPP enabling frameworks to make it real. Further, to attract private parties for such projects, it was suggested that a viability gap fund shall be established. In the view of experts, viability gap funding would either be in the form of capital grant, annuity payment or a combination of both forms. Experts from government sector, private sector as well as donor agencies identified lack of knowledgeable professionals in commercial banks as a detrimental issue to attract local debt funding to PPPs. Therefore, as a long-term measure on enhancing financial environment for PPPs, national PPP unit in collaboration with multilateral donor agencies can train and make banking professionals conversant about PPPs as stated in Table 2. The findings confirmed literature synthesis by showing the suitability of establishing a private sector infrastructure development fund in developing countries such as Sri Lanka as a short-term strategic measure whereas in the long run, private investors should be encouraged with number of facilities. Moreover, policy and economic reforms succeed if stakeholders understand the necessity and effects of such initiatives (The World Bank, 2008).

4.1.5 Communication Framework

The success of a PPP project is related to positive relationship between PPP project stakeholders themselves as well as stakeholders and civil society. A PPP project might get to a standstill at the outset if the community goes against such an initiative or if the project stakeholders do not have a good relationship. As short-term measures to counter this issue, this research identified public perception management should take an important role in PPP project development. Even if there are no genuine reasons for the public to averse to a particular PPP project, a simple misconception might be enough to create a huge uproar. As GE4 in government sector stated, *"If we consider these mini-hydro projects, most of the time a lot of resistance comes from the community. They are annoyed about the usage of water sources by private companies. If we can communicate effectively the value of such projects and their requirement, I'm sure people won't resist. That will become a requirement of high priority if we are going to use PPP procurement system for sensitive sectors such as health and education".* Hence, this research identified that PPP project implementing agency shall take the initiative to prepare a communication strategy that involves all important parties whenever they are required. Hence, short term strategies of improving public perception immensely influences the success of a PPP project and maintaining communication amongst project stakeholders can be proposed while establishing an inter department communication channel to disseminate knowledge and gain efficiencyisproposed as long term strategies as presernted at Table 2. As the key findings derived through this research, the requirement of private sector involvement in infrastructure, establishing a national policy for PPPs, having a political will or committed national leadership is prerequisite to establish an effective policy framework.

Fiscal policy changes to encourage PPPs such as tax structure, minimum revenue guarantee, debt guarantee and exchange rate guarantee and creating a contingent liability fund were identified as strategies pertaining to policy framework while making amendments to existing legislations to cater to PPP requirements, eliminating ambiguities of various legislations and making them coherent and enacting a separate PPP Act were proposed as legal strategies. Consequently, institutional, financial and communication strategies were also proposed. The outcome addressed the research problem by demonstrating a strategic outline to create an enabling environment which includes facets of policy, legal, institutional, financial and communication frameworks with both short term as well as long term measures. Further, the consideration of some strategies under the national initiatives attested that the research findings are more worth to implement in other developing countries. Thus, the proposed outline can be used as a basis to overcome existing issues that hinder implementation of PPPs in Sri Lanka, as it covers all long and short-term strategies. However, it requires a detailed study and further validation prior to implementation, as this research proposal is an outline indicating only probable strategies.

5. CONCLUSIONS

This research is about a new era on infrastructure procurement of developing country like Sri Lanka. One of the major concerns of low and middle-income countries is improvement of infrastructure to stimulate growth. In that regard, PPP projects have become an innovative method of infrastructure procurement that allows off-balance sheet infrastructure development. However, the issues in the practice hinder use of PPPs especially due to lack of legal and institutional frameworks and political backup. Specially to create and enabling environment for PPPs in developing countries, a strategic outline was proposed. PPP project implementing agency, private organisations, ministry of finance, ministry of justice, bank system and community are the major responsible parties to implement the proposed framework. As the first step, short term and long-term strategies were recognised for PPP projects in terms of policy framework, legal framework, institutional framework, financial framework, and communication framework. Among the proposed the strategies, some of them, such as ensuring private sector involvement in infrastructure, making amendments to existing legislations, making expressed provisions for, dispute resolution, establishing a national PPP unit in Ministry of Finance, identifying the functions of national PPP unit, establishing PPP cells in line ministries, provincial councils and improving public perception immensely influences the success of a PPP project etc have considered to initiate. However, further investigation is essential to assure their appropriateness to the infrastructure development in Sri Lanka. The strategies outlined may create an enabling PPP environment and still requires additional capacity to undertake PPPs in other critical sectors such as roads, water, waste, social services etc. Further, those long term and short-term strategies may create an enabling environment for PPPs in Sri Lanka, which would generate more economic and social benefits at the national and society level of implementation. However, a further validation and justification on the proposed guideline through a detailed study is exceedingly important before implementing in other developing countries.

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STRATEGIES TO IMPLEMENT LEAN MAINTENANCE CONCEPT FOR HIGH-RISE COMMERCIAL BUILDINGS IN SRI LANKA

K.K. Arasakulasooriya[1], P. Sridarran[2] and T. Sivanuja[3]

ABSTRACT

Maintenance management (MM) is an important function in managing high-rise commercial buildings. In comparison to low-rise and mid-rise structures, commercial high-rise buildings have severe maintenance management deficiencies. According to prior studies, implementing lean in maintenance is a well-known and effective strategy to improve maintenance efficiency. Thus, this study aimed to identify strategies to implement the lean maintenance concept for high-rise commercial buildings in Sri Lanka. Due to the lack of literature on building maintenance in the context of Sri Lanka, a pilot survey was carried out to establish the research problem of the study. Consequently, a comprehensive literature synthesis was conducted revealing building maintenance, lean and lean maintenance. Further, the applicability of lean maintenance in the global context of building maintenance had been reviewed. Consequently, under qualitative research methodology, a case study strategy was adopted. The findings of the study identified the experts 'perception of lean principles in building maintenance and challenges in implementing lean maintenance in commercial high-rise buildings in Sri Lanka from the selected cases. Lack of knowledge about lean, ineffective tactics, and the absence of standards, regulations, and policies are some of the major challenges to lean adoption in Sri Lanka. Then, experts who have extensive experience in both lean and maintenance were interviewed to identify strategies to address the identified challenges in commercial high-rise buildings in Sri Lanka.

Keywords: *Commercial High-Rise Buildings; Implementation Challenges; Lean Maintenance; Maintenance Management; Strategies.*

1. INTRODUCTION

Organisations concern maintenance as a crucial necessity to deliver a better-built environment to the end-users by ensuring assets and equipment are in operating condition (Mong et al., 2019). Modern maintenance practices are considered activities that contribute to an organisation's strategic objectives. According to De Silva et al. (2012), several maintenance management (MM) concerns are involved with maintaining high-rise buildings in the Sri Lankan context. To illustrate, the authors have identified, a lack of knowledge of effective maintenance strategies, no proper use of policies, schedules,

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and maintenance documents, budgetary constraints, shortfalls of IT applications, and shortage of professional staff and commitment as the main hinders of MM in local high-rise buildings. Consequently, imperfect MM practices performed in local high-rise buildings significantly impact building operability and operation costs. Lean philosophy has been recognised as one of the most successful philosophies applied across the globe, which increases the efficiency and capability of organisations (Jasiulewicz-Kaczmarek & Saniuk, 2018). It has been established that a lean thinking approach can be utilised to address issues in managing maintenance while aligning maintenance with business objectives, thus maximising profits (Davies & Greenough, 2003; Ghayebloo & Shahanaghi, 2010). According to Jasiulewicz-Kaczmarek and Saniuk (2018), lean maintenance focuses on achieving the optimum level of equipment reliability, while consuming the least amount of resources. Additionally, maintenance performance can be improved via adopting lean maintenance tools (Jasiulewicz-Kaczmarek & Saniuk, 2018; Mostafa, Lee, et al., 2015). The application of the lean maintenance concept for high-rise commercial buildings in Sri Lanka has numerous challenges, which require appropriate strategies to overcome them. This paper starts with a literature review on why lean maintenance is required for high-rise commercial buildings. Section 3 presents the research methodology. The research findings and discussion are presented in Section 4 followed by conclusions and recommendations.

2. LITERATURE REVIEW

2.1 FIVE PRINCIPLES OF LEAN

According to Womack and Jones (1996), lean thinking is the antidote to process waste which involves five basic principles as shown in Figure 1.

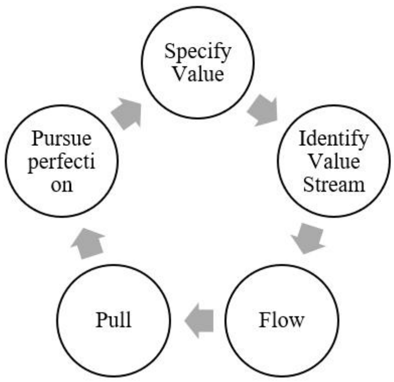

Figure 1: Five Lean Principles

The first lean principle involves defining value according to the customer, then secondly, the value stream should be identified as comprising all the actions needed to bring a product to the customer (Womack & Jones, 2003). Thirdly, value-creating steps will be arranged in a flow and fourthly customers will be let to pull the product and finally measures will be taken to achieve perfection (Womack & Jones, 2003).

2.2 LEAN MAINTENANCE TOOLS

Lean principles have not been only limited to the manufacturing industry but have also increasingly extended to other sectors as well (Bruun & Mefford, 2004; Holweg, 2007). In parallel, Womack and Jones (2003) have hypothesised that lean principles can be adopted in all organisations. Integration of lean thinking into maintenance activities via applying lean principles and tools is known as lean maintenance (Mostafa, Dumrak, et al. 2015). Non-value-adding activities within maintenance can be reduced substantially by implementing lean tools (Jasiulewicz-Kaczmarek, 2013).

A study performed in 2013 using an integrated list of lean tools in both industrial firms and the service sector shows that Total Quality Management (TQM), Just In Time (JIT), work teams and job re-engineering are the most commonly used lean tools in both sectors: work teams and job reengineering held more important than other tools in the service sector (Krishnan & Parveen, 2013). Abreu et al. (2016) have proposed a model comprising pillars to support the implementation of a lean approach in building maintenance, which is given in Figure 2.

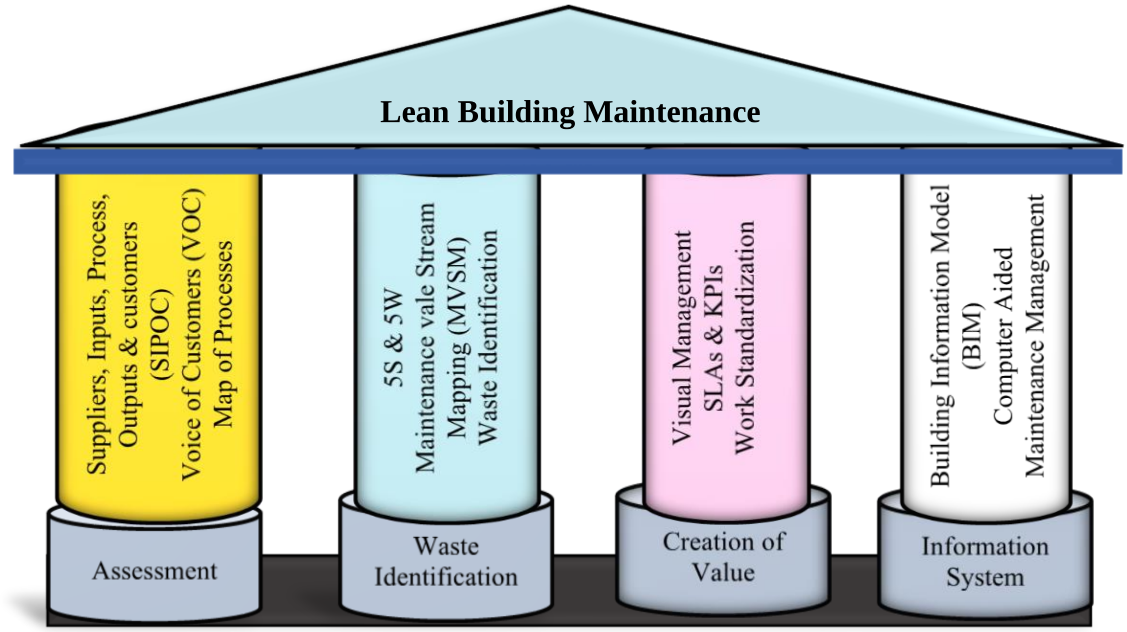

Figure 2: Pillar diagram of lean building maintenance

Source : (Abreu et al., 2016)

The pillar diagram comprises four pillars: assessment, waste identification, creation of value and information system. The first represents the identification of the value of maintenance to the end-users and then via the second pillar, it is expected to identify the available waste in maintenance operations. Subsequently, the third and fourth pillar aims to eradicate waste and enable continuous improvement.

2.3 CHALLENGES IN IMPLEMENTING LEAN MAINTENANCE IN HIGH-RISE BUILDINGS

De Silva et al. (2012) have established eight challenges of lean maintenance out of fifty-one maintainability causes associated with building maintenance in a study conducted using thirty high-rise buildings in the Colombo district as, (1) Architecture and design, (2) Materials and spare parts, (3) Structural and detailing, (4) Maintenance requirements, (5) Services integration, (6) Construction quality, (7) Accessibility, and (8) Maintenance Management. Other than MM, all the other challenges are initiated in the construction and design phase of a building, thus not plausible to address in the operational stage. Similarly, Wood (2005) states that building maintenance lacks the involvement of long-term and cost-effective strategies such as preventive and conditioned bases methods. Most of these issues hinder the optimal utilisation of resources and thus become challenging in the process of implementing lean. In addition, people resist change since they feel more comfortable and safer being in the immediate environment and fear the consequences of the change (Asnan et al., 2015). According to Almehareb and Graham-Jones (2010), a key challenge in implementing lean philosophy is the resistance from the management and the employees. In conclusion, the implementation of lean maintenance is having scores of challenges given the context of high-rise buildings.

3. RESEARCH METHODOLOGY

Due to the lack of recent research carried out for MM and maintenance practices relating to commercial high-rise buildings in the Sri Lankan context, a pilot survey was carried out by interviewing two professionals who have been engaged in MM and maintenance practices in the targeted context for more than ten years. As proven in the background study and literature synthesis, it is evident that MM in high-rise commercial buildings in Sri Lanka has not been paid enough attention and can be improved by utilising lean maintenance principles and tools. Therefore, MM practices in commercial high-rise buildings in Sri Lanka were selected as the unit of analysis for this study. A comprehensive literature review was conducted to perceive theory-based knowledge regarding the concept of lean maintenance and identify the applications of lean maintenance in building maintenance. The case study technique was used as this study's research problem necessitates a thorough investigation. Excel-based Manual content analysis is used for this study due to the smaller number of respondents and to become more familiar with the respondents' responses. Since this research is focused on the applicability of lean maintenance in commercial high-rise buildings in Sri Lanka, concluding multiple cases was mandated to conduct content analysis. Accordingly, a multiple-case design was selected and the unit of analysis, number of cases and criteria for the selection of cases were defined. Due to the Colombo district's dominance of commercial high-rise buildings relative to other districts, three cases were chosen within it. This study focuses on how lean maintenance and its tools can be applied to improve the efficiency and effectiveness of MM activities in commercial high-rise buildings in Sri Lanka, a qualitative approach would be the best suitable approach for this study. Except for two respondents with more than five years of experience, eight respondents with managerial to executive level expertise who were directly involved in maintenance operations and had more than 10 years of experience been chosen for semi-structured interviews to evaluate the viability of implementing lean maintenance in high-rise commercial buildings in the setting of Sri Lanka. Furthermore, only two specialists with experience in lean maintenance were chosen to provide strategies to overcome identified challenges from Sri Lankan high-rise commercial buildings. A cross-case analysis was used to further analyse the themes found in the manual content analysis. The data gathered from expert interviews are analysed using a qualitative data analysis technique called template analysis.

4. RESEARCH FINDINGS

Table 1 provides a brief description of the selected cases.

Table 1: Profile of the selected cases

Case Name	Description
Case A	A building with 39 floors owned by a property development company which exceeds 150 meters in height.
Case B	A private bank-owned building with 24 floors exceeding 80 meters in height.
Case C	A state bank-owned building with 33 floors exceeding 100 meters in height.

Table 2 presents a summary of the respondents selected from each building.

Table 2: Profile of selected case study respondents

Building	Respondent	Designation	Experience in High-Rise Building Maintenance
A	A1	Head of Facilities Management	10 years
	A2	Electrical supervisor	15 years
	A3	Mechanical Engineer	More than 5 years
B	B1	Assistant Manager- Facilities Management	10 years
	B2	Senior Supervisor Maintenance	More than 10 years
C	C1	Mechanical Engineer	More than 15 years
	C2	Civil Engineer	More than 12 years
	C3	Senior Supervisor - Mechanical	More than 5 years

Table 3 presents a summary of the experts selected.

Table 3: Profile of selected respondents as experts

Expert Respondent	Description
E1	Certified Total Production System & Total Management System Practitioner (Grade IV) by a leading automobile manufacturer in Japan with more than 12 years of industry experience
E2	Systems Consultant (KAIZEN, TQM, Japanese 5'S, TPM Japanese Management Practice) with 25 years of industry experience

4.1 EXPERTS' PERCEPTION OF LEAN PRINCIPLES IN BUILDING MAINTENANCE

Two experts' views on applying lean in high-rise building maintenance are discussed under the following categories. Table 4 presents a summary of the experts' responses on lean principles and respective lean tools in maintenance.

Table 4: Summary of Expert's Responses on Lean Principles Relating to Building Maintenance

Lean Principle	Lean Tools
Specify Value	Activities support achieving Total Productive Maintenance (TPM)'s major goals; Zero breakdowns, zero accidents and zero defects

Lean Principle	Lean Tools
	Voice of the customer (VOC) and Suppliers, Inputs, Process, Outputs and Customers (SIPOC)
Identify Value	Process Mapping
	Value Stream Mapping (VSM)
Flow the Value	Improve availability and eliminate waste
	Eliminate bottlenecks in the process.
Pull the value	Use Kanban and Machinery KPIs
	Centralised system to track progress
Pursuing perfection	KAIZEN
	5S

4.1.1 Specify the Value

E1 explained the first principle, specifying the value involves defining the activities that support achieving the three goals of the TPM: zero breakdowns, zero accidents and zero defects. By specifying the value, the maintenance crew can eliminate intermediate breakdowns (zero breakdowns), minimize defects (zero defects) and eliminate accidents (zero accidents). So, major KPIs from the TPM can be considered to specify the values. Lean maintenance is oriented based on TPM. Contrasting to E1, E2 said "*First, you have to identify the external and internal customers. Then we have to listen to the VOC. We can draw a SIPOC Diagram. We use SIPOC to identify customer requirements. In SIPOC we investigate customer-stated and inclined requirements*". Finally, it can be concluded that to specify value it is required to identify and define the requirements of the customers or the value they expect from doing maintenance. In concluding the experts' assertions, it can be decided that customers' value can be decided based on the SIPOC diagram, VOC and TPM goals.

4.1.2 Identify the Value

Describing the second principle, identifying the value E1 said "*To identify those value-adding activities we perform process mapping.* The maintenance team can easily identify all value-adding and non-value-adding activities by using process mapping, as well as which activities lead to zero breakdowns and zero accidents. Similarly, E2 explained that either VSM or process mapping can be utilised to identify the value. Therefore, according to both experts, VSM or process mapping can be used to identify value-adding activities.

4.1.3 Flow the Value

To flow the value, E1 stated it is required to improve the availability of both maintenance staff and machines. Further, he added *"By eliminating waste as much as possible we can improve the availability of both the staff and machines. We must always try to keep 100% availability.* Further, he highlighted there is no point in holding machinery with 70% of availability. E2 said that to flow the value, it is required to smoothen the flow of processes by eliminating bottlenecks in between processes. Thus, again to eliminate the bottlenecks it will be required to eliminate the waste in between processes. Therefore, it can be concluded that both experts have agreed on eliminating waste to flow the value.

4.1.4 Pull the Value

According to E2 to pull the value it is essential to have a central dashboard notifying the current progress of the maintenance jobs. In the fourth stage, "pull the value", the crew should create a system to pull the smoothened flow. Computerised systems are more likely to be used to show the current progress of the maintenance jobs. These systems can give insight to the maintenance crew about the completed tasks, upcoming tasks and delayed or paused tasks. According to Abreu et al. (2016), CMMS can be utilised to manage building maintenance activities. Thus, CMMS can be used to create a central dashboard and thereon pull the maintenance value-adding activities. E1 suggested to use of Kanban by citing it is utilised by Toyota to control its entire pull system. Further, he highlighted that KPIs for machinery such as OEE and Mean Time Between Failures (MTBF) can also be established to pull the value. In conclusion, it can be affirmed that to pull the value it is essential to have a centralised system for maintenance management as CMMS. Further, it is better if the same system can handle KPIs engaged with maintenance.

4.1.5 Pursuing Perfection

E1 stated that pursuing perfection means continuing improvements. Further, he illustrated the lean tool Kaizen that can be used to maintain continuous improvement. Tools such as equipment Kaizen, workplace revitalization theories, 5S Kaizen, and logistic Kaizen can be used to pursue perfection. 5S Kaizen helps to visualise the workplace how to improve effectiveness and to know how your machine is visualised, and how you can abnormalities of the machine. Logistic Kaizen helps to organise the inventory. Equipment Kaizen focuses on the internal modifications of machines. In parallel, E2 stated that 5S and Kaizen are the main tools that can be used for continuous improvement. In conclusion, Kaizen and 5S are the main lean tools that can be used to ensure continuous improvement.

4.2 IDENTIFICATION OF CHALLENGES IN IMPLEMENTING LEAN MAINTENANCE IN COMMERCIAL HIGH-RISE BUILDINGS IN SRI LANKA

Challenges identified in the literature (Refer to Section 2.4) that will be faced while implementing lean maintenance in the high-rise buildings were discussed with the interviewees to verify their existence in commercial high-rise buildings in Sri Lanka. Subsequently, the presented challenges were modified based on the interview findings and arrived at the list of challenges shown in Table 5.

Table 5: Responses on challenges in implementing lean maintenance

Theme	Category	Case A			Case B		Case C			Total
		A1	A2	A3	B1	B2	C1	C2	C3	
Identification of Challenges in implementing lean maintenance in Commercial	Ineffective Strategies	✓	✓	✓	✓	✓	✓	✓	✓	8/8
	Lack of standards and regulations	✓	✓	✓	✓	✓	✓	✓	✓	8/8
	Lack of policies	✓	✓	✓	✓	✓	✓	✓	✓	8/8
	Lack of lean knowledge	✓	✓	✓		✓	✓	✓	✓	7/8
	Poor involvement of top management	✓	✓		✓	✓	✓	✓		6/8

high-rise buildings in Sri Lanka.	Infirm feedback-collecting mechanisms	✓		✓	✓	✓	✓		✓	6/8
	Lack of technology usage	✓	✓		✓	✓	✓	✓		6/8

Above table shows that all the respondents agreed that they confront ineffective strategies, and a lack of standards, regulations, and policies. Furthermore, it was found that out of all eight respondents, only one respondent knows about lean and its applications. In addition, poor involvement of top management, infirm feedback collecting mechanisms and lack of technology usage also prevail in all the selected cases. The following subsections (4.2.1 to 4.2.7) present the derivation of the challenges shown in Table 5.

4.2.1 Poor Involvement of Top Management

Out of the eight respondents, six respondents highlighted that top management's perception of maintenance is one of the major barriers to introducing innovative strategies in maintenance. Respondents A1, A3, B1 and C2 stated that getting approval from the top management is difficult without sufficient data regarding the implementation of new procedures and systems in the maintenance sector. Generally, top management looks to the maintenance staff for financial data while the maintenance staff only keeps records and data connected to maintenance. Moreover, respondents C1 and C2 also highlighted that top management is not interested in bringing new maintenance strategies into the building since most of them are capital-intensive. All respondents affirmed that the top management does not understand the importance of maintenance upgrades and improvement required over time and they are unconfident in returns that can be gained by improving maintenance processes and systems. Thus, it is identified that introducing new strategies is hindered due to the leading decision-makers and the inability of operation managers to prove the return of the implementations.

4.2.2 Ineffective Strategies

All the respondents agreed that they currently performing preventive maintenance as the main maintenance strategy. There it was shown that only Cases A and B have adopted conditioned-based maintenance up to a certain extent whereas Case C only follows preventive maintenance and corrective maintenance. It is revealed that currently none of the cases has fully adopted cost-effective strategies such as condition-based maintenance. It will be challenging to adopt lean with traditional methods of maintenance.

4.2.3 Infirm Feedback Collecting Mechanisms

As per the statements made by respondents, it was disclosed that none of the cases has a proper mechanism to collect and record feedback on the complaints attended. Respondent A3 further explained that collected feedback is not recorded and reviewed later. Respondent A1 declared that to improve the existing feedback system they have decided to implement a help desk software that will bridge the communication between tenants and the maintenance personnel where real-time status of the tenant complaints are monitored. Since the tenants are requested to give feedback in the presence of the technicians, they are reluctant to reveal their true thoughts on the job. Moreover, respondent B2 affirmed that collected feedback is not evaluated later. Therefore, it is evident that in both cases, current feedback-collecting mechanisms are not well established and collected feedback is not reviewed. Converse to both Case A and Case B, respondent C1 stated that currently there is no feedback mechanism for maintenance.

Respondent C3 further said that no attention has been paid to post-evaluation or feedback mechanisms to assess the maintenance jobs because there are no external tenants in the building. Thus, Case C needs to be introduced with a feedback mechanism. To fine-tune, the services provided it is essential to review and evaluate feedback from the end users and customers. Without properly collecting feedback and not reviewing feedback from end-users, it is difficult to assess the customer value and the quality of the services provided. Most facilities nowadays use helpdesk software to collect feedback from customers which is very effective and less time-consuming. Thus, it is recommended to implement such a computerised mechanism to collect and review feedback from end-users.

4.2.4 Lack of Knowledge in Lean

Out of the eight respondents, seven respondents stated that they are not aware of the lean and lean maintenance concept. Respondent B1 is the only interviewee who has some theoretical knowledge of lean. Further respondent B1 stated that though he has prior knowledge of lean, he has not specifically come across lean maintenance before. Thus, it is revealed that the majority of the respondents do not know about lean. Thus, for the successful implementation of lean, it will be required to educate maintenance staff on lean, its principles, and its tools.

4.2.5 Lack of Standards and Regulations

All the respondents confirmed that for the moment, they do not follow any standard or regulation relating to maintenance. Further respondent A1 added that unlike for hotels, there are no statutory imposed regulations for high-rise building maintenance. Respondents A2 and A3 also confirmed that they do not comply with any standard or regulation relating to maintenance. Similarly, respondents C1, C2 and C3 also stated that currently, they do not comply with maintenance-related regulations or standards. Respondent B2 stated that they only adhere to health and safety guidelines in the context of maintenance. Thus, it is certain none of the cases are following or complying with standards or regulations relating to maintenance. Further, as per respondent A1's statement, it was revealed that in the Sri Lankan context, there are no statutory imposed regulations for high-rise building maintenance.

4.2.6 Lack of Policies

It was discovered that none of the cases has an explicit maintenance policy. All the respondents affirmed this. Respondents A1 highlighted that though there is no written policy for maintenance they always aim to reduce maintenance costs and reduce breakdowns as much as possible. In parallel, respondent B1 stated, *"We have no written policy, but we always focus on not having any major breakdowns that close our business"*. Respondents from case C also stated that there is no maintenance policy. Therefore, it can be concluded that none of the cases has identified maintenance aims and objectives explicitly in a maintenance policy.

4.2.7 Lack of Technology Usage

According to all the respondents currently, there is no technological advancement used in the context of maintenance. Respondent A2 mentioned that they are currently *using MS Excel, MS Project and BMS.* In parallel respondent, B1 stated, *"No, we do not use advanced software for maintenance. Our management is also not interested in investing in that kind of engineering software for maintenance"*. Respondent C1 also affirmed that currently no advanced software is used to aid maintenance processes. Further elaborating, respondent C2 added, *"No we don't use advance software. As I know some buildings use Enterprise Resource Planning software likewise, but we don't use such things. We use simple software only for maintenance job costing".* Thus, as per the statements made it is clear that none of the cases uses advanced software to improve and support maintenance activities.

4.3 IDENTIFICATION OF STRATEGIES IN IMPLEMENTING LEAN MAINTENANCE IN COMMERCIAL HIGH-RISE BUILDINGS IN SRI LANKA

Identified challenges in implementing lean maintenance in the selected cases were discussed with the two experts to obtain solutions. Both experts stressed that adopting modern technology solutions is essential to overcome most of the challenges to implement lean maintenance. Further, they stated that most organisations lack knowledge about lean and its potential. E1 mentioned that most of the time it is required to conduct awareness programmes for staff on lean and its purpose.

4.3.1 Strategies to Overcome Poor Involvement of Top Management

When pursuing novel proposals or implementations, poor top management involvement is a problem that affects all types of organisations. It is also typical for top management to evaluate new implementations in terms of their financial worth rather than the actual benefits that the maintenance team will experience from them. Both experts suggested conducting awareness programs on lean methods to increase top management's involvement in lean implementations. In addition, experts added that since top management persons are reluctant to involve in capital-intensive maintenance projects it would be better to introduce low-cost or no-cost lean suggestions as pilot projects.

4.3.2 Strategies to Overcome Ineffective Strategies

Organisation would not have any proper strategies for lean implementation as it was new for the organisation. KPIs give you the information you need to assess the performance and overall health of your company and make the necessary changes to your execution to meet your strategic objectives. KPIs are essential to make strategies effective. Experts added that it is better to adopt strategies that have generated positive results in the building maintenance sector. Maintenance teams can accomplish expected results more quickly in lean implementation by selecting the appropriate KPIs and measuring them. Further experts added that conducting brainstorming sessions will help the maintenance crew and top management to fine-tune the existing strategies and practices. It is proven that brainstorming sessions conducted with the people on the work the floor will give effective results as these sessions will enhance workers' experience in every perspective.

4.3.3 Strategies to Overcome Infirm Feedback Collecting Mechanisms

Good performance management of every new implementation requires timely and effective feedback. Infirm feedback-collecting mechanisms will ruin the accomplishment of intended goals. Both the experts unanimously agreed that it is essential to implement computerised feedback software to collect feedback from customers. Streamlined feedback through a computerised feedback system is the best option for lean maintenance implementations where the maintenance crew and top management can continuously improve the implementation accordingly. Further experts added that the maintenance crew can easily trace the maintenance tasks requested, and actions taken and give feedback on the tasks performed. Thus, it is apparent that implementing a computerised feedback-collecting system is essential.

4.3.4 Strategies to Overcome Lack of Knowledge in Lean

A lack of knowledge and understanding of lean maintenance is also a barrier to the proper implementation of lean maintenance. Both the experts jointly agreed that to increase awareness of lean among maintenance managers and engineers, it is crucial to conduct awareness programmes. Further experts added that practical knowledge on implementing lean can be gained by engaging in lean professional qualifications for instance lean six sigma professional qualification.

4.3.5 Strategies to Overcome the Lack of Standards and Regulations

The lack of standards and regulations will worsen the proper implementation of lean maintenance. Addressing the challenge regarding the lack of standards and regulations, experts suggested following the best industry practices or complying with other available and relevant concepts or standards. Experts suggested developing SOPs, which is a method specific to a given operation or implementation that outlines the steps required to accomplish tasks following rules and regulations for the industry. Experts further validated that to standardise maintenance operations SOPs are necessarily required.

4.3.6 Strategies to Overcome the Lack of Policies

A policy is a collection of principles or guidelines which serve as the foundation for decision-making. So, a lack of policies will impact the proper implementation of lean maintenance. Both experts also highlighted that the implementation of lean maintenance's goals is outlined in policies which will also offer instructions on how to accomplish the objectives. Further, they suggested that proper maintenance policies are required in place and those policies need to be drafted integrating SMART (specific-measurable-achievable-relevant-timely) objectives.

4.3.7 Strategies to Overcome Lack of Technology Usage

Nowadays, organisations are reluctant to switch toward new implementations due to a lack of technical knowledge and usage. Proper awareness should be given to all workers related to the importance of technological utilisation. Commenting on the challenging lack of technology usage E1 suggested adopting Industry 4.0 applications in maintenance since it is the recent face of the technological revolution. Correspondingly, E2 also contended that it is necessary to adopt information technology advancements to improve conventional maintenance practices. However, both experts suggested hiring or training employees with technological knowledge to the organisation.

5. CONCLUSIONS

Lean maintenance focuses on maximising the availability of assets with minimum input. Maintenance management and related activities in the context of high-rise buildings involve a unique set of waste due to the complexity of maintenance and the nature of the structure. Lean maintenance evolved to assist lean manufacturing processes and involves reducing all input resources to the least possible level while achieving the required level of equipment reliability by adopting lean principles in maintenance, repair, and overhaul operations. Experts' perceptions of lean principles in building maintenance were investigated. Key challenges in implementing lean maintenance in Sri Lankan high-rise commercial buildings are identified as: (1) ineffective strategies, (2) a lack of standards, regulations, and policies, (3) poor involvement of top management, (4) infirm feedback collecting mechanisms, (5) lack of technology usage and knowledge on lean prevail in all the selected cases. Experts proposed strategies such as conduct awareness and brainstorming programmes, implementing computerised system and low-cost or no-cost lean tools, preparing SOPs and applying Industry 4.0 to overcome the challenges in implementing lean maintenance in Sri Lankan high-rise commercial buildings. Maintenance practitioners in high-rise commercial buildings can apply the findings of this study for the proper implementation of lean maintenance.

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SUITABILITY OF SMART CAR PARKING FOR SHOPPING MALLS IN SRI LANKA

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ABSTRACT

Smart parking is a technical advancement that makes use of sensors and information technology to assist users in finding available parking spaces. It is a management approach for parking lots in many facilities for users to find satisfactory parking places. Shopping malls are one of the facilities that face different parking management issues due to the large crowd. Smart car parking solution is one of the best solutions to mitigate the issues associated with parking management systems. Thus, this study aims to investigate the suitability of smart car parking as a solution to mitigate the current parking management issues faced by Sri Lankan shopping malls. A case study approach is employed using three shopping mall facilities located in Colombo metropolitan area to analyse the current parking management issues. Further, a questionnaire survey was carried out to identify the issues from the customers' perspective. The data collected from structured interviews and the questionnaire survey was analysed using manual content analysis and statistical analysis, respectively. The findings revealed that the choice of shopping at the facility is strongly affected by the availability of parking, and this has a significant impact on the facility. Further, this paper highlights the major issues associated with shopping mall parking management systems and the suitability of smart car parking to mitigate those issues. The findings of this study are useful in developing smart car parking solutions for shopping malls in Sri Lanka.

Keywords: *Car parking; Shopping malls; Smart car parking.*

1. INTRODUCTION

Vehicle purchases are no longer considered a luxury and it is more like a need than a luxury to own a vehicle (Chandran et al., 2019). Further, ownership of vehicles is increasing with the improvement of the financial status of individuals and as a result, the complications, and tensions of parking increase. The functionality of classic parking systems may have been adequate in the past, however modern structures confront new issues that require fresh solutions (El-Din & Ahmed, 2017). Smart Parking is by far the most widely acquired and evolving smart solution for issues in classic parking systems with the use of sensing tools like cameras, sensors embedded in the pavement, and vehicle counting equipment (Chandran et al., 2019). Powerful sensing systems are developed to evaluate data in real-time and send it to a database further, smart parking could be used to make parking easier and faster in personal parking lots, hospitals, hotels, shopping malls, public parking garages, and workplaces, among other places (Gunasekara et al., 2015).

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Shopping malls or shopping complexes are large shopping centres with a variety of retailers, restaurants, and other businesses situated in a sequence of connected or neighbouring buildings or in a single enormous structure (Aravinthkumar et al., 2020). During peak hours (lunch, evening, weekends), and sales seasons, large crowds are common in shopping malls and the majority of customers arrive at the shopping centre in their own vehicles, which creates an indirect challenge for car drivers in terms of obtaining available parking spaces (Khang et al., 2010). Parking management at shopping malls can be made easier with the smart parking management system and this method would ensure that parking at shopping malls is easily accessible during operating hours and especially during rush hours (Aravinthkumar et al., 2020).

Though automated car parking is quite popular in Sri Lanka, smart car parking is not that popular among Sri Lankans. Radio frequency identification (RFID) systems and light emitting diode (LED) signalling are the commonly used smart access controlling and smart car parking solutions used in the Sri Lankan context (Maduranga et al., 2021). When considering car parking in shopping malls in Sri Lanka, people spend a lot of time searching for car parking slots inside the parking areas. As access control and payment handling for parking are controlled manually, results in customers wasting a considerable amount of time (Chaaminda, 2019). Further to the author, from the perspective of the facility, at least two guards have to be placed at the entrance and exit to perform the above task. The facility has to spend additional labour costs for maintaining the car parking facility. Considering those issues, a specifically designed smart car parking solution can help to mitigate the issues faced by the customers while parking their vehicles in shopping malls, and at the same time, it will be beneficial to the facility as well.

Thus, this paper presents the findings of a study that aimed at investigating the suitability of smart car parking as a solution to mitigate the current parking management issues faced by Sri Lankan shopping malls. The paper starts with a literature review on car parking. Then it presents the research methodology followed by data analysis and research findings. Finally, the conclusions of the study are presented.

2. LITERATURE REVIEW

2.1 SMART PARKING SYSTEM

Smart parking is a technological solution that uses sensors and information technology to help users to locate open parking places (Elsonbaty & Shams, 2020). According to Hassoune et al. (2016), utilising a variety of technologies, smart parking is a management strategy for parking lots in different types of facilities. Smart parking uses information and communication technology to make it quick and easy for users to find satisfying parking spaces, especially on-street parking (Hassoune et al., 2016). Another definition of smart parking is a parking system that aids vehicles in finding an open place by employing sensors to determine if a car is there or not before directing drivers to available spaces (Krishna Chaitanya et al., 2021).

Urban areas are getting more and more crowded and the amount of traffic in a city that is accounted for by people seeking parking is thought to be 30% of all traffic (Lin et al., 2017). By 2050, it is expected an increase in the world population from 55% to 68% in urban areas (Smart Parking Infrastructure, 2020). Smart parking will transform urban driving by making it easier for users to identify vacant spaces and giving authorities the ability to influence the driving habits of their citizens and by reducing travel time and fuel consumption. Smart parking will also considerably aid in the reduction of greenhouse gases and pollution in the transportation sector (Smart Parking Infrastructure, 2020). If implemented suitably, smart parking can save 0.85 million litres of gasoline until 2030 and about 1.15 million litres of fuel by 2050, according to research, and smart parking maximises the use of existing parking spots, resulting in increased revenue for parking lot owners (Kalašová et al., 2021).

2.2 VEHICLE MANAGEMENT SYSTEMS

This section explains the technologies, that make it easier for the motorists to find an open parking space.

Global Positioning System: To locate and monitor a vehicle's precise location, global positioning system (GPS) technology is employed. GPS allows for the determination of the quickest/best route from a given location. The data about parking place occupancy cannot, however, be obtained solely using GPS (Paidi et al., 2018).

Machine Vision: License plate recognition (LPR) and machine vision detection of parking lot occupancy may both be done with visual cameras. The camera ought to be situated close to the LPR parking lot's entrance (Enríquez et al., 2017; Paidi et al., 2018). Finding the number of vacant parking spots might be aided by knowing how many cars entered and departed the area. However, this technique cannot be used to determine if parking spots are occupied (Enríquez et al., 2017).

RFID: For the identification of the vehicle radiofrequency tags will be utilised and each car will be given a unique radiofrequency tag to specifically identify the vehicle. To identify the tag and allow the car to park there, a transceiver and antenna might be installed at the lot's entrance (Singh & Gupta, 2016).

QR Code-based System: In parking and access control applications, QR code-based solutions have shown potential. According to Jiang et al. (2020), a parking management system based on QR codes allows users to enter parking lots, make payments, and keep track of available spots. According to the study, QR codes are a practical and effective way to manage parking operations and improve customer satisfaction.

Compared to alternative methods for managing car parking, the QR code-based approach has a number of advantages including accessibility and user-friendliness, cost-effectiveness, easy implementation and integration, flexibility and scalability and integration with mobile applications (Jiang et al., 2020). Further to the author, the appropriateness of a QR code-based system or other system may rely on certain criteria, such as the size of the parking facility, the required level of security, and the available resources. Before making a choice, organisations should thoroughly assess their requirements and consider the benefits and limits of each system.

2.3 REQUIREMENT FOR SMART PARKING SYSTEM

Classic or traditional car parking is the most available car parking type around the world which is handled and managed manually by security guards (Melsen, 2013). Traditional garages are open 24/7 and since there might not be enough space in certain typical parking lots, drivers must search for an empty place before parking (Krishna Chaitanya et al., 2021). Thomas (2019) stated that traditional parking will incur higher labour to manage and secure the parking facility. Since traditional parking systems are completely dependent on guards, the guards are in charge of manually entering data, processing payments, updating the availability status, and overseeing the parking lot's overall operations (Melsen, 2013).

Given that manual parking systems still use paper records and data collection and input are manually carried out by parking staff, it is challenging to sort through such a large amount of data (El-Din & Ahmed, 2017). Customers with manual parking management systems waste time waiting in lines to access and depart the parking lot because of antiquated or manual processes; as a result, the long-term profitability of the business is put at risk (Melsen, 2013). However, with the number of cars surging and the shrinking amount of urban land, there is a need for an alternate, sustainable solution (Gautham, 2019).

Instead of adding additional parking spots, smart parking focuses on making it simpler for drivers to find available spaces right away, cutting down on the amount of time they spend driving (Khare, 2021). Drivers and parking lot managers receive information from smart parking technology, which combines the utilisation of detectors, street lighting, intelligent global positioning systems (GPS) technologies, and online payment platforms (Shah et al., 2021). Smart parking may minimise traffic by making it easier to locate vacant parking spaces and lowering the likelihood of distracted driving (Biyik et al., 2021). Sensors that can assess whether a spot is empty or filled, together with illumination that can indicate vacancy, are used by smart parking technology to help cars find parking places (Joshi et al., 2020).

Sensors and illuminated parking spots are just the beginning of smart parking technology (Orrie et al., 2015). According to the author, the most recent IoT innovations allow for the syncing of sensors to a cloud platform, which then feeds data into a mobile app. These applications may then send the car using a GPS to the next parking place that was open (Alharbi et al., 2021). The driver may avoid seeking parking places and retain their focus on the road as a result. Making payment simpler is another way that smart parking may reduce traffic (Hassoune et al., 2016).

2.4 CAR PARKING SYSTEMS IN SRI LANKAN SHOPPING MALLS

Shopping malls or shopping complexes are large shopping centres with a variety of retailers, restaurants, and other businesses situated in a sequence of connected or neighbouring buildings or a single enormous structure (Aravinthkumar et al., 2020). A parking lot is a designated place on the mall grounds for parking automobiles and depending on the size and popularity of the vehicle, all malls offer specialised parking spaces with room for two and four-wheelers (Kumar, 2019). In order to ensure that customers have a hassle-free experience and to avoid resource and financial waste, malls may have a greater need for effective parking lot management systems due to the increased number of customers who prefer to arrive in their vehicles (Thomas, 2019).

It could be challenging to manage parking spaces in shopping mall parking lots without real-time information. If the parking structure has several levels, navigating it could be challenging, causing customers to waste time seeking a spot to park for nothing (Parklio.com, 2021). Even with technology, some people still misplace how they obtained a parking spot, while others become frustrated when they repeatedly fail to find a spot and this has been a major issue in shopping mall parking in Sri Lanka (Thomas, 2019). Over six million automobiles are registered under the fuel permit QR code on Sri Lankan roadways and with a near to 22 million projected population, the country has a car of some type for every fourth person (Edirisinghe, 2022). According to the author, many people try to use private automobiles to fulfil their needs because of the current state of the public transportation system and concerns about social standing.

One of the biggest repercussions of the lack of suitable parking, especially in metropolitan areas, is the growth in city traffic, and due to this, looking for an empty parking space during peak hours takes a lot of time and wastes fuel (Lotlikar et al., 2016). However, many service providers, both private and public, have failed to grasp this fact and have neglected to give their clients or service seekers' convenience enough attention and therefore, in addition to the organisation's primary facility, service providers should pay appropriate attention to the fundamental needs like parking and convenience of their clients and service seekers (Edirisinghe, 2022).

2.5 ISSUES RELATED TO THE IMPLEMENTATION OF A SMART CAR PARKING SYSTEM

For many of the parties concerned, using a smart parking system provides significant benefits. However, it also has certain drawbacks of implementation as this is a newer solution and required some amount of technological knowledge (Andriana et al., 2018).

Though a smart car parking system provides greater financial benefits to the facility by reducing the manpower associated with it, implementing a smart car parking system requires a significant initial cost as the components, sensors, and other technical features are higher in cost (Patil & Bhonge, 2013). Yahng et al. (2012) stated that the cost of data collection, analysing the most suitable system in the market, and customising the system according to the requirement of the facility will incur some amount of cost to the initial cost of implementation. Apart from that, a significant amount will incur in the operational and maintenance of the solution as it requires periodic maintenance, software updates, the labour cost of managing the software, and the maintenance cost of physical components (Andriana et al., 2018).

To address parking concerns, smart parking employs sensors, wireless communication technologies, data analytics, etc. (Aggarwal, 2011). Since the employed sensors are largely identical, greater emphasis will be placed on the various locations and any accompanying hardware used in combination with the sensors (Idris et al., 2009). In order to identify suitable locations for sensor placement, select the best type of sensor, and identify the other suitable associated equipment well technical knowledgeable personnel are required (Idris et al., 2009). Further to the authors, lack of resource personnel is the major technical issue faced by the facilities regarding implementing the smart car parking system. Apart from that, considering the Sri Lankan context, the availability of smart car parking solution providers is less compared to the global context (Maduranga et al., 2021). Further to the authors, Sri Lanka is a bit behind the other countries when it comes to technological advancements, and therefore, incorporating the latest technologies into the solution is quite hard and the availability of the latest technological equipment is less compared to the other countries.

The continuous flow of work is only possible with proper planning and management and administration ensures a skilled and efficient flow of work. For a smart car parking system, proper administration and management are highly required in order to manage the functions effectively and efficiently (Lotlikar et al., 2016). The main issue related to the administration is, management personnel does not have the required amount of technical knowledge to manage the system and it requires providing proper training regarding the system before implementing it (Krishna Chaitanya et al., 2021). Further to the authors, a lack of confidence of the management personnel in managing a smart system is another issue faced by facilities when implementing a smart car parking system.

3. RESEARCH METHODOLOGY

This study aims to investigate the suitability of smart car parking as a solution to mitigate the current parking management issues faced by Sri Lankan shopping malls. To identify the issues, in-depth expert knowledge from the facility's perspective and opinions from the customers' perspective is generally required. As customers are the centre of stakeholders, issues faced by the customers need to be carefully evaluated as it directly affects the growth of the facility. On the other hand, to provide a better customer experience facilities need to provide the best parking management services and to increase customer satisfaction, issues with current parking management systems need to be reviewed and solved.

The availability of expert knowledge in this area is limited due to the presence of limited number of shopping malls in the Colombo metropolitan area. As a result, it is difficult to draw a large sample of respondents for data collection. Additionally, the information extracted is mostly made up of opinion evidence, which requires descriptive evaluation. On the other hand, in order to identify the difficulties faced with current car parking designs, level of satisfaction with current designs and expected requirements, a questionnaire survey was done targeting motorists of Colombo metropolitan area who uses shopping malls. In addition, the information extracted is mostly made up of quantitative data, which requires statistical evaluation.

Three (03) shopping malls were selected as the cases for investigation and all the selected facilities are located in Colombo metropolitan area. Out of the three, two facilities are mixed developments that contain residential units, shopping malls and one includes a hotel. One respondent from the managerial level of each facility who is engaged in managing the property was interviewed. Matters identified in the literature review were the basis for the interviews and the issues of current parking management systems were identified.

The profile of the selected shopping malls and respondents are provided in table 1.

Table 1: Details of the selected facilities and interviewees

Case Code	Description	Interviewee Code	Designation	Awareness of the smart car parking concept
C1	Mixed development includes a shopping mall and residential units.	R1	Building Services Manager	Well- aware
C2	Shopping mall	R2	Property Manager	Unaware
C3	Mixed development includes a shopping mall, hotel, and residential units.	R3	Property Manager	Well- aware

The primary objective of the case studies was to identify the current parking management practices in shopping malls in Colombo metropolitan area and the current issues faced during the parking management process. The secondary objective was to identify the feasibility of implementing a smart car parking system, factors to be considered when implementing the system, required features and technologies and the feasibility of the smart car parking in the Sri Lankan context.

Apart from the case study, an internet-based questionnaire survey was done to identify the current issues faced by motorists when using the car parking area of a shopping mall. To gather information for the study, a sample of 40 people was chosen for the survey. The purposive sampling technique was used as the method of sampling and motorists who have used shopping mall facilities within two weeks of time were selected. This is a descriptive inquiry which aims to characterise the present state of a variable that has been discovered. To determine the motorists' experiences with the current parking systems, the questionnaire primarily consists of closed-ended questions with a few Likert scale questions.

The major objective of the survey was to evaluate how difficult it was for motorists to locate empty parking spaces inside the car park as well as the problems they encountered. Another goal was to calculate the typical amount of time required to locate an open slot. The survey was also conducted to identify how parking issues affect people's decisions to shop at the facility. Through this survey, the knowledge about smart car parking systems among motorists and their opinion about smart car parking system deployment to reduce parking-related problems were also identified.

4. RESEARCH FINDINGS AND DISCUSSION

4.1 ISSUES IN THE CURRENT PARKING MANAGEMENT SYSTEM

One of the most frequently discussed concerns among professionals and the general public alike is parking issues in shopping malls, which are growing more and more significant. The main cause of these parking issues has been attributed to an imbalance between parking supply and demand. To find a solution, identifying the most common challenges and issues faced is an essential part. The issues were analysed both from the facility's perspective as well as from the customers' perspective. Therefore, as the first step, respondents from each facility were asked to briefly describe the parking management issues that they are dealing with, as it was the primary goal of the case study to identify the difficulties and problems encountered during the management of the automobile parking space.

According to the critical analysis of the collected data regarding the common issues in the current parking management system, accidents, behavioural complaints, guidance system issues, inadequate parking facilities, management, and monitoring issues were highlighted as major issues. According to R1, accidents are one of the major issues they faced in managing the parking area. R1 further stated that "*Hit and run is a major problem in the parking area as people tend to escape from the place without negotiating the issue with the other party. Management has to always deal with the victims and have to examine CCTV footage to identify the wrongdoer but most of the time the wrongdoer cannot be identified*". Confirming that, R2 and R3 stated, negotiating with victims who faced accidents consume a lot of time for both the management and the security, and sometimes they had to deal with the legal parties as the accidents happened inside their facility.

R1 and R2 both stated that there are few complaints from the client's side regarding the behaviours of the security guards. Unpleasant behaviours and rude actions were some common complaints. In addition, R3 indicated that the expense of maintaining the parking lot is high because they are currently practicing a smart car parking system. R2 added that management has had a few complaints about the insufficient parking spaces.

R1 and R2 both agreed that there are a few issues in managing the parking area as they have to manually control the payment process and the cost of management is high due to the employment of a high number of security guards. Further, R2 stated that they faced technical and monitoring issues regarding the car parking area. Further to the respondent, "*Parking lots will be in use most of the time because malls are frequently open late and almost every day of the week. In the event that an entry management system malfunctions in any way, there can be delays that annoy customers. This has happened quite a few times and it incurs a loss of parking charges to the company*".

Additionally, R1 claimed that since they are lacking a guidance system, motorists spend a considerable time finding a free parking spot, and manually guiding them toward free parking slots is a significant challenge to them. Confirming R1's statement, R3 further expressed that, though they have implemented a smart car parking system they still face the same issue when it comes to guiding motorists toward an empty parking slot.

The analysed responses from the questionnaire survey are demonstrated in Figure 1. The intention of this survey was to identify the current parking issues faced by the customers.

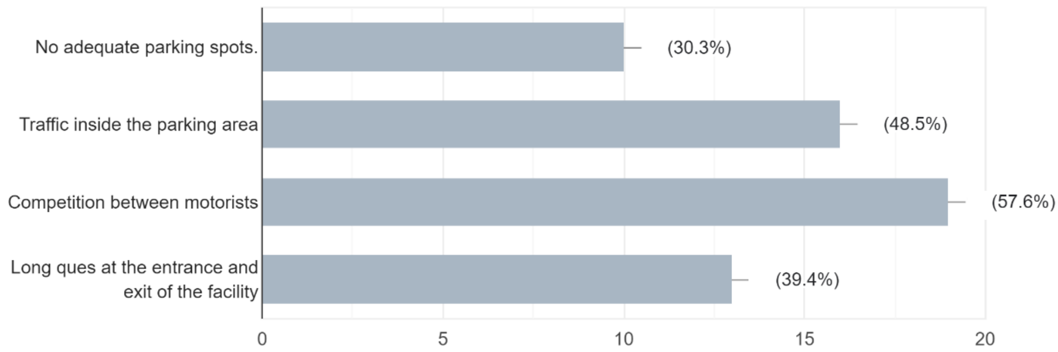

Figure 1: Difficulties faced in car parking

The competition between motorists to find an empty parking space was cited by 58% of respondents as the most challenging aspect of the existing parking arrangement. No sufficient parking spaces was cited by 30% of respondents as a challenge they encountered when parking in shopping mall facilities.

4.2 LEVEL OF DIFFICULTY AND AVERAGE TIME SPENT ON FINDING A PARKING SPOT

According to the responses from the survey, 65% have stated that they spent around 5-10 minutes finding an empty parking spot inside the car parking area. When considering the level of difficulty, 60% stated that they face neither easy nor difficulty in finding a free parking slot.

The average time spent on finding an empty parking spot has a significant effect on the decision of shopping in the facility. Based on the responses received from the survey, 97.5% of the respondents stated that the time spent finding an empty parking spot affected their decision of shopping in the facility. Table 2 depicts the correlation between the average time to find a free parking spot and how it affects the decision of shopping in the facility.

Table 2: Correlation between time to find a parking spot and the decision to shopping

		Average time to find a free parking spot	**Does this affect the decision of shopping in the facility?**
Average time to find a free parking spot	Pearson Correlation	1	.685
	Sig. (2-tailed)		.008
	N	40	40
Does this affect the decision of shopping in the facility?	Pearson Correlation	.685	1
	Sig. (2-tailed)	.008	
	N	40	40

There is a strong positive correlation between the average time spent on finding a free parking spot and the decision to shopping in the facility. The Pearson correlation is 0.685, indicating a strong positive correlation, meaning that increasing the average time spent on finding a parking spot will highly affect the decision of shopping in the facility. If the time spent on finding an empty parking facility increases the decision of shopping at the facility will decrease. Further, as the Sig. (2-tailed) value is 0.008, it can be said that the relationship between the average time spent on finding a free parking spot and the decision of shopping in the facility is statistically significant.

4.3 IMPACT OF PARKING ISSUES TO THE FACILITY

As the shopping malls are commercial facilities, issues with parking will lead to a negative impact on the facility and on the public around the facility. According to the responses given by R1, "*issues with parking negatively impact the company's reputation and sometimes it will decrease the customer's future decision on shopping at the facility. This will have an impact on the sales of the facility*". Confirming R1's view, R2 and R3 stated that apart from that "*this will negatively affect the adjoining facilities and the public around the facility. Due to the parking issues, most of the time motorists tend to park on street and in front of adjoining buildings. It will affect the aesthetic of the building and most of the time it will be a burden to the public*".

Further R3 expressed that, they receive lots of complaints from adjoining properties regarding the blocking of entranceways. Further to the respondent, it will affect the reputation of the facility badly and will have an impact on the revenue of car parking.

4.3.1 Suitability of smart car parking to the Sri Lankan Context

The general view of the respondents was smart car parking is suitable for Sri Lanka. Further evaluating the views, R3 specifically mentioned that "*theoretically we can say this is suitable but when it comes to design and implementation sometime this will not be that much suitable. So as the first step, we have to conduct a pilot project collaborating with the government to identify the feasibility, cost, risks, and benefits associated with this concept*". Further to the respondents, "*it is preferable to generate test data and test* *network performance before installing the system. Additionally, it is necessary to re-evaluate the initial considerations in order to confirm that they still apply".*

R1 expressed his opinion on the behaviours of the users. "*If the facility wanted to implement the smart parking system, behaviours of the users need to be changed".* Further, he stated that "*there is no guarantee that the users will use the allocated parking to them use the payment options correctly. In that point of view, smart parking will not be suitable for now but in the future, with behavioural changes, this concept will be highly advantageous and cost-effective to function".*

Moreover, R2 commented that "*since Sri Lanka is a developing country, some technological advancements may not be suitable to the Sri Lankan context. Before planning to implement, those features or tools need to be tested to identify the suitability and operation conditions of those tools".* He further elaborated, "*If we used such technology, it might be difficult to test it even here in Sri Lanka. Some of the causes behind them include a lack of funding and government involvement".*

Summarising the views presented by the respondents, smart parking is suitable to the Sri Lankan context with some technological and behavioural changes. All the respondents agreed that conducting a pilot project will be a more accurate way to identify the actual suitability of the system.

4.4 DISCUSSION

4.4.1 Facilities Perspective

The facility has to provide a better parking management system in order to increase customer satisfaction and mitigate the issues faced during the current parking management. To develop the most suitable solution, the issues faced by the facility, requirements of the facility, feasibility of the facility, and barriers from the facilities side need to be evaluated. Both traditional parking management and smart parking management system were evaluated, and the following are the summary of issues faced by the facilities.

Table 3: Traditional and smart parking management issues

Issues	Traditional Parking System	Smart Parking System
Accidents	X	X
Long queues at the entrance and exit gate	X	X
No proper mechanisms to guide motorists to the available slot	X	X
Issues of real-time space availability monitoring	X	X
Inadequate parking facility	X	
Behavioural issues of the guards	X	
Management issues	X	

4.5 CUSTOMERS PERSPECTIVE

Evaluation of the issues faced by the clients was discussed in the previous section. To provide a better solution for the issues, those identified issues need to be ranked and prioritised. The following shows the prioritisation of the identified issues:

1. Competition between motorists,
2. Traffic inside the parking area,
3. No adequate parking spots, and
4. Long ques at the entrance and exit of the facility.

When providing the solution, the issues need to be addressed in the above order.

4.6 SMART PARKING AS A SOLUTION FOR CURRENT PARKING ISSUES

After evaluating the awareness of the smart car parking concept, the respondents were asked about their opinion on implementing smart parking as a solution to the current issues in the parking management system. All the respondents stated that smart parking will provide a solution for the waiting time at the entrance and exit gates and it will reduce the waiting time of the customer. Further, it will increase customer satisfaction and cause minimum disturbance to the customer. R3 further explained smart parking will provide a solution to the management issues of the parking area, will generate revenue, and save unnecessary costs on parking management. R2 mentioned that it will indirectly increase business as smart parking solutions will increase customer attraction. Furthermore, smart parking lots provide many more benefits than traditional parking lots. "*Attracting and retaining clients is crucial to our business success, thus it must be done consistently. As a result, it must be met as soon as they arrive at our place, particularly if parking lot management is involved. Thus, it can achieve through implementing a smart parking system",* is another idea expressed by R3.

In order to provide the solution, all the respondents were asked to select the most suitable option for smart parking type among the two options which are reservation-based parking and onsite parking selection. Reservation-based parking is a solution that allows motorists to reserve their parking spots prior to arrive the facility through a mobile app or through a website on the other hand onsite parking selection is an option that allows the motorists to select their parking location after arriving at the facility. All the respondents commented that onsite parking selection will be the best option for the Sri Lankan context as still the people are not familiar with advanced technologies.

Summarising the expressed views, all the respondents agreed that implementing smart parking is a practical solution to the current parking management issues and it will be more beneficial to the facility compared to the traditional or manual parking management systems. Further, all the respondents agreed that onsite parking selection is the most suitable option for the Sri Lankan context.

5. CONCLUSIONS

Parking management concerns are one of the main difficulties that the management team of the shopping mall amenities must overcome. The number of people owning cars is rising along with their financial situation, which magnifies the difficulties and tensions associated with parking. A personalised parking management solution has to be offered in order to address the problems with the present parking management systems. According to the analysis, the facility's most frequent parking management problems include accidents, lengthy lines at the entrance and exit gates, a lack of proper mechanisms to direct drivers to available spaces, problems with real-time space availability monitoring, an inadequate parking facility, behavioural issues with the security personnel, and management problems. The challenges experienced by motorists include traffic inside the parking lot, a lack of suitable parking spaces, and long lines at the facility's entry and departure.

Analysis of the findings revealed that there is a strong positive correlation between the average time spent on finding a free parking spot and how it affects the decision of shopping in the facility. Thus, the development and implementation of a smart parking solution is recommended in order to address the concerns indicated.

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SUSTAINABILITY PRACTICES IMPLEMENTED IN THE INDIAN CONSTRUCTION INDUSTRY: A FOCUS OF CONSTRUCTION PHASE

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ABSTRACT

The construction industry is crucial to the global economy, significantly contributing to local economies and their overall productivity. This is evident in India also, where the construction sector has substantially driven economic growth and development. However, as this industry grows, it poses a significant risk to environmental degradation. While sustainability in construction industry is often investigated from the perspective of design and planning phases, there is also growing recognition of the importance of addressing sustainability during construction phase. A quantitative approach was utilised to investigate the degree to which sustainable practices during construction phase (SPCPs) are implemented in India. Data was gathered from clients, contractors, and consultants, and 40 responses were obtained from 147 respondents contacted. The level of implementation of SPCPs was ranked, and analysis of variance (ANOVA) was conducted to test the significant difference in perceptions among the three groups of respondents. The results indicated that five most frequently implemented SPCPs are: (i) health and safety inspection and auditing; (ii) health and safety training and education; (iii) preservation of archaeological sites, vegetation, and trees; (iv) construction equipment/machinery handling and utilisation strategy and (v) quality management systems. Some of the other fundamental sustainable practices that are under-implemented are: (i) construction noise/ vibration reduction measures; (ii) preassembly or off-site fabrication; (iii) sustainability assessment and recognition program and (iv) stormwater and greywater management plan. Findings of this study can provide guidance to construction industry practitioners in identifying areas that require enhancements, thereby fostering a collaborative approach towards advancing sustainable development goals.

Keywords: *Construction; Construction Phase; India; Sustainability; Sustainable Development.*

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1. INTRODUCTION

The construction industry's activities generate about one-third of the world's greenhouse gas (GHG) emissions (Adebowale & Agumba, 2023). GHG emissions are the primary environmental pollutants. In 2017, India was ranked as the world's fourth largest carbon emitter, with 19% of its emissions coming from the construction sector. In addition, it is estimated that construction and demolition (C&D) waste in India accounts for about 10-12 million tons annually. Furthermore, the industry consumes significant non-renewable resources (Banerjee et al., 2016). The industry not only has impacts that alter the natural environment, but they also impact the health and overall quality of life of humans. Therefore, given India's expected emergence as the world's third-largest construction market by 2025 (Saigal, 2020) and the rapid growth of urbanisation, adopting sustainable construction practices becomes crucial in achieving global sustainable development objectives.

Given the increasing body of evidence pointing to environmental degradation and the concerns for workers' health and safety in the construction industry, there has been a noticeable surge in the momentum behind sustainability in construction practices. Numerous research studies have focused on enhancing energy efficiency or reducing consumption in planning and design or reporting sustainability practices at the corporate level (Fernandez-Sanchez & Rodriguez-Lopez, 2010; Rooshdi et al., 2014; Yates, 2014). In India, some construction companies have begun promoting sustainability by reporting their efforts through the Global Reporting Initiative (GRI) and annual sustainability reports, but primarily at the corporate level, to facilitate sustainable development. The Indian construction industry, however, faces challenges in implementing sustainable tools and practices and is relatively low awareness of sustainability (Manzoor & Sharma, 2023).

Since the construction industry is the most resource-intensive industry, its role in attaining sustainable development goals is indispensable. Sustainability in construction is a multifaceted concept encompassing various phases, including planning, design, construction and operation. Traditionally, sustainability in construction has been primarily focused on planning and design, as these phases present opportunities to incorporate sustainable features such as energy-efficient designs, the use of renewable materials, and waste reduction strategies. However, it is true that the construction phase itself can also have significant sustainability implications, which are sometimes overlooked, primarily due to the complexity of analysis or the perception that the impacts are insignificant (Guggemos & Horvath, 2006; O'Connor et al., 2016). The construction phase involves on-site activities, such as material procurement, transportation, construction waste management, and energy use during construction, which can directly impact resource consumption, greenhouse gas emissions, and waste generation. While there is a growing awareness of the need for sustainable construction practices during the construction phase, comprehensive studies and reporting on this aspect may be relatively limited compared to the focus on design and planning (O'Connor et al., 2016; Omopariola et al., 2022; Yates, 2014). Therefore, this study aims to address this gap by examining the extent of sustainable practices implementation in India by clients, contractors, and consultants during the construction stage.

2. LITERATURE REVIEW

Sustainability emerged from the ‘‘sustainable development’’ concept, defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987, p. 37). Sustainability is a matter that pertains to all industries of the economy. The notion of it is a comprehensive concept that has the potential to impact, and be influenced by, every aspect of infrastructure development. Companies must ensure compliance with a wide range of requirements to follow the various directives and regulations regarding CO2 emissions, air, water and noise pollution, product safety, and product recycling (Shurrab et al., 2019).

Previous studies have comprehensively examined the environmental impacts associated with construction activities, which typically encompass energy consumption, dust and gas emission, noise pollution, waste generation, land misuse, and depletion of non-renewable natural resources. While multiple factors contribute to adopting sustainable construction practices, the environmental attribute has been extensively investigated. In recognition of the construction industry's significant impact on the environment, the industry is increasingly facing mounting legal and commercial demands to adopt eco-friendly practices and has been responding accordingly. Moreover, many nations that seek sustainable development have made it a priority to promote green construction practices.

The concept of "sustainable construction" and its guiding principles were initially introduced to define the construction industry's role in achieving sustainability (Kibert, 2008). In contrast to conventional design and construction, which prioritises cost, scope, time and quality; sustainable design and construction also take into account resource conservation, preventing environmental damage, and promoting human welfare and comfort (Sev, 2009). Several research studies have focused on sustainable construction at project design and operational stages, mainly by introducing energy-efficient strategies (Joseph & Mustaffa, 2023). In addition, sustainable design has been the subject of numerous studies in the construction industry for many years. Nevertheless, sustainable strategies during the construction stage are crucial as it involves several activities that may pose environmental, social, and health risks to workers. Moreover, the scarcity of information and practical guidance on sustainability during construction has intensified the demand for such guidance (O’Connor et al., 2016).

Shurrab et al. (2019) emphasised the significance of "green construction factors" that pertain to the implementation of energy-efficient measures during the construction phase. Yates (2014) highlighted integrating sustainable development practices into industrial construction projects, particularly in selecting reusable, recyclable, or resource-efficient materials. Other researchers have also underlined sustainability practices during the construction phase of such projects that reduce energy consumption during construction and operation and incorporate renewable energy technologies (Goh & Yang, 2014; Rooshdi et al., 2014; Shen et al., 2007). In addition, sustainability considerations in waste management involve reducing waste production and increasing recycling efforts (Krajangsri & Pongpeng, 2017; Ugwu & Haupt, 2007). Awareness and recognition of sustainable initiatives and incorporating sustainability clauses into contracts are crucial in achieving sustainable development in the construction industry (Ugwu & Haupt, 2007; Yates, 2014). Promotion of specialised expertise, skill and knowledge, and technical tools and techniques are some factors that can drive the implementation of sustainability practices (Omopariola et al., 2022). The summary of sustainability practices during the construction phase is summarised in table 1.

Table 1: Sustainability practices implemented during the construction phase

Sustainability practices	References											Frequency
	1	2	3	4	5	6	7	8	9	10	11	
Preservation of archaeological site, vegetation, and trees	*	*	*	*	*	*	*	*			*	9
Sustainable temporary structures and labour camps						*	*					2
On-site power savings and energy efficiency		*	*	*	*	*	*	*	*	*	*	10
Eco-friendly dust and erosion control		*	*	*	*	*	*	*			*	8
Construction and demolition waste management	*	*	*		*	*	*				*	7
Interior air quality control	*	*	*		*	*	*	*	*			8
Stormwater and greywater management plan	*	*	*		*	*	*		*	*		8
Consideration of sustainable, local and regional materials/ services	*	*	*	*	*	*	*	*	*	*	*	11
Minimise generation of material waste			*	*		*	*	*	*	*	*	8
Construction equipment/ machinery handling and utilisation strategy		*	*	*	*	*	*	*		*	*	9
Reusable shoring, formwork, and scaffolding	*	*					*					3
Balanced earthwork and excavation operations		*		*	*		*					4
Preassembly or off-site fabrication		*					*			*	*	4
Construction noise/ vibration reduction measures	*	*	*	*	*	*	*	*	*			9
Site logistics and efficient route planning for project transport	*		*	*	*	*	*	*	*		*	9
Experts with knowledge in management of sustainable projects		*					*				*	3
Supporting local employment and skill development initiatives	*	*	*			*	*			*	*	7
Health and safety inspection and auditing	*	*	*			*		*	*		*	7
Health and safety training and education	*		*			*		*	*	*	*	7
Quality management system	*		*		*		*	*	*			6
Stakeholder engagement and community social responsibility plan	*	*	*			*	*	*	*		*	8
Sustainability-related provisions in project documentation and contracts	*					*	*					3
Sustainability risk management			*				*	*			*	4
Sustainability assessment and recognition program			*			*	*			*	*	5
Paperless site						*	*					2

[1] Ugwu and Haupt (2007); [2] Shen et al. (2007); [3] Fernandez-Sanchez and Rodriguez-Lopez (2010); [4] Goh and Yang (2014); [5] Rooshdi et al. (2014); [6] Yates (2014); [7] O'Connor et al. (2016); [8] Amiril et al. (2014); [9] Krajangsri and Pongpeng (2017); [10] (Shurrab et al., 2019); [11] (Omopariola et al., 2022)

3. RESEARCH METHODOLOGY

3.1 RESEARCH SURVEY DESIGN AND ADMINISTRATION

This study adopted a quantitative research methodology. First, a thorough examination of the literature and interaction with subject matter experts was conducted to identify the sustainability practices. As a result, 25 SPCPs (Table 1) were identified and utilised to design the questionnaire. Then, data were collected using the questionnaire survey with experts from the Indian construction industry. The questionnaire contained two sections. The first section requires respondents to give their background information. The second section asked the respondents, "*how frequently were these 25 SPCPs applied on your projects*" on a 5-point Likert scale, with 1= never, 2= rarely, 3= sometimes, 4= very often, and 5= always.

This study adopted purposive and snowballing sampling techniques. Potential respondents were identified through GRI and sustainability reports, web search and databases of construction firms, who (1) have worked for a minimum of three years in the Indian construction industry, and (2) have experience in managing construction projects or have acquired extensive knowledge of sustainable practices. Using the snowball sampling technique, the participants were requested to suggest additional respondents who were experts in the subject area. A total of 147 subject matter experts from various stakeholders, including clients, contractors and consultants, were identified, and questionnaires were sent out. Forty (40) respondents returned complete questionnaires representing a response rate of 27%. This response rate is consistent with previous research studies conducted with a focus on the Chinese (Ke et al., 2010) and Malaysian (Yap & Skitmore, 2018) construction industries.

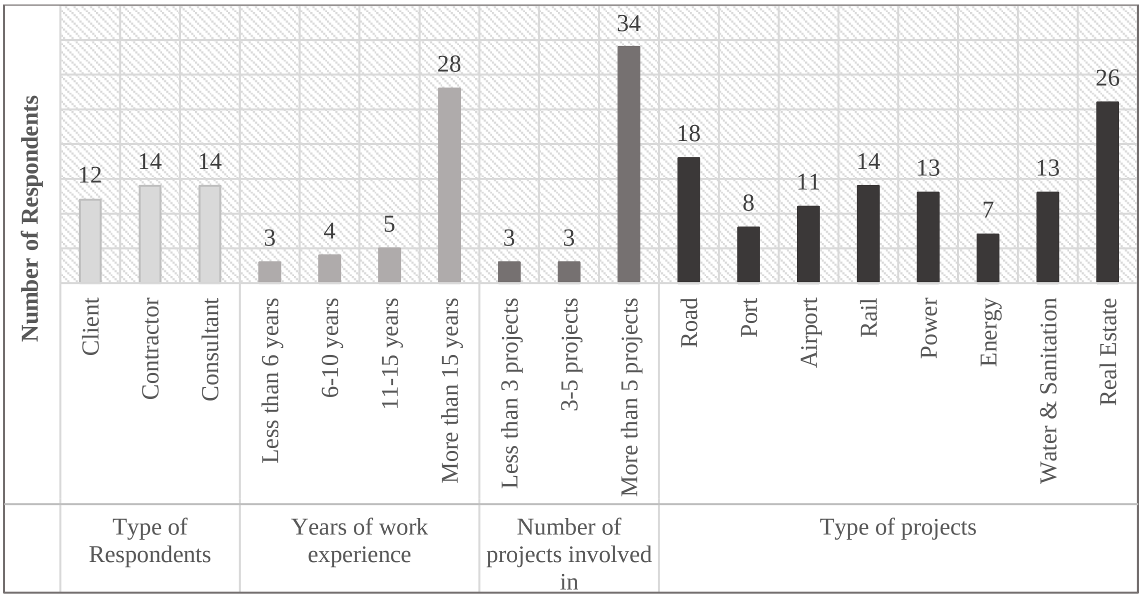

Figure 1: Respondents' Profile, N= 40

Figure 1 provides the demographic details of the respondents. 14 responses (35%) represent contractors, and an equal number of 14 responses (35%) represent consultants. The remaining 30% of respondents represent the client. Furthermore, 34 respondents (85%) had been involved in more than five projects. In addition, 28 respondents (70%) had worked for at least 15 years and were in senior positions. Their extensive experience ensured reliable responses. The respondents were involved in road, port, airport, rail, power, energy, water and sanitation, and real estate industries. Figure 1 provides the background information of these respondents.

3.2 TOOLS FOR DATA ANALYSIS

To assess the consistency of the rating scale utilized for the factors, Cronbach's alpha test was conducted to evaluate the data's reliability. Bonett and Wright (2015) stated that a score of 0.70 or greater suggests that the rating scale's internal consistency is satisfactory. The outcome of this test was a value of 0.91, demonstrating the reliability of the Likert scale utilised to rate the factors; thus, the data collected is deemed reliable. Furthermore, the frequency of application of the 25 SPCPs was analysed using the frequency index within different groups (clients, contractors and consultants). The frequency indexes are calculated by the formula adapted from the index formulated by Wang et al. (2000),

$$\text{Frequency Index (FI)} = \frac{1n^1+2n^2+3n^3+4n^4+5n^5}{5(n^1+n^2+n^3+n^4+n^5)}$$

where n^1, n^2, n^3, n^4 and n^5 are the number of respondents who responded 'never, but applicable', 'rarely', 'sometimes', 'very often' and 'always' respectively.

To further determine the statistical difference in perceptions between the clients, contractors and consultants, ANOVA test was conducted. The ratio of the F-statistics in ANOVA tells us about the variability between the group means compared to within the groups (Anderson, 2001, p. 34). If the F value is larger, it is less likely that the null hypothesis, which suggests no significant difference among the group means, will be true. The null hypothesis in this analysis is that clients, contractors and consultants equally consider the mean frequency index of the 25 SPCPs.

4. RESULTS AND DISCUSSION

Based on the five-point frequency of application scale, the frequency indexes are used to rank the level of implementation of 25 SPCPs. Ranked in descending order of frequency indexes, Table 2 provides the overall ranking of the SPCPs. Three different groups of respondents rated each SPCP. Consequently, Table 2 also provides ranking based on the three types of respondents. Overall, the findings indicated the most frequently implemented practices, based on frequency index, are *Health and safety inspection and auditing* (FI of 0.89), and *Health and safety training and education* (FI of 0.88). Ensuring the well-being of workers is crucial for their future availability in upcoming projects. One possible explanation for these findings is the current active efforts to promote health and safety through intensive campaigns and programs that aim to increase awareness of the health and safety of workers (Ugwu & Haupt, 2007). In contrast with the findings of this study, Omopariola et al. (2022) found absence of effort to govern workers' health and safety in the Nigerian construction industry. Furthermore, *Preservation of archaeological site, vegetation, and trees* ranked third most frequently implemented SPCP, with a combined frequency index of 0.85. This finding corroborates the finding of Omopariola et al. (2022). Infrastructure projects and their associated areas of influence are typically large, resulting in the disturbance, degradation, and destruction of significant natural habitats. Effectively addressing induced impacts can often be challenging and may involve cooperation between the parties accountable for constructing infrastructure projects and managing protected areas. Nonetheless, many significant conflicts between construction projects and biodiversity conservation can be prevented by meticulous project placement, with particular attention given to avoiding critical natural habitats or other extremely delicate zones, such as tropical forests, and the protection of archaeological sites.

Construction equipment/ machinery handling and utilisation strategy and *Quality management system* (both having FI of 0.83) are ranked fourth and fifth in their implementation frequency. The CO_2 emission levels are substantially influenced by construction machinery, transportation of materials, and travelling within site. By minimising equipment idling and using new techniques to improve equipment efficiency, it would be possible to reduce energy consumption and consequently decrease the amount of emissions released (O'Connor et al., 2016; Yates, 2014). To promote eco-friendly construction practices, the Ministry of Road Transport & Highways (MORTH) under the Government of India has introduced emission standards for construction equipment and vehicles and encouraged the use of dual fuel technology.

Furthermore, the majority of the sustainability indicators are centred on measuring environmental, social and economic performance of the construction project (Nguyen et al., 2018). Therefore, incorporating performance-based indicators into the Quality Management System (QMS) is crucial to keep track of construction activities at the site level (Ugwu & Haupt, 2007). In addition, sufficient quality control is necessary to guarantee that waste is minimised by preventing the need for rework. Rooshdi et al. (2014) also highlighted that quality management is a crucial factor, as it is essential to have well-designed and constructed methods to achieve and sustain a green highway. Nevertheless, the company's ability to grow sustainably and maintain its competitiveness is closely tied to the effective functioning of the QMS. Often, the construction sector shows a significant interest in implementing a QMS since the "presence of a QMS is a warranty mark" (Lukichev & Romanovich, 2016, p. 1719).

The next tier of frequently implemented practices is *Reusable shoring, formwork, scaffolding* (FI of 0.82), and *Sustainable temporary structures and labour camps* (FI of 0.81). Yates (2014) emphasised the significance of adopting eco-friendly temporary facilities (worker camps, construction site buildings, and storage structures) with lighting management systems that can decrease energy consumption at construction sites. Moreover, according to the study conducted by Ugwu and Haupt (2007), engineers place significant importance on the reuse of resources, including the reusability of formworks and moulds, as a key sustainability indicator. The next set of practices frequently implemented are C*onsidering sustainable, local and regional materials/ services* and *Site logistics and efficient route planning for project transport* (both having FI of 0.80). This finding is corroborated by National Highways Authority of India's (NHAI) promotion of using sustainable and locally available materials to construct roads cost-effectively. The strategy includes exploring new and alternative materials and technologies and optimising costs to meet higher targets while maintaining quality and sustainability. Likewise, to promote the sustainable and economical use of fly ash, the Ministry of Environment, Forest and Climate Change (MoEFCC) of Government of India, has mandated its use in road and flyover embankment construction within 300 km of thermal power plants. Moreover, as per the findings of the study conducted by Yates (2014), construction professionals have indicated that implementing pre-planned site logistics and traffic routes can effectively reduce the generation of pollution during construction activities.

Other frequently implemented practices are *Minimising material waste generation* (FI of 0.77), and *On-site power savings and energy efficiency* (FI of 0.77). On the contrary, Omopariola et al. (2022) found that contractors are hesitant to adopt innovative technologies, such as minimising energy consumption and reducing material waste, leading to predominant unsustainable practices at Nigerian construction sites. On the other hand, Shurrab et al. (2019) emphasized the significance of employing green technologies. These technologies not only minimize energy consumption but also provide economic benefits. Nevertheless, identifying appropriate operating strategies is crucial for construction decision-makers, especially when conflicting objectives arise between economic potential and emission reduction. Furthermore, Yates (2014) found that the industrial construction industry is now selling, reusing, and recycling more material by-products than before the introduction of sustainability practices on projects. Experts effectively managed construction by-products by segregating recyclable metal for resale, sending scraps to corporate inventory, sharing with other construction sites, and aggregating disposable waste to reduce energy use.

Table 2: Ranking of implementation of SPCPs

SPCPs	Clients		Contractors		Consultant		Combined		ANOVA test*	
	F.I.	Rank	F.I.	Rank	F.I.	Rank	F.I.	Rank	$F^{\#}$	p value
Health and safety inspection and auditing	0.87	3	0.91	2	0.87	1	0.89	1	0.287	0.752
Health and safety training and education	0.91	1	0.93	1	0.83	2	0.88	2	1.354	0.271
Preservation of archaeological site, vegetation, and trees	0.91	2	0.84	3	0.81	3	0.85	3	0.800	0.457
Construction equipment/ machinery handling and utilisation strategy	0.85	6	0.83	5	0.80	6	0.83	4	0.279	0.758
Quality management system	0.87	4	0.83	4	0.80	5	0.83	5	0.606	0.551
Reusable shoring, formwork, and scaffolding	0.84	9	0.81	9	0.81	4	0.82	6	0.055	0.947
Sustainable temporary structures and labour camps	0.85	7	0.83	6	0.76	7	0.81	7	0.918	0.409
Consideration of sustainable, local and regional materials/ services	0.85	8	0.83	8	0.73	10	0.80	8	2.251	0.120
Site logistics and efficient route	0.83	11	0.83	7	0.74	8	0.80	9	1.144	0.330

SPCPs	Clients		Contractors		Consultant		Combined		ANOVA test*	
	F.I.	Rank	F.I.	Rank	F.I.	Rank	F.I.	Rank	F#	p value
planning for project transport										
Minimise generation of material waste	0.84	10	0.77	13	0.74	9	0.78	10	0.949	0.397
On-site power savings and energy efficiency	0.87	5	0.74	15	0.71	14	0.77	11	1.784	0.182
Experts with knowledge in management of sustainable projects	0.80	12	0.79	11	0.73	11	0.77	12	0.523	0.597
Stakeholder engagement and community social responsibility plan	0.69	19	0.79	12	0.73	12	0.74	13	0.703	0.502
Sustainability risk management	0.65	21	0.81	10	0.64	20	0.71	14	2.990	0.063
Balanced earthwork and excavation operations	0.80	13	0.69	18	0.66	17	0.71	15	1.500	0.237
Eco-friendly dust and erosion control	0.78	14	0.71	17	0.64	21	0.71	16	1.056	0.358
Supporting local employment and skill	0.73	18	0.73	16	0.66	18	0.70	17	1.169	0.322
Construction and demolition waste management	0.75	15	0.63	22	0.73	13	0.70	18	1.254	0.297
Interior air quality control	0.75	16	0.64	21	0.69	16	0.69	19	0.548	0.583
Sustainability-related provisions in project documentation and contracts	0.62	23	0.76	14	0.66	19	0.68	20	1.264	0.295
Construction noise/ vibration reduction measures	0.75	17	0.66	20	0.61	23	0.67	21	1.176	0.320
Preassembly or off-site fabrication	0.64	22	0.63	23	0.70	15	0.66	22	0.648	0.529
Sustainability assessment and recognition program	0.67	20	0.69	19	0.60	24	0.65	23	0.501	0.610
Paperless site	0.53	25	0.61	24	0.63	22	0.59	24	0.654	0.526

SPCPs	Clients		Contractors		Consultant		Combined		ANOVA test*	
	F.I.	Rank	F.I.	Rank	F.I.	Rank	F.I.	Rank	F#	p value
Stormwater and greywater management plan	0.58	24	0.49	25	0.43	25	0.49	25	0.762	0.474

*H_0: There is no significant difference in ranking of present frequency implementation of SPCPs among different groups of respondents.
#Fcrit (critical) is 3.327 at 0.05 significance level. If F > Fcrit or p< 0.05, reject H_0

It is interesting to note that practices including Preassembly or off-site fabrication (FI of 0.66), Sustainability assessment and recognition program (FI of 0.65), Paperless site (FI of 0.59) and Stormwater and greywater management plan (FI of 0.49) were found to be not frequently implemented on site. However, many studies mentioned these practices as essential strategies to improve sustainable construction. Therefore, the implementation of these sustainable strategies ought to be considered by the construction industry in India to facilitate sustainable development in their construction projects. For instance, a Hong Kong construction industry study found that expanding the use of prefabrication techniques decreases the amount of waste generated during construction and helps reduce the difficulties associated with waste management (Jaillon et al., 2009). In addition, Killingsworth et al. (2021) found multiple benefits to utilising off-site structural framing systems, including reduced erection time, waste generation, project costs, safety risks, and on-site labor; at the same time, it improved logistics, quality, and collaboration among all parties involved in construction.

Furthermore, programs that include recognition system for innovative and effective practices is important to encourage the widespread adoption of green construction practices (O'Connor et al., 2016). In addition, introducing lessons learned and suggestions for future improvements, along with incentives that support and reinforce the vision of sustainable construction practices, would be crucial in enhancing sustainable construction (Omopariola et al., 2022; Yates, 2014). Shurrab et al. (2019) highlighted in their study that there is a rise in construction organisations showing their dedication to applying for sustainability standards and certifications. Furthermore, it is important to implement stormwater management practices, such as piping systems, retention ponds, or tanks, during construction to address the potential impact of runoff on construction sites. These strategies can also enable the treatment and reuse of water for various purposes, including sewage conveyance, vehicle washing, urinal and toilet flushing, and dust control (O'Connor et al., 2016).

In comparison to the findings of this study with existing literature, some similarities and notable differences are observed. Previous studies have shown successful implementation of practices such as local sourcing of materials, reuse of formwork systems, efficient construction equipment utilisation strategies, and optimisation of job site layouts in both developed (Yates, 2014) and developing countries (Oladokun et al., 2021). Certain techniques, such as air quality control, modularisation, and the promotion of local employment, have been implemented in other global contexts (Oladokun et al., 2021; Omopariola et al., 2022; Yates, 2014) but are not observed in this study. Existing literature has also highlighted areas that require further implementation and improvement. These areas include on-site power savings and energy efficiency, processes aimed at reducing waste generation, and the prequalification of vendors or suppliers based on their sustainability practices.

Furthermore, this study conducted ANOVA test to the statistical difference in perceptions between different groups of respondents. The result shows no significant difference in perception among the respondents (clients, contractors and consultants) on the ranking of the implementation of SPCPs. The high degree of agreement on ranking shows that the respondents have a common understanding of the SPCPs implementation in India, and their rankings' reliability is likely to be high.

5. CONCLUSIONS

Sustainability has become an important facet in the construction sector, and it is being more and more integrated into the phases of design, planning, construction, and operation. This study explores the implementation of sustainability practices during the construction phase in the Indian construction industry. This study found that major areas of SPCPs being adopted are *health and safety inspection and auditing, health and safety training and education, preservation of archaeological site, vegetation, and tree, construction equipment/ machinery handling and utilisation strategy* and *quality management system*. Other important sustainable practices such as *reusable shoring, formwork, and scaffolding, sustainable temporary structures and labour camps,* and *consideration of sustainable, local and regional materials/ services, site logistics and efficient route planning for project transport, minimise generation of material waste,* and *on-site power savings and energy efficiency* are also moderately implemented. Notwithstanding, evidence suggests that several crucial practices, including, but not limited to, *construction noise/ vibration reduction measures, preassembly or off-site fabrication, sustainability assessment and recognition program*, and *stormwater and greywater management plan*, are currently being under-implemented within the Indian construction industry. Including these critical practices in the construction strategy is essential to realise the goal of creating a sustainable environment. Overall, the findings of this study indicate that the results of this research suggest that the Indian construction industry is incorporating sustainable practices to a considerable degree. However, there are opportunities for increased awareness among construction experts and a need for further improvement.

It is important to acknowledge that this study has some limitations. Firstly, the sample size considered in this study was limited to n = 40, which may have implications for the generalisability of the results. Future studies should strive to include a larger sample size to increase the reliability of the findings. Secondly, this study is limited to the sustainable practices identified from the literature and analysed using a quantitative methodology. Future research should adopt a mixed-method research approach that incorporates the views and opinions of experts in the field to enhance the comprehensiveness of the findings. Thirdly, it should be noted that the findings of this study are within the Indian construction context and limited to generalising to other contexts.

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SYNERGY BETWEEN BLOCKCHAIN AND CIRCULAR ECONOMY IN IMPROVING CONSTRUCTION WASTE MANAGEMENT: A LITERATURE REVIEW

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ABSTRACT

The inverse relationship between the development of the construction sector and the preservation of the ecosphere is highly manifested by the excessive waste products resulting from the construction processes that are irrepressible by the existing waste management practices. Research has been conducted on utilising smart technologies such as blockchain technology and modern concepts such as the circular economy (CE) in enlightening waste management practices. Yet, the applicability of intervening the synergy of the two concepts of "blockchain-circular economy" is not adequately addressed in the existing literature from the perspective of effective construction waste management. Therefore, this study aimed at identifying the applicability of blockchain technology and circular economy in enhancing the effectiveness of construction waste management. Accordingly, a comprehensive literature review was conducted on the existing research on the enablers, barriers and strategies for the integration of the blockchain-circular economy, blockchain-waste management, and circular economy-waste management. The collected data were analysed using content analysis. The findings suggested that enablers such as supportive legislations and sustainability increments, barriers such as risks and lack of knowledge, and strategies such as introducing regulatory standards and adaption to technologies are common for the integration of the concepts. Accordingly, this study reveals the potential of assessing the practicability of integrating blockchain, circular economy and waste management in a common platform to establish resource optimisation in the construction sector.

Keywords: *Blockchain; Circular Economy; Construction Industry; Waste Management.*

1. INTRODUCTION

For decades, the construction sector was considered as the mirror image of a nation's technological advancement as it reflects the prosperity and industrial development of a country (Sepasgozar et al., 2018). Explicitly, the construction industry is the major

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contributor to global revenue growth and it sustains a contribution of 6% of the global GDP (El-Sayegh et al., 2020). Aleksanin (2019) affirms that the construction industry is dynamically progressing and simultaneously Crawford et al. (2017) stressed about the corresponding progression in construction waste. Construction waste can be identified as the unwanted products and resources that are generated during the construction processes (Fikri et al., 2020) and the global construction waste generation is approximately 10 billion tons per annum (Ahmed & Zhang, 2021). Furthermore, Osmani and Villoria-Sáez (2019) stated that the ratio between construction waste and inputs is higher than 0.5 which manifests that more than half of the construction resources are sent to landfills. Moreover, the excessive generation of waste is a key reason for the cost overruns of construction projects, that emphasise the apparent need for proper waste management systems in the construction sector (Udawatta et al., 2015).

The necessity of proper waste management (WM) systems is explicit with the growing complexity of WM in the world (López et al., 2020; Malinauskaite et al., 2017). Specifically, many applications are used to reduce the generation of construction waste and among these applications, the waste hierarchy principle and zero waste principle are considered important (Umar et al., 2017). Further, the use of closed-loop models is considered a highly effective way for WM since these circular models optimise the use of resources by effectively circulating the value of the materials while integrating with waste cycles (Malinauskaite et al., 2017). In this sense, circular economy models which is a multi-WM model are relished by the industries for their peculiarity of circulating the material streams while being environmentally sustainable and economically permissible (Hidalgo et al., 2019).

The circular economy (CE) is defined as a regenerative system where materials and energy loops are decelerated, narrowed, and closed intending to reduce waste generation and energy emissions (Geissdoerfer et al., 2017). Benachio et al. (2020) affirm that traditional economies are revolved around linear economy models where the resources are streamed in a linear process, i.e., take, make, use, dispose and Jones and Comfort (2018) argue that the circular process of the CE, i.e., take, make, use, reuse is the best solution for the excessive waste generation in linear models. Besides, the increasing scarcity of natural resources and supply deficiencies emphasise the apparent need for an immediate transition to a CE (Bianchini et al., 2019). However, Guerra and Leite (2021) highlight that several challenges hinder the transition to a CE, yet Romero-Hernández and Romero (2018) emphasise that a CE is essential to overcome the existing WM issue. Hence, Rada et al. (2018) stress the need for assessing the link between WM and CE in manifesting the productivity of this integration. Moreover, Islam et al. (2020) emphasised that intervention between different concepts can be easily managed with the capabilities of new technologies such as blockchain.

In this context, the technology of blockchain (BC) can be identified as a method of sharing data in a verifiable, transparent, and secure manner, and can be effectively adapted for urban WM since it develops a uniform and combined platform (Ahmad et al., 2021). Within a short period, people identified the advantages of this technology with its capacity to act as a decentralised environmental network and be used as the basis of modern concepts such as cryptocurrencies (Wang et al., 2018). Lamichhane et al. (2019) identified the key features of BC technology as anonymity, auditability, and persistence and Zheng et al. (2017) mentioned that BC technology can maximise the cost-effectiveness and efficiency of the systems without third-party involvement. In the construction industry, BC technology is mainly used to mitigate issues in design drawings and Building Information Modelling (BIM) (Li et al., 2019b). It is because BC allows identifying how and where the discrepancy occurred since each step of the BC is stored in a block while linking to the final system (Perera et al., 2020). Accordingly, Wu et al. (2018) identify BC technology as a drive to modern economic patterns.

Gopalakrishnan and Ramaguru (2019) mentioned that the applications of BC such as Plastic Bank, Recercum and Swachhcoin are being employed for productive WM in the world. At the same time, BC is used for the collaboration of the CE concept by coordinating among the specific databases which are accessible to all the relevant stakeholders in the process (Upadhyay et al., 2021). Accordingly, BC technology allows effective implementation of CE practices (Kouhizadeh et al., 2020) and many studies have been directed at the synergy of CE and BC (Akinade & Oyedele, 2019; Institute of Electrical and Electronics Engineers [IEEE], 2018; Nandi et al., 2021; Yildizbasi, 2021). However, there is a noticeable gap in the existing research on the invention of the synergy of BC and CE to increase the effectiveness and the efficiency of WM even if there are studies conducted separately on the integration of BC and WM (Akram et al., 2021; Bamakan et al., 2022; Chaudhary et al., 2021; Ongena et al., 2018; Scott et al., 2022) and the integration of CE and WM (Sharma et al., 2021; Luttenberger, 2020; Priyadarshini & Abhilash, 2020; Salmenperä et al., 2021). Therefore, to fill the above-identified gap, the study is aimed at synthesising the synergy of BC and CE concepts in improving construction WM based on the existing literature.

2. RESEARCH METHOD

Conducting a literature review can be identified as a methodical approach aimed at identifying and synthesising the existing body of knowledge regarding a specific area (Booth, et al., 2021). In addition, Hart (2018) identified that literature reviews lay the foundation of research, irrespective of the field of study and literature reviews direct the researchers to further studies on empirical grounds. Hence, the quality and reliability of the identified literature need to be at a high level, and journal articles, books and conference proceedings with well-cited references are considered high-quality sources (Xiao & Watson, 2019). Accordingly, this study was conducted by reviewing the existing literature focusing on the integration of the concepts of BC, CE and WM. Figure 1 presents the process adopted in conducting the literature review.

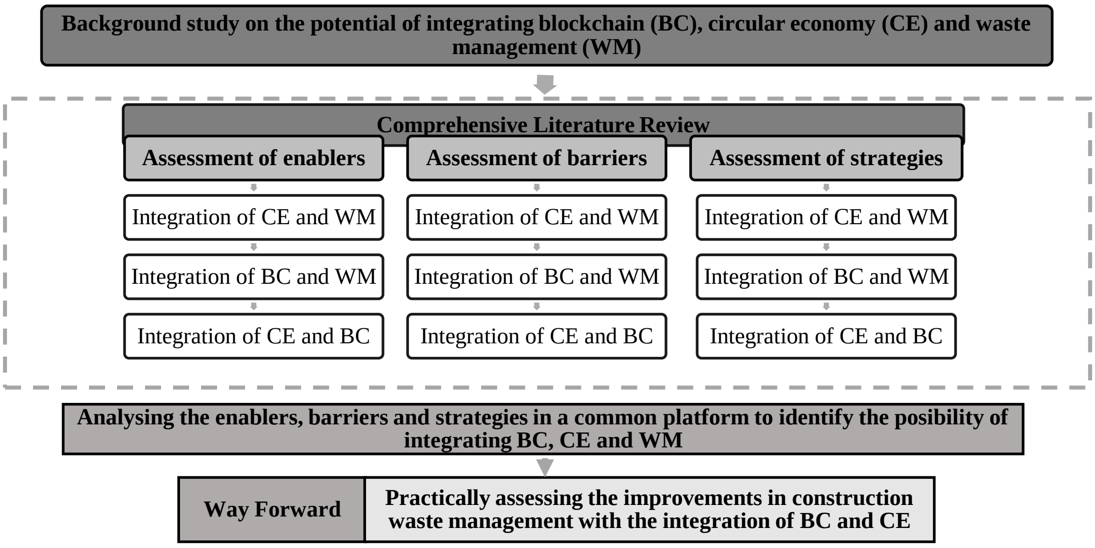

Figure 1: Research process

As Figure 1 explains, a background study was conducted, followed by a comprehensive literature survey on the enablers, barriers and strategies of the integration of CE and WM, BC and WM, and CE and BC. Subsequently, a theoretical framework was developed after analysing the enablers, barriers, and strategies in a common platform using the content analysis method since content analysis assists in deriving inferences systematically (Aggarwal & Singh, 2019). According to Osanloo and Grant (2016), the theoretical framework provides the structure for research and demonstrates the rationale of the research. This study also presents a theoretical framework for the integration of BC, CE and WM as guidance for the empirical studies on the research area.

3. FINDINGS

3.1 ENABLERS OF THE INTEGRATION OF BC AND CE FOR THE IMPROVEMENT OF THE CONSTRUCTION WM

After analysing the literature, enablers for the integration of CE and WM, BC and WM, and CE and BC were identified and common enablers of integrating the three concepts were derived. Accordingly, Table 1 provides a holistic view of the enablers of the integration of CE and WM, BC and WM, and CE and BC as per the existing literature and the highlighted enablers were identified as the common enablers for the integrations.

Table 1: Enablers for the integration of CE and WM, BC and WM, and CE and BC

CE and WM	BC and WM	CE and BC
Pre-existing policies	Guaranteeing data integrity	Offering alternative energy sources
Application of current informal circular activities	Ability to combine BC with new technologies	Development of the secondary material market
Availability of WM financing mechanisms	Way to obtain 17 Sustainable Development Goals	Reverse logistic improvement
The connection between manufacturers and traders	Creating job opportunities	Eco-industrial parks development
The ability of the government to monitor and enforce CE policies	Tracing and tracking of supply chains	Ability to monitor supply chain

CE and WM	BC and WM	CE and BC
Job opportunities	Automated and decentralised incentive system	Chance to improve company knowledge/value
Government revenue increment	Peer-to-peer transaction	Chance to improve consumer knowledge/behaviour
Revealing new revenue streams	Transparency/ disintermediation	Unchangeable databases/ immutability
Increment of new raw materials as recycled materials	Cost saving method	Way to new trading networks
Reductions in unnecessary packaging	Automated WM practices	Improving sustainability (economic, environmental, social)
Publicity for the organisation	Monitoring ability and accessibility	Trackability and traceability
Cost reduction	Immutable auditing facility	Accessibility to records
Improvements in sustainability	Efficiency	Smart contracts
Promoting new green solutions	Immutability	Decentralisation
Generation of new energy sources	Smart contracts	Disintermediation
New investors	Improved workflow	Low transaction cost
Development of enabling technologies to recover material		Incentivisation
Enhancing the value of material/product		Auditability

Sources: (Alexandris et al., 2018; Wang et al., 2020; Ezeudu et al., 2021; França et al., 2020; Guerra & Leite, 2021; Xiao et al., 2020; Hamledari & Fischer, 2021; Hamma-adama et al., 2020; Hatzivasilis et al., 2021; Kayikci et al., 2022; Kouhizadeh et al., 2020; Kumar & Chopra, 2022; Lenz & Tsangaratos, 2022; Li et al., 2019a; Paes et al., 2019; Perera et al., 2020; Rejeb, Zailani, et al., 2022; Romero-Hernández & Romero, 2018; Sahoo et al., 2021; Schneider et al., 2017; Scipioni et al., 2021; Symeonides et al., 2019; Yildizbasi, 2021)

As identified in table 1, Guerra and Leite (2021) identified that integration of CE and WM can result in cost reduction in construction projects while Sahoo et al. (2021) identified that integration of BC and WM can also result in cost savings which can be identified as a common enabler for these concepts. In addition, Rejeb, Zailani, et al (2022) identified the ability to incorporate smart contracts as an enabler for the integration of CE and BC, whereas Perera et al. (2020) identified this ability as an enabler towards the integration of BC and WM. Moreover, Schneider et al. (2017) emphasised that the integration of CE and WM can generate new energy sources which act as a major enabler while Kumar and Chopra (2022) identified the ability to offer alternative energy resources as an enabler towards the integration between CE and BC.

3.2 Barriers to the Integration of BC and CE for the Improvement of the Construction WM

The barriers to the integration of CE and WM, BC and WM, and CE and BC identified through the existing studies have been summarised in Table 2 and the highlighted barriers were identified as the common barriers to the integrations.

Table 2: Barriers to the integration of CE and WM, BC and WM, and CE and BC

CE and WM	BC and WM	CE and BC
Ineffective construction WM practices	Complications in fixing incorrect data	Scalability limitation
Lack of consideration for green designing	Inability to identify the ownership of the person who is responsible for waste in the chain	Specialised software development tool requirement

CE and WM	BC and WM	CE and BC
Low recyclable material usage and low willingness to use circular material	Permanent storing of personal and private data	Confusion in BC application within CE
Non-sustainable construction methods	Difficulties in selecting the correct person for incentivisation	Insufficient technological infrastructure
Lack of incentives for adaptation of CE and uncertainty of return on investment	Government rules, laws, and regulations	High development
Inadequate legal framework and policies/ supervision	Difficulties in authenticity validation without revealing private information	Low experience
Lack of responsibility in material production	Low knowledge of BC	Resistance by firms
Lack of goals to move towards CE in WM	Security risks (hacking, attacks, hijacks)	Low regulatory support and practice
Low knowledge of CE towards WM	Energy consumption	The cost of data storing, and processing is high
The high complexity of integrating CE into WM	Interoperability	Lack of performance and operational objectives
Lack of sustainable integration with WM	Resistant to change	Occurs privacy/security issues
The low number of literature	Scalability	High initial cost
Risk aversion	Risk and cost allocation	Lack of efficient communication/ collaboration
Lack of individual engagement	Data storage	Technological immaturity
Insufficient accessibility to data		Conversion to a new system
Low funding		Interoperability issues
The purpose of an organisation to save cost and time is high		Cultural differences
The low commitment of management		
Negative customer perception of used material		
Sources: (Arena et al., 2021; Ayçin & Kaya, 2021; Wang et al., 2020; Bakajic & Parvi, 2018; Dieckmann et al., 2020; Ezeudu et al., 2021; Xiao et al., 2020; Hamledari & Fischer, 2021; Hamma-adama et al., 2020; Hatzivasilis et al., 2021; Kayikci et al., 2022; Kerdlap et al., 2019; Kouhizadeh et al., 2020; Kumar & Chopra, 2022; Li et al., 2019a; M. G. Sharma & Kumar, 2020; Mahpour, 2018; Paes et al., 2019; Perera et al., 2020; Rejeb, Rejeb, et al., 2022; Rejeb, Zailani, et al., 2022; Romero-Hernández & Romero, 2018; Sahoo et al., 2021; Salmenperä et al., 2021; Stanislaus, 2018; Symeonides et al., 2019; Taylor et al., 2020; Yildizbasi, 2021)		

As shown in Table 2, Ayicin and Kaya (2021) identified that one of the most common barriers towards the integration of CE and WM is the lack of knowledge regarding the adaptability between these two concepts while Sharma and Kumar (2020) identified the lack of knowledge as a major barrier in integrating BC and WM. Furthermore, Li et al. (2019a) stated that the interoperability between different concepts can be a main barrier towards integrating different concepts such as BC and WM, whereas Rejeb et al. (2022) identified that this can be a major barrier when integrating CE and BC. In addition, Dieckmann et al. (2020) stated that inadequate legal frameworks and policies can be a barrier to integrating CE and WM while Yildizbasi (2021) identified that lack of proper legal and regulatory support is a barrier to integrating CE and BC.

3.3 STRATEGIES FOR THE INTEGRATION OF BC AND CE FOR THE IMPROVEMENT OF THE CONSTRUCTION WM

To overcome certain barriers in integrating different concepts and enhance the enablers, different strategies need to be identified, which can be used to ensure smooth integration between the concepts. Accordingly, strategies for the integration of CE and WM, BC and

WM, and CE and BC were identified through a literature review and common strategies for integrating the three concepts were derived. Table 3 presents the strategies which were identified in the existing literature for the integration of CE and WM, BC and WM, and CE and BC and the highlighted strategies were identified as the common strategies for the integrations.

Table 3: Strategies for the integration of CE and WM, BC and WM, and CE and BC

CE and WM	BC and WM	CE and BC
Conducting pilot programmes	Conducting strategic analysis and development	Development of governance and legislative tools
Building collaboration with institutions (financial, WM etc.)	Obtaining regulatory support from the government	Adaptation of proper designing
Enhancing sustainability mindsets	Adapting privacy data securing methods	Using new technologies and resources
Long-term strategic planning (ERP – Enterprise Resource Planning etc.)	Using common data schema to collect and represent data	Proper organisational control and management
Enforcing policies, targets, or achievements	Entering into smart contracts	Adaptation of multi-level analysis
Using improved WM practices	Introducing tokenisation concept	Individual motivation
Adaptation of new technologies	Adapting IoT-based waste collection devices/ process	Constant monitoring
Minimising waste sources	Implementing a productive payment method	Renewable energy usage (minimise regeneration)
Conduction of awareness programmes	Securing easy accessibility to data	Utilising goods to minimise duplications (sharing economy concept)
Increasing the durability of products	Tracing and tracking of wastes	Reducing non-value-added activities (optimising)
	Reliable channelisation of waste	Adapting coopetition strategy
	Proper WM documentation	Intra-organisational collaboration
	Robot assistance	Adaptation of artificial intelligence
	Adapting proper WM practices	Using big data analytics

Sources: (Adami & Schiavon, 2021; Ahmad et al., 2021; Akram et al., 2021; Camana et al., 2021; Dao et al., 2020; Dua et al., 2020; Elia et al., 2017; Fedotkina et al., 2019; Ferronato et al., 2019; França et al., 2020; Hatzivasilis et al., 2021; Hemidat et al., 2022; Khan et al., 2022; Kouhizadeh et al., 2020; Kouhizadeh et al., 2021; Laouar et al., 2019; Luttenberger, 2020; Narayan & Tidström, 2020; Rejeb, Zailani, et al., 2022; Ribić et al., 2017; Romero-Hernández & Romero, 2018; Sahoo et al., 2021; Sen-Gupta et al., 2022; Upadhyay et al., 2021; Woodside et al., 2017; Xavier et al., 2021)

As identified in Table 3, numerous common strategies can be used to integrate different concepts and according to Fedotkina et al. (2019), the adoption of new technologies can be a proper strategy to overcome the barriers to integrating CE and WM. Similarly, Ahmad et al. (2021) identified that utilising new technologies such as IoT and Robot assistance as a strategy that can be used to successfully integrate BC and WM while Upadhyay et al. (2021) stated that new technologies can address numerous barriers to integrating CE and BC. In the same context, Hatziyasilis et al. (2021) identified that the use of big data analytics can further enhance the process of integrating CE and BC and therefore, it is evident that the use of new technologies can be a main strategy that must be considered in integrating these concepts.

4. THEORETICAL FRAMEWORK FOR INTEGRATION OF BC, CE, AND WM

Based on the findings of the literature review, a theoretical framework can be developed to assess the integration of the concepts of BC, CE and WM. As the literature review suggests, there are similarities in the enablers, barriers, and strategies in the existing studies on the integration of BC-WM, CE-BC and CE-WM. Accordingly, the common enablers, barriers and strategies can be analysed to understand the practicability of integrating these concepts. Eventually, it is important to develop a theoretical framework to demonstrate the significance of understanding the enablers, barriers, and strategies in a common platform to enable the successful integration of BC and CE in improving the construction WM. Ultimately, a theoretical framework is developed as per Figure 2 for the integration of the concepts.

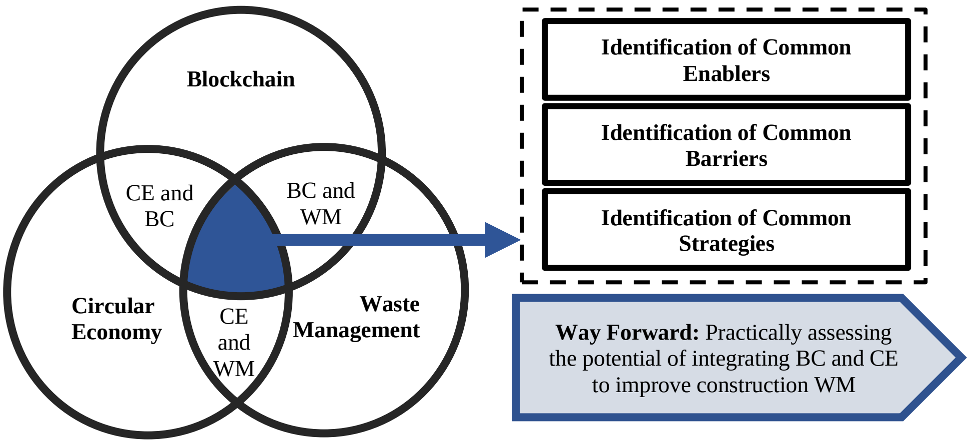

Figure 2: Theoretical framework on the integration of blockchain, circular economy and waste management

As Figure 2 explains, it is important to assess the common enablers, barriers and strategies for the integration of these concepts since it is rather productive to implement the strategic movements in a common platform. Besides, as illustrated in Figure 2, the identification of enablers, barriers and strategies particularly for the intervention of BC-WM, CE-BC and CE-WM and the identification of the similarities among these enablers, barriers and strategies paves the way to assess the potential of integrating BC and CE to enhance existing WM practices. More specifically, it will guide further studies to evaluate the practicability of the integration of BC and CE to improve construction waste management in a pragmatic approach. As identified by Mahpour (2018), integrating different concepts cannot be identified as a simpler task and therefore, how to integrate the three concepts will be the future direction of this study.

5. CONCLUSIONS AND RECOMMENDATIONS

The growing complexity of the construction processes has increased the complications in the construction WM by highlighting the need for more organised WM tools and applications. This study revealed the potential of integrating BC technology and the CE concept in enhancing the existing WM systems while limiting to the construction sector. Specifically, it was discovered that the enablers such as supportive legislations and sustainability increments, barriers such as increased risks and lack of knowledge, and strategies such as establishing regulatory standards and increasing the use of emerging technologies are common for the integration of the concepts. Accordingly, this study contributes to academia by bridging the gap between the BC, CE and WM by highlighting their enablers, barriers and strategies in a common platform. Furthermore, this study contributes to the industry by strengthening the successful intervention of the two significant concepts of BC and CE in improving construction WM.

It is important to highlight that the similarities in the enablers, barriers and strategies pave the way for the researchers to further assess the concepts of BC, CE and WM with an integrated perspective. It is further recommended that industry practitioners increase the involvement of BC and CE to enhance the existing WM techniques. Specifically, it is highly recommended to conduct further research on the practicability of integrating BC, CE and WM based on pragmatic studies.

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THE CUSTOMER SATISFACTION ON THE RAILWAY INFRASTRUCTURE IN SRI LANKA: A STUDY ON RAILWAY STATIONS

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ABSTRACT

Railway infrastructure is one of the core items of railway systems, which ensures the quality and efficiency of the service. As it appears, the railway infrastructure in Sri Lanka is not well maintained. This underperforming situation can lead to a considerable negative impact on the satisfaction of railway users. Hence, conducting an in-depth investigation on customer satisfaction in railway stations under railway infrastructure in Sri Lanka is a timely requirement. Thus, this study aimed to investigate the present customer satisfaction level at Sri Lankan railway stations. Specifically, this study focuses on improving customer satisfaction at railway stations based on the services and facilities provided. A comprehensive literature review has been conducted to review the railway infrastructure, Sri Lankan Railways (SLR), facilities and services provided by SLR, and factors that affect customer satisfaction. Further, data was collected through the distribution of a questionnaire survey among a sample of railway users. The quantitative research approach was undertaken to derive reliable outcomes with the support of RII analysis. As per the key findings, customer satisfaction on railway stations remains in a low to medium level based on several factors. The key issues recorded under the facilities and services of railway stations are delays in train arrival, uncleaned condition, and lack of data sharing.

Keywords: *Customer Satisfaction; Facilities and Services; Railway Infrastructure; Railway Stations; Sri Lanka Railways (SLR).*

1. INTRODUCTION

The railway infrastructure is the foundation of which the railway system is built (Market Data Forcast, 2022). It ensures that trains run safely, steadily, and reliably with greater railway scale and speed, and higher demands are placed on railway infrastructure maintenance quality (International Union of Railway, 2021). However, the railway infrastructure system is very complex, it covers a large distance, has a greater number of supporting components and structural layers to safe and dependable services for customers and freight (Kaewunrune et al., 2015). Moreover, various types of railway infrastructure can be identified such as railway stations, bridges, viaducts, equipment, railway drainage systems and electrification systems (Ueda et al., 2003).

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The railway infrastructure influence customer satisfaction and the quality of railway services as well (Sooriyabandara & Hewage, 2015). In terms of the combination of customer satisfaction and railway infrastructure, railway station is an important location, which are being stopped for passengers on their journey (Hagen, 2015). Further to the author, improving the quality of railway stations has a significant impact on passenger satisfaction with train travel. Thus, customers' needs are critical in improving the quality of a train journey, including the use of railway stations to design user-friendly railway stations. Hence, it is important to determine what passengers find appealing and what aspects are most important.

In Sri Lanka, 'Sri Lanka Railways' (SLR) is the government department functioning under the Ministry of Transport, which is a major transport service provider and is the only rail transport organisation in the country (Sri Lanka Railways, 2023). It is solely responsible for providing transport service and railway infrastructure in Sri Lanka. The SLR is the owner of all the railway tracks and other railway infrastructure (Damsara & Srisoma, 2019). The department transport around 135 million people per year (The Central Bank of Sri Lanka, 2019). Further, the railway transportation of daily commuters to their workplaces is unavoidable in Sri Lanka (Ministry of Transport and Highway, 2022). Each day, the railway transports over 3.72 million people via 396 trains, including 67 long-distance and 16 intercity trains (Ministry of Transport and Highway, 2022).

However, the people are not appealing to the railway services in the country, simply because of the quality issues, and hence, it affects passenger intentions to use railway service (Ranawana & Hewage, 2015). Similarly, most railway users are not much satisfied with the services and quality of railway stations (Randiwela & Jayaweera, 2017). The authors further elaborated that Sri Lankan railway customers are particularly unsatisfied with the services and facilities in railway stations.

As observed, railway stations create a high impact on the level of customer satisfaction. Therefore, this study focuses on the current facilities and services, which are provided by SLR for railway users and evaluates the level of customer satisfaction for each service and facility provided by them for their customers. Further, this research is provided with information relating to the current condition of railway stations in Sri Lanka. Since the scope of this research aligned with assessing customer satisfaction with public railway infrastructure in Sri Lanka, the level of customer satisfaction on the services and facilities provided by railway stations in Sri Lanka was assessed under railway infrastructure. Accordingly, this research paper is reflected the current customer satisfaction level and factors, which are affected the level of customer satisfaction in the railway stations in Sri Lanka.

2. LITERATURE REVIEW

2.1 RAILWAY INFRASTRUCTURE

The infrastructure of transportation is one of the main factors in the nation's assets portfolio in every country (Dimitriou & Sartzetaki, 2016). Further, railway infrastructure is a very complicated and multi-disciplinary engineering system that includes structures, steelwork, timberwork, bridges, and tunnels which support giving flexible guidance for the railway system (The railway Technical, 2019). Over the past century, rail transportation has developed comparatively most sufficiently than ever (Kaewunruen et al., 2015). Further to the authors, the key social and environmental benefits of rail travel include, minimising carbon emissions, less traffic congestion, minimising traffic fatalities and increased usage of land. Similarly, railways as a form of mass transit have distinctive features such as large capacity and high safety standards and are free of traffic congestion (Brons et al., 2009). According to Fulmer (2018), the types of railway infrastructure in the world can be categorised as railway stations, railway tracks, bridges, tunnels and railway yards.

According to various railway infrastructure, railway stations are the main parts of the railway service, which directly holds the passenger crowd (Sideris et al., 2015). Further, the contradictions between the facilities provided by railway stations and the requirements of the population are the main factors which affect customer satisfaction with railway service (Brons et al., 2009).

2.2 CUSTOMER SATISFACTION WITH RAILWAY INFRASTRUCTURE

Satisfaction of the customer is the key to success, and it is heavily influenced by the actions of front-line service providers (Lee et al., 2016). Further to the author, the customers should be treated like assets, by respecting their different needs, preferences, and habits. In terms of railway transportation, the quality of the services is the main factor for increasing customer satisfaction; at the same time the quality of railway transportation is based on the quality of the railway infrastructure (Zitrický et al., 2015). The authors further stated that safety, quality, flexibility, and efficiency are the main factors for increasing customer satisfaction in the railway system in a country. Further, the evaluation of customer satisfaction is more important for the railway system, to make decisions regarding improving railway facilities in the railway system, adjusting the railway trip provided, openings of new railway stations and capacity changes for passengers (Chandrasena & Silva, 2019). When referring the customer satisfaction with railway infrastructure is ideal to move with the railway stations (Hagen, 2015; Petrovic et al., 2010; Randiwela & Jayaweera, 2017).

2.3 SRI LANKAN RAILWAYS (SLR)

The railway of Sri Lanka is one of Asia's oldest rail networks, recently celebrated its 150th anniversary. Considering the history of the railway in Sri Lanka, rail transportation was introduced by the British to transfer the coffee plantation from Kandy to Colombo port because coffee is most famous in a European country and on the world market (Sri Lanka Railways, 2011). After the development of road transportation, the revenue from railway transportation become lost, and also the SLR operated with losses (Jayasinghe & Pathiranage, 2013). Nevertheless, the SLR has survived more than 150 years even with losses due to the everyday commuters such as workers, students and tourists (Sri Lanka Railways, 2011). The SLR is now customer-focused and has a market share of roughly 6.0% for passenger travel and 0.7% for goods travel and it is inescapable that it will transport daily commuters in Sri Lanka to their places of employment. In addition, Sri Lanka has a monopoly market regarding the railway system (Yaparathna & Ratnajeewa, 2018). Most countries use electrical railway systems even before the 20th century, but still, Sri Lanka uses diesel engines for railway transportation (Halpita et al., 2011).

2.3.1 Railway Stations in Sri Lanka

In Sri Lanka, there are 167 main railway stations,153 substations, and 40 train halts combined (Sri Lanka Railways, 2014). Most of the railway stations were built by the

British during the British colonial period; however, still, Sri Lanka is using the railway station built by the British (Samarasinghe & Jayasinghe, 2019). Even though railway stations represent the unique social character and culture in the area for instance, compared to coastal line railway construction, upcountry railway line construction is substantially more enclosed (Samarasinghe & Jayasinghe, 2019). However, the Sri Lankan railway station architecture design is closer to the European railway design (Samarasinghe & Jayasinghe, 2019). The Colombo Fort is the main and first railway station, as well as this station, was constructed and put into use in 1980 (Sri Lanka Railways, 2011). At present Colombo Fort operates ten railway platforms and also serves 0.2 million passengers per day consisting of cafeterias, changing rooms, passenger waiting areas, and so on. Further, disabled passengers can use special accommodations at some of the railway stations (Sri Lanka Railways, 2011).

2.4 FACILITIES AND SERVICES IN SRI LANKA RAILWAYS STATIONS

Facilities and services of the railway stations support to attract people for the railway service (Masirin et al., 2016). The facilities and services to be provided in railway stations as per Randiwela and Jayaweera (2017) and Sri Lanka Railways (2022) are listed below:

- Seat reservation and ticketing services,
- Season ticketing services,
- Providing information (customer information screens),
- Waiting room facility,
- facilities (separate and common toilets),
- Seating facilities in stations,
- Retaining room facilities,
- Canteen facilities,
- Safety lockers facilities,
- Wi-fi facilities, and
- Disability access to railway stations.

2.5 CUSTOMER SATISFACTION FOR SERVICES AND FACILITIES IN SRI LANKA RAILWAY STATIONS

In SLR, passengers are mostly considering the schedule of the train, cancellation of the train, availability of facilities in stations and trains, accessibility, and safety of the railway system (Randiwela & Jayaweera, 2017). In that case, most of the customers are not much satisfied with the services and facilities provided by the SLR stations (Chandrasena & Silva, 2019). Due to that reason, this study is focused on identifying the significant factors that affect railway customer satisfaction in Sri Lanka. However, a lack of studies had been carried out to improve customer satisfaction in public railway stations in Sri Lanka. Therefore, this research focuses on filling that gap. The most common issues in services and facilities in railway stations, which impact customer satisfaction observed from the literature were tabulated in Table 1.

Table 1: Issues in services and facilities in railway stations

Issues in Services and Facilities in Railway Stations	References
• Antiquated ticket-issuing procedures and information-providing procedures • Less number of customer information screens	(Chandrasena & Silva, 2019)

Issues in Services and Facilities in Railway Stations	References
• There is no suitable procedure for reserving suitable seats based on passenger preference	(Mihiranga et al., 2021)
• Disabled people, there is no access to enter the train by wheelchair • No well-programmed seat reservation process at the railway stations • Available restrooms and waiting rooms in stations are not consistently cleaned	(Praja, 2019)
• Delays of the trains • Unclear information • Security issues • Issues with seating facilities	(Sunarto, 2009).
• Toilets in the railway station are in poor cleaning condition. • Restroom, retaining room and platforms are not cleaned	(Warakapitiy, 2016)

3. RESEARCH METHODOLOGY

In terms of assessing customer satisfaction with railway stations, it was recommended to cover a considerable size of sample from SLR users. In this regard, a quantitative survey is the best option if the researcher needs to make inferences from a representative data set (Rouse, 2017). In terms of research approaches, the quantitative approach supports drawing results from a large population (Neuman, 2011). Therefore, the quantitative research approach was used to continue the study. As well as many researchers mentioned, between 30-500 is a sufficient sample size for collecting the data through a quantitative questionnaire survey and this sample size is appropriate for the selection of a sample using the random sampling method (Delice, 2002). Therefore, the group of 40 railway users were used as the sample via the random sampling method by vising the Western province railway stations in Sri Lanka. Regarding the evaluation of customer satisfaction with services and facilities in railway infrastructure, the RII method was used. Further, for calculating the RII, a quantitative questionnaire survey was conducted (Azman, et al., 2019).

According to Fernando (2010), the satisfaction level was ranked as high level, medium level and low level based on the result of analysis of RII,

- Low Level (RII<50%),
- Medium Level (50%<RII<70%),
- High Level (RII>70%).

According to Akadiri (2011) and Hamdoun (2021), five impact and importance levels are identified from the RII value. Such values are presented in Table 2.

Table 2: RII value for impact level

Value	Impact/Importance
$0.8 \leq RII \leq 1$	High
$0.6 \leq RII < 0.8$	High-Medium
$0.4 \leq RII < 0.6$	Medium
$0.2 \leq RII < 0.4$	Medium- Low

Considering identified issues in railway stations, the above-mentioned table was used as a reference table for categorising the level of impact of each issue on customer satisfaction. This study will be a representative of the current facilities and services which are provided by SLR for railway users and evaluates the level of customer satisfaction for each service and facility provided by SLR for their customers. As a whole, this research is provided overall information relating to the current condition of all the railway stations in Sri Lanka.

4. RESEARCH FINDINGS

4.1 LEVEL OF CUSTOMER SATISFACTION FOR SERVICES AND FACILITIES IN RAILWAY STATIONS IN SRI LANKA

When considering evaluating customer satisfaction, the Likert scale was applied. The RII values given in Table 3 are used to rank the level of satisfaction at railway stations.

Table 3: RII value for level of customer satisfaction

RII value	Satisfaction Rank
RII < 50 %	Low
50%< RII<70%	Medium
RII > 70%	High

Adapted from: (Fernando , 2010).

Literature findings on the services and facilities available in railway stations were used to assess the level of customer satisfaction. The findings were analysed by using the RII analysis method. According to the satisfaction categories in Table 3, the satisfaction of the railway customers are calculated and presented in Table 4.

Table 4: Customer satisfaction level on service and facilities in railway stations

Services and Facilities in Railway Stations	RII	Percentage of RII (%)	Satisfaction level
Seat reservation and ticketing services	0.67	67	Medium
Season ticketing services	0.62	62	Medium
Providing information (customer information screens)	0.50	50	Medium
Waiting room facility	0.47	47	Low
Toilet facilities (separate and common toilets)	0.46	46	Low
Seating facilities in stations	0.50	50	Medium
Retaining room facilities	0.525	52.5	Medium
Canteen facilities	0.354	35.4	Low
Safety lockers facilities	0.28	28	Low
Wi-fi facilities	0.314	31.4	Low
Disability access to railway stations	0.56	56	Medium

Considering the final result of the survey carried out for identifying the level of customer satisfaction, it was identified all factors in medium and low-level customer satisfaction.

According to that results, SLR customers are not highly satisfied with the services and facilities provided by railway stations. Further, “seat reservation and ticketing services (RII value - 0.67)” and “season ticketing service (0.62 RII)” these two factors in a medium level of customer satisfaction as well as comparing other factors these two factors had the highest RII value. However, “customer information screens (0.50 RII value)”, “seating facilities (RII - 0.50), retaining room facilities (RII 0.525)” and “disability access facilities (RII - 0.56)” are in the broader line of the medium satisfaction level and those are closer to the lower satisfaction level. Moreover, “waiting room facilities (RII - 0.47)”, and “toilet facilities (RII - 0.46)” in a low customer satisfaction level as well as “canteen facilities”, “safety lockers” and “Wi-Fi facilities” had very low RII values compared to other facilities and services. As well as above-mentioned three factors also have lower customer satisfaction levels. Considering the findings of the questionnaire survey, the minimum range of RII value factors (<50%) needs more attention.

4.2 EVALUATE THE IMPACT OF ISSUES IN CURRENT SERVICES AND FACILITIES IN SRI LANKA RAILWAYS STATIONS

Literature findings on the issues faced by railway users in the railway station’s services and facilities were used to assess the current existence of those issues, based on the customer experiences. The findings were analysed by using the RII analysis method. According to the availability of issues the impact categories in Table 2 (Akadiri, 2011; Hamdoun 2021) were used. The impact of those issues on customer satisfaction at the railway stations was tabulated in Table 5.

Table 5: Impact level of issues in services and facilities in railway stations

Issues in Services and Facilities in Railway Stations	RII	Rank	Impact Level
Poor quality of ticketing service (Antiquated ticket issuing procedures)	0.474	10	Medium
No proper procedure for the reservation of a seat based on passenger preference	0.560	8	Medium
Lack of availability in customer information screens	0.702	4	High-medium
Available restrooms and waiting rooms in stations are insufficient and uncleaned	0.782	2	High-medium
No access for disabled people, to enter the train by wheelchair.	0.514	9	Medium
Poor cleaning condition in platforms	0.697	5	High-medium
Limited seating facilities and poor quality of seating facilities	0.691	6	High-medium
Security problems in railway stations	0.617	7	High-medium
Lack of information provided by stations to customers	0.702	3	High-medium
Poor cleaning condition in toilets	0.862	1	High

Based on the outcome of the survey, the RII was applied to rank the items based on their impact level. According to the rank “Poor cleaning condition in toilets (0.862)” is the highest rank factor based on the RII analysis. Further, this issue is a high impact on customer satisfaction. The second highest factor is “Available restrooms and waiting rooms in stations are insufficient and cleaned (0.782)”. The next impactable factor on customer satisfaction is "Lack of information provided to customers" and "lack of availability of customers information screens in railway station" Both these factors have the same RII value such value is 0.702. Further, ranks 5 to 7 have the same range of RII value which has a high-medium impact on customer satisfaction. Moreover, rank 8, and 9 have low RII value than other RII rank value and these two factors have a medium impact on customer satisfaction. However, rank 10 is the lower rank of this study and it is 0.474 regarding the "poor quality of the ticketing system". Further, this factor has a low impact on railway customer satisfaction based on the RII value table.

Considering the above-discussed issues based on RII value, the highest RII values should need high priority than other factors. According to this study "poor cleaning condition of toilets" and "insufficient and uncleaned condition of available restrooms and waiting rooms in stations" are the main dissatisfied areas of the customers.

5. CONCLUSIONS

Sri Lanka is a mixed economic country and most of the services and goods are provided by the government of the country. Further, this mixed economy always focused on the customers while providing services and goods. Considering customer, satisfaction is the benchmark for identifying the quality of services and facilities. The railway is the main transportation service in Sri Lanka. Also, this railway service directly aligns with the customers who have used the railway as their transportation media for different purposes. Therefore, evaluating customer satisfaction with the railway is useful to identify the quality of the SLR service. Hence, most foreign customers also use this railway as their transportation mode. Most customer-aligned railway infrastructure are railway stations. Therefore, this study focuses on evaluating customer satisfaction with railway stations under the services and facilities provided. According to the research finding literature review useful to identify the facilities and services provided by the railway stations in Sri Lanka as well as through the literature review identified the significant factor which is impact on customer satisfaction. Further, the RII method is used to evaluate the level of customer satisfaction and identify the Identity impact level for each factor (issue) for customer satisfaction. Based on research findings most customers are not much satisfied with the services and facilities provided by SLR and most of the services and facilities have low satisfaction levels on research analysis. Considering the factors which impact customer satisfaction, these factors were ranked based on RII value and this research paper presents the RII rank of each identified factor. Moreover, this research provides a clear understanding to users of this research regarding the current satisfaction level for each service and facilities are provided by railway stations also this research is useful for identifying the main factor which affects the level of customer satisfaction. Further, this research paper reflects the current condition of all railway stations in Sri Lanka.

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THE IMPACT OF THE DEPLETION OF FOREIGN CURRENCY RESERVES ON THE SRI LANKAN CONSTRUCTION INDUSTRY

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ABSTRACT

The construction industry is highly diverse and interconnects with many other industries The industry generated job opportunities to many and a significant economic multiplier. However, it was observed that an economic change in the country affects the industry adversely. The depletion of foreign currency reserves has significantly impacted Sri Lanka's construction industry in the recent past, from 2019 to date. Many stakeholders are currently encountering many issues, and as a result, many construction projects are in temporary shutdown. This study aimed to investigate the impact of foreign currency depletion on the Sri Lankan construction industry. The data collected from 15 semi-structured interviews conducted among professionals from the construction industry who work under contractors and professionals from the finance industry who are involved in the economic sector. A detailed literature study was undertaken to determine the causes and effects of the depletion of foreign reserves and qualitative semi-structured interviews were used to identify the positive and negative effects of the depletion of foreign currency on the construction industry. As a result, the findings featured results such as financial issues, unemployment, and frequent price escalation as severe impacts on the industry. The discussion also highlighted the strategies which are already imposed and suggested by the government and construction organisations. It included, implementing more foreign-funded projects, outsourcing new contracting or consulting overseas projects and expanding the export industry. Finally, the paper reveals the possible remedial strategies to minimise the impact of foreign currency depletion in the future.

Keywords: *Depletion; Economic Crisis; Foreign Currency Reserves; Impact; Sri Lankan Construction Industry.*

1. INTRODUCTION

A financial crisis occurs when financial institutions or assets suddenly lose a major portion of their value. The world's financial crises date back to 1819, when the United States of America had a serious financial crisis (Hemachandra, 2012). Financial crises can generally be divided into multiple types, including currency, banking, domestic debt, external debt, inflation, and capital market crises (Hlaing & Kakinaka, 2018). A financial crisis can impact a country's macroeconomy, leading to global financial crises. As the

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crisis worsens and spreads rapidly, it affects the entire economy, transforming it into an economic crisis. The term "economic crisis" refers to a wide range of scenarios in which some financial institutions or assets lose a significant portion of their value (Shibly, 2013). Sri Lanka's economic crisis began due to interconnected factors like tax cuts, money creation, organic farming, Easter bombings, and COVID-19's impact (George et al., 2022).

International reserves, also known as foreign exchange reserves, are a country's external assets, including gold, Special Drawing Rights (SDR), foreign currency deposits, and bonds (Kashif et al., 2017). This is also known as forex reserves or FX reserves (Chowdhury et al., 2014). These reserves are typically held in the form of government bonds, treasury bills, and other financial instruments denominated in foreign currencies. Foreign reserves are crucial for a country's economy, maintaining exchange rate stability, resilience against external shocks, speculative attacks, liquidity, monetary policy support, and attracting foreign investments (Kashif et al., 2017). Chowdhury et al., (2014) as cited in Batten (1982) identified four key factors for reserve keeping include international payments variability, import proclivity, opportunity cost of retaining reserves, and transaction size scale variable. Foreign reserves are a crucial indicator of a country's economic strength and stability, with high reserves indicating better ability to weather downturns and maintain financial stability. Thus, having large foreign exchange reserves is generally desirable and beneficial (Chowdhury et al., 2014).

Sri Lanka's industries face severe circumstances due to rapidly decreasing foreign reserves. Foreign exchange reserves impacted by imports, exchange rate volatility, debt, opportunity cost. (Kashif et al., 2017). Poor foreign exchange liquidity in Sri Lanka's banking system contributed to the current financial crisis. The Central Bank of Sri Lanka (CBSL) imposed surrender requirements on export revenues to secure adequate foreign exchange liquidity, causing shortages of essential commodities like fuel and food. This led to a decline in foreign reserves and a need for a more stable banking system. Key imports, including fuel, food, fuel, pharmaceuticals, and cement, are experiencing shortages due to the pandemic (Sharma, 2022). Sri Lanka's economy faces significant impacts from financial crisis and COVID-19 pandemic (Sharma, 2022).

Factors like poor initial estimation, financial issues, changes, lack of experience, conflicts, target cost, technical, political, natural, schedule variance, and compressing schedules in construction projects significantly impact during crisis times. This behaviour is also observed when foreign currency reserves deplete (Islam & Islam, 2020). Thus, Sri Lanka's construction industry faces significant setbacks due to financial and economic crises, government restrictions, and the depletion of foreign currency reserves. The industry faces immense impacts on import expenses and a lack of foreign currency reserves. Contactors, clients, investors, and consultancies were directly and indirectly affected by such impositions. Nevertheless, no existing research explores the nature and magnitude of the impact of the depletion of foreign currency reserves on the Sri Lankan construction industry.

Therefore, this study aimed to identify and analyse the impact of the depletion of foreign currency reserves on the Sri Lankan construction industry. In order to pursue the aim of the study, a few research objectives were developed, namely: (1) to review the current economic crisis evolving in Sri Lanka and its implications for foreign currency reserves in Sri Lanka, (2) to identify and analyse the challenges and problems faced by the Sri

Lankan construction industry due to the depletion of foreign currency reserves in the country, and (3) to determine the ways and means to overcome the challenges and problems faced by the Sri Lankan construction industry due to the depletion of foreign currency reserves in the country.

2. LITERATURE REVIEW

2.1 AN OVERVIEW OF MULTIFACETED CRISES IN THE WORLD AND THE EVOLUTION AND CAUSES OF THE ONGOING MULTIFACED CRISIS IN SRI LANKA

According to Canyon (2020), a crisis is "*an uncertain situation possessing latent risks and opportunities that must be resolved within a given timeframe"*. Similarly, the Babcock Gove & Merriam-Webster (2008) dictionary identifies the word "crisis" as "*an unstable or crucial time or state of affairs in which a decisive change is impending".* An economic crisis represents a situation in which the economy of a country passes through a sudden decrease in force, a decrease usually brought about by a financial crisis. The economic crisis may take the form of stagflation, a recession, or an economic depression (Cazan & Cucos, 2013). For example, in 2001, the Turkish government faced a severe crisis, of which the main cause was a combination of both the fragile banking sector and poor macroeconomic performance (Özatay & Sak, 2002). Argentina also had an economic crisis in 2001, which was caused by frequent structural changes in the government with a "*tragicomic spectacle of a succession of five presidents taking office over a mere ten days*" (Burke-White, 2008), unstable political and economic situations, and fixed exchange rates. Another first sign of a global economic crisis began in 2008 in the U.S. housing market (Shibly, 2013). It affected not just the US government; it dragged in many European countries as well as Asian countries (Helleiner, 2011). On the other hand, the Spanish economy has had one of Europe's fastest growth rates and highest levels of success. This outstanding feat was made possible by immigration, low interest rates, and economic freedom. This success, however, came to an end in 2007, when Spain experienced a severe economic collapse.

Since 2019, Sri Lanka has also started experiencing a crisis, financially, politically, and economically, which can be called a "multi-faced crisis". Several reasons contributed to Sri Lanka's current multi-faceted crisis. Economic mismanagement, an increase in foreign debt, dwindling foreign reserves, a weaker currency, and increased prices are examples of the causes (George et al., 2022). In 2019, the Sri Lankan government cut the number of taxpayers by 33.5%, reduced VAT to 8%, reduced corporate tax from 28% to 24%, eliminated the Economic Service Charge tax, and abolished NBT tax affecting from 1st December 2019. Additionally, increasing external debt issues, agricultural issues due to the ban on fertilizer, and issues in the tourism industry also contributed as the main causes of the economic crisis (George et al., 2022). Moreover, the Easter Sunday attack in Colombo in 2019 and the breakout of the global pandemic impacted Sri Lanka's foreign currency-generating industries, namely tourism, remittances, and exports (Sharma, 2022).

2.2 FOREIGN CURRENCY RESERVES IN SRI LANKA

From 1977 to 1997, the US dollar reserves in Sri Lanka increased from 278 million to 2029 million. However, by the end of 2000, it had declined to 1049 million. By introducing the independent floating exchange rate on the 23 January 2001, commercial banks could freely determine the exchange rate. The intervention's goal is to prevent excessive volatility in the short term while also increasing the country's foreign reserve position in the medium term. Thus, the managed floating regime may be viewed as an intermediary phase (before the market matured considerably) in Sri Lanka's progression of currency rate policy toward independent floating (Central Bank of Sri Lanka, 2006). The foreign reserves increased to 3,500 million, and in 2009 they decreased to 1,300 million (Karunaratne, 2010). Currently, Sri Lanka is facing the most crucial stage, as the country is on the brink of bankruptcy.

At the end of 2019, the country's reserves stood at 7.6 US billion dollars but by the end of 2020, reduced to 5.7 US billion dollars as the foreign currency inflows reduced due to the pandemic. The gross official reserve position of the country deteriorated to critically low levels by the end of 2021 due to higher foreign currency debt service payments amidst inadequate foreign exchange inflows. In August 2020, Sri Lanka started losing its foreign reserves, but it majorly lost in November 2021. As of December 2021, Sri Lanka had only US$ 3,137 million foreign exchange reserves and according to the weekly economic indicators published by the CBSL, at the end of April 2022, the foreign reserves stood at 1812 US million dollar. At the end of the year 2022, foreign reserves stood at 1,898 US million dollar (Central Bank of Sri Lanka, 2023). By January 2023, it increased to 2,120 US millions dollar (Central Bank of Sri Lanka, 2023). When reserves decrease, it impacts the exchange rate, affects liquidity, decreases foreign investments, causes issues with international payment obligations, and reduces development (infrastructure). Thus, unemployment and poverty, rising inflation, fuel shortages, health concerns, forced migration, and people's dissatisfaction were all major issues that arose during the year 2022.

2.3 RELATIONSHIP BETWEEN THE ECONOMY AND THE CONSTRUCTION

Han and Ofori (2001) suggest those mature economies have larger construction industries that contribute 5%–8% to the gross domestic product (GDP), whereas the construction industries in developing countries contribute only 3%–5%. Construction and the economy are linked, with some studies suggesting that construction influences the economy while others suggest that the economy influences construction (Ramachandra et al., 2013). When there is a boom in a nation's economy, there will be a boom in the construction sector, but when there is a downturn, there can be a slowdown in construction activities (Ramachandra et al., 2013). Anyhow, any changes in the economy may have an impact on industries, including construction, and vice versa. Ozkan et al. (2012) conclude that in Turkey, the long-term relationship in infrastructure investments is not affected by economic shocks in the short run, but building and residential investments get affected by short-term economic shocks.

The construction industry includes a broad range of activities, operations, and sectors, including the construction of buildings, roads, and railways. When the construction industry is at its peak, a significant number of individuals are employed (Gnanothayan & Kauškale, 2022). In 2005, just after the tsunami, Sri Lanka had to face a series of its toughest years as rehabilitation and rebuilding of houses started. With that, in 2005, the contribution from the construction sector was 7.2%, which decreased to 6.7% in the year 2010. But when considering the 2012 contribution, it was marked at 8.1%, which was a significant increase. The Sri Lankan construction industry was actually on an upward trend in the post-conflict scenario in the country. The end of the island's ethnic war in

2009 revived economic activity and resulted in an infrastructure-building boom. Significant reconstruction activities were expected to be undertaken in the North and the East of the country after 2009. The other regions of the country were also expected to see significant development activities (Jayalath & Gunawardhana, 2017), which actually became a reality to a greater extent until 2016. In the year 2016, the contribution to the GDP from the construction industry dropped to 7.1%, which continued to go down in the year 2018 to 6.8%, and further decreased in the year 2020 to 6.2%. Accordingly, in 2021, the GDP contribution from the construction sector was recorded at only 6.1% (CBSL, 2022). The Government indicated that Sri Lanka was insolvent when it announced a temporary suspension of repayment of all external debt and stated that due to the country's worsening financial situation brought on by external and internal shocks, it is no longer able to honour its commitments (Cassim, 2022).

3. METHODOLOGY

The process through which researchers perform their research is known as the research methodology. It demonstrates the process by which these researchers define their problem and objective and then provide their findings based on the data collected over the study period (Sileyew, 2019). To examine the possibility of undertaking research on or studying a subject about which little or no information is available, exploratory research methods are used (Kumar, 2018), which is the case with this study as well. Quantitative, qualitative, and mixed methodologies are the three most common research approaches (Williams, 2007). Developing an understanding of the meaning and experience aspects of people's lives and social environments is the aim of qualitative research (Fossey et al., 2002).

A case study is a research strategy used to develop an in-depth, multifaceted understanding of a complex topic in its real-life environment (Creswell, 2014) whereas the survey strategy is useful when the research problem deals with a large population, and thus gathering information from a large group of people is possible to understand their opinions, attitudes, behaviours, or characteristics. As the research problem of this study (i.e., the impact of the depletion of foreign currency reserves on the construction industry) is a widely known and experienced phenomenon by the entire construction industry in the country, a large population is involved, from which a large sample can be drawn for the data collection. Therefore, this study adopted the survey strategy.

Within the survey strategy, the semi-structured interview technique was adopted over the questionnaire technique as the study is exploratory in nature and somewhat in-depth knowledge and experience of the interview participants were required to be gathered in the form of qualitative data. Öhman (2005) states that rather than pre-defined hypotheses, the qualitative approach is mainly based on the participants' knowledge, opinions, and experiences, which are expressed in thoughts, ideas, feelings, and perceptions. 15 professionals from the construction industry who work under contractors and professionals from the finance industry who are involved in the economic sector were selected for the data collection sample using the purposive sampling technique. According to Kumar (2018), the most significant thing to consider in purposive sampling is determining who can provide the most information to aid in the study's objectives. The profiles of interview participants are provided in Table 1.

Table 1: Interviewee information

Participant		Designation	Experience
Participant no 1	P1	Project Manager	5
Participant no 2	P2	Senior Quantity Surveyor	20
Participant no 3	P3	Project Engineer	15
Participant no 4	P4	Engineer, Construction Manager	12
Participant no 5	P5	Quantity Surveyor	8
Participant no 6	P6	Ch. Quantity Surveyor	22
Participant no 7	P7	Chartered Accountant, Director	17
Participant no 8	P8	Chartered Accountant	15<
Participant no 9	P9	Chartered Accountant, Director General	23
Participant no 10	P10	Ch. Quantity Surveyor	20
Participant no 11	P11	Project Engineer	10
Participant no 12	P12	Quantity Surveyor	14
Participant no 13	P13	Ch. Quantity Surveyor	15
Participant no 14	P14	Construction Manager	6
Participant no 15	P15	Project Manager	18

Two separate sets of interview guidelines were prepared for the financial sector professionals and the construction sector professionals. It enables the researcher to compare and contrast different perspectives and viewpoints of professionals on the depletion of foreign reserves and its impact on the construction industry. All the data generated through the interviews was analysed using the manual content analysis technique. The researchers usually look for patterns, themes, or biases in linguistic, visual, or behavioural data in the content analysis (Williams, 2007).

4. DATA ANALYSIS AND DISCUSSION

4.1 CAUSES OF THE CURRENT ECONOMIC CRISIS IN SRI LANKA

Interview participants pointed out that the economic crisis in Sri Lanka is mainly caused by the Easter bomb attack in 2019, the COVID-19 pandemic, which started in early 2020, and the political instability in the country from the year 2019 on. Table 2 and 3 shows these causes and effects along with the root causes as revealed during the interviews.

Table 2 : Classification of effects of the economic crisis in Sri Lanka

Easter bomb attack	**COVID- 19 Pandemic**		
Tourism Industry	Tourism Industry	Lack of export	Remittance
P1, P2, P5, P8, P9, P12, P15	P1, P3, P4, P5, P6, P7, P9, P12, P13	P1, P2, P3, P4, P5, P6, P7, P9, P10, P13, P14	P1, P2, P4, P8, P9, P10, P14, P15

Table 3: Classification of causes of the economic crisis in Sri Lanka

Political dimensions				
2019 Government policies		Political Instability	Corruption	Huge external debt
Tax reduction	High-interest rates			
P1, P2, P3, P4, P5, P7, P8, P9, P1,P12,P13, P14, P15	P1, P2, P3, P5, P8	P3, P7, P9	P1, P9	P1, P3, P7, P8, P12, P13, P14

4.1.1 Easter Bomb Attack in 2019

The Easter bomb attack that took place in April 2019 targeted popular hotels in Colombo and historical churches in Sri Lanka. Interviewees P1, P2, P5, P8, P9, P12, and P15 highlighted that the attack directly hit a main international reserve revenue stream, tourism. P2 said in the month of May 2019, the number of arrivals significantly dropped, but by December 2019, the tourism industry had improved because of the high level of security in the country. The attacks had a significant impact on the tourism industry, as well as other sectors such as air transportation, domestic transportation, wholesale and retail trade, accommodation, food and beverage service activities, leisure and entertainment, and agriculture. Foreign investment from the government securities market and the Colombo Stock Exchange also suffered, with price indexes and market capitalisation falling (Central Bank of Sri Lanka, 2019).

4.1.2 COVID-19 Pandemic

The unpredicted pandemic situation of COVID-19 in December 2019 created sudden lockdowns and health and safety restrictions. Everyone stated that the COVID-19 pandemic affected the tourism industry, foreign remittances, and the export industry. P1, P3, P4, P5, P6, P7, P9, P12, and P13 highlighted restrictions imposed by the government to control the virus that blocked one of the main foreign revenue streams, tourism. COVID-19 resulted in the unemployment of many immigrants, resulting in a decrease in the flow of foreign currency. As the Sri Lankan construction industry is a highly import-oriented industry, the travel and border restrictions temporarily blocked the raw materials importation impacting the projects, as per P1, P2, P3, P5, P6, P9, P10, P13 and P14.

4.1.3 Political Dimensions

With the new appointment of the government in 2019, new policies and regulations were imposed, which resulted in many issues in the economy, said the participants. The 2019 government" created drastic changes that greatly impacted the foreign currency to deplete. P11 mentioned that the cancellation of taxes such as the NBT and ESC (Economic Service Charge) had an impact the revenue of the government. Also, with effect from 1 December 2019, the VAT rate was decreased from 15% to 8% on imports, and/or supply of products, and the delivery of services. The financial sector professionals admitted that the high bank savings and fixed deposit interest rates discouraged many future investments and interest on loans and interest on investments are much higher than previously. P3 mentioned, *"These days you and I both prefer to deposit money in the bank* *rather than invest"*. Corruption and non-transparency have caused a social crisis in the country, leading to protests against the poorly managed economy and government policies. P1 and P9 strongly believed that corruption had impacted the economy for a long time. By the end of June 2022, the government had Rs. 24,264.4 billion in total outstanding debt (Statistics Department, 2022). Huge external debt for the long term is also a major result of the depletion of foreign reserves. P8, P10, and P15 concluded by saying that long-term unnecessary import patterns, huge external debts, political instability, and poor decision-making led to the foreign currency crisis in Sri Lanka.

The literature sources, such as George et al., (2022), Sharma et al., (2022), and Aryal & Balashanmuganandam (2022), and the findings of empirical data are in line in terms of the causes of the economic crisis, and accordingly, the main causes were confirmed as the Easter bombing attack of 2019, the COVID-19 pandemic, new government policies, corruption, and huge government debts.

4.2 FOREIGN CURRENCY RESERVES AND SRI LANKA CONSTRUCTION INDUSTRY'S RELATIONSHIP

The construction industry has an immense relationship with foreign reserves, as 70% to 80% of materials are imported from different countries, and a very small percentage of products are manufactured in the country mentioned by P6. All participants mentioned that the construction sector heavily depends on imported materials such as steel, sanitary fittings, electrical fittings, aluminium, petroleum, etc. In order to purchase the materials, the country should have sufficient foreign currency. Due to the depletion of foreign reserves in the country, contractors especially faced issues with material imports and restrictions imposed on importing materials such as steel, sanitary fittings, tiles, and glass. This created delays and reductions in quality in construction projects, as said by P9 and P15 mentioned that materials such as cement, steel, aluminium, and glass have had to be imported as the production in the local market does not meet adequate quality and quantity. Moreover, P4 mentioned that fuel is also one of the main materials required to run a construction site, which has a serious shortage in supply. Further, P6 stated that the construction industry adds to the trade deficit, which means the construction sector imports rather than exports and creates a negative balance of trade.

The interview participants came up with more negative than positive impacts of the foreign reserve crisis. P12 mentioned, *"It is devastating to talk about the negatives only, I wish there were positive impacts as well to talk about"*. Accordingly, the empirical data can be analysed using two main criteria as below.

4.3 THE IMPACT OF THE DEPLETION OF FOREIGN CURRENCY RESERVES ON THE SRI LANKAN CONSTRUCTION INDUSTRY

4.3.1 Negative Impacts

The construction industry heavily depends on raw material importations. All participants strongly elaborated that the restrictions imposed by the government were directly affecting the construction industry, as the industry depends on many imported items. P4, P7, and P8 mentioned that, though some items are not restricted, banks are not supporting payments because of government regulations. Many contractors had to face difficulties due to this issue, as essential items such as cement, steel, aluminium, tiles, and fittings got restricted by the Imports and Exports (Control) Regulations No. 05 of 2022, issued on 9 March 2022, as expressed by P4, P6, P7, P8, P9, P11, P12, and P13. P5, P6, and P14 emphasised that huge price fluctuations were happening in market prices and that the high inflation of materials caused a temporary suspension of projects. Additionally, the rejection of LCs (Letters of Credit) by foreign banks and suppliers led Sri Lanka to impose a 100% cash margin on LCs for over 600 items. Moreover, the unavailability of imported materials creates a significant demand for the available materials in the country, such as tile, cement, and steel. These material shortages, which created an unnecessary demand for certain local items, ultimately led to drastic price increases on the local materials. P8 responded that the new taxation and higher borrowing rates affected the construction industry because many contractors run their projects using loans from commercial banks. On the other hand, construction clients are reluctant to invest in projects due to the high risk in the construction industry, and small-scale construction clients consider saving in banks to be more advantageous to them, said P7. Exchange rate fluctuation impacted the construction industry, both positively and negatively.

Due to the loss of income sources for the government, such as tourism, workers' remittances, and exports, many outstanding bill payments for contractors are on hold for parties. According to the P7, the insufficient reserves as well as rupee components had a big impact on the payments of the large-scale contractors who were engaged in government projects. Therefore, many construction companies had to terminate staff to reduce overhead costs, posing a threat to the currently employed skilled, unskilled, and professional employees, as mentioned by P2, P3, P5, and P13.

4.3.2 Positive Impacts

P4, P5, and P6 stated that with the restrictions imposed on importation, local manufacturing items started becoming highly demanded. P5 mentioned, *"Previously, we were planning to import our tiles, but due to the current scenario, we purchased the necessary materials locally."* P6 stated that "*I wished the local manufacturing was enough to cater to the needs of the industry, but unfortunately, it wasn't."* Due to the unavailability, the local manufacturers have started to expand their production levels and try to accommodate the needs of the industry. P1, P3, and P5 expressed the positive side of foreign currency depletion, as many projects are run by multilateral and bilateral funding or foreign investments, and public-private partnerships created a safe scenario during the crisis period. P1 specifically mentioned that his project was not much affected by the economic crisis as it was foreign-funded. He added that, though the government is unable to do interim payments, the interim payments from foreign clients were not interrupted. Also, he said it benefited because the restricted items to import were supplied by the foreign client. Further, P1 and P4 said that if they are under a foreign client, the payments are done in foreign currency, and due to the increased exchange rates, the contractor benefits from this scenario.

Overall, the interviewees broadly explained how the foreign currency depletion affected directly and indirectly. Some newspaper articles and website authors also confirmed that there are many challenges and effects due to the depletion of foreign currency. Soysa (2022), Fernandopulle (2022), and Hewage (2022) identified that there are critical issues such as rising material costs, payment delays, suspended government projects, difficulty in importing goods, and increased interest rates that the construction industry in Sri Lanka is facing. Thus, the findings from the semi-structured interviews are very much in line with the literature findings.

4.4 ORGANISATIONAL DECISIONS TO MINIMISE FOREIGN CURRENCY DEPLETION IMPACT ON SRI LANKA'S CONSTRUCTION INDUSTRY

According to the project type and organisational capacity, the strategies taken to minimise the impact vary. P14 said that organisational-level decision-making can impact the whole organisation. It can either propel it forward and into success or it can destroy the company's value. P5 mentioned that some organisations were able to support their employees financially as well during the economic crisis. Table 4 shows the actions or the decisions implemented by various construction organisations, which are critically analysed and discussed within this section.

Table 4: Actions and decisions taken at an organisational level

Actions and Decisions	Interviewee
Temporary suspended new construction projects	P7, P12, P13
Stopped importing through Sri Lankan commercial banks	P1
Supply material by international construction clients	P1
Up to 40% increase in the advance payment	P1
Reduce expenses	P4, P6, P10, P12, P13, P14
Termination of employees	P4, P7, P12, P14
Implementing foreign collaboration	P2, P3, P4, P9, P15
Scaling down the capacity	P4
Moving away from the industry	P5
Foreign franchises companies closed down	P5, P15
Pay only basic salaries	P5
Implementing new export areas	P6, P11, P14

Especially, many contractors, as well as clients, have stopped implementing new projects that affect the organisation, said P7, because new projects have many risks with the economic crisis and as the private sector companies do not undertake any project that is not profitable. They are not willing to take any risk regarding any loss of profit, stated P5. With the import restrictions imposed in March 2022, international clients supplied the items, for example, fuel, steel, and sanitary fittings. This minimised Sri Lanka's foreign currency outflow to some extent.

The construction projects have a high percentage of overhead. It is considered an excellent decision implemented at the organisational level to cut down on unnecessary expenses, P12 stated. P12 continued to state that his company started to be more digitalised in the documentation process to minimise the paper usage because Sri Lanka had a period of paper shortages and because it is environmentally friendly too. Moreover, digitalisation at the organisational level improves efficiency.

One of the major negative dimensions that was implemented by many organisations was to terminate staff members to reduce the cost of the overhead of the company, as stated by P4, P7, and P12 participants. P3 mentioned that some organisations only paid the basic salary. P4 said that the organisations have scaled down their operation levels. For example, large-scale construction companies have scaled down their operations to medium-scale projects to avoid any risks. Some organisations move away from the construction industry slowly as there is no profit from the income, said P5.

There were decisions implemented that resulted in positive effects for organisations or the country. According to P2, P3, P4, P9, and P15, there were some organisations that focused on foreign collaborative projects to increase their foreign currency cash flow. In foreign collaborative projects (PPP), the client, according to the agreement, either builds and owns it or transfers it, or operates and transfers it; by doing this, both parties' benefit. The other positive side that P6, P11, and P14 mentioned was that companies have implemented or are trying to implement export areas where foreign income can be generated. Participants suggest that consultancy services and precast materials can be exported. P1 mentioned that contractors increase their advance payment up to 40% as a condition of their agreement so they are able to purchase more materials before further price fluctuations. Furthermore, P1 mentioned the government should intervene in the situation so organisations could be strong in this economic crisis situation.

The actions taken by individual organisations to minimise the impact of the depletion of foreign currency reserves, such as reducing expenses and starting new foreign collaboration projects, can be identified as the most effective decisions because Tang et al., 2010 cited in Cumming (2007) mentioned that one of the primary benefits of the PPP model is that it can save resources in a range of ways. Edkins and Smyth (2006) said that because of private sector participation, government assets, data, and intellectual property can be used more productively, resulting in significant improvements in the quality of public buildings and services.

4.5 GOVERNMENT ACTIONS TO MINIMISE FOREIGN CURRENCY DEPLETION IMPACT ON SRI LANKA'S CONSTRUCTION INDUSTRY

During the interview process, the interview participants expressed dissatisfaction with the level of support received from the government for the construction industry. P15 said that it is not just the foreign reserve issue but also the local currency (LKR) issue in the government that has caused severe problems in the construction industry. P6 added that only the IQSSL (Institute of Quantity Surveyors Sri Lanka) Annual Forum "*Emerging through the crisis*" conducted regarding the crisis situation; other than that, he was not aware of any positive decisions made to stabilise the construction industry during the economic crisis, and he continued to say that the government is discussing only concessionary measures for contractors because the contractors keep pressuring the government to invest in projects during the crisis. P8 declared that first the priority has to be given for the most important projects in the country and said that according to CIOB president Dr. Rohan Karunaratne, Cabinet Ministers granted to reimburse the contractors for price fluctuations that do not exceed 20% of the contract value utilising the Construction Industry Development Authority's (CIDA) Price Verification Formulae. Yet, the overall point of view of the participants was that the support of the government is not up to the expected level. The government introduces a special liquidity facility to the construction sector and to other government suppliers that enables contractors to get loans that are equal to the value of outstanding payments from the government. There are new opportunities implemented by the government to increase foreign employment opportunities and improve the remittance cash flow. The Foreign Employment Bureau and Foreign Employment Ministry conduct several latest skill-related programs and courses that enable Sri Lankans to work overseas. Overall, interviewees had a negative perception of the government, and many weren't satisfied with the actions taken and decisions made by the government. Some pointed out that the government should take responsibility and implement solutions to help the professionals to survive in the industry.

4.6 SUGGESTIONS AND RECOMMENDATIONS TO MINIMISE THE IMPACT OF DEPLETION OF FOREIGN RESERVES

The interviewees of the study stressed different perspectives on the actions taken and decisions made by different parties as presented and discussed in the previous section, and as the last part of the interviews, it was able to obtain the suggestions and recommendations for the construction industry, which are summarised in Table 5.

Table 5: Suggestions and recommendations

Suggestions and recommendations	Interviewee
Foreign funded projects	P1, P3, P5, P8, P10
Should resolve the material unavailability issue	P2, P11, P13
Resolving outstanding payments to contractors by the government	P2
Outsourcing new contracting or consulting overseas projects	P4, P9, P14, P15
Research to find indices	P4
Expand the organisation to other sectors	P5
Development parallel to other countries	P5
Increase production level of raw materials	P6
Value addition in global production and supply chain	P6
Export local manufacturing products and services	P1, P3, P7, P10, P12, P13
Engaging in public-private partnerships	P7, P8

As per Table 5, it is clear that most of the interviewees have stressed that as a nation as well as an industry, the export industry should be focused on improving. P7 and P10 mention that the construction industry can export items such as precast concrete to middle eastern countries or the Maldives, where there is a great demand. Also, P1, P3, P5, P8, and P10 state that it is important to create opportunities for the organisations with relevant capacity to implement foreign-funded projects in Sri Lanka. Many have seen a very positive aspect due to the implementation of foreign-funded projects in Sri Lanka in terms of payment by clients and flexibility to supply materials.

P4, P9, P14, and P15 also spoke about outsourcing facilities and services overseas. P4 stated that most large-scale organisations outsource only 10% of their work, but that this should be increased to 50% at the very least to help the economy. Moreover, P5 said that there are experienced and well-educated professionals in the country, so the government should get the best results from them by creating an atmosphere for them to serve the country. P7 and P8 said improving and adopting Public Private Partnerships in future projects is considered a recommendation because there are many positive outcomes. Expanding the business to other sectors would create a safe environment in a crisis, said P5, and he continued by saying that most importantly, adopting new technologies such as BIM concepts is his suggestion to survive any crisis situation.

The Construction Industry is essential for the national economy, generating a significant portion of GDP and creating employment opportunities. It stimulates the National Development Process through its forward and backward connections, leading to continuous growth (Construction Industry Development, n.d.). A causal relationship between economic growth and construction activity can be postulated, when an economy is booming, construction activity increases. A slowing economy slows down construction, leading to decreased economic growth The government should devise a better plan for making the payments that are expected to be made to the majority of contractors, and the government should perform more research to uncover indices, said P4. P4 also said that preparing for the future should be done at the organisational level, not just at the government or national level. Furthermore, the government should try to solve the issue of shortage of materials, stated P2. According to P6, the Sri Lankan construction industry should improve in manufacturing products used in construction and exporting materials, which increases the production level of the country, and expose itself to international supply chains, which creates international relationships and a marketplace in the industry and improves foreign cashflows. The most important finding of the interview data analysis is that most of the interviewees have great potential and enthusiasm to improve as an industry as well as a nation. These professionals from the construction and financial sectors suggest solutions to overcome or minimise the situation, but they agree that it cannot be done overnight, but with support from the professionals and authorities, challenging situations can be overcome.

5. CONCLUSIONS

This research aimed at investigating the impact of foreign currency reserve depletion on the Sri Lankan construction industry. Three objectives were formulated to achieve this aim, and a qualitative research design was implemented. The literature mainly gave an overview of the current economic crisis and foreign currency depletion in Sri Lanka. The empirical findings established causes of the economic crisis in Sri Lanka, which are the Easter bomb attack in 2019, COVID-19 pandemic, and political dimensions. The causes were further classified into dimensions such as the tourism industry, the lack of export industries, a downward trend of the remittance income, new government policies that resulted in tax reductions and high inflation and loan rates, corruption, and huge external debts.

The construction industry is an import-oriented industry, which got affected due to the depletion of foreign currency reserves. In this study, the negatives and positives of the depletion of foreign currency are discussed as the second objective of the study. The current actions and decisions taken at construction organisation and government levels were discussed as the third and final objective of the study. Organisational and government-level actions and decisions are not at a satisfactory level, as per the evidence suggested by the empirical data, and it was found that most of the construction sector professionals are at risk in their careers, many organisations wind up their operations, and some liquidate the company. On the organisational level, both positive and negative actions and decisions have been made during the economic crisis period. The study proposes that the government of Sri Lanka should take responsibility and act immediately to minimise the impact on the construction industry, as well as that the government and organisations should implement research studies to identify the factors that affect and help overcome a situation like an economic crisis. Additionally, it recommends creating better awareness of the risks and strategies to overcome economic instability in the future. The study was limited to the Sri Lankan construction industry and how it affected the contractor’s party because the participants were professionals employed under contractors.

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THE POTENTIAL OF INDUSTRIAL SYMBIOSIS: AN ANALYSIS OF BARRIERS TO ITS IMPLEMENTATION FOR BETTER WASTE MANAGEMENT IN INDUSTRIAL ZONES IN SRI LANKA

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ABSTRACT

Industrialisation has led to a massive increment in resource consumption and waste generation, which demands improved management strategies for Waste Management (WM), especially in Industrial Zones (IZ). Thus, the application of Industrial Symbiosis (IS) in an IZ is demanded as a solution. It is a collaborative approach in which different industries and organisations work together to create a closed-loop system that maximises resource efficiency, reduces waste, and improves environmental sustainability. Sri Lankan IZs still have not yet established a proper method to manage industrial waste, which has led to heaps of waste. Since IS is an effective and timely solution for this issue, this paper was intended to analyse barriers to the potential implementation of IS for better WM of IZs in Sri Lanka. A qualitative research approach with two case studies were used in this study. A total of 12 interviews were conducted and collected data was analysed using code-based content analysis. The barriers were extracted through the analysis of case findings using an abductive analysis. The empirical findings revealed 34 barriers under six categories, namely economic, organisational, regulatory, technological, risk and information. The higher initial cost, lack of financial ability, competition among participants, unavailability of institutional support, and lack of regulatory incentives for IS initiations were some of the key barriers identified in this study. The knowledge generated through this research can be used by respective industry practitioners to take informed decisions in addressing these barriers, which will be crucial to unlocking the potential of IS in IZ.

Keywords: *Barriers; Industrial Symbiosis (IS); Industrial Waste (IW); Industrial Zone (IZ); Waste Management (WM).*

1. INTRODUCTION

There is an emerging need for a system to recover waste for secondary uses where it lowers the cost of manufacturing, enables efficient use of resources, encourages eco-friendly product designs and ultimately it minimises the environmental and human health issues (Mohamed, 2009). In this context, Industrial Symbiosis (IS) concept is raised as a

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suggestion for waste management (WM) in Industrial Zones (IZs) through resource optimisation. IS enables industries to shift to a circular model where waste generated from one organisation is transformed into another organisation as its feedstock and vice versa (Bocken et al., 2016). IS engages a variety of organisations in different sectors in a network to bring up long-term culture change and eco-innovation through facilitating the creation and sharing of knowledge for novel sourcing of inputs, value adding usage of non-product outputs, and enhancing the efficiency and effectiveness of business and technical processes (Lombardi & Laybourn, 2012).

In the process of facilitating and developing a robust IS network, it is increasingly important to have a greater understanding of barriers applicable to the development as it plays a critical role in the context (Domenech et al., 2019; Paquin & Howard-Grenville, 2012; Södergren & Palm, 2021). The previous research studies identified that the reason for most of the catastrophes in IS projects is due to the inability in identifying the barriers that could arise during the implementation. Hence, despite the abundance of research on IS networks, a gap in the literature could be identified, when it comes to exploring the barriers of implementation of IS networks. This has become a timely requirement in bridging this knowledge gap to boost the successful implementation of IS networks in Sri Lanka. Therefore, this paper aimed at analysing the barriers to the successful implementation of IS networks in IZs of Sri Lanka.

2. LITERATURE REVIEW

2.1 WASTE MANAGEMENT DEFICIENCIES IN INDUSTRIAL ZONES

The phrase "IZ" refers to a vast tract of land that has been subdivided and constructed for the simultaneous use of numerous enterprises, distinguished by shared infrastructure and close proximity of organisations (Chertow, 2000). Rather than solely providing products to consumers, IZs enable a large percentage of employment, community presence, and economic strength (Duflou et al., 2012). Even though, being recognised as most visible morphological form of manufacturing facilities (Sacirovic et al., 2019), IZs also pose challenges due to rapid development including excessive use of resources and increased pollution from industrial activity in the zones.

In IZs, improper and isolated WM procedures cause more environmental problems and spread diseases (Karunasena & Kannangara, 2012). Bandara and Hettiarachchi (2010) have identified environmental consequences of improper waste disposal as unpleasant surroundings, loss of property values, increased flooding possibilities, creating health and safety issues to public, spreading diseases, soil pollution and degradation of other natural resources. Lack of WM knowledge, high transportation cost, negative attitudes, unsatisfactory service from facilitators, lack of labour, communication inefficiencies, poor monitoring of responsible parties, financial issues, outdated strategies, poor legal enforcement for WM, and insufficient investment from government on WM initiatives are identified as main causes for prevailing WM issues in IZs (Karunasena & Kannangara, 2012).

2.2 APPLICATION OF THE CONCEPT OF INDUSTRIAL SYMBIOSIS IN INDUSTRIAL ZONE

IS seems to have found a renewed impetus in the framework of the Circular Economy (CE), a novel approach to sustainability and Sustainable Development (SD) that has been rapidly gaining momentum worldwide (Cecchin et al., 2020). It deliberately engineered the items to be modular, robust, and recyclable, allowing for closed loop metabolism while maintaining the highest possible added value proportion (Fischer & Pascucci, 2017). CE appears to prioritise the economic system while giving direct advantages to the environment and indirect benefits to social aspects (Geissdoerfer et al., 2017). When organisations form part of a metabolism, they collaborate to create IS in which materials and energy withdrawn from one process or organisation can be used for another (Ashton, 2008). In this perspective, IS concept is utilised as the main instrument that assist in reducing industrial reliance on natural resources by expanding waste recovery (Geng et al., 2007; Mohamed, 2009). The same finding was further confirmed in a study by Islam et al. (2016) where they mentioned that IS concept is a key tool, which is used in industrial system which enhance sustainability. Several researchers such as Geng et al. (2007), Van Berkel et al (2009), Chertow et al. (2019) and Shi (2020) highlighted the efforts, which have been taken to develop IS networks in IZs to identify untapped potential of IS. For example, IZs, which are currently practicing IS are visible in Europe, Australia, North America, and Singapore, and planning for new initiatives are taken place in emerging economies like Cambodia, Colombia, China, Egypt, Costa Rika, El Salvador, Morocco, India, South Africa, Peru, Vietnam, and Tunisia as stated by Shi (2020). IZ managers of China have been adopted this concept as an innovative tool for management of industries (Geng et al., 2007). IS networks have been developed by national initiatives in Japan with the aim of revitalising industries (Van Berkel et al., 2009). According to Chertow et al. (2019), an analysis based on 1000 enterprises concludes that 84,000 tons of annual industrial waste (IW), 74,000 tons of annual carbon dioxide emissions, and 22 million litres of daily wastewater have been reduced as a result of IS applications. A vast range of benefits can be acquired by applying IS concept to IZs (Domenéch, 2010). Hence, there is an evidential background for applying IS concept to gain prospect of IW within the IZ.

2.3 BARRIERS TO THE APPLICATION OF THE CONCEPT OF INDUSTRIAL SYMBIOSIS CONCEPT

Barriers can be considered an important attribute of IS networks, which directly affect the success of developing the networks (Islam et al., 2016). Hence, it is important to have considerable concern for barriers in the application of IS concept for WM of IZs. The barriers identified through the literature review are presented in terms of six perspectives, namely, Economic, Technology, Organisational, Regulatory, Risk and Information (Refer to Table 1). According to many authors such as Paquin and Howard-Grenville (2009), Walls and Paquin (2015), Domenech et al. (2019) and Sodergren and Palm (2021), the economic, organisational and information barriers play a vital role in preventing firms from engaging in IS application. As shown in Table 1, higher initial cost and financial incapability were discovered as major economic barriers. When paying attention to the technological aspect, a lack of technical capacity and expertise was identified as the most persistent barrier over other factors by the authors. Diversified and competitive participants and a lack of institutional supports were the critical factors identified as organisational barriers in IS applications. Referring to the regulatory barriers, the main concern raised by the authors was the lack of regulatory incentives for IS initiations (Islam et al., 2016). The summary of the barriers derived from the previous studies is presented in Table 1.

Table 1: Summary of barriers of initiating IS concept

Barrier category	Barrier factor	Reference
Economic barrier	Initiation cost, transport, and logistical cost Adaptation cost to procedures, transaction cost Lack of financial ability Unknown cost-benefit ratio	[1] [2] [3] [4] [5] [6]
Technology barrier	Lack of technical capacity and expertise Rapid technological change Issues relating to waste quality Lacking infrastructure and logistical integration	[2] [3] [5] [6]
Organisational barrier	Power, status, lack of trust of participants Lack of time and spatial facilities Competition among participants Lack of environment concerns and management support Resistant to change Lack of collaboration due to isolation Lack of institutional support	[1] [2] [3] [6] [7]
Regulatory barriers	Restrictive regulations for establishment and operation Lack of regulatory incentives Difficult approval processes Conflicting regulations	[1] [6] [7]
Risk barriers	Risk and uncertainty of investments, system performance, and outcomes Risk of inter-dependency	[1] [2] [7]
Information barriers	Poor awareness on the concept Lack of information on synergistic possibilities Lack of trainings and technical information Lack of management of operational information Lack of information sharing mechanisms Lack of information of job roles and responsibilities	[2] [6] [7] [8]

[1] Walls & Paquin, 2015; [2] Domenech et al., 2019; [3] Paquin & Howard-Grenville, 2009; [4] Islam et al., 2016; [5] Bossilkov et al., 2005; [6] Södergren & Palm, 2021; [7] Domenéch, 2010; [8] Chertow, 2007

However, when it comes to the Sri Lankan context, barriers of IS network development have not been discussed in literature yet. Thus, in bridging this knowledge gap, this paper intends to discuss the barriers to the IS network development in IZs. The next section discusses the research process adapted in bridging this knowledge gap.

3. METHODOLOGY

This study intends to analyse barriers to the successful implementation of IS networks in IZs of Sri Lanka. Accordingly, the research question was developed as follows.

> ***RQ:*** *"How could barriers influence the successful implementation of IS networks in industrial zones?*

Yin (2009) suggested that a research approach has to be selected based on the type of research question, the extent of control an investigator has over actual behavioural events and the degree of focus on contemporary or historical events. Since, this research followed an in-depth exploration of the contemporary phenomenon within its real-world context, with a "How" type of research question, a case study research strategy could be justified. A multiple-case design was selected as this research area is broad and not limited to a certain industry as it focuses on IZs where variety of industries are operated with "application of IS concept for WM in IZs" as the unit of analysis.

Yin (2009) recommended that the number of cases should be decided based on literal replications and theoretical replications expected through the study. Following such argument and the robustness of the data collection techniques used with proper data triangulation, similar two IZs were selected as the cases expecting literal replications. Further, the high data saturation experienced during data analysis justified the adequacy of the number of cases selected. The profile of selected cases is given in Table 2.

Table 2: Profile of case studies

Case	Area (in acres)	Number of Factories	Number of workers	Main categories of factories operated	Estimated waste generated per year
A	531	86	39,000	Hi-end apparel, rubber production, electronic production	21,328 tonnes
B	450	77	26,000	Fabric production, rubber productions, chemical production, printing services, and ceramics	38,487 tonnes

Referring to both cases, "handing over to scavengers" and "co-disposal" are commonly used WM strategies where the ultimate disposal mechanism is questionable. Moreover, "landfilling" and "incineration" are practiced as waste management strategies, which have a huge effect on biodiversity. In addition to that, "3R strategy", "life cycle assessment", and "green purchasing" are used as WM strategies, which cover only a small portion of waste generated at IZs. Only a few organisations adhere to advanced strategies such as "cleaner products", "eco-designs" and "extended producer's responsibility" for WM. A higher portion of waste generated at IZs is being open dumping, open burning, or incinerated. These inappropriate WM practices at IZs are a huge threat to the environment and create public nuisance and severe health issues.

A total of 12 semi-structured interviews were conducted, with six personnel from each case (Refer to Table 3). The number of interviews was limited by the fact that there are no experts on IS network development since practical applications have not been implemented yet in Sri Lanka. The interview guideline focused on 27 barriers identified through the literature review. Respondents were requested to elaborate their answers based on their current exposure to the barriers.

Table 3: Respondent's details

Case	Respondent Code	Years of experience	Designation
A	A1	6 years	Senior Manager - Environmental Sustainability
	A2	5 years	Assistant Manager - Sustainability
	A3	3 years	Executive - Sustainability
	A4	3 years	Executive - Compliance and Sustainability
	A5	3 years	Executive - Environmental Sustainability

Case	Respondent Code	Years of experience	Designation
	A6	4 years	Executive - Environmental Safety & Health
B	B1	4years	Executive - Compliance and Sustainability
	B2	5 years	Executive - Environmental Safety & Health
	B3	3 years	Executive - Compliance and Sustainability
	B4	5 years	Factory Engineer - Head of Engineering
	B5	4 years	Assistant Manager - In-charge of Operation
	B6	5 years	Manager - Facilities and Administration

Data analysis was conducted using code-based content analysis. It is vital to have an in-depth understanding of the barriers as it essential to mitigate them to ensure successful application of IS network in IZs. However, so far, there has been no systematic academic analysis of the application of IS in IZs in Sri Lanka. Thus, to investigate barriers in depth, this paper applies the categorisations identified through literature review (Refer to Section 2.3). Similar categorisations have been widely used in previous studies (Domenech et al., 2019; Paquin & Howard-Grenville, 2009; Södergren & Palm, 2021; Walls & Paquin, 2015). According to Sodergren and Palm (2021), the use of such categorisations provides a multifaceted approach to assess big-picture forces for a better understanding of the barriers in a broader view. The barriers were extracted through an analysis of case findings using an abductive analysis. Furthermore, the findings unveiled an inter-relationship among certain barriers, resulting in synergistic effects. To illustrate this relationship, a cognitive map was developed.

4. CASE STUDY FINDINGS

Case study findings are discussed and presented under the five subsections: technological barriers (Section 4.1), economic barriers (Section 4.2), organisational barriers (Section 4.3), regulatory barriers (Section 4.4), risk barriers (Section 4.5), and information barriers (Section 4.6).

4.1 TECHNOLOGICAL BARRIERS

Findings generated through the case study analysis revealed that IS initiatives demand extensive technological knowledge and applications for their operations. Table 4 shows the technological barriers of IS network development.

Table 4: Summary of technological barriers

Code	Barrier
T/B1	Lack of technical knowledge and expertise
T/B2	Rapid technological change
T/B3	Issues relating to the quality of the waste
T/B4	Lacking infrastructure and logistical integration
T/B5	**Lack of utilising advanced equipment and machineries***

T/B – '**T**echnological/**B**arrier'
Note: ***Findings that are identified only from the analysis of cases

Hence, lack of technical knowledge and expertise (T/B1) can limit the involvement of participation in the network. Further, rapid technological change (T/B2) is a common barrier where the technological applications tend to be outdated soon with innovative technologies. Thus, organisations may struggle to keep up with the latest technologies, hindering their ability to participate effectively in the IS network. Issues related to the quality of the waste (T/B3) can be emphasised as another devastating barrier in technological aspect. It was witnessed by A6 by asserting that *"inputs of organisations need to be in expected level of quality where unsatisfactory quality conditions* function *as a barrierwithin IS network"*. Moreover, lacking infrastructure and logistical integration (T/B4) exerts limitations on capacity of the IS network, which is a barrier for operations and expansion of the network. More interestingly, with the application of IS, the process required the advanced equipment and machineries to be used. Unfortunately, it was proved that IZs and the participant are lack of utilising advanced equipment and machineries (T/B5). It has been proven that organisations with limited financial resources are unable to allocate funds for technological advancements, which include provisions for infrastructure, equipment, machinery, and hiring expertise to manage the processes (refer Code E/B3 and E/B4).

4.2 ECONOMIC BARRIERS

A summary of economics barriers of IS network development is listed in Table 5.

Table 5: Summary of economic barriers

Code	Barrier
E/B1	Initial cost, transport, and logistic cost
E/B2	Adaptation cost to new procedures or transition
E/B3	Lack of financial ability
E/B4	**Lack of fund allocation***
E/B5	Cost-benefit ratio

E/B – '**E**conomic/**B**arrier'

Note: ***Findings that are identified only from the analysis of cases.

Since all the required resources should be planned for new initiatives and transition to newly established set up to match the IS network operations including required infrastructure, transportation, equipment, and machineries (refer Code T/B4 and T/B5), it incurs huge cost to organisations. It entitles to considerable amount of initial cost, transport, and logistic cost (E/B1), cost of adaptation to new procedures or transition (E/B2) at once which prevents the entry of organisations to IS network. Collaboration of above both barriers may not only lead to limited resources available for investment in IS initiatives but also strain the financial resources of organisations, making it challenging for them to undergo the necessary changes and participate in the IS network. As expressed by A1 and B4, lack of financial ability (E/B3) and lack of fund allocation (E/B4) are similar economic barriers of IS in which organisations with lower financial position would not participate in this type of massive initiation. Further, organisations would like to have a demonstrable return on their project investments, which is also completely similar for IS initiatives. Thus, not having clearly defined cost-benefit ratio (E/B5) may restrict organisation from accessing the IS network.

4.3 ORGANISATIONAL BARRIERS

Since the concept of IS is novel to Sri Lanka, institutional support must be at its maximum to ensure the initiation and operation of the network. However, such kind of an assurance cannot be expected in Sri Lanka as stressed by respondents.

A summary of the organisational barriers of IS network development is listed in Table 6.

Table 6: Summary of organisational barriers

Code	Barrier
O/B1	Lack of institutional support
O/B2	Power, status, lack of trust of participants
O/B3	Competition among participant
O/B4	Lack of collaboration due to isolation
O/B5	**Conflicting participant***
O/B6	Lack of time
O/B7	**Lack of knowledge on IS concept ***
O/B8	Lack of environment concerns and management support
O/B9	Resistant to change
O/B10	**Lack of employee engagement on new processes***

O/B – '**O**rganisational/**B**arrier'

Note: ***Findings that are identified only from the analysis of cases.

According to the findings, unavailability of institutional support (O/B1) can be proclaimed as a major barrier to IS network development where it limits the progress and sustainability of the network, making it difficult to gain momentum and secure resources. Moreover, the lack of institutional support may stem from inadequate regulatory incentives (refer Code R/B2) and a lack of proper attention to IS-oriented regulations (refer Code R/B3), which in turn limits the encouragement for initiation. Power, status, lack of trust of participants (O/B2), competition among participants (O/B3), lack of collaboration due to isolation (O/B4), and conflicting participants (O/B5) were identified as few of other organisational barriers which limit the formation of strong relationship among participants in an IS network. Competitiveness and a preference for isolation may prevent the effective exchange of resources and limit the overall efficiency and effectiveness of the network. On the other hand, the presence of conflicting participants, who have diverging interests or incompatible objectives, can disrupt the smooth functioning of the IS network by interrupting decision-making, resource sharing, and the achievement of collective goals. B6 highlighted that *"individual concerns of participants such as status, power, competition and trust may affect the formation of linkages in an IS network where it limits the formation of linkages, and it affects the operation of the network"*. Lack of time (O/B6) is another organisational barrier to IS network development. B1 stated that *"higher workload on organisations may not spare time to manage operations of IS network, which reduces their involvement in the network"*. Lack of knowledge on IS concept (O/B7) was pointed by the respondents as an organisational barrier where A2 stated that *"lack of knowledge on benefits of the application and possibilities of the application prevents the participants from obtaining maximum output* *of the IS network"*. It was proved that without a clear understanding of the concept and its advantages, organisations may miss opportunities for resource optimisation and waste management. When examining the factors contributing to a lack of knowledge, it was discovered that insufficient training and technical expertise (refer Code I/B3) as well as a deficient knowledge sharing mechanism (refer Code I/B5) could be highlighted. Addition to those barriers, lack of environment concerns and management support (O/B8), resistant to change (O/B9) and lack of employee engagement on new processes (O/B10) were also identified as other organisational barriers. However, as believed by A1 and B4, both the barriers; O/B8 and O/B9 cannot be accepted as barriers where prevailing industrial system forces to consider on environmental facts as well it keeps on adapting to rapid changes.

4.4 REGULATORY BARRIERS

A summary of regulatory barriers of IS initiation are listed in Table 7.

Table 7: Summary of Regulatory Barriers

Code	Barrier
R/B1	Restrictive regulations for establishment and operation
R/B2	Lack of regulatory incentives
R/B3	**Not having proper concern on IS oriented regulations***
R/B4	Difficult and delayed approval processes
R/B5	Conflicting regulations

R/B – '**R**egulatory/**B**arrier'

**Note: ***Findings that are identified only from the analysis of cases

Restrictive regulations for establishment and operation (R/B1) of IS network prevent facilitators from involving in IS initiatives. This fact was further emphasised by A4 where he stated that *"there are restrictions to the initiation of IZs where several requirements should be adhered"*. It became evident that such regulatory restrictions may limit the opportunities for organisations to engage in IS activities. Lack of regulatory incentives (R/B2) and not having proper concern on IS oriented regulations (R/B3) are co-related barriers of IS network development where no encouragement is made for initiations. The opinion became sustain through the empirical study where A1 who has 6 years of experience in environmental sustainability emphasised that *"unavailability of IS oriented regulations and guidelines is a major barrier for initiations"*. The absence of specific regulations and guidelines related to IS initiatives hinders the clarity and guidance required for organisations to navigate and comply with relevant standards and practices. Difficult and delayed approval processes (R/B4) in Sri Lankan government is another barrier to initiations of IS that vital to be made a discussion. It made sense where B3 specified that *"government institution's processes are much complex and not timely where it discourages people to hands in to it"*. Furthermore, it can be argued that the initiation process may experience delays and difficulties due to the restrictive regulations governing establishment and operation (R/B1). Addition to those, conflicting regulations (R/B5) was identified as regulatory barrier where B1 stated that *"IZs are govern by BOI where regulations of other related institutions are overrun by BOI regulations which may arise conflictions in IS application"*.

4.5 RISK BARRIERS

A summary of risk barriers of IS network development is listed in Table 8.

Table 8: Summary of Risk Barriers

Code	Barrier
Ri/B1	Risk on uncertainty of investment, system performance and outcomes
Ri/B2	Risk of inter-dependency
Ri/B3	**Risk of changes in demand and supply by participants***

Ri/B – '**Ri**sk/**B**arrier'

Note: ***Findings that are identified only from the analysis of cases.

Risk and uncertainty of investments, system performance, and outcomes (Ri/B1) was identified as a major barrier where participants refuse to involve in IS projects. A3 stated that *"there are not any IS initiated IZs in Sri Lanka where the return on investment is not visible and also the performance of the application is not clear, which negatively affects the mindset of organisations"*. Hence, participants in IS projects may hesitate to get involved due to the perceived risks and uncertainties associated with investments, system performance, and expected outcomes. Risk of inter-dependency (Ri/B2) and risk of changes in demand and supply by participants (Ri/B3) are co-related barriers as identified through the study. This risk can hinder collaboration and resource sharing, as organisations may be hesitant to depend on others for their business operations. This barrier limits the formation of strong partnerships and inhibits the smooth functioning of the IS network. On the other hand, the risk of changes in demand and supply by participants can create uncertainties and challenges within the IS network. Organisational behaviour and shifts in market demand can impact the availability and reliability of resources exchanged within the network. These changes may disrupt the balance and effectiveness of resource utilisation, affecting the operational stability and efficiency of the IS network. It became apparent through the findings that organisations refuse to rely on other organisations where the behavioural changes of organisations may interrupt the business operations of dependent organisations.

4.6 INFORMATION BARRIERS

A summary of information barriers of IS network development is listed in Table 9.

Table 9: Summary of Information Barriers

Code	Barrier
I/B1	Poor awareness on the IS concept
I/B2	Lack of information on synergistic possibilities
I/B3	Lack of training and technical information
I/B4	Lack of management of operational information
I/B5	Lack of information sharing mechanisms
I/B6	Lack of information of job roles and responsibilities

I/B – '**I**nformation/**B**arrier'

Note: *Findings that are identified only from the analysis of cases

Poor awareness on the IS concept (I/B1) is identified as a barrier where optimum output of application may not be obtained as a result. B5 specified that *"poor awareness on the scope, applicable possibilities and areas of applications of IS concept may lead to ineffective performance of the network".* Lack of information on synergistic possibilities (I/B2) prevent formation of exchange links. Organisations may not be aware of the potential synergies and resource-sharing opportunities, limiting their engagement and collaboration in the network. Lack of training and technical information (I/B3) leads to outdated processes within the network. This situation can occur due to a lack of technical knowledge and expertise (refer Code T/B1). On the other hand, organisations may face challenges in initiating training programs or improving the relevant expertise within their organisation, primarily due to limited financial resources (refer Code E/B3) and inadequate fund allocation (refer Code E/B4). Lack of management of operational information (I/B4) affects the smooth operation of the network. B2 stated that *"lack of management information creates handling difficulties and interruptions to operations".* It indicates that clear and effective information management systems are essential for facilitating collaboration and knowledge sharing among participants. Lack of information sharing mechanisms (I/B5) leads to the isolation of participants knowledge. B4 stated that *"isolation of knowledge negatively affects the main purpose of IS initiation".* It prevents the exchange of valuable insights and experiences impeding the collective learning and development of the network. Lack of information of job roles and responsibilities (I/B6) is another information barrier to IS network development, which leads to deficient performance of the network due to unclear expectations and responsibilities that can create confusion and inefficiencies in the coordination and execution of tasks.

5. DISCUSSION

By reviewing the existing literature, a total of 27 barriers were identified. However, these findings were in general and not specific to the Sri Lanka. These barriers seem to be possible for Sri Lanka as per case study findings. Paquin and Howard-Grenville (2012) stressed that higher initial cost and financial incapability are major barriers that hinder the successful application of the IS network, falling under the economic category. The same finding was discovered through the analysis of case study findings. Diversified and competitive participants and lack of institutional supports are some of the main barriers identified as the organisational barriers in IS application (Domenech et al., 2019; Paquin & Howard-Grenville, 2009; Walls & Paquin, 2015). It became apparent through the analysis of case findings that though there is an impact from competitive participant, unavailability of institutional support can be highlighted as most pressing barriers to IS initiation in Sri Lanka. Referring to the regulatory barriers, the main concern was given by the authors on lack of regulatory incentives for IS initiations. Precisely, the same finding was derived within the case study.

Additionally, seven barriers including one technological (refer code T/B5), one economical (refer code E/B4), three organisational (refer codes O/B5, O/B7 and O/B10), one regulatory (refer code R/B3) and one risk barrier. These barriers were specific to the context of Sri Lanka. The lack of interest and involvement from various stakeholders, including the government and institutional support in the IS concept in Sri Lanka, has contributed to the emergence of these barriers, as evidenced by the case study findings. Unfortunately, it may cause lack of awareness or enforcement of IS-oriented regulations in Sri Lanka. Thus, organisations may not feel compelled or obligated to embrace IS practices. Moreover, the uncertain market conditions and changes in demand and supply patterns in Sri Lanka, coupled with limited funding, may make participants hesitant to engage in IS arrangements. These factors may hinder industries from implementing such novel processes, despite their potential to provide valuable inputs to the organisation. Further, the results of data analysis reflect to determine the inter-relationship among few barriers itself (Refer to Figure 1). It was observed that not all barriers are interconnected; however, a meaningful relationship can be observed among certain barriers, which mutually influence each other, leading to a synergistic output. (refer code Ri/B3) barriers were solely identified through the case studies.

6. CONCLUSIONS

IS has gained increasing attention in recent years as a promising solution to address the challenges of resource depletion and environmental degradation. While IS has the potential to deliver significant economic, environmental, and social benefits, there are several barriers that may hinder its adaptation. However, a better knowledge of barriers is vital to have a wide range of identification about the negative influence which leads to restricting the IS initiation in the IZ. Thus, this paper aimed to explore barriers to the successful implementation of IS networks in IZs of Sri Lanka. Altogether, 34 barriers, including 05 technological, 05 economic, 10 organisational, 05 regulatory, 03 risk, and 06 information barriers were identified throughout the study. All barriers were discussed with reference to the Sri Lankan context. The higher initial cost, lack of financial ability, competition among participants, unavailability of institutional support, and lack of regulatory incentives for IS initiations were some of the key barriers identified in this study. Overall, addressing these barriers will be crucial to unlocking the potential of IS in IZ and realising its economic, environmental, and social benefits.

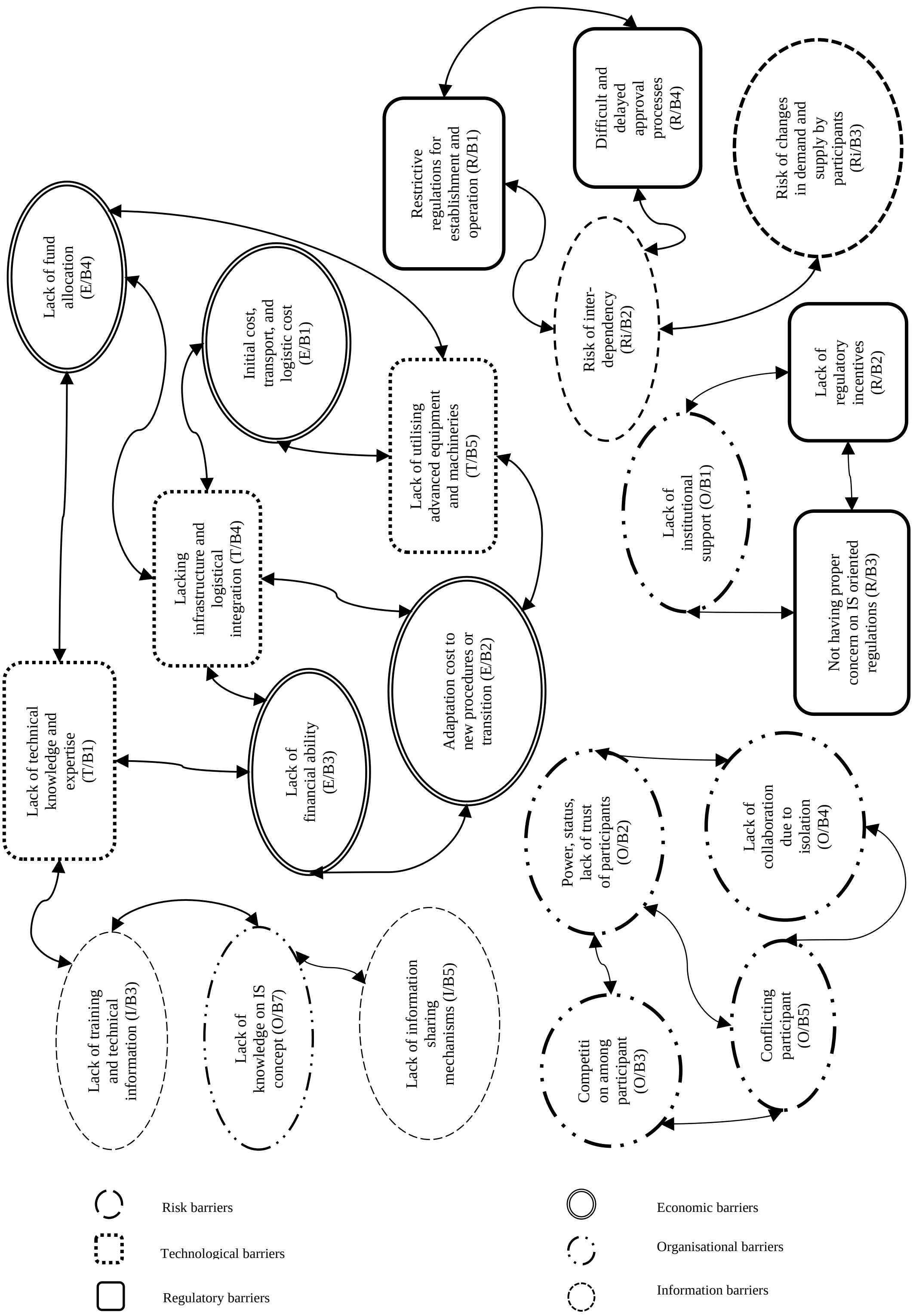

Figure 1: Inter-relationship among barriers

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THE USE OF PROJECT GOVERNANCE MODES TO MINIMISE CONTRACTORS' OPPORTUNISTIC BEHAVIOUR

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ABSTRACT

The nature of the contractual relationship between the contractor and the client creates opportunities for opportunistic behaviour (OB) on the part of the contractor, which can result in project delays, cost overruns, and quality issues. Project governance (PG) is a set of processes, policies, and procedures that aim to ensure the effective management and control of projects. It was identified that PG helps to minimise different issues related to construction projects where different stakeholders are involved. The use of trust and formal control as PG modes in the global construction industry is well-established. However, there is a lack of research specifically focusing on the appropriate PG modes to minimise the effects of Contractors' Opportunistic Behaviour (COB) in the Sri Lankan construction industry. The purpose of this paper is to examine the use of PG modes to minimise COB. To address this research gap, a qualitative research approach was adopted in this study. A comprehensive literature review was conducted to gather knowledge and theories about PG modes and COB. Furthermore, case studies were conducted to investigate the synergy between the identified PG modes and COB management in the Sri Lankan context. These case studies involved real-world construction projects in Sri Lanka, where the researchers' collected data through interviews. By analysing the findings of the literature review and case studies, this study aims to provide insights into the suitable PG modes that can be used to minimise the effects of COB in the Sri Lankan construction industry. The findings suggest that PG modes can be effective in COB. The use of a hybrid mode, for example, can create a partnership-like relationship between the client and the contractor, which promotes cooperation and trust while having some contractual obligations. Similarly, the use of a formal control mode, which involves the use of detailed contracts, can help to clarify the rights and obligations of the parties involved and reduce the likelihood of OB. Overall, the paper highlights the importance of PG in managing contractual relationships and minimising OB. It provides practical recommendations for clients and other stakeholders on how to select and implement appropriate PG modes to ensure successful project outcomes.

Keywords: *Client; Construction Industry; Contractors' Opportunistic Behaviour (COB); Project Governance (PG).*

1. INTRODUCTION

Construction activities involve uncertainty, exposure to high-risk and imperfect information, overcoming the need for quick decisions and an orientation towards conflict can be identified in the industry (Lau & Rowlinson, 2009). Despite the huge contribution

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to countries' economic development, construction projects are characterised by low productivity due to the complicated interaction between various parties involved in a project that eventually leads to the occurrence of delays in different construction operations where cost and time overruns occur (Hossain et al., 2019). Zhang and Qian (2017) mentioned that relationships between the owner and contractor have a major impact on project performance in the construction industry.

Opportunistic behaviour (OB) is identified as one of the common behavioural phenomena in social-economic activities (Brookes et al., 2015). OB could gently increase under the circumstances of an environment with dissimilar information (Liu et al., 2016). Contractors' opportunistic behaviour (COB) is outlined as the contractor practising private control, withholding or distorting data, withdrawing commitments or pledges, shirks obligations, and violate specific agreements, and stretching to get unilateral returns at the expense of the owner (Lu et al., 2016). Various parties have different tolerance limits for OB (Das & Kumar, 2009). Besides, Qian and Zhang (2018) explained that tolerance of OB explains, why owners with different administrative focuses have different tastes in governance modes to reduce the COB. Project governance (PG) is identified as an oversight function which is aligned with the organisation's governance model and encompasses the project life cycle (Alie, 2015). It is found that trust and formal control are two regular PG modes that can be utilised to execute governance in projects, which are widely viewed as reasonable techniques that can decrease OB to a certain level (Meng, 2015). There are number of gaps that are still not filled related to PG and there is a necessity to identify the use of PG to reduce the effect of COB to maximise the project performance and identify the factors that directly affect the COB.

2. LITERATURE SYNTHESIS

2.1 THE OPPORTUNISM AND THE OPPORTUNISTIC BEHAVIOUR

According to Loosemore and Lam (2004) when people live through unreliable times and subsequently, individuals are edgy and prepped for the risks that may occur and acting with caution in this manner it prompts opportunism within individuals. It is due to institutionalising caution, the precautionary principle imposes limitations, offering security but lowering expectations, restricting growth, forestalling experimentation, and changing the very premise of OB. Opportunistic behaviour is considered as an act or behaviour of partnership motivated by the maximisation of economic self-interest and occasioned the loss of the other partner which is very much like the opportunism definitions (Luo, 2006). The author classifies OB into strong form OB, which breaches contracts, and weak form OB, which violates ethics also mentioned as relational norms which are not written in contracts. Both forms of OB increase conflicts increase the difficulties of coordination (Luo, 2007) and may lead to impromptu termination of contracts and relationships (Das & Rahman, 2010). It is important to identify the effect on the construction industry by the COB.

2.2 CONTRACTORS' OPPORTUNISTIC BEHAVIOUR AND ITS EFFECTS ON THE CONSTRUCTION INDUSTRY

OB in construction can result in production disruptions, disturbance to team orientation (Fong & Lung, 2007), and negatively changing economic outcomes (Nunlee, 2005). According to Das and Rahman (2010), contractor opportunism can be characterised as the conduct of the contractor that is inspired to seek after personal matters at the expense of owners. Luo (2006) mentioned COB as the contractor's acts of exercising private control, concealing, or altering information, disengaging from commitments or promises, avoiding obligations, and breaches explicit or implicit agreements, trying to earn for themselves at the expense of the owner. Lu et al. (2016) identified that uncertain events happen outside the project and the complex nature of construction projects as the forerunners of opportunism. Losses that arise from OB are less than the cost of premature termination, thus the party specially the client may endure and acknowledge the other party's OB to maintain a strategic distance from a more noteworthy misfortune (Chang & Qian, 2015). Table 1 provides different effects on the construction industry identified by the researchers related to COB.

Table 1: Effects of opportunistic behaviour on the Construction Industry

Reference	Effects of opportunistic behaviour
(Chang & Chen, 2016)	• Bid opportunistically by offering a low price to win. • Renegotiate for compensation during the execution phase.
(Das & Teng, 2001)	• Leads to not keeping promises and misinforming stakeholders.
(Zhang & Qian, 2017)	• Leading to the breaching of contractual clauses. • Shirking obligations. • Illegal subcontracting and collusion. • Conflict with relational norms. • Disengaging from commitments or promises. • Taking advantage of contractual loopholes. • Deliberately ignoring design errors in drawings and specifications to profit from payment recovery for re-work or alterations.
(Pang et al., 2015)	• Use renegotiation to amend clauses in the signed contract.
(Arsecularatne & Sandanayake, 2021)	• Leading to time and cost overruns. • Affecting the quality of the final output • Project objectives are not achieved. • Dissatisfaction occurs between parties. • Contractors will be blacklisted. • Claims will be increased. • Demotivate the clients in investing. • Affect all other stakeholders. C • Leads to mistrust between all parties

Construction projects require various professionals and their skill sets and collaborative relationship among members in different professions (Li et al., 2019). Better project performance depends on the good relationships between parties (Lau & Rowlinson, 2011).

2.3 CRITICAL FACTORS AFFECTING PROJECT PERFORMANCE AND ITS RELATIONSHIP WITH CONTRACTORS' OPPORTUNISTIC BEHAVIOUR

Different ethical and moral challenges affect the construction industry, which includes questionable contractor claims, collusion, and lack of commitment by contractors. This directly affects the project performance, and contractor competitiveness and it sometimes leads to business failure (Ho, 2011). Phelps and Reddy (2009) considered not keeping promises, misinforming stakeholders can affect project performance negatively. The following are the key critical factors affecting the project performance.

2.3.1 Client Focus and Contractors' Focus

The motivational direction of individuals or parties would indicate the interpretations of parties' goals, behaviours, and actions (Das & Kumar, 2011). In addition, the authors mentioned that the owners' motivational orientation refers to the perspective that an owner takes when entering into a contract, in terms of maximising success or minimising failure. A large portion of the organisational decisions is made by the individuals of the top management group that overwhelmingly has the ability and power to deal with the members of the organisation (Qian & Zhang, 2018).

Contractors mainly focused on achieving the least possible costs (Kalsaas et al., 2018). Haupt and Whiteman (2004) identified that the competitiveness of the industry has made contractors focus on maximising revenue and completing work within the briefest conceivable timeframes. Based on the client's focus or the contractors' focus, the contractor's behaviour will be changed.

2.3.2 Risk and Uncertainty, Contractual Complexity and Project Complexity

Risks can be identified as negative and positive, but most contractors are concentrated on the risks that affect them negatively (Hartono et al., 2014). The potential losses related to risks may prompt the OB of contractors to mitigate or recover (Das & Teng, 2001). Construction projects, for the most part, depend on contracts to motivate and regulate the behaviours and practices of the participants (Turner, 2004). A contract, as a formal governance instrument, regulates each party's rights and duties, responsibilities, application of intellectual property and breaches, coordination between the parties, and mitigation methods for unforeseen events (Schepker et al., 2014). The construction industry has seen fast development in projects of increasing size and complexity (Luo et al., 2017). The project complexity is caused by internal and external environmental aspects, the stakeholders, the tendering procedure, and procurement law (Griffioen, 2017). Based on risk and uncertainty, contractual and project complexity, the contractor's behaviour will be changed.

2.4 BENEFITS OF MINIMISING CONTRACTORS' OPPORTUNISTIC BEHAVIOUR

The factors that affect the COB namely are contractors' focus on revenue maximisation, external uncertainties, contractual complexity, and dynamic complexity (Arsecularatne & Sandanayake, 2021). Opportunism has major negative impacts on the relationship between the owner and contractors and the general procedure of a construction project (Lu et al., 2016). Furthermore, the authors mentioned that due to the major impacts of opportunism, researchers have concentrated on the most proficient method to limit it. It was identified that because of minimising COB, benefits such as narrowing the scope of OB (Anderson & Dekker, 2005; Arsecularatne & Sandanayake, 2021), legal and economic consequences taken into consideration by contractors (Arsecularatne & Sandanayake, 2021; Jap & Ganesan, 2000), increase contractors' sensitivity to their duties and responsibilities (Arsecularatne & Sandanayake, 2021; Lu et al., 2016) and parties might become flexible (Arsecularatne & Sandanayake, 2021; Yilmaz et al., 2005) can be achieved.

2.5 MINIMISING CONTRACTORS' OPPORTUNISTIC BEHAVIOUR USING PROJECT GOVERNANCE

In the construction sector, one of the essential explanations for project failures is the unequal and hazy division of risks between client and contractor (Rahman & Kumaraswamy, 2002). Academics and practitioners attempt to discover powerful techniques to forestall COB in the last decades (Lu et al., 2015). The most common methods were project management, project alliance, and PG (Arsecularatne & Sandanayake, 2021).

PG aims to guarantee a steady and foreseeable delivery of projects with the management of parties' behaviour (Müller et al., 2013). Too and Weaver (2014) identified PG as a system that exists at an elevated level and gives oversight of, the project management system. Two main types of governance modes have been identified as important to inter-organisational relationships in the construction industry (Zhang et al., 2016). Trust and formal control (FC), as two typical PG modes, are highly considered as better methods that can control OB to a considerable amount (Meng, 2015). FC and trust can be said as contractual governance and relational governance (Lu et al., 2015).

It was identified that the COB harm construction projects, mainly related to the performance of the projects. Reducing COB would provide benefits such as transparent parties in a contract as well as parties becoming more flexible. Hence, PG can be utilised to reduce the impact of COB on the success of a project. The research of the literature suggests that there are not many materials available concerning using PG to reduce COB in Sri Lanka's construction industry. It is crucial to consider the impact of employing PG to reduce COB in the Sri Lankan construction industry.

3. RESEARCH METHODOLOGY

Tan (as cited in Rodrigo & Perera, 2016) has identified research design as a technique for changing a research problem into a conclusion. This research design is surrounded by background study, comprehensive literature synthesis, data collection method and analysis of the data collected through data collection. Creswell (2014) mentioned three approaches to research quantitative, qualitative, and mixed methods. The author further mentioned qualitative approach incorporates gathering data and information through raising questions and strategies comprehensive of the researcher making interpretations of the data.

This study aimed to investigate the PG modes that can be used to minimise the effects of COB. Hence, to achieve that aim, investigating COB, factors leading to COB, different PG modes used in the Sri Lankan construction industry and the relationship between COB and the choice of PG mode by the client needed to be done. To suggest appropriate PG modes to the local environment, case studies were required to get in-depth opinions of industry practitioners who had experience in PG. However, because PG was a recent breakthrough, there were very few projects in Sri Lanka's building sector that used this idea. This resulted in a small sample size being available. Furthermore, a thorough analysis was required because the information and data collected were mostly based on the practitioners' opinions. Consequently, a qualitative method was required for the study. A thorough examination of the literature was done to examine OB, COB, PG, and customer preferences for PG approaches to reduce competitors' OB. The literature review was built using journal articles, books, conference proceedings, and unpublished dissertations. The research's primary goal is to assess the applicability of PG modes to reduce COB in the Sri Lankan construction sector. The case study analysis was chosen because it was difficult to obtain literature on PG. There were four projects total, with two having a public client and the other two having a private client. Because the study is based on a qualitative methodology, semi-structured interviews were used to gather qualitative data. The data analysis method used was content analysis.

4. RESEARCH FINDINGS AND ANALYSIS

Four construction projects for buildings were chosen as samples. Formal control mode was used to govern Cases A and B, trust was primarily used to govern Case C, and a combination of two modes was used to govern Case D. Two projects were owned by the public institute, while the other two were privately owned. Only Case C of the other three scenarios lacked a consultant for their chosen project. In order to determine the applicability of each mode to the Sri Lankan environment and to determine whether employing various PG models is practical and advantageous, cases of both types were chosen. Also, selecting between public and private projects results in a variety of viewpoints about the PG approach taken in each situation. A brief description of the four cases has been shown in Table 2 and Table 3 provides a brief description of the respondents.

Table 2: Details of selected cases

	Case A	Case B	Case C	Case D
Nature of the project	Building Construction	Building construction and renovation	Building Construction	Building construction including hotels and apartments
Project duration	9 months	6 months	2 Years	2 Years
Tendering method	Open tendering	Open tendering	Direct negotiation	Direct negotiation
The standard form of contract	SBD 2	SBD 2	SBD 2	FIDIC
Governance mode used	Formal Control	Formal Control	Both but mostly Trust	Combination of both Trust and Formal Control equally

Table 3:Details of respondents

Case	Respondent	Type of the organisation	Ownership of the organisation	Designation	Industry experience
Case A	Respondent 1 (RA1)	Client	Public	Chief Manager Technical Services	30 years
	Respondent 2 (RA2)	Consultant	Private	Chief Architect	12 Years
	Respondent 3 (RA3)	Contractor	Private	Project Manager	10 Years
	Respondent 4 (RA4)	Contractor	Private	Project Quantity Surveyor	8 Years
Case B	Respondent 1 (RB1)	Client	Public	Assistant Director Construction	5 Years
	Respondent 2 (RB2)	Consultant	Public	Chief Engineer	24 Years
	Respondent 3 (RB3)	Contractor	Private	Chief Quantity Surveyor	9 Years
	Respondent 4 (RB4)	Contractor	Private	Chief Quantity Surveyor	35 Years
Case C	Respondent 1 (RC1)	Client	Private	Director Project Management	20 Years
	Respondent 2 (RC2)	Client	Private	Senior Quantity Surveyor	8 Years

	Respondent (RC3)	3	Contractor	Private	Project Quantity Surveyor	3 Years
	Respondent (RC4)	4	Contractor	Private	Project Manager	11 Years
Case D	Respondent (RD1)	1	Client	Private	Director (CFO)	3 Years
	Respondent (RD2)	2	Consultant	Private	Director Operation	25 Years
	Respondent (RD3)	3	Contractor	Private	Project Manager	10 years
	Respondent (RD4)	4	Contractor	Private	Director Projects	14 Years

The researcher asked about the respondents' opinion on: (a) the meaning of PG and awareness of PG modes, (b) the use of PG help to minimise the COB, (c) the importance of minimising OB, (d) drawbacks of existing OB in construction projects, (e) relationship between COB and the client's choice on PG modes, (f) other factors affect when choosing a suitable PG mode and (g) suitable PG mode to construction projects in Sri Lanka. The answers given by 16 respondents in the 4 cases are given below.

4.1 MEANING OF PROJECT GOVERNANCE AND AWARENESS OF PROJECT GOVERNANCE MODES

Respondents identified that PG is a process that can be used to manage and control a construction project to get an expected outcome from it within the expected time and cost. RB3 mentioned PG was a strategic process which will drive the project towards its expected outcome. RD1 said PG was making sure the project was performed as agreed initially within the binding law of the country. RD4 mentioned PG as an advanced step of project management, and it can use for successful project delivery of any construction project within the expected time and cost.

The professionals were questioned on their knowledge of the PG modes. All the respondents knew about the formal control mode. According to them, formal control is using the contract document to strictly govern and manage the project by the rules, procedures, and guidelines on it. RC3 had a view that formal control is an implemented framework for decision-making and setting definite processes and guidelines for the contractor to follow in the project for any decision to be made. Out of all RA4 and RB4 were not aware of the trust PG mode. According to the respondents' the trust mode was based on the mutual understating between parties and trust with the experience in the privately funded project. Out of sixteen respondents RA2, RC3, RD1 and RD2 mentioned intermediate mode where the contract will be used to control some aspects of the project and trust to control other aspects which will be more effective than other modes because they are used separately.

4.2 USE OF PROJECT GOVERNANCE HELPS TO MINIMISE THE CONTRACTORS' OPPORTUNISTIC BEHAVIOUR

All the respondents except for RB3 and RD2 agreed that PG can minimise COB. RB3 mentioned that "lack of proper PG is only one factor/reason for a Contractor to go for OB, there are so many other reasons to be opportunistic such as low profitability, organisation culture, the capability of Engineer's staff, etc.". RD2 had a view that 'for some projects, it can minimise the OB due to the different methods incorporated in PG mode but for some projects sometimes PG cannot change any aspects because the chosen method is not correct for the project'.

RD4 had a similar view to RD2 and mentioned that proper PG can minimise COB, but it will depend on the factors such as the level of PG implication, procedures used for PG and ethics of the organisation. RA2 mentioned that PG provides a framework that helps to proper management of the construction project thus COB can be minimised. RA3 said that due to the PG owner does not rigidly follow the contract and reasonably solving the disputes considering the circumstances of the case, the contractor would not submit claims on every single loophole in the contract.

From the literature, it was identified that PG can alter the power of behavioural uncertainty (Ive & Chang, 2007), could move exposure to risk between parties (Smith et al., 2014) and could decrease the project's general risk exposure (Chang, 2015). Hence, it can be said that PG would be a useful mechanism to minimise COB in the construction industry.

4.3 IMPORTANCE OF MINIMISING OPPORTUNISTIC BEHAVIOUR

The importance of minimising OB identified through the literature synthesis and responses collected from interviews were also summarised in Table 4.

Table 4: Importance of minimising opportunistic behaviour

Importance of minimising contractors' opportunistic behaviour	**RA1**	**RA2**	**RA3**	**RA4**	**RB1**	**RB2**	**RB3**	**RB4**	**RC1**	**RC2**	**RC3**	**RC4**	**RD1**	**RD2**	**RD3**	**RD4**
Reduce the violation of the contract	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
Minimise the conflicts	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Reduce the transaction cost by penalising	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
Reduce the losses incur	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Increase the chance of timely completion	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓

RC3 mentioned that the contractor should not violate the contract and the thing that can be done was to stop the contractor from taking advantage of loopholes and uncertainties of the contract. RC3 had a view that the timely completion of the project cannot be achieved even though the OB is minimised because the decision-making process will take a long time thus the work had to be halted till a decision is made. RA4 identified that the OB of the contractor will not impact the penalising cost due to all legal actions taken by parties in a construction project not related to the OB thus it cannot reduce the cost related to the penalising cost. RD1 mentioned that contractors become opportunistic not to drag the project but complete the project within the allocated time. Apart from the literature findings professionals mentioned minimising OB will lead to a win-win situation for both parties and minimise the chance of reducing quality by the contractor.

4.4 DRAWBACKS OF EXISTING OPPORTUNISTIC BEHAVIOUR IN CONSTRUCTION PROJECTS

The professionals were requested to comment on the relevancy of the identified drawbacks of existing OB in construction through the literature synthesis. The drawbacks of existing OB identified through the literature synthesis and other reasons recognised through interviews are summarised in Table 5.

Table 5: Drawbacks of opportunistic behaviour

No	Drawbacks of opportunistic behaviour	Respondents
Drawbacks Identified through Literature		
1	Can increase distrust between parties	All respondents agreed except RA4
2	Increase conflicts over every detail when negotiating	All respondents agreed except RB3
3	Can prevent the development of a relationship between the parties	All respondents agreed
4	Increase project-related costs	All respondents agreed
5	This leads to delays in the project orientation	All respondents agreed except RD1
Other Drawbacks Identified by Respondents		
6	Quality issues arise	Proposed by RA2
7	The project becomes more complex	Proposed by RC3

RB3 said that when there are unfavourable details for the contractor then there will be conflicts when negotiating but not due to the COB. Respondent RD1 mentioned that with his experience contractors be opportunistic to complete the project sooner than dragging the project beyond the project duration. Thus, delays did not happen due to COB but for other reasons such as bad weather conditions and interference from the outside. According to the findings of both literature synthesis and data analysis, it can be said that COB could have a major impact on the outcome of the project, and it leads to dissatisfaction among other parties involved in the project.

4.5 RELATIONSHIP BETWEEN CONTRACTORS' OPPORTUNISTIC BEHAVIOUR AND THE CLIENT'S CHOICE OF PROJECT GOVERNANCE MODES

It was identified that COB would have an impact when the client selects a PG mode. RC3 and RD4 mentioned that with the client's experience on previous projects related to the COB clients would choose a PG mode because if the methods used previously not helped to control the contractor's opportunism and lead to losses for the client most probably client would select a formal governance mode, not a trust-based mode. Respondents RA2, RB1 and RC1 all mentioned that clients would consider the outcome of the COB and based on that they would select the suitable PG mode. RA4 said when there are multiple barriers in the project which can lead to COB client would go for the formal control mode. RB2 said when the reliability of the contractor is questionable then the client should select formal control mode. RA3 mentioned that if the client had trust in the contractor's behaviour, then the client would select a trust-based mode of decision-making. RC2 mentioned how a client would think about the suitable mode by saying "The client will consider formal method when the design is completed and knows that they are going for open tendering where an unknown person will get the project and due to that they will be opportunistic. If they negotiate with someone, they know they can either go for trust or contract-based method because they know about them".

4.6 OTHER FACTORS AFFECT WHEN CHOOSING A SUITABLE PROJECT GOVERNANCE MODE

Respondents were questioned about the factors which can affect when selection of a suitable PG mode by the client other than COB and the range of factors provided by them were mentioned in Table 6.

Table 6: Other factors affect choosing a PG mode.

Factors	Responses	Factors	Responses
Time	RA1, RA2, RA4, RC2, RC4, RD3	**Chances for opportunistic behaviour within the project**	RB2
Cost	RA1, RA2, RC1, RC2, RD3	**Social and political factors**	RB4
Quality	RA1, RA2, RC2, RD3	**The method to tackle professional negligence**	RB4
Transparency	RA1	**Environmental factors**	RB4
Trust	RA1, RC3	**Client beliefs and expectations**	RC1, RC3
Nature of the project	RA2, RA3, RA4, RB3, RD3	**Level of completion of the design and specification**	RC2
Stakeholders of the project	RA3, RA4	**Level of variations that can happen**	RC2
Complexity of project	RA4, RB3, RC1, RC2, RC3, RC4, RD1, RD3	**Engineer's mode of administrating the Contracts**	RC3
The focus of the client	RA4, RD4	**Contractual requirements of the project**	RC3
Consultant teams' experience	RA4, RC4	**Financial capability of the client**	RC4
Client knowledge about the industry and experience	RB1, RB2, RC3, RD1	**Who the possible contractors**	RD1
Experience of the contractor	RB1, RB2, RC1	**Structure of the project**	RD1
Past projects of the selected contractor	RB1	**Cost of project governance**	RD1, RD2
The volume of the work done	RB1	**Availability of resources for the project governance**	RD1
The reputation of the organisation	RB1	**Contractor's performance**	RD2, RD4
Number of parties involved in the project	RB2	**Client's Performance**	RD2, RD4
The capability of the Engineer	RB3	**Contractors can do the project or not.**	RD2
Historical facts related to the Contractor	RB3, RC1	**Identify the method used in similar types of projects**	RD2
Market condition	RB4, RC1	**Goodwill of the organisations**	RD4
Economic situation	RB4	**Frequency of having jobs (projects) for the Contractor**	RD4

Out of sixteen respondents, nine respondents identified project complexity's effect on the client's decision when selecting a suitable PG mode for a project. Time, cost, nature of the project, quality, stakeholders of the project, focus of the client, the experience of the contractor and financial capability of the client are the factors mentioned by more than two respondents. All the factors are relevant when choosing a PG mode. RA1 mentioned time, cost and quality are the main factors that will provide an on-time project for the client.

4.7 SUITABLE PROJECT GOVERNANCE MODE FOR CONSTRUCTION PROJECTS IN SRI LANKA

Professionals identified that it would be beneficial to implement PG in the Sri Lankan construction industry. RA1 mentioned feasibility and benefits would depend on the effort put in by the parties. RC1 also had a similar view regarding feasibility where the respondent mentioned that it also depends on the ability of the client and contractor. RC3 also said that the feasibility would depend on the complexity of the project, the contractor, and the client. RB2 agreed that using PG in the Sri Lankan construction industry is beneficial as well as feasible. RD4 also said project stakeholders should have sound knowledge of the PG to get the fullest output of implementation. RA3 mentioned that it would be difficult to adopt PG in the publicly funded project. RC2 said that "*In Sri Lankan industry only a few contractors will get the idea of PG like contractors above C2* *and therefore it will not be used by small contractors thus feasibility cannot be achieved*". RB4 mentioned that implementing PG in mixed development projects would be hard but beneficial for other projects. RB1 mentioned that PG is beneficial because in the construction industry, lots of projects go beyond the time frame but using PG would make sure projects are completed within a time frame. RD1 also said a reason for thinking PG provide benefits to the construction industry and the reason was the industry is not organised properly in Sri Lanka, but PG would help with proper organising and management.

The study found that it is difficult to completely eradicate COB in the construction sector, which suggested that PG could not completely eradicate COB but might assist to minimise it to a larger extent. Professionals have recognised both the formal control mode and the mode that combines trust and formal control as being acceptable for the construction business.

5. CONCLUSIONS

The constantly evolving nature of the construction sector, its level of competition, and the workplace environment that is influenced by both internal and external forces have compelled businesses to develop effective management techniques to meet the objectives of projects for clients. For the past several years, a structure called "project governance" has been used for building projects all over the world. It has to be implemented to more construction projects in the Sri Lankan context to deal with the changes in the sector. The background literature review indicates that there is a dearth of research on the application of PG to reduce COB in the Sri Lankan construction sector. The capacity of customers to manage the OB of the contractor and their choice of PG options were also proven to be less important to construction industry practitioners. In order to maximise project performance and minimise the impact of COB, it was necessary to analyse the usage of PG and identify the elements that directly influence this behaviour. The level of tolerance by a client to the COB has a greater influence on the owner's choice of governance modes to reduce OB. A party that has a lower tolerance level of OB may use FC, which can improve the consistency of other parties' behaviour. On the other hand, a party that has a higher tolerance level of OB would select a trust, which might be effective to build relationships among the parties.

This study revealed that formal control and a combination of trust and formal control as the most suitable PG modes for the Sri Lankan construction industry. Therefore, this research offers factors to consider when selecting a PG mode such as complexity, duration, and cost of the project. When a client selects a PG mode, the client would consider the complexity of the project, time duration of the project, cost of the project, nature of the project and quality expected from the final product other than the COB.

The research's findings will be useful to those working in the construction sector because they will help them improve project performance in Sri Lankan construction organisations by reducing COB in a way that will improve the satisfaction of all project stakeholders and improve the sector's corporate image. Following are a few suggestions for industry practitioners.

- Remove the factors that can lead to the COB from the project by methods that will not impact the overall outcome of the project.

- Employing the findings of this research as guidance to use as a management mechanism over project management and project alliance.

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TRANSACTION COSTS IN AUSTRALIAN CONSTRUCTION PROJECTS

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ABSTRACT

Construction projects involve transaction costs (TCs) both during the pre and post-contract phases. If these costs are not managed appropriately, they can lead to project cost overruns. The purpose of this study is to explore the transaction costs, their determinants and mitigation strategies in the Australian construction industry. Qualitative data were collected by conducting semi-structured interviews with professionals who have been working as contract administrators, project managers, quantity surveyors and construction managers. The data were then analysed using thematic and content analysis techniques by using NVivo software. The research identified context-specific transaction costs such as statutory charges, opportunity costs, cost of compliance, and lost-time costs. Moreover, the findings indicate that factors affecting transaction costs are interrelated; hence, each factor affects more than one type of transaction cost. It was also found that rules and regulations imposed by regulatory bodies, the type of bidding procedure used, and the use of non-integrated procurement methods increase transaction costs. Further, mitigation strategies for minimising TCs such as recruitment of qualified experts, building trust and relationships, and the use of digital technologies such as BIM, drones and point cloud were identified.

Keywords: *Construction Industry; Cost Overruns; Project Cost; Transaction Costs.*

1. INTRODUCTION

One of the success factors for construction projects is to complete them within budget. However, various researchers in Australia and other countries frequently reported project cost overruns. Terrill et al. (2016) identified that up to 52% of construction projects experience cost overruns. Similarly, Love et al. (2013) found that an average of 12.22% of projects had experienced cost overruns. The most prevalent causes of cost overruns as identified by previous researchers were design changes, increases in the prices of construction materials, labour shortages, variations in scope, and force majeure (Abidin & Azizi, 2021). However, most of these causes are related to production costs. Indirect costs, unforeseen costs, or costs related to the transactions between project parties are often overlooked. According to Li et al. (2013), construction project cost includes not just the production costs, but also transaction costs (TCs) such as the cost of bidding, acquiring information, processing claims, and contract administration and dispute resolution. Also, Guo et al. (2016) explored TCs and classified them into pre-contractual and post-contractual. According to Rejeh et al. (2015), pre-contractual TCs are costs

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incurred before signing the contract such as costs related to information gathering, communication, tender documentation, bidding, feasibility studies, environmental impact assessments, and negotiations. Post-contractual TCs are costs incurred on activities such as set-up and running, enforcement, decision-making, and dispute resolution after signing the contract. Nonetheless, previous studies did not thoroughly examine how these TCs and their determinant factors affect the project cost performance and propose mitigation strategies for each transaction cost. Therefore, this study is conducted to fill the aforementioned knowledge gap. Hence, this research aims to explore context-specific transaction costs and their mitigation strategies.

2. LITERATURE REVIEW

Previous studies revealed that the cost of a construction project consists of both production and transaction costs (Winch, 2006; Li et al., 2015; Rajeh et al., 2015). These TCs were categorised into the two main phases of a construction project: pre-contract and post-contract TCs. Rajeh et al. (2015) discussed that pre-contractual TCs are related to information gathering and procurement, whereas post-contractual TCs are related to contract administration and enforcement activities. Pre-contract costs are borne as a result of time spent on procurement activities before signing a contractual arrangement and post-contract TCs incur due to the time spent implementing and monitoring activities after contracts are signed. Li et al. (2015) expanded pre-contract TCs by introducing costs incurred in drafting contracts, negotiation of agreements, training, site visits, attending meetings, conducting feasibility studies, transition observations and bidding. Furthermore, post-contractual TCs were also expanded by including costs related to setting up and running, bonding, dispute and conflict resolution, verifying compliances, and decision-making (Li et al., 2015). According to a study by Elbaz et al. (2020), TCs occur throughout the lifecycle of a construction project, and there are hidden TCs involved in a project, such as lost-time costs, trust damage costs, delay recovery costs, emotional costs, which are intangible yet can influence the total construction project cost. This signifies that apart from pre-contract and post-contract classification, there are hidden TCs as well. Further, it was identified that outsourcing from external organisations incurs extra TCs such as negotiation, measuring, and monitoring costs (Rajeh et al., 2015). Over the years, the complex and dynamic nature of construction projects has resulted in many cost overruns (Afzal et al. 2020). According to Love et al. (2013), 95% of a sample of 58 Australian infrastructure projects have been impacted by cost overruns. Love et al. (2013) suggest that Australia is likely to have high rates of cost overruns. In light of the aforementioned findings, many researchers have attempted to reduce cost overruns in construction projects. According to Durdyev (2021), identifying the causes of cost overruns was considered a good starting point for optimising project cost performance. Durdyev (2021) identified the main causes for cost overruns in construction projects such as inaccurate estimations, design problems, and shortage of skill and experience. Lee et al. (2009) argued that TCs that develop throughout project phases can also result in cost overruns and ultimately reduce the profitability of contractors. However, it can be opined that the majority of published construction management research focused on the production cost rather than the TCs.

3. RESEARCH METHODOLOGY

The three main research approaches commonly used include qualitative, quantitative, and mixed. The qualitative research approach is well suited to this research because it allows for the exploration and critical analysis of a wide range of ideas from a diverse group of industry professionals. According to Ary et al. (2018), there are various data collection methods specified under the qualitative research approach such as observations, interviews, literature review, ethnography, case study and historical review. Among these methods, interviews were used as the research method in several past research studies related to TCs (De Schepper et al., 2015; Haaskjold et al., 2020; Wu et al., 2021). This research used semi-structured interviews as the data collection instrument. The interviewees comprise of 10 industry professionals, namely construction managers, quantity surveyors, project managers, and contract administrators. The participants have experience ranging from 3 to 28 years. According to Malterud et al. (2016), data collection via interviews can be stopped when the interviewees start giving similar answers to the questions or at saturation point. After completing eight interviews, it was discovered that the interviewees provided similar responses. As a result, the data collection's saturation point was determined to be eight. However, the researchers conducted two more interviews and completed the data collection. The semi-structured interview consists of two sections. The first section was designed to collect background information about the interviewees, and the second section consists of open-ended questions related to TCs. Some of the questions include: "In your opinion, what are the typical TCs in Australian construction projects?" "Do you think that TCs have an impact on project cost performance? If yes, please explain"; "What strategies would you suggest to reduce TCs?" All the interview questions were carefully crafted to obtain data that help to meet the study's objectives. The semi-structured interviews were conducted on a face-to-face basis and virtually. Each interview lasted approximately 30 to 40 minutes. Both notetaking and recording were carried out with the consent of the interviewees, and this helped to generate verbatim transcriptions of all the interviews. There are various approaches for analysing qualitative data such as narrative, content, thematic, grounded and discourse analysis (King & McCarthy, 2018). Content and thematic analysis approaches are widely used methods because they allow for an objective study of textual material, topics and concepts (King & McCarthy, 2018). Furthermore, content analysis allows for the comparison of diverse viewpoints and descriptions of current practices (Smith & Firth, 2011). Thus, this method of data analysis is effective for this research, in identifying the many features and viewpoints on TCs and their impact on project cost performance. Thematic analysis was conducted to identify themes from the verbatim transcripts of the ten interviewees, and the themes were further analysed using the content analysis technique. NVivo 12 software was used to carry out the thematic and content analysis for this research study. The software was used in identifying multiple themes, comparing theme labels, and looking for interrelationships across themes.

4. FINDINGS

4.1 PRE- AND POST-CONTRACTUAL TRANSACTION COSTS

One of the most reported pre-contractual TCs was searching costs which include costs associated with conducting a feasibility study to determine the type of development, scouting a suitable land, conducting market research on profitable investments, professional fees associated with calculating the capital requirement, and preparing a preliminary cost plan, researching the rates of materials, and numerous site visits. The second most cited category of cost was negotiation costs. As outlined by Interviewee 5, "*It is not as simple as picking up the phone and asking them for the price they want to give and closing the deal upright. It takes a day or two to follow up with suppliers and subcontractors because there will be many back-and-forth meetings"*. Another important pre-contractual TC was the bidding cost. This cost includes all the document preparation costs, acquiring bonds and insurances (i.e., bid bonds, professional indemnity bonds, and cost of acquiring building licenses). Interviewees mentioned statutory charges as another pre-contractual TC. It was also emphasised that planning and building permits should be obtained from the relevant local council or registered building surveyor before commencing construction. This is a lengthy procedure that involves gathering documentation, filling out forms, adhering to planning standards, and justifying any variances. These activities require additional time and effort from the professionals, implying a different type of transaction. Participants identified several other TCs, including the cost of obtaining a software license and legal fees for contract preparation. Interviewee 9 (IR9) suggested that opportunity cost is also a TC. For example, as per IR9, "*during the process of obtaining a planning permit for a proposed school project in Melbourne, the council promised the client that if they agree to upgrade the water main running to the proposed site and the surrounding neighbourhood, the proposal would be approved immediately. As a result, the client was forced to bear the cost of upgrading the water main as an opportunity cost to obtain the planning permit for the profitable project"*. Procurement costs were the most reported TC in the post-contract period. The contractor has to manage subcontractors, suppliers and labourers, all of which require different contract documents to be drafted. TCs incur as a result of these procurement actions. Moreover, the data collected revealed that post-contractual TCs include negotiation costs as well as administrative costs associated with handling variations, claims, and change orders, as well as managing supply chain activities. Conflicts and disagreements between parties are prevalent throughout the transactions, resulting in conflict resolution expenses and additional administrative expenditures that can be categorised as TCs. IR2, representing a contracting organisation said that "*TCs are a portion of company development costs. Furthermore, he defined them as expenses such as marketing, advertising, client entertainment, payroll tax, fringe benefits tax, vehicle costs, and cost of managing the fleets all of which are necessary to keep the business running"*. Several interviewees said that there are significant costs associated with simply complying with clients in Australia, particularly when working with aged care and childcare clients. This approach will necessitate a lot of communication and paperwork with subcontractor's employees and requires a devoted professional throughout the project. Other post-contractual TCs include the cost of purchasing safety equipment, the cost of maintaining registrations and licenses, and bank charges. Regarding the comparison of the extent of pre and post-contractual TCs, the interviewees gave different responses. More than half of the participants said that most TCs occur during the pre-contract stage. Their rationale was based on the idea that, except for some unforeseen costs, the post-contract stage would contain a rough outline of the transactions to occur. The pre-contract stage, on the other hand, may result in a range of transactions, with the quantity of work required being unknown. The respondents who reported that the post-contract stage would have higher TCs were assuming that the post-contract stage would be the longest and most complicated of the two stages, depending on the type and size of the project. As a result, compared to the pre-contract stage, there may be many transactions involved throughout that procedure. However, all the interviewees agreed that it is difficult to exactly tell which stage has the highest.

4.2 EFFECT OF OWNER'S AND CONTRACTOR'S BEHAVIOUR ON TCS

All the interviewees agreed that the owner's behaviour has an impact on TCs. It was discovered that a client's lack of experience in the construction sector would have a significant impact on TCs. Because clients may not make diligent decisions promptly. Moreover, the interviewees have addressed how the client's relationship with the other stakeholders and their demeanour affects project TCs. Both of these behaviours would increase the number of transactions in the project, resulting in higher administration, negotiating, and statutory costs. Lack of contractor experience, due diligence, and motivation in working as a team were all cited as factors that impact TCs. The contractor's opportunistic behaviour was another key influencing element for TCs. According to the responses, unbalanced bidding is a common contractor's behaviour. Frontloading is a way of unbalancing a bid in which a bidder overestimates the unit price of the items planned to be completed early in the project while underestimating the unit price of the items scheduled to be completed later. This will increase the number of claims for low bids later in the project. Consequently, transaction expenses will be incurred as a result of the drafting of claims, continuous negotiations, and additional effort for the project team in the administration of claims. Furthermore, another participant remarked that the contractor's negative attitude toward risks, by attempting to avoid and transfer all risks to the other stakeholders, would result in unnecessary TCs.

4.3 EFFECT OF PROJECT MANAGEMENT EFFICIENCY ON TCS

The respondents mentioned that project management efficiency, expertise, leadership, and knowledge have an impact on TCs. Project managers' inefficient behaviour would result in project delays, rework and variations, which results in greater transaction expenses, especially in the post-contract stage. Meanwhile, most respondents stated that unnecessary TCs such as enforcing costs and information costs are incurred as a result of the project management team's lack of quality communication. Greater project uncertainty produces higher TCs because it allows an opportunistic trading partner to jack up its bids, do extra work, and demand various claims, which rises post-contract TCs, according to the findings. Another set of respondents stated that failing to have a good action plan for project risks will result in higher TCs as a result of the need to interact and consult in-house or external experts to find solutions. Around 70% of the responses mentioned that an incomplete design or missing schedules will create many ambiguities which will lead to dispute resolution costs, site meeting costs, and searching costs. Additionally, some participants claimed that the majority of project TCs are attributed to insufficient contract paperwork. Because not properly drafting contracts will result in unnecessary TCs such as rework, disagreements, and losses. About 50% of respondents mentioned that the complexity of a project would result in greater TCs because there will be more micro-components to look at when the project is more complex, and more transactions will be involved in understanding the project. Another respondent, on the other hand, said that project complexity is multi-varied, arguing that a laid-back customer might make a difficult project simpler. As a result, the impact of complexity on TCs will be determined by the trust and synergy between the client and contractor. Whereas in the respondent's opinion, all these factors are interlinked. According to the replies gathered from the interviews, most respondents believe that TCs have a substantial impact on project cost performance. The results showed that a maximum of 2% of the construction project cost consisted of TCs. IR8 illustrated his point with a scenario that occurred in one of his ongoing projects, a high-rise building in Melbourne's CBD. "*Since the design phase, the building has had private screens in the terraces. However, the architect has not completed a feasibility analysis on this design, and it was identified during the construction stage that special approval was needed to add these screens. This resulted in additional TCs that eventually impacted the total project cost due to further delay charges.*" Another example given by an interviewee is that, on average, roughly 10% of the cost of a construction project is committed to consulting fees. Clients, on the other hand, manage to obtain consultants for 2-5 percent of the fee proposed instead of 10%. As a result of decreased TCs, these consultants will be unable to provide high-quality designs, documentation, and project management. At the end of the day, the 8% savings will be irrelevant because project cost overruns will outnumber savings. However, IR5 stated that TCs are not very huge to impact an overall construction project cost materially.

4.4 STRATEGIES TO MITIGATE TCS

The data analysis yielded many strategies that may be used to minimise TCs. According to the findings, most experts strongly advised employing an experienced project team since technical competency and experience can minimise a significant amount of unnecessary TCs incurred during project transactions. The interviewees agreed that the most important element of a project is the project scope and contract. As a result, having a well-defined scope, good documentation, and readily available information would reduce most TCs. Following that, most participants suggested strategies such as maintaining uniform procedures and policies, as well as allocating sufficient resources within the organisation. Furthermore, since bidding behaviour was found to be a significant factor influencing TCs, it was suggested that a more transparent pricing technique could be used, and more competitive bidding procedures could be implemented. Maintaining a positive relationship between the contractor and the client, and developing trust with the consultant or contractor, was suggested as a passive approach to reducing TCs. Summary of the strategies are presented in Table 1.

Table 1: List of strategies to minimise TCs

Categories	Strategies to Mitigate Transaction Costs
Technical Competency	Recruiting a qualified and expert project team Recruiting a project team who are diligent in decision making Recruiting employees who are competent in using new software and platforms. Implementing a proper methodology before negotiating with clients
Scope and Contract	Allowing appropriate time to go through contract documentation. Incorporating more time to plan and research. Having information readily available to use Maintaining clear and proper documentation and records Trying to maximise the detailing of the project
Organisational Aspect	Having a proper organisation structure with a key point of communication Establishing standards procedures and templates Installing efficient software/systems for compliance works Implementing digital technologies such as BIM, drones and point cloud Focus on procuring sufficient resources to cater to project needs

Categories	Strategies to Mitigate Transaction Costs
Bidding Behaviour	Encouraging a more transparent bidding procedure Advising on more competitive bidding than bidding low Advising on an apple-to-apple bidding procedure Conducting an advanced feasibility study before factoring
Trust and Relationships	Entrusting the selected builder from the beginning Use a single and double-pointed contractor base Making good relationships with all parties with mutual trust
Client's Behaviour	Recruiting a consultant/Superintendent if having less experience and knowledge in construction projects Following a timely payment system Having sufficient capital/funds in hand before entering a project Indulge more time to decide the requirements and scope of the project Taking decisions diligently and on time
Procurement Aspect	Installing efficient software/systems for procurement Involving more collaborative procurement methods which increase early contractor involvement. Following selection criteria or a matrix to find the best-suited procurement method
Contractor's Behaviour	Increasing transparency during variations and claims Following a more diligent approach with clients Implementing more flexibility in project works
Leadership and Management	Maintaining a strong leadership Agreeing on a proper conflicts management process Implementing a swift, smooth, and an efficient communication system Planning on a sustainable vendor management procedure
Proper Planning	Proposing to add an extra percentage to cover up TCs at the planning stage Incorporating more time to plan and research Applying a proper feasibility
Risk Allocation	Identifying project risks from an early stage Implementing a fair risk allocation process

5. DISCUSSION

5.1 TCs IN CONSTRUCTION PROJECTS

A list of distinct types of TCs in Australian construction projects was found during the analysis and categorised under two main phases of projects. Several academics have found a similar type of TCs to those discovered through this study. Such as searching costs, cost of feasibility studies, bidding costs, documentation cost, cost of site visits, negotiation costs, bank charges, setting up and running costs, cost of administering contracts and claims, dispute resolution costs, cost of compliance, and legal charges (Li et al., 2012; Li et al., 2015; Guo et al., 2016; Anderson et al., 2020). This shows that regardless of the geographical locations, these sets of fundamental TCs are common in construction projects. Business development costs are one of the newly found post-contractual TCs. According to the analysis, business development costs include payroll tax, fringe benefits tax, car charges, and fleet management costs. These costs occur during transactions between the contractor and the suppliers when procuring resources and they have an impact on construction project costs. These TCs may change with the economic stability of the country and government regulations. Another important post-contractual TCs obtained in this study is marketing costs. Elbaz et al. (2020) stated in their study that TCs can occur at any time during the project's life cycle. Hence, marketing costs could be identified as TCs incurred near the end of the project's post-contract period which will be borne by the client. Therefore, marketing costs will include generating commercials, locating advertisers, and erecting mock-up houses among other things. Apart from the above-described TCs, most respondents noted another sort of TC which is a time cost. Based on the findings of the literature analysis, this type of cost was also classified as intangible TCs (De Schepper et al., 2014).

5.2 FACTORS AFFECTING TCS

It was found that the client's lack of experience has a huge effect on the project's TCs. This is because the lack of experience could lead to several requests for information which has transaction cost implications. Li et al. (2012) stated that the effectiveness of the owner's experience in similar projects would be determined by the lessons learned from finished projects. This means that experienced owners can make informed decisions, reducing the cost of time losses to obtain approvals. Unclear scope will cause the owner to change his requirements at any time. This will increase the TCs by requiring reapplication for planning approvals as a result of design adjustments, and there will be extra administration costs owing to the changes. This factor was also highlighted by other researchers, that owner-initiated changes have become a substantial factor that affects TCs (Li et al., 2012; Guo et al., 2016). The contractors' experience and expertise in construction projects and solid relationships with subcontractors are found to have a significant effect on the TCs. Previous study has shown that if a transaction occurs frequently, it provides a level of trust that reduces the need for more expensive protective coverage and offers opportunities for learning (Melese et al., 2010). The opportunistic behaviour of the contractor was also the key factor affecting TCs. When a contractor opportunistically bids for a construction project by providing a low price in anticipation of seeking reimbursement during the project's execution by way of raising an absurd number of claims is an example of opportunistic behaviour. As a result, extra TCs will be paid when administering claims and dispute resolution when settling contract parties' unfair and unethical behaviour. Similarly, a previous study has identified that construction contractors frequently engage in excessive risk-taking, which results in negative financial accruals (Ikuabe et al., 2020). According to the findings of this study, most of the day-to-day TCs in a project, such as the cost of administration of claims and change orders, and dispute resolution, are heavily dependent on project management efficiency. Similarly, several research studies have argued that the project management team should have the technical expertise necessary for project tasks (Walker & Wing, 1999; Li et al., 2012; Li et al., 2015). Furthermore, the quality of communication within the project management team was found to have a significant influence on TCs. Likewise, in a study based on collaborative construction projects, quality of communication was found to be one of the factors that affect TCs (Anderson et al., 2020). According to the theory of TCs, the transaction environment involves complexity, uncertainty, frequency, and asset specificity (Williamson, 1998). Similarly, the expert interviewees believed that these elements were regarded as the most significant aspects impacting TCs in the construction industry. It was found that administrative costs and business development costs can increase if the project complexity is high. Project uncertainty was also pointed out as the factor that impacts TCs. By the same token, empirical research shows that environmental uncertainty increases TCs (Guo et al., 2016). Uncertainty could be related to the type of materials to be used, material prices, weather conditions, soil conditions and contract conditions. Finally, the interview responses uncovered the bidding procedure, as well as the authority's regulations and requirements as factors influencing TCs. There are a variety of bidding techniques, including open bidding, competitive bidding, nominated bidding and E-tendering. As a result, each operation will have different steps and administrative needs, which will increase or decrease TCs during the bidding process. Farajian (2010) acknowledges that a lower level of competition can result in lower TCs during the pre-contract stage, but the overall project costs will likely be higher as a result of the less competitive procurement process. Through the analysis of the responses of the expert interviews, contradictory opinions about the impact of TCs on project cost performance resulted. Based on the findings of this study, TCs account for no more than 2% of the total project cost in Australia. However, Dudkin and Valila (2005) found that contractors in the United Kingdom spend between 0.24 and 0.57 percent of project costs on TCs, while TCs in the Czech Republic is around 0.25 percent of the contract value. Some interviewees had an opinion that a TCs percentage is too small to affect the overall project cost because the effect of such a small amount can be easily recovered once the project begins to make profits. On the other hand, others believed that, while such a small sum would not have a substantial impact on the project's cost, it would be critical to keep track of all the costs that had a material impact on the project. Given the conflicting opinion of the interviewees, it is suggested that large datasets should be collected and analysed quantitatively to verify the percentage of TCs in Australian construction.

6. CONCLUSIONS

The influence of TCs on project cost performance was explored in this study. This was investigated by conducting semi-structured interviews with professionals in the Australian construction sector. Different types of TCs were revealed through this study; among them, statutory charges, compliance costs, and opportunity costs are newly discovered pre-contractual TCs in the Australian environment. Similarly, newly identified or context-specific post-contractual TCs include business development, marketing, and time-lost costs. Furthermore, it was identified that TCs have an impact on project cost performance, both directly and indirectly, despite the low percentage of the impact. Furthermore, the owner's and contractor’s lack of experience and knowledge, negative demeanour towards the project, contractor’s opportunistic behaviour, rules and regulations implied by construction authorities, bidding procedures, and non-integrated procurement methods, have been highlighted as factors that can cause TCs to increase unnecessarily. Several mitigation strategies for minimising TCs were also identified. These include recruitment of qualified experts, building trust and relationships, and the use of advanced software or digital technologies such as BIM, drones and point cloud. Moreover, it was revealed that all these factors and mitigation strategies are interrelated; therefore, one strategy alone may not mitigate the effect of TCs on total project cost. This research has both theoretical and practical implications. The findings of the study are an important addition to the body of literature on TCs. Because this study contributed distinct factors that affect the TCs, in addition to the findings available in the existing literature. Some of these factors include the bidding procedure as well as the rules and regulations imposed by the industry's governing bodies. From the practice point of view, stakeholders involved in the construction of building projects can adopt the strategies identified in this research to minimise transaction costs or avoid unnecessary TCs in their projects. This will eventually aid them to reduce project cost overruns. Although this study met its aim and objectives, it has some limitations. The data collection for the study was limited only to the opinions of professionals who work for main contractors and cost consultants. Consequently, the views of the owners and other stakeholders were not considered. Moreover, the focus of this research was on TCs associated with building projects. Therefore, it is suggested that future studies can explore the views of other stakeholders such as owners, material suppliers, and subcontractors on TCs, and analyze the data using mixed methods to arrive at a more accurate percentage of TCs. Additionally, further research might be conducted by collecting data from other countries' construction industries and develop context-specific strategies.

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USE OF BUILDING INFORMATION MODELLING TO MITIGATE COST OVERRUNS IN DESIGN AND BUILD PROJECTS

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ABSTRACT

Cost overrun in the design and build (D&B) procurement method is a significant obstacle in achieving the project goals. Therefore, it has become critical consideration over its numerous benefits when selecting this procurement method. However, applying new technologies, such as Building Information Modelling (BIM), can significantly minimise this issue. Thus, this study aims to investigate the use of BIM to manage the cost overrun issues in D&B projects. A qualitative approach based on two rounds of interviews was conducted to collect the data. The study findings revealed ten highly important causes of cost overrun in D&B projects. Continuous design and drawings changes due to incomplete initial drawings prepared with insufficient design data at tendering stage, errors or omissions revealed during construction, and inefficient planning and scheduling by the contractor were the top three causes. Further, BIM functions such as interoperability and exchange of information, clash detection, digitalised quantity take off, and cloud computing were identified as they can be used to manage highly important causes of cost overrun in D&B projects. This research assists professionals in identifying the most appropriate BIM functions to reduce the fear of price uncertainty when implementing the D&B procurement method in their projects. Further research on identifying the barriers and suitable strategies for implementing BIM in D&B projects to reduce cost overrun can be based on the present study.

Keywords: *Building Information Modelling (BIM), Causes, Cost overrun, Design and Build projects, BIM Functions.*

1. INTRODUCTION

The design and build (D&B) procurement technique is a project delivery method that assigns the contractor both design and construction responsibility (Ruvinda & Bamunuachchige, 2020). Although the D&B procurement method has various advantages, it can still pose significant risks to contractors if not adequately mitigated through effective risk management (Oztas & Okmen, 2004). Pham et al. (2021) listed several risk factors in D&B projects, such as cost overrun, delays, lack of collaboration

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among the team, complexities in designing, and frequent design changes. Literature suggests that using proper innovative technology to improve the performance of selected procurement can enhance overall productivity and minimise cost overrun risk in construction projects (Borg, 2015). Among various digital technologies, BIM has a higher degree of potential for offering a collaborative platform and is majorly helpful in identifying design clashes and minimising the cost of correction (Bello et al., 2021; Muhammad et al., 2019).

The D&B procurement method is gaining popularity since it gives clients a comparatively higher price certainty than the traditional method (Brahim et al., 2018). However, from the contractor's standpoint, using the lump-sum (fixed price) payment system in D&B necessitates strict cost control measures (Cunningham, 2015). Identifying design clashes, minimising the cost of correction, and maintaining proper information management are all made possible by BIM (Bello et al., 2021), which directly contribute to reducing the contractor's pricing risk in D&B projects.

Even though BIM deployment may be highly beneficial, BIM as a collaborative platform for construction management is still in its infant development stage and has some significant barriers to implementation (Muhammad et al., 2019; Siddiqui et al., 2019). Construction sector's adoption of new technologies is slower than that of other industries (Haupt et al., 2019). Therefore, this research aims to investigate the use of BIM to manage the cost overrun in D&B projects. The objectives of this research are to investigate the important causes of cost overrun in D&B projects, identify common BIM functions used in construction projects, and investigate the suitable BIM functions that can be used to manage each highly important cause.

2. LITERATURE REVIEW

2.1 PRICING RISK IN DESIGN AND BUILD PROJECTS

The separation of design and construction stages is identified as the root cause of some critical issues in construction projects, such as lack of responsibility of both parties, issues in constructability, and increment of variation (Rahmani et al., 2017). Thus, combining those two stages, the notion of D&B was raised to respond to those issues (Adamu et al., 2017). In that case, the D&B contractor is solely responsible for the design and the construction (Ahmed & El-Sayegh, 2020). Consequently, the risk for D&B contractors will significantly rise (Jimenez et al., 2020). This critical amount of risk shifted to the contractor is a major concern for D&B projects. To effectively address this issue contractor shall adequately identify the risks at the earliest phase in D&B projects (Ahmed & El-Sayegh, 2020). Rostiyanti et al. (2019) described pricing risk that arises from greater price uncertainty as a characteristic of D&B projects. The main reasons for pricing risk for D&B contractors are the unavailability of precise employer requirements, design discrepancies, and comprehensive specifications at the time of tender pricing (Rostiyanti et al., 2019; Saaidin et al., 2017). In addition, poor coordination among the project team is also considerably involved in this risk (Pham et al., 2021). Also, errors in taking off, rework due to clashes, problems in constructability, and errors identified during the construction phase are highlighted causes of pricing risk due to contractors' faults (Ogunsanmi et al., 2011; Pham et al., 2021; Ramanathan et al., 2011). Yusoff et al. (2022) stressed that implementing novel technologies could efficiently address most of these issues.

2.2 CONCEPT OF BUILDING INFORMATION MODELLING (BIM)

BIM is the basis for the construction sector's digitalisation (Gilkinson et al., 2015). It is a process or a concept used to successfully develop, manage, and distribute information across the life cycle of a construction project using different tools and technologies (Ahmed & El-Sayegh, 2020). In the construction industry, BIM enables the simulation of construction projects in a virtual environment (Azhar, 2015). The virtual model can be used precisely and efficiently for data extraction, analysis, and processing to make more accurate decisions (Liston, 2008). Literature suggests that 3D visualisation, constructability analysis, and clash detection are the key functions of BIM (Gholizadeh et al., 2018). Additionally, construction planning, cost management, interoperability of information, and digitalised taking off are other commonly discussed functions of BIM (Ganbat et al., 2020). Ultimately, these multiple usages of BIM are gradually increasing the construction industry's productivity and eventually improving its cost-effectiveness.

2.3 USE OF BIM TO MINIMISE PRICING RISK IN D&B PROJECTS

The implication of BIM enables and acknowledges a higher level of interaction between the different elements of the design. Subsequently, when design modifications are made, all relevant elements are automatically updated and disseminated electronically to all project stakeholders (Gad et al., 2022). Frequently this will happen in the earlier phase of the project when the cost of making design modifications is minimal (Gilkinson et al., 2015). Therefore, this process dramatically reduces the cost overrun in construction projects.

In D&B projects, clients prefer lump sum contracts due to the price certainty it offers to the client (Adamu et al., 2017). Conversely, the contractor faces greater price uncertainty when offering lump sum prices in the contract (Adnan et al., 2012). Therefore, D&B contractors should adequately manage the risk to achieve the predetermined financial goals. In that case, the impact of price risk sources, such as poor coordination, poor information flow, discrepancies, and errors, can be decreased by implementing novel technologies that support collaborative working environments with better data accuracy (Braglia et al., 2022). In that scenario, results from different studies suggest that BIM has dramatically reduced cost overruns and promoted price certainty by increasing collaboration and accuracy (Badran et al., 2020; Muhammad et al., 2019). Therefore, successful implementation of BIM in D&B projects may be beneficial for the D&B contractor to tackle price uncertainty in the project systematically. Hence in-depth discussions to identify the synergy between BIM adaptation and mitigating pricing risk in D&B will effectively relieve D&B contractors from the disadvantageous situation. Several types of research are available on the D&B procurement method based on its adaptability (Adamu et al., 2017), contractual and legal background (Gad et al., 2020), and risk management (Ayuningtyas & Rarasati, 2020). Similarly, a tremendous amount of research is available regarding BIM based on various areas, such as new trends (Disney et al., 2021), risks related to BIM adoption (Badran et al., 2020), barriers and strategies for BIM implementation (Olanrewaju et al., 2022), and cost overrun and delay management (Muhammad et al., 2019). Nevertheless, studies to investigate the adoption of BIM in D&B projects are limited (Brahim et al., 2018; Yusoff et al., 2022). Even though there is a high likelihood that using BIM features effectively will produce significant results in pricing risk management in D&B projects, research on this topic from the contractor's perspective is rarely found.

3. RESEARCH METHODOLOGY

This research investigates how BIM can be used to manage cost overrun for pricing in D&B projects. A comprehensive literature review was conducted based on the D&B procurement method and concept of BIM in construction. Those literature findings are required to validate the selected D&B project contexts. Since this research is keen to obtain expert opinion rather than numerical data, the qualitative approach is selected as suitable for the study (Saunders et al., 2019). An interview survey was selected to collect data because it facilitates gaining a holistic view from the selected, experienced, expert interviewees (Döringer, 2021). In addition, semi-structured interviews were used for data collection to acquire flexible and elaborative opinions within the limited time frame (Döringer, 2021). Two rounds of interview surveys were incorporated, considering the requirements of the study, and details were demonstrated in Figure 1.

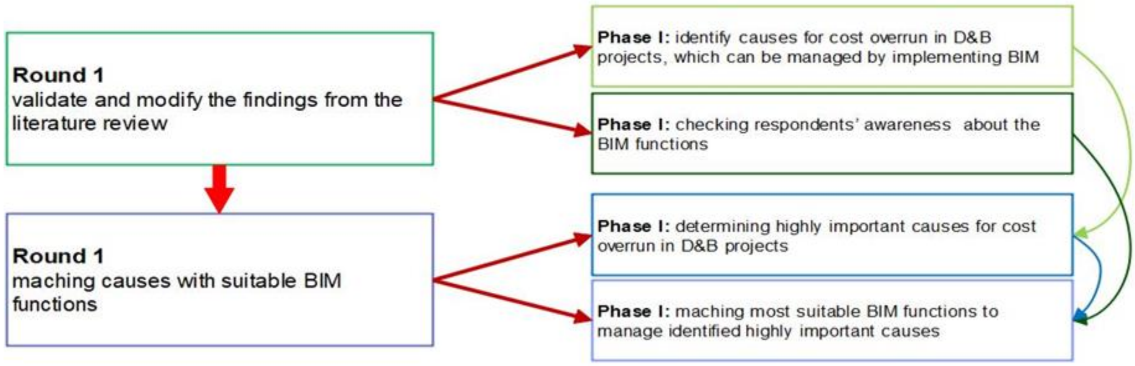

Figure 1: Details of Delphi rounds

Manual content analysis was used to analyse the collected data to generate meaningful outcomes from the textual data (Medelyan, 2020). A Delphi study's effectiveness boosts when conducted with a heterogeneous sample of experts (Skulmoski et al., 2007), so this research adopted a heterogeneous sample. Respondents were selected through purposive sampling as it allows the researcher to choose experts according to the requirements of the study (Campbell et al., 2020). The selected 12 respondents for the study have working experience in the digitalization-built environment from Australia, the United Kingdom, New Zealand, United Arab Emirates, and Sri Lanka. They were selected according to the following criteria, and Table 1 elaborates on the interviewees' profile.

Compulsory criteria (At least one must be satisfied):

- **C1-** At least five years of working experience in the construction industry
- **C2-** Working experience in at least 3 D&B projects
- **C3**- Research experience in D&B procurement method and/or BIM

Additional criteria

- **A1-** Participated in at least three BIM-applied projects
- **A2-** Interest in modern technologies for construction
- **A3-** Completed a postgraduate qualification related to the built environment
- **A4**- Certificate level qualification in BIM

Table 1: Interviewees' profile

Code	Profession	Compulsory Criteria			Additional Criteria			
		C1	C2	C3	A1	A2	A3	A4
I01	Chartered Quantity Surveyor (Consultant)	✓	✓			✓		
I02	BIM Modeler (5D quantity surveyor)	✓		✓		✓		✓
I03	Chartered Quantity Surveyor (BIM practitioner)	✓	✓		✓	✓		
I04	Chartered Quantity Surveyor (BIM practitioner)	✓	✓			✓		
I05	BIM expert (5D BIM lecturer)	✓	✓		✓	✓	✓	✓
I06	Quantity Surveyor (BIM practitioner)	✓		✓		✓		✓
I07	Chartered Quantity Surveyor (Contract manager)	✓	✓		✓	✓		✓
I08	Chartered Quantity Surveyor (BIM practitioner)	✓	✓			✓		
I09	Research Scholar (In digital technology)			✓		✓	✓	
I10	Quantity Surveyor (BIM practitioner)	✓	✓			✓		
I11	Site Quantity Surveyor (In a D&B project)	✓	✓			✓		
I12	Project Manager (In a D&B project)	✓	✓			✓		

4. FINDINGS AND ANALYSIS

4.1 CAUSES FOR COST OVERRUN IN DESIGN AND BUILD PROJECTS

The literature review reveals thirty (30) causes for cost over-run in D&B projects. Even though most identified causes are directly related to D&B projects, few are not specified. Therefore, round 1 phase 1 of the interview survey was used to confirm the applicability of findings to D&B projects, check the possibility of managing them using BIM, and add any new causes. As a result, four (04) new causes were added (indicated in bold text), and nine (09) causes were rejected. Ultimately, twenty-five (25) causes were confirmed from this stage. In the interview round 2 phase 1, respondents were asked to categorise identified causes according to their level of importance as high, medium, and low. Out of the twenty-five (25) identified causes, ten (10) causes were confirmed as highly important causes, with more than 75% agreement from the respondents. Further, another ten causes were identified as moderately important causes while the other five were categorised as less important. Findings are summarised in Table 2.

Table 2: Causes of cost overrun

No.	Item Code	Description	
01	C01	Continuous changes in design and drawings due to incomplete initial drawings prepared with insufficient design data at the tendering stage	**High**
02	C23	Errors or omissions revealed during construction	
03	C19	Inefficient planning and scheduling by the contractor	
04	C21	Inadequate constructability of the design	
05	C17	Inappropriate construction methods followed by contractors	
06	CN01	Lack of clarity in the employer's brief	
07	CN03	Issues relating to D&B are not properly addressed in the Conditions of Contract	
08	C26	Improper geotechnical investigations	

09	C07	Unforeseen weather and site conditions experienced D&B contractor could not have predicted	
10	C25	Poor communication between design and construction teams	
11	C02	Frequent changes in construction drawing during the execution of construction works	**Medium**
12	C05	Delay in revising and approving design documents by consultant or employer	
13	C14	Cash flow problems faced by the contractor due to the delayed payment from the client	
14	C22	Quality control and assurance-related causes	
15	C18	Slowness in decision-making by employer and consultant which cause additional cost for material idling	
16	C30	Mistakes in tender document preparation and misinterpretation of contractual clauses	
17	CN02	Mistakes in communicating the requirements of basic design parameters	
18	C29	Poor material selection and waste management strategies	
19	CN04	The inexperience of client's and/or contractor's project management teams	
20	C11	Lack of materials at the site due to difficulty in extracting exact material quantity from incomplete and unapproved drawings	**Low**
21	C12	Rework due to design clashes, poor and inaccurate identification of employer requirements, and lack of final quality caused by work acceleration	
22	C13	Poor judgement in estimating time and resources due to inadequate experience of the contractor	
23	C03	Mistakes in quantity take off at the time of tender pricing by design and build contractor	
24	C08	Delays in early procurement of the specialist subcontracting work due to incomplete designs and specifications	
25	C15	Additional works required on site conditions and the employer's request	

Experts rejected "dependency on specialist works without alternatives", "shortage of local materials", "insufficient pricing for preliminaries and fewer allocations for contingencies", and "unqualified workforce" as those causes are *not unique to D&B projects*. Further, "environmental issues", "delays in material approval by consultant/employer", and "delays in getting authority approvals" were rejected since those causes *cannot be managed with BIM*. Additionally, respondents rejected "price fluctuation in materials and fuels" and "catastrophes", reasoning with both above.

Although high constructability is considered a vital benefit of the D&B procurement method, inadequate planning, experience, and expert knowledge in designing and time constraints can be challenging. Due to that, the constructability of the design can be reduced compared to the traditional method. Respondents identify this is a common situation in developing countries because contractors may not have the matured experience dealing with the unique characteristics of D&B projects, which can cause cost overrun. Suggesting "lack of clarity in employer's brief" as a new cause for cost overrun in D&B project I01 stated, "*clients who are unfamiliar with D&B procurement method do not provide sufficient details about their requirements. So, the contractors tend to design the project based on their own experience disregarding the clients' actual requirements*". Further, I05 suggested "mistakes in communicating the requirements of basic design parameters" is a unique cause for cost overrun in D&B project due to the overlapping of design and construction phases. Another common problem is clients are unable to address the issues adequately, through particular conditions of the contract, because of their lack of knowledge related to the D&B method. Further lack of experience in the contractor's project management team is another factor not discussed in the literature. I10 stated that "*some engaged in D&B projects are not familiar with the* *integrated nature of this method; they are familiar with the traditional method and completely subcontract the design responsibility to another party which is not the ultimate goal of this D&B method".* Therefore, additional cost is required for the design and unable to obtain cost-effective opportunities in the D&B method for the contractor.

4.2 FREQUENTLY USED FUNCTIONS OF BIM IN CONSTRUCTION PROJECTS

Thirty-five (35) BIM functions were identified through the literature, and in round 1 phase 2, respondents were asked to highlight any modifications or additions. However, no modifications/new functions were raised. Respondents confirmed that almost all the functions they know were included in the given list.

In round 2 phase 2, respondents were asked to select the five most suitable BIM functions for each highly important cause identified in round 2 phase 1. Out of those thirty-five functions, ten (10) functions were rejected in this stage. The suitable BIM functions were selected to manage the cost overrun in a project's design and construction stages in this study. Therefore, "program area and space validation", "asset management", "record model/ as-built model", "operations and maintenance scheduling", and "building maintenance scheduling" functions were not preferred since those functions are insignificant in the stages. Additionally, "digital fabrication" and "field supplements" functions were rejected because they were incompatible with managing highly important causes. Even though some respondents identified "quality management", "energy analysis and optimisation", and "field supplements" as suitable to manage some highly important causes, they were unable to obtain more than 60% of agreement from the respondents. Finally, twenty-five (25) BIM functions were selected to manage the highly important causes, with the confirmation of more than 60% of the respondents. Results from this stage were summarised in Table 3.

4.3 SUITABLE BIM FUNCTIONS THAT CAN BE USED TO MANAGE THE HIGHLY IMPORTANT CAUSES OF COST OVERRUN IN D&B PROJECTS

In round 2, phase 2, each respondent was asked to select five (5) most suitable BIM functions, considering their significance towards managing the particular highly important cause of cost overrun. Out of the matched BIM function to each cause, functions with more than a 60% agreement rate from the respondents were selected as suitable BIM functions to manage the particular cause of cost overrun. Findings are summarised in Table 3.

Table 3: Most suitable BIM functions to manage highly important causes for cost overruns in D&B projects

No.	Highly important cause	BIM functions
01	Continuous changes in design and drawings due to incomplete initial drawings prepared with insufficient design data at the tendering stage	Change and revision management Cost estimation (5D) and management Interoperability and exchange of information Design documentation Digitalised quantity take-off Cloud computing
02	Errors or omissions revealed during construction	Digitalised quantity take-off Clash detection Design and constructability reviews

No.	Highly important cause	BIM functions
		Structural analysis Modelling existing conditions Interoperability and exchange of information Modelling design and engineering analysis
03	Inefficient planning and scheduling by the contractor	Planning and scheduling (4D) Safety planning and review Trade coordination Site utilisation planning Clash detection Field and management tracking
04	Inadequate constructability of the design	Constructability reviews and building simulation Modelling existing conditions Site condition analysis Clash detection
05	Inappropriate construction methods followed by contractors	Construction system design Site condition analysis In-field construction layout preparation
06	Lack of clarity in the employer's brief	Modelling existing conditions Constructability reviews and building simulation Interoperability and exchange of information Design coordination Design documentation Cloud computing
07	Issues relating to D&B are not properly addressed in the Conditions of Contract	Design authoring Design documentation Interoperability and exchange of information Safety planning and review
08	Improper geotechnical investigations	Site condition analysis Disaster planning Constructability reviews and building simulation
09	Unforeseen weather and site conditions experienced D&B contractor could not have predicted	Site condition analysis Disaster planning Sustainability evaluation Safety planning and review Occupational safety analysis (8D) Modelling design and engineering analysis
10	Poor communication between design and construction teams	Interoperability and exchange of information Cloud computing Clash detection Change and revision management Design authoring Digitalised quantity take-off Design coordination

According to Table 3, BIM functions commonly selected for managing the highest number of causes are "interoperability and exchange of information" and "clash detection". Those two functions were recognised to address five and four highly important causes, respectively. Some other BIM functions such as "digitalised quantity take off", "cloud computing", "design documentation", "safety planning and review", "constructability reviews and building simulation", and "site condition analysis" were chosen to manage three different highly important causes for cost overruns for each.

4.4 DISCUSSION

Adamtey (2021) stressed that D&B contractors should pay immediate attention to addressing the price uncertainty of the projects. Most previous studies on cost overrun are based on traditional procurement methods, and limited studies focused on D&B projects (Potty et al., 2011; Saaidin et al., 2017;). Therefore, validating the applicability of common causes for cost overrun for D&B projects was required. El-Ahwal et al. (2016) declared that scope changes, design errors, inadequate planning, and delays increase the risk of cost overrun in typical projects. This study confirms that these exact causes apply to D&B projects. Ramanathan et al. (2011) also identified "continuous changes in design and drawings at tendering stage" as a critical factor for cost overrun in D&B projects. This study approved it as a highly important cause in round 2. Further, several studies describe "errors revealed during construction" (Akinradewo et al., 2019; Johnson & Babu, 2020) and "contractor's inefficient planning and scheduling" (Akinradewo et al., 2019) as important causes for cost overrun in construction projects and present study confirms it is applicable in a similar way to D&B projects. Even though there is significant potential to adopt BIM to manage cost overrun in D&B projects, literature has not addressed that area. Therefore, identifying suitable BIM functions to manage critical causes for cost overrun in D&B projects was the research gap that was intended to fulfill through this study. In that case, common functions of BIM, recognised from the comprehensive literature, were validated through the interview process, and no alterations happened. Many past researchers identified "interoperability and exchange of information" and "clash detection" are the most specific and unique functions of BIM (Abdel-Hamid & Abdelhaleem, 2023; Ganbat et al., 2020; Gholizadeh et al., 2018). Respondents also recognised their significance and highlighted that these two functions could be used to manage multiple highly important causes of cost overrun in D&B projects. Furthermore, several other BIM functions as "digitalised quantity take-off", "cloud computing", and "constructability reviews and building simulation", were previously identified by different authors (Bello et al., 2021; Brahim et al., 2018; Gholizadeh et al., 2018) are recognised by the respondents as effective in managing multiple critical causes for cost overrun in D&B projects.

5. CONCLUSIONS

The aim of this study was achieved through the literature review and two rounds of interviews. Twenty-five causes for cost overrun in D&B projects were identified, validated and categorised into three categories according to their criticality level. Ten causes were recognised as highly important causes for cost overrun in D&B projects such as "continuous changes in design and drawings ", "errors/omissions revealed during construction", "inefficient planning and scheduling by contractor", "inadequate constructability of the design" and "inappropriate construction methods followed by contractors". A significant proportion of the causes identified as contributing to cost overrun in the D&B method can be alleviated by implementing efficient construction management practices. Given this observation, it is reasonable to assert that BIM represents a promising solution to address these challenges. Thirty-five BIM functions were identified from the literature review and validated by the respondents as they are aware of them. Identified BIM functions were matched with the highly important causes as their applicability to manage the cause successfully. In that case, "interoperability and exchange of information", "clash detection", "digitalised quantity take-off", "design documentation", "cloud computing", "constructability reviews and building simulation", "safety planning and review", "site condition analysis" were confirmed as functions that can be commonly used to manage multiple highly important causes for cost overrun in D&B projects. The study revealed that the interoperability of BIM could mitigate continuous changes in design drawings, increase the clarity of the client's brief, increase the coverage of conditions of contract to address issues in the D&B method and improve communication. Most importantly, the clash detection function is undeniably helpful in reducing errors and omissions, improving planning efficiency and the design's constructability. Overall, these findings highlight the potential of BIM to improve project outcomes in D&B construction, making it a valuable tool for the industry.

This research aims to investigate the use of BIM to manage cost overrun issues in D&B projects. Thus, the study findings can be used as a reference when conducting further studies on managing pricing risk in D&B projects with BIM and other digitalisation technologies. The findings will foster and encourage the successful adoption of digitalisation technologies for managing unique and critical challenges in the construction industry. Since the majority of the respondents of this research have their experience related to the Sri Lankan context, the study cannot be generalised in the global context,

Despite their essential advantages over traditional procurement method, the risk of cost overrun is one of the most common, critical and unsolved issues in D&B projects faced by the contractor. Therefore, identification of highly important causes for cost overrun and suggesting the most suitable BIM functions, industry professionals will be able to prioritise the risks and implement the most appropriate and convenient BIM function to address them. The full potential of BIM has not been revealed yet. Thus, this study can be used as a benchmark for future studies by revealing another parameter of the applicability of BIM in reducing the pricing risk of D&B projects. Furthermore, future studies can be conducted to identify barriers to implementing identified BIM functions and suggest suitable strategies to overcome those barriers.

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UTILISING SMART VISITOR MANAGEMENT SYSTEM TO ENHANCE SUSTAINABLE PRACTICES IN HIGH-RISE BUILDINGS IN SRI LANKA

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ABSTRACT

With the growing importance of sustainability and environmental conservation, effectively managing visitor flows in high-rise buildings poses unique challenges and opportunities. Smart visitor management systems (SVMSs) offer innovative solutions to optimise resource allocation, minimise waste generation, and promote eco-friendly practices in this context. Through an in-depth analysis of relevant data, case studies, and expert perspectives, this study investigates the implementation and potential benefits of smart visitor management systems (SVMSs) in high-rise buildings, with a specific emphasis on sustainability. The findings reveal that the adoption of these systems can lead to significant positive impacts, including improved energy efficiency through intelligent lighting and HVAC controls, reduced carbon emissions by streamlining transportation and parking, enhanced waste management through digital registrations and real-time monitoring, and improved visitor experiences through streamlined check-ins and personalised services. Moreover, the integration of smart visitor management systems (SVMSs) enables high-rise buildings to achieve sustainability certifications and contribute to the overall environmental goals of Sri Lanka. The article also addresses the potential challenges and considerations associated with implementing these systems, such as data security and privacy concerns, initial investment costs, and the need for stakeholder collaboration. The insights derived from this study provide valuable guidance for building owners, facility managers, policymakers, and other stakeholders involved in sustainable practices in high-rise buildings in Sri Lanka and similar contexts.

Keywords: *Barriers; Drivers; High Rise Buildings; Smart Visitor Management System; Sustainable Practices; Visitor Management.*

1. INTRODUCTION

One of the most pressing issues that have prompted the construction of high-rise buildings and are likely to continue is the enormous growth in urban population paired with wealth accumulation (Ali & Al-kodmany, 2012). High-rise structures appear to congregate in the centre of major cities, when land is scarce (Frenkel, 2004). High-rise building development addresses territorial planning difficulties, boosts urban environment diversity, and improves usability (Dement'eva & Dement'eva, 2018). However, the

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environmental implications associated with such urbanisation cannot be overlooked. The massive energy consumption, waste generation, and carbon emissions from these buildings necessitate the adoption of sustainable practices to mitigate their environmental impact (Ali et al., 1995).

One significant aspect of sustainable building management is the effective control and monitoring of visitor activities within these high-rise structures. Traditional Visitor Management System has many drawbacks: they are time-consuming and labour-intensive and often rely on paper based processes (Chiang, 2018). The pen-and-paper visitor record system raised inefficiencies, security concerns, and excessive resource utilisation (Isaiah & Solomon, 2019). A visitor management system is essential because it is capable of streamlining the registration process and providing visitors with accurate and integrated data and enhance sustainable practices in high-rise buildings (Oktaviandri & Foong, 2019) .

Al-Ghaithi and Eaganathan (2016) stated that the visitor management systems (VMS) can be implemented by installing the Visitor Management software program on existing computers on the premises. The database-driven visitor management software can be tailored to the organisation’s needs (Olhausen-Kaylor, 2019). This password-protected, web-based management system allows authorised users to pre-register visitors before arriving at a facility (Craighead, 2009). This additional information can include a photo of the visitor, the reason for the visit, to what location the visitor is going, a time stamp, and more (G2 track, 2021). (Al-Ghaithi & Eaganathan, 2016). According to Kazlauskas, (2015), many factors are driving the utilisation of VMS to improve security and facility management implementation in high-rise buildings. They are used as tools and as resources to improve quality of life, achieve sustainable development, and create a more open and innovative urban context through the participation of several actors (Asmone et al., 2014). However, only the integration of all of the domains of intervention based on the contribution of SVMSs can help cities to achieve long-lasting and sustainable economic growth and a better quality of life for urban stakeholders in high-rise buildings (Marjaba & Chidiac, 2016). Several barriers are also impacting the implementation of automated VMS.

However, global research has been conducted on the design and development of VMS (Mahmud, 2018). There is a lack of evidence on the utilisation of SVMS to enhance sustainable practices in high rise building drivers and barriers to applying the VMS system at high-rise buildings in Sri Lanka. To this end, this paper aims to identify the need for VMS, enablers, and barriers to the application of VMS systems to improve sustainable practices at high-rise buildings in Sri Lanka.

2. SUSTAINABLE PRACTICES VS SMART VISITOR MANAGEMENT

Sustainable practices are activities and policies that strive to reduce negative environmental, social, and economic impacts while maintaining long-term viability (Marjaba & Chidiac, 2016). It promotes low-cost energy and technological advancements in lighting and HVAC, waste reduction, potable water conservation, and awareness of material use and waste disposal issues in order to persuade designers to incorporate more sustainable elements into high-rise structures (Ali et al., 1995). Despite meeting the issues of the increasing population in such locations, a sustainable solution and assistance in transitioning to a low-carbon economy are required (O'Dwyer et al., 2019).

While technological knowledge on how to achieve this goal is growing, it is critical to understand the relationship between technology improvements in sustainable structures and the behaviours and impacts of building users (Wener & Carmalt, 2006). Organisations reshape their processes in line with on-premise technologies such as SVMSs (Gökalp & Martinez, 2021).

Typically, a VMS is a structure that keeps track of visitors' activities in an organisation or public building (Oktaviandri & Foong, 2019). Visitor management is a modern-day problem, and with its use, various frauds, privacy concerns, and other difficulties may be readily discovered and avoided (Makwana et al., 2019). An organisation's operations depend on visitor management (Phua, 2009). The focus on security, data integrity, and compliance has shifted from simply digitalisation procedures like paper logbooks and manual security checks to a greater emphasis on security, data integrity, and compliance (Traction Guest, 2020).

Integrating sustainable practices with smart visitor management can lead to more efficient resource use, reduced environmental impact, enhanced visitor experiences, and improved overall sustainability (Wener & Carmalt, 2006).

3. APPLICATION OF VMS TO IMPROVE SUSTAINABLE PRACTICES IN HIGH-RISE BUILDINGS

VMSs are essential because they allow organisations to track who is on the premises at any given time (Redyref, 2020). Additional layers of advanced visitor management safety, such as kiosks and visitor management software, are critical in keeping personnel and intellectual property safe (Traction Guest, 2020). The impact of VMS on stakeholders continues to be positive (Bonne et al., 2013). In addition to security, advanced digitalisation capabilities can provide scope for new functionality, higher reliability, greater efficiency, and optimisation opportunities that exponentially increase the value companies deliver to customers (Annarelli et al., 2021). A well-implemented VMS can enhance the visitor experience by providing a seamless and efficient check-in process. By reducing waiting times and minimising manual paperwork, it contributes to a positive impression of the building and promotes visitor satisfaction (Noorhuzaimi-Karimah et al., 2008).

VMS enhances security and safety measures, which indirectly contributes to sustainability (Weingart et al., 2006). Because the pen-and-paper visitor record system lacks a mechanism for recycling prior visitor records for new input, statistical reports cannot be generated. It is disorganised, incomplete, and difficult to find information. The data acquired in the prior system is stored in a book (Isaiah & Solomon, 2019). Instead of pen and paper visitor record, VMS generates digital reports that assist in waste reduction efforts by promoting digital communication and documentation (Isaiah & Solomon, 2019).

To improve operational efficiency, it may handle facility booking, approval, and billing procedures across enterprises (Sierra ODC Private Limited, 2020). In advance, the meeting organiser can provide visitor information and requests such as parking space, allergens, and accessibility needs (Shackley, 2009). Other than making a reservation, meeting rooms, conference halls, office space, auditoriums, sports facilities, high-cost equipment, and training facilities can all be reserved via the system to efficient space utilisation (Sierra ODC Private Limited, 2020).

Facility managers may find it difficult to manage several tenant organisations and their visitors, off-site personnel, deliveries, and vendors (Veristream, 2020). Using VMS can simply and efficiently make data driven decisions (Thoti et al., 2009). A VMS is a system that encompasses all of an organisation's processes and practices for managing the movement of visitors from beginning to end as part of the visitor experience (Veristream, 2020). VMS generates valuable data about visitor patterns, preferences, and facility usage. This data can be analysed to identify areas for improvement, optimise operational efficiency, and make informed decisions regarding resource allocation, space utilisation, and sustainability initiatives (Cooman, 2019).

4. DRIVERS AND BARRIERS OF VMS TO IMPROVE SUSTAINABLE PRACTICES IN HIGH-RISE BUILDINGS

Tables 1 and 2 summarise the enablers and barriers of VMS to improve sustainable practices in high rise buildings, respectively.

Table 1:Drivers of VMS to improve sustainable practices in high-rise buildings

Drivers	Description	Sources
Enhance company image	A competent VMS demonstrates that the facility takes security seriously. A strict security system will impress the visitors who enter an organisation, allows to improve the company's image.	(Kazlauskas, 2015); (Bosstab, 2020)
Accuracy and productivity	As visitor particulars do not have to be manually typed in, having an electronic way to capture visitor information ensures accuracy for all types of visitors. Because they have a system monitoring security, it will only take a few minutes to verify the identity of a visitor, and productivity will improve.	(Kazlauskas, 2015); (Penarubia, 2020)
Security	A formal visitor check-in system and a designated point of entry/exit work hand in hand with access control to improve overall site security.	(Harrison, 2018); (Raker, 2019)
Efficient site control/customisable	This technology allows an organisation to efficiently manage the site by quickly tracking who is where and who enters and exits the premises.	(Fadiyah, 2019)
Cost-saving	VMS is more cost-effective and efficient than security solutions that rely on scanning technology. One of the strengths of this system is how adaptable and scalable it is. Organisations can choose only the elements that are required.	(Fadiyah, 2019); (Zaman et al., 2017)
Resource Conservation	Sustainable practices aim to minimise resource consumption and waste generation. VMS can contribute to these efforts by optimising energy usage through features like automatic lighting and HVAC controls. By ensuring that spaces are only active, when necessary, these systems help conserve energy and reduce environmental impact.	(Khalid et al., 2018)

Table 2: Barriers of VMS to improve sustainable practices in high rise buildings

Barriers	Description	Sources
Interruptions	As most systems rely on electricity to operate, they will be disrupted if there is a power outage.	(Penarubia, 2020); (Tarco marketing, 2018)
High cost	Owing to system's benefits, it can be costly to purchase, and additional components will raise the cost of maintaining a VMS, especially if they perceive a lack of immediate cost savings or return on investment.	(Penarubia, 2020); (Starter story, 2017)
Technical support	The smart VMS requires technical assistance to resolve a VMS software issue.	(Kazlauskas, 2015); (Starter story, 2017)
Unawareness	Not aware of the benefits and potential of visitor management systems in improving sustainability practices. Learning how to use a software program is a little more complicated, and because it is new, a training program is required to increase awareness.	(Kazlauskas, 2015); (Visipoint, 2021)

5. METHODOLOGY

A qualitative approach is used for this study, considering the data gathering method and the research kind (Punch, 2005). The installation of VMS to improve sustainable practices in high-rise structures is a new concept to Sri Lanka. This data was captured by expert interviews. As a result, a thorough literature review was undertaken to determine the reasons for the necessity for a VMS and the usage of a VMS to improve sustainable practices and identify the drivers and barriers to utilising VMS for improving sustainable practices in a global context through books, journals, and conference proceedings.

As the second method, the expert interview method was used, one of the most used data collection methods for conducting qualitative approach research (Punch, 2005). Among the many interview formats, semi-structured interviews were chosen because they allow the researcher to ask both organised and unstructured questions and allow for the clarification of doubts. Since the VMS is a novel idea and only a few industry practitioners know it, expert interviews were chosen as the best data collection strategy. Further, VMS and sustainable practices are grooming areas, hence, the number of experts was limited. As a result, expert interviews were performed with six experts.

Table 3:Summary of interview respondents

No	Interview Participant	Profession	Designation	Years of experience
01	IA1	Facilities Management – Residential	Front office manager	11
02	IA2	Engineering – Hotel	Chief engineer	14
03	IA3	Engineering – Hospital	Assistant Manager IT	11
04	IA4	Facilities Management – Commercial	Senior Manager - Premises	28
05	IR1	Facilities Management	Managing director	15
06	IR2	Facilities Management	Director	13

Hence, all the participants in the sample have more than 10 years of experience in the industry, and the collected data can be considered reliable data. Both literature findings and data gathered from interviews were used to analyse the data.

6. FINDINGS AND ANALYSIS

According to the findings of a comprehensive literature review, many researchers worldwide identify the enablers and barriers to implementing VMS to improve sustainable practices. However, there is a lack of specific literature resources related to the Sri Lankan context. Therefore, to determine the application of VMS to improve sustainable practices in high-rise buildings in Sri Lanka investigated the knowledge of the professionals in organisations that have experience using VMS and professionals of VMS software and component suppliers. In this section, research- findings on drivers of VMS to improve sustainable practices in high-rise buildings, barriers, and strategies to minimise identified barriers are discussed.

6.1 APPLICATION OF VMS IN HIGH-RISE BUILDINGS TO IMPROVE SUSTAINABLE PRACTICES IN SRI LANKA

The findings of the existing literature were directed to an expert via a semi-structured interview guideline to determine the demand for VMS, as well as the drivers and barriers impacting the implementation of VMS for improving sustainable practices in high-rise buildings. The findings from both expert interviews and a comprehensive literature review are presented in the sections that follow.

The experts’ opinion on sustainable practices encompasses a wide range of activities, such as reducing resource consumption, minimising waste generation, conserving energy and water, promoting renewable energy sources, supporting social responsibility, and fostering ecological conservation. Therefore, experts explain that the goal of sustainable practices is to create a harmonious balance between environmental protection, social well-being, and economic development for long-term sustainability.

VMS explores features such as pre-registration, identity verification, badge printing, and access control integration. Experts expressed the benefits of VMS in preventing unauthorised access and ensuring a secure environment. According to all the experts, VMS can streamline visitor processes in high-rise buildings, reducing waiting times and improving overall efficiency. It explores features such as self-registration, automated check-in/out, appointment scheduling, and digital notifications. The potential for reducing queuing time, enhancing visitor experiences, and increasing operational efficiency is emphasised.

Interviewees mentioned that reducing manual processes and increasing digital efficiency can identify significant drivers. The concept of digital efficiency is based on the elimination of manual processes and workflow components that require multiple touches. As experts mentioned, VMS to reducing resource consumption and waste generation in high-rise buildings. It discusses how digitalising visitor processes through VMS can significantly reduce paper waste, including visitor badges, registration forms, and logbooks. The potential for optimising resource allocation and achieving cost savings.

According to the experts, VMS can integrate with building automation systems to control lighting, HVAC, and other energy-consuming devices based on visitor presence and occupancy. This improves energy efficiency and reduced the carbon emission. High-rise buildings often have limited space, and efficient utilisation is crucial. VMS can provide real-time insights into visitor traffic and occupancy patterns, enabling facility managers to optimise space allocation. By understanding peak and off-peak periods, building operators can implement strategies like shared workspaces or flexible seating arrangements, reducing the overall footprint and maximising space utilisation.

As per the interviewees, VMS can use to improve sustainable practices by collecting and analysing visitor data, such as visitor demographics, entry/exit patterns, and occupancy trends. Experts mention that the generation of comprehensive reports and actionable insights for building managers to optimise operations and resource planning.

Another critical motivator is that technology such as VMS can improve employee well-being by providing a safer workplace and making a pleasant first impression. According to the experts, VMS can utilise to send out a branded invite. Therefore, that advises visitors where to go and highlights the organisation's identity and branding and a QR code to scan on arrival in an invite to boost customer and tenant satisfaction. Visitors can add the details to their calendars with a single click, and host contact information is available. Experts mentioned that digital transformation models like VMSs are very novel to Sri Lanka. Therefore, there is high unawareness regarding most of the new technology advancements come under digitalisation. Experts stated that VMS offers vivid, robust, and adaptable solutions that assist to reducing carbon footprint, minimising waste generation, and optimising resource utilisation and optimising day-to-day activities while still offering better service to visitors.

6.2 DRIVERS OF USING VMS TO IMPROVE SUSTAINABLE PRACTICES IN HIGH-RISE BUILDINGS IN SRI LANKA

VMS technology enables an organisation to manage the site more efficiently by rapidly tracking who is where and who enters and departs the premises. VMS enhances security and safety measures, which indirectly contributes to sustainability. Interviewees identify that VMS generates valuable data about visitor patterns, preferences, and facility usage. This data can be analysed to identify areas for improvement, optimise operational efficiency, and make informed decisions regarding resource allocation, space utilisation, and sustainability and initiatives. Interviewees highlighted that VMS reduces coronavirus transmission by keeping track of who comes into your company and protects your premises from unwanted visitors who may spread the virus. Experts mentioned that "*A visitor management system could provide businesses with health and safety elements to help fight COVID*". It enables online booking, for example, offers COVID solutions, including health screening for guests. Experts identified that requesting guests to complete a questionnaire based on COVID-related health issues and a copy of their completed questionnaire can be stored securely in the online portal and can be set up notifications, this function helps to reduce COVID infection and spread. Experts also noted that there are features in automated VMS to automatically check the temperature at the entrance and provide a sanitizer, all above improve the health and safety of the workplace.

In addition, they stated that "*VMS allows an organisation to keep track of occupancy levels while also offering real-time data and insights on the safety of the facility*". Further, "*The visitor management system will digitise the entire process, saving money in the long run*". High-rise buildings often have limited space, and efficient utilisation is crucial. VMS can provide real-time insights into visitor traffic and occupancy patterns, enabling facility managers to optimise space allocation. By understanding peak and off-peak periods, building operators can implement strategies like shared workspaces or flexible seating arrangements, reducing the overall footprint and maximising space utilisation.

As per the experts, VMS systems can integrate with many services like housekeeping, car parking, security, food, and beverage, room service, gymnasium, pool, and spa, from that organisations can easily do the billing and payment process of services that guests consume. Energy-efficient measures, optimised resource utilisation, and waste reduction can result in lower utility bills, reduced maintenance costs, and improved operational efficiency, motivating organisations to adopt sustainable practices.

According to the experts, "*A visitor management system provides a mobile dashboard with essential data*". It can enhance the organisation's public image because of the first good impression mentioned by the interviewees. The availability of a visitor management system might provide a great first impression of the organisation to a digitally savvy guest. Experts stated that "*VMS can promote branding on the solution's front end*" Company colours may be shown on hardware devices, logos uploaded to the solution's front end, and can be made screensaver rolls to follow corporate rules. These elements are sometimes necessary to catch the attention of potential clients, who may have a higher opinion of the company. Embracing sustainability can enhance the reputation and brand image of high-rise buildings and organisations. Sustainable practices aligned with VMS can attract environmentally conscious tenants, investors, and customers who value responsible and sustainable operations.

In addition to things found in the literature, most experts emphasise that VMS can assist in waste reduction efforts by promoting digital communication and documentation. Instead of printing visitor badges or passes, the system can generate digital credentials or QR codes that visitors can store on their mobile devices. This reduces the production of physical waste associated with traditional badge printing.

The drivers of application of SVMSs in high-rise buildings can optimise energy consumption, improve resource utilisation, reduce waste, enhance security, and enable data-driven decision making. These benefits collectively contribute to improving sustainable practices and promoting a more environmentally friendly and efficient operation of high-rise buildings.

6.3 BARRIER OF USING VMS TO IMPROVE SUSTAINABLE PRACTICES AT HIGH-RISE BUILDINGS IN SRI LANKA

Visitors can be registered, employees can be contacted promptly, visitor badges can be printed, eSignatures on legal documents can be captured, and a digital visitor logbook can be created. That is readable and available from anywhere; therefore, for that high technology is needed. Experts stated that there should be standard hardware devices that support the VMS software. "Unawareness about the software program" was another barrier. Organisations may be unaware of the specific ways VMS can contribute to sustainability or may underestimate its impact on resource conservation and operational efficiency. Experts mention that "*VMS is a new concept to Sri Lanka and most organisations are not familiar with technologies like VMS*". Therefore, they may need technical support until they are familiar with modern technology. Security issues indicate that data about visitors is confidential. If a visitor's driver's license or ID is scanned, the data can be used to steal their identity, therefore, encryption is required. Otherwise, data can be hacked, and data must also be backed up.

Experts mentioned that one of major barriers is technological limitation. There may be technological limitations that hinder the implementation of specific sustainable practices. For example, certain energy-saving features may require integration with building management systems or the availability of advanced sensors and control. Resistance to change from building owners, staff, or visitors can pose a significant barrier to the successful adoption of sustainable practices through VMS.

Apart from the GDPR, in Sri Lanka, there are no legal requirements or regulations to follow when implementing the VMS with visitors' private information. The absence of standardised sustainable practices or guidelines specific to VMS in high-rise buildings, can make it challenging for organisations to develop and implement consistent sustainability strategies. This can lead to uncertainty and delays in decision-making and implementation, when dealing with many visitors, passes. Some organisations have different passes for different departments, floors, and buildings. Therefore, staff or tenants must use many keys to visit various departments, and floors and that decreases tenant, and staff satisfaction.

In addition to those findings, almost every expert identified "High investment cost due to numerous advantages" as a common barrier. Integrating sustainability practices through VMS may require upfront investments in technology, infrastructure upgrades, and employee training. The initial costs involved can be perceived as a barrier, particularly for organisations with limited financial resources. Due to VMS's many features and technological advancements, hardware equipment and software can cause high costs. Organisations need to request for awareness programs and training due to lack of technical knowledge. Cost for those added to the investment cost and errors may happen at the beginning of the operation period, which will increase costs and interruptions.

As per the experts, a smaller number of VMSs existence can discourage organisations from establishing VMS and make less trust in the business of VMS. Since VMS is not common in Sri Lanka, some organisations don't like to take risks in establishing VMS. The expert mentioned that few examples exit on VMS, so most organisations are worried about the investment outcome. Some experts stated that "*automated VMS rely entirely on machines, and frequent machine breakdown hugely impacts the entire process of visitor management*". Sustainable practices often require the collaboration and participation of multiple stakeholders, including building owners, tenants, employees, and visitors. Limited engagement or resistance from stakeholders can impede the successful implementation of sustainable practices through VMS.

Overcoming these barriers requires a comprehensive approach involving education and awareness campaigns, financial incentives, stakeholder engagement, clear communication of the benefits, and demonstration of successful case studies. By addressing these drivers and barriers, organisations can better implement sustainable practices through VMS and foster a more environmentally responsible operation in high-rise buildings.

6.4 STRATEGIES TO OVERCOME IDENTIFIED BARRIERS

Based on the identified barriers, this section offers recommendations and strategies to overcome these challenges and promote the successful integration of VMS technologies for sustainable practices in high-rise buildings in Sri Lanka. The recommendations may include raising awareness through education and training programs, incentivising sustainable initiatives, addressing financial concerns through cost-benefit analyses, fostering collaboration between stakeholders, and advocating for supportive policies and regulations.

According to the experts, to overcome high investment costs, it can be arranged loan facilities for VMSs. Sri Lankan government can reduce taxes for hardware equipment that are used for VMS to support local manufacturers and distributors of VMS. Experts mentioned that developing a comprehensive financial plan that outlines the costs and potential long-term savings associated with implementing sustainable practices through VMS can manage the high cost and explore government incentives, grants, or financing options available for sustainability initiatives to alleviate the initial financial burden.

Encourage technology providers to develop user-friendly, cost-effective, and scalable VMS solutions that align with sustainability objectives, get support from experts, assess the technological capabilities of the VMS and identify any limitations that may hinder sustainable practices fulfil the lack of technological knowledge and support. According to the experts, exploring opportunities to upgrade or integrate VMS with building management systems, advanced sensors, or controls enable more sophisticated energy management and resource optimisation.

According to the experts, it can conduct awareness campaigns and training programs to educate stakeholders about the benefits of sustainable practices and how VMS can contribute to achieving those goals and provide clear information on the positive impacts of sustainable practices on cost savings, energy efficiency, and environmental stewardship. Experts mentioned that VMS suppliers can provide free trials to the organisation to check the suitability and improve the awareness of stakeholders that help organisations to evaluate the needs for the VMS and accordingly choose VMS software with the required features and build a good co-relationship with the client and other regulatory bodies.

In addition, every expert identified implementing effective change management strategies such as communication plans, involving stakeholders in decision-making processes, highlighting the benefits of sustainability, and providing training and support for employees during the transition addressed the resistance to change. The expert mentioned that working with industry organisations, regulatory bodies, and sustainability experts to develop standardised best practices specifically for sustainable practices through VMS in high-rise buildings encouraged the adoption of these standards to provide clarity, guidance, and benchmarks for organisations to follow. To obtain stakeholder engagement and collaboration organisations can create forums for open dialogue, seek feedback and suggestions, and establish collaborative partnerships with stakeholders to jointly develop and implement sustainable practices. According to experts, organisations can share successful case studies and examples that have implemented sustainable practices through VMS in high-rise buildings and highlight the positive outcomes, cost savings, and environmental benefits to inspire and motivate other organisations to follow suit. Implement a robust monitoring and evaluation system to track the progress and effectiveness of sustainable practices through VMS. Regularly review and analyse data on energy consumption, resource utilisation, waste reduction, and stakeholder feedback to identify areas for improvement and make informed decisions.

By adopting these strategies, organisations can address the barriers and create an environment conducive to the successful implementation of sustainable practices through VMS in high-rise buildings. It requires a combination of financial planning, stakeholder engagement, technological enhancements, and a focus on education and awareness to foster a culture of sustainability.

7. CONCLUSIONS

The utilisation of a smart VMS presents significant opportunities to enhance sustainable practices in high-rise buildings, particularly from the perspective of Sri Lanka. By adopting a holistic approach that integrates technology, energy efficiency, waste management, and occupant satisfaction, VMS can contribute to creating environmentally responsible and socially conscious building operations.

The implementation of a smart VMS enables efficient energy management by optimising lighting, HVAC systems, and other energy-consuming equipment based on real-time occupancy data. Furthermore, VMS facilitates effective waste management by monitoring and managing visitor access. The system also provides valuable data and analytics to support efficient waste disposal strategies, minimising waste generation and promoting sustainable waste management practices. Occupant satisfaction is a key aspect of sustainable practices, and a smart VMS enhances the overall experience of building occupants. Satisfied occupants are more likely to support and engage in sustainable behaviours, fostering a culture of sustainability within high-rise buildings.

In the context of Sri Lanka, where sustainability is gaining increasing importance, the adoption of smart VMS can play a crucial role in promoting sustainable practices in the facilities management of high-rise buildings. However, careful planning, effective implementation strategies, and stakeholder collaboration are essential for successful integration. Embracing the potential of smart VMS can pave the way for a more sustainable and environmentally responsible future of high-rise buildings in Sri Lanka.

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BARRIERS TO THE ADOPTION OF EMERGING TECHNOLOGIES FOR SUSTAINABLE CONSTRUCTION IN SMES.

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ABSTRACT

The construction industry activities contribute to and impact the environment; hence the industry continuously strives to adopt sustainable principles into its process and products. Another critical aspect to achieving this in the current technological revolution is the adoption of technology for achieving sustainable construction. Various technologies are available and have been explored to achieve sustainable construction. However, there is a dearth of studies on adopting technology for sustainable construction by construction SMEs and from the perspective of developing countries. This study investigates the adoption of technology for sustainable construction by SMEs in the South African construction industry. A total of eighty responses were collected through well-structured questionnaires administered randomly. It was observed that all barriers are significant, but the most significant barrier is the high cost of adopting technologies. The study recommends the provision of financial incentives and support for SMEs. Also, SMEs must not resist change birthed by the adoption of technology for sustainable construction.

***Keywords**: SMEs; South Africa; Sustainable construction; Sustainability; Technology Adoption.*

1. INTRODUCTION

Sustainable construction practices are becoming progressively vital as the world shifts towards a greener future. This involves a total commitment to adopting practices supporting economic, environmental, and social sustainability (Hussin et al., 2013) in every facet of the construction process. Achieving sustainable construction, therefore, requires fulfilling the basic principles of sustainability in the construction process and products. Hill & Bowen (1997) classified the principles of sustainability into four social sustainability, economic sustainability, biophysical sustainability and technical sustainability. Achieving sustainability preserves and promotes the quality of life and the environment. In addition, it promotes prudence in the utilisation of the earth's resources. From literature, drivers for achieving sustainable construction practices in the construction industry include implementation of research outcomes, legislation framework supporting implementation, and awareness among others (Oke et al., 2019).

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In the framework for enabling sustainable construction in developing countries, Du Plessis (2007) posited that technology is a critical enabler for achieving sustainable construction. Technology plays a vital role in achieving sustainable construction (Miyatake, 1996); it is an essential ingredient to achieving sustainable construction. The integration and adoption of emerging technologies by the construction industry have also been identified to promote sustainability in the construction industry (Adekunle et al., 2021; Ejohwomu et al., 2021). Some of the technologies that have been identified and explored for sustainable construction include 3D printing (Hager et al., 2016), the Internet of Things (Arowoiya et al., 2020; Oke & Arowoiya, 2021), cloud computing (Oke et al., 2021; Oke et al., 2021), data mining (Aghimien, 2019).

However, despite the benefits of technology adoption, its implementation has numerous barriers. Generally, the barriers to technology adoption in the construction industry include high initial costs, lack of awareness, and resistance to change (Adekunle, et al., 2021; Aghimien et al, 2019; John et al., 2022). However, there is a dearth of research on technology adoption by SMEs. SMEs are generally given less attention in the adoption of innovations and technologies, and hence many struggle to be competitive (John et al., 2023). Many factors impact the adoption of technology by construction SMEs; for instance, Hardie & Newell (2011) identified regulatory climate as being critical in Australia. This study explores the barriers to the effective adoption of technology for sustainable construction by SMEs in South Africa. Articulating these barriers supports and accelerates the adoption of sustainable technologies.

2. SMALL AND MEDIUM-SIZED ENTERPRISES (SMES)

Since the introduction of SMEs in the late 1940s, they have become an integral and important aspect of economies around the world. Although the size, classification, and contribution to the economy vary from economy and context (Keskin & Şentürk, 2010), their importance is not disputable. SMEs, including those in the construction industry, create jobs, and generate income. According to Keskġn et al. (2010), they are anti-poverty enterprises, Robu (2013) describes them as the engine of the modern economy. In South Africa, SMEs contributed 22% to the total turnover in 2019 (Statistics South Africa (STATSSA), 2020). Therefore, the importance of SMEs cannot be overemphasised. Despite the critical role construction SMEs play, they face various challenges in the South African construction industry, including difficulty securing projects and failure to gain cost advantage, among others (Wentzel et al., 2016). The adoption of emerging technologies for sustainable construction will help SMEs gain a competitive advantage(Aghimien et al., 2021) and be more profitable.

3. METHODOLOGY

The study's objective was to investigate the barriers to adopting emerging technologies for sustainable construction by SMEs in the South African construction industry. The data for this study was collected through a structured questionnaire administered to industry professionals in the South African construction industry (the respondents' information is presented in Table 1). The questionnaire was administered through an online survey platform randomly; this allows all respondents equal chances of being selected for the study. The administered instrument contained a cover letter explaining the study objective and assuring the respondents of the ethical considerations and their anonymity. Eighty questionnaire responses adequately filled were received and considered suitable for the study; this satisfies a minimum of thirty sample size requirement (Ott & Longnecker, 2010). Structured questionnaires have been adopted in previous construction industry studies to collect data from industry professionals (Adekunle et al., 2022; Akinradewo et al., 2022; Aliu et al., 2022;

Ikuabe et al., 2022) and understand various industry phenomena. The questionnaire was designed to collect respondents' background information (section A). The other section collected respondents' perspectives on the barriers to adopting emerging technologies for sustainable construction (designed for ratings on a five-point Likert scale). The approach is considered suitable for causal relationship testing and generalisation. The Cronbach's Alpha was computed for reliability, and a value of 0.985 was achieved, which is above the threshold (Pallant, 2010).

4. FINDINGS

4.1 RESPONDENTS BACKGROUND

The respondents for the study consist of different professionals; the professional composition consists of 5.0% Architects, 30% Quantity Surveyors, 8.8% Civil Engineers, 7.50% Project Managers, 12.50% Construction Managers, 2.50% Structural Engineers, 2.5% Land Surveyors, 2.50% are Site Surveyors, 11.30% are Health and Safety Officers, 2.50% are Site Agents, 7.50% are Foreman, 6.3% are Site Engineers, and 1.30% are other professionals. These professionals possess different experience levels in the construction industry, measured in years. 28.21% possess 0-1 year of industry experience, 37.5% have 1-5 years of working experience, 16.30% have 6-10 years of experience, 10% have been working for 11-15 years, 2.50% have 16-20 years working experience, while 5.00% have been working for 20 years and above. Other information about the respondents is presented in Table 1. The respondents' background provides a blend of diverse experience and expertise required for the study.

Table 1: Respondent background

Professional qualification	**%**
Structural Engineer.	2.50%
Site Surveyor.	2.50%
Site Foreman.	7.50%
Site Engineer	6.30%
Site Agent.	2.50%
Quantity Surveyor.	30.00%
Project Manager.	7.50%
Other.	1.30%
Land Surveyor.	2.50%
Health and Safety Officer.	11.30%
Construction Manager.	12.50%
Civil Engineer.	8.80%
Architect.	5.00%
Years of experience	**%**
6 – 10 years.	16.30%
20 years & above.	5.00%
16 – 20 years.	2.50%
11 – 15 years.	10.00%
1 - 5 years.	37.50%
0 – 1 year.	28.70%

Educational qualification	%
Matric	5.00%
Master's Degree	11.30%
Honours Degree.	12.50%
Doctorate	1.30%
Diploma.	12.50%
Bachelor’s Degree.	57.50%
Location of the organisation	**%**
Western cape.	3.80%
Northwest.	1.30%
Northern cape.	2.50%
Mpumalanga.	7.50%
Limpopo.	8.80%
Kwa-Zulu natal.	6.30%
Gauteng.	60.00%
Free state.	2.50%
Eastern cape.	7.50%

From the data analysed (Table 2), the respondents reveal the top ranking barriers include high cost with a mean item score of 3.83 and standard deviation of 1.271, budgetary priorities with a mean item score of 3.77 and standard deviation of 1.154, resistance to learning new technologies with a mean item score of 3.67 and standard deviation of 1.248 and lack of Incentives with a mean item score of 3.66 and standard deviation of 1.292. The least ranked barriers are Organizational Size (MIS =3.46, SD=1.377), Organizational Culture (MIS=3.39, SD=1.285), Proof of value (MIS=3.38, SD=1.38) and Complex Operation (MIS=3.32, SD=1.455). It is worth noting that all barriers presented in this study are significant to the adoption of emerging technology for sustainable construction.

Table 2: Barriers to emerging technology adoption for sustainable construction.

Barriers	Mean	Std. Deviation	Ranking
High Cost.	3.83	1.271	1
Budgetary priorities.	3.77	1.154	2
Resistance to learning new technologies.	3.67	1.248	3
Lack of Incentives.	3.66	1.292	4
Understanding of and ability to implement.	3.62	1.38	5
Accessibility of Technical Knowledge.	3.62	1.251	6
Lack of required skill.	3.61	1.319	7
Lack of Experience.	3.61	1.463	8
Availability of technologies.	3.6	1.27	9
Maintenance.	3.56	1.227	10
Lack of available information on technology reliability.	3.55	1.364	11
Lack of Top Management Support.	3.55	1.456	12

Difficulty of technologies.	3.54	1.396	13
Structure Of the Organization	3.53	1.224	14
Lack of Financial Support	3.53	1.404	15
Time to make changes and adjust.	3.51	1.273	16
Return on investment not clear.	3.51	1.331	17
Lack of client mandate.	3.5	1.331	18
Lack of Knowledge.	3.5	1.467	19
Updating the Technologies periodically	3.49	1.326	20
Legal and contractual constraints.	3.49	1.375	21
Reliability.	3.49	1.421	22
Social implications (changes in collaboration communication styles)	3.48	1.302	23
Long lead time required for full-scale implementation.	3.47	1.346	24
Government regulations.	3.47	1.367	25
Organisational Size.	3.46	1.377	26
Organisational Culture.	3.39	1.285	27
Proof of value.	3.38	1.38	28
Complex Operation.	3.32	1.455	29

Despite construction SMEs' importance and critical role, access to finances and weak financial strength are characteristics. It is, therefore, not surprising that the major barrier to adopting technology for sustainable construction is the issue of high cost. These findings align with Aghimien et al (2019) whereby high cost was identified as a critical barrier to adopting emerging technologies. Also, Cant et al. (2016) opined that a lack of financial resources is a critical barrier to the adoption of technology by SMEs. To overcome this, there is a need for financial support, incentives and access for SMEs. SMEs should also consider sharing technology and leasing. Secondly, there is a need for a change in stakeholders' perspective from viewing the adoption of technology for sustainable construction as an investment instead of viewing it as a cost. This enables stakeholders to consider the economic benefits of adoption instead of the short-term cost of procurement. SMEs must also prioritise the adoption of emerging technologies to achieve sustainable construction in their budgeting. This is important, especially from the management perspective, during financial planning. However, this can only be achieved if the top management is receptive to technology adoption and the training of staff to acquire new skills and competencies (Adekunle et al., 2022; Aliu et al., 2022). Stakeholders need to be receptive to new technology adoption and abandon the traditional approach to the construction industry process (Adekunle et al., 2020).

5. CONCLUSION

This study assessed the barriers to the adoption of technologies for sustainable construction by SMEs. From the data gathered and analysed, it was observed that all the barriers studied were significant; however, the most significant barrier was high cost. Other barriers identified by the study include budgetary priorities, resistance to learning new and lack of Incentives. To overcome these barriers and adopt technology for sustainable construction by SMEs there must be increased investment in emerging technologies by SMEs. Furthermore, SMEs should consider partnering, technology sharing and leasing to ease the cost requirements. SMEs must also be incentivised to adopt emerging technologies to overcome the resistance to the adoption. There is also the need for stakeholders to be receptive to the adoption of innovations and technologies. It is worth of note that SMEs play a critical role and are important to achieving sustainable construction in the construction industry. Consequently, there is a need for government support for SMEs in this regard to overcome the identified barriers. Future research can explore which technologies SMEs adopt and how they are being adopted for sustainable construction in developing countries. It should be noted that the results of the study are specific to the South African construction industry where it was conducted.

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ENCUMBRANCES OF THE COMPETITIVENESS OF SOUTH AFRICAN CONSTRUCTION ORGANISATIONS IN THE BUSINESS ENVIRONMENT OF OTHER AFRICAN COUNTRIES

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ABSTRACT

The study aims to assess the challenges posed to the competitiveness of South African construction contractors in other African countries. This was instituted to formulate a pathway for the penetration of South African contractors into the business environment of other African countries. The study employed a quantitative method underpinned by a post-positivism philosophical approach using a questionnaire as the research instrument. The target respondent of the study was construction professionals, while the study area was Gauteng province of South Africa. The data analysis methods were mean item score, Kruskal-Wallis h-test, and Student Newman Kaul post hoc test. Findings from the study showed that the most significant challenges faced by South African construction organisations in exploring business opportunities in other African countries are collusive acts, high cost of financing, lack of technical skills, and difficulties in obtaining loans. Also, the difference in viewpoints given by the sampled professionals is outlined in the study's findings. Based on the results obtained from the analysis, the study made recommendations that would aid the competitive capabilities of South African construction organisations in the business landscape of other African countries.

Keywords: *African Countries; Competitiveness; Construction; Contractors; South Africa.*

1. INTRODUCTION

The construction sector plays an important role in any nation's socio-economic development as it makes provision for the necessary infrastructure required for nation-building (Ikuabe et al., 2021; Chigara and Moyo, 2014). The sector aids in delivering the

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needed infrastructure required by other sectors of the economy, which includes urban utilities (sewerage, water supply, drainage, residential buildings, railways, roads, ports, health facilities, recreation centres, agricultural facilities, telecommunication, and airports (Ikuabe et al., 2022a; Rangelova, 2015). Also, the sector provides a significant base for the employment of labour both in the informal and formal sectors (Stats SA, 2010), hence contributes to the socioeconomic welfare of the country's populace. The construction sector is projected to contribute 13% of the world's gross domestic product (GDP) (Araya, 2021). This gives credence to the significance of the sector on a global scale. The construction sector in South Africa contributed R83 billion to the country's GDP in 2020 (Statistica, 2021), notwithstanding the associated encumbrances of the coronavirus (COVID-19) pandemic.

The business climate of the South African construction sector is highly competitive and attributed to a plethora of stakeholders, usually from private and public organisations, having varying interests and obligations. These include contractors, sub-contractors, consultants, government entities, regulatory organisations, manufacturers, and marketers, suppliers. The contractors are a vital economic actor in the construction business scheme. About 56653 listed contractors are on the country's Register of Contractors (CIDB, 2020). This underscores the stern competition characterising the business environment in the country's construction sector. According to Emuze and Smallwood (2014), many of these contracting organisations feature in the 'heavy bottom' strata of the total formation of all the organisations. Consequently, limiting their prospects of being engaged for high-priority construction projects within the business landscape. Resulting of the highly competitive business environment of the South African construction sector, construction contracting organisations can attempt to break through the construction market of other countries, particularly within the African continent.

The high competitiveness of the South African construction sector results in the need for contractors in South Africa to explore cross-border prospects, which proffers less competition cannot be overemphasised (Oyewobi et al., 2016). Luiz and Stephan (2012) noted that the entrance of South African organisations into the economic landscape of other African countries is a 'high risk-high reward' strategy characterised by a significant degree of risk and uncertainty, albeit the unraveling of rewarding opportunities. Furthermore, a construction organisation's competitiveness is portrayed as a significant 'predictor' of its cumulative business persistence and its capacity for sustenance in a volatile business environment (Oyewobi et al., 2016; Ikuabe et al., 2022b). Therefore, it becomes important to evaluate the challenges confronting the competitiveness of South African construction organisations in the business environment of other African countries. The study's outcome would help unravel the encumbrances faced by organisations attempting to explore the construction market in other African nations. Moreover, the study's findings would aid in boosting capital flow within African countries while also creating a platform for boosting economic activities, improving employment opportunities, enhancing technology transfer, and encouraging knowledge transfer.

2. LITERATURE REVIEW

Construction is a considerably competitive business that requires deliberate strategies by contracting organisations to maintain accomplished or projected goals (Ikuabe et al., 2020). Due to the stiff competition among economic actors, the South African construction business landscape presents a peculiar offering. Although, the concept of vying for economic gains in other African countries is receiving a significant boost. However, this is confronted by several bottlenecks which potentially hinder the benefits of the cross-border business pursuit. According to Tembo et al (2022), cultural difference is a hindering factor for foreign organisations to thrive in the business climate of the host nation. Cultural diversity could be in the form of language, religion, honoring social events, etc. A major challenge for most foreign organisations seeking to explore other climes is the lack of technical and managerial skills within the country to be explored. Araya (2021) noted that most African nations constantly face a shortage of requisite managerial and technical skills for construction project delivery. The lack of these skills hinders the smooth conceptualisation, execution, and delivery of construction projects. Moreover, economic policies leading to high taxation and volatile exchange rate hinder the construction organisation from seeking prospects in other African countries. Kerur and Marshal (2012) affirmed that unfavorable local tax policies might subject foreign organisations seeking prospects in a country to be discouraged from competing in such an economic climate.

The volatility of the local currency is a considerable cause of concern for prospective economic actors. Since construction project execution would oftentimes mandate the use of foreign materials, a volatile local currency would place the contractor on the losing end. Mukumba (2012) opined that striving to seek foreign currencies for material purchase contributes negatively to construction project delivery, such as late completion and an increase in the contract sum. These downsides serve as deterrents to prospective contracting entities who seek to explore opportunities in the construction market of other countries. Also, the delay in payment of construction projects executed is seen as a challenge to competing for projects in African countries. Ogbeifun and Pretorius (2022) noted that non-payment of completed works from clients is a major source of cash flow problems for contractors, leading to project delays, tighter profit margins, lower productivity, and abandonment of projects. The non-availability of materials for construction project execution is also a significant barrier to the prospects of foreign contractors in most nations, particularly in the African continent. Adeyemi and Masalila (2016) stated that the shortage or non-availability of required materials for project execution negatively impacts the outcome of construction projects. At the same time, the tendency of corrupt practices exhibited by stakeholders and economic actors in the construction business is also a major bottleneck. Chan and Owusu (2017) stated that some government officials use their access and positions to influence the award of contracts to preferred contractors in anticipation of receiving 'kickbacks'. This act distorts contractual arrangement and relegates deserving and competent contractors. These issues dissuade prospective contracting organisations from seeking prospects in other climes.

3. RESEARCH METHODOLOGY

The study employed a quantitative method underpinned by a post-positivism philosophical approach using a questionnaire as the research instrument. Data were obtained from construction professionals situated in the Gauteng province of South Africa. The choice of the study area results from the large pool of construction organisations domiciled in the area which also boasts a large number of construction professionals. Also, the choice of the questionnaire for the study stems from its ability to cover a large number of respondents within a short time frame and its ability to elicit quantifiable data (Tan, 2011). The respondents comprised of quantity surveyors, construction project managers, architects, construction managers, and engineers. The sampling technique employed was purposive and snowball sampling. The first was used in identifying professionals who have professional experience in other African countries, thereafter referrals were made for similar attributes among the target respondents. The questionnaire involved two sections. The former dwelt on the demographic information of the study's respondents, while the latter inquired on the challenges facing construction organisations in seeking opportunities in the construction sector of other African countries. Fifty-two responses were retrieved from the respondents of the study who were deemed fit for analysis. Retrieved data were analysed using mean item score (MIS), Kruskal Wallis *h*-test (*K-W*), and Student Newman Kauls (SNK) post hoc test. MIS was employed to rank the challenges facing the exploration of the construction business environment of African countries by South African contractors. At the same time, Kruskal Wallis *h*-test was used to establish if there is a statistical discrepancy in the opinions given by the groups of respondents based on their professional designation. Also, SNK post hoc test presented the difference in the mean responses given by the respondents using the categorisation of their professional designation. Furthermore, the validity and reliability of the research instrument were ascertained with the use of Cronbach's alpha test. The analysis gave a value of 0.891, thus affirming the validity and reliability of the research instrument since the resulting alpha value is above the threshold of 0.7 and tending towards 1.00 (Tavakol and Dennick, 2011).

4. FINDINGS

4.1 BACKGROUND INFORMATION OF RESPONDENTS

The research instrument comprised two sections. The first section focused on eliciting information on the respondents' demographic details. Results from the analysed data retrieved for the study show that the aggregate formation of respondents includes quantity surveyors who made up 38% of the entire respondents; engineers made up 21% of the total respondents, while construction managers and construction project managers had 18% and 16% of the total respondents respectively, and architects were made up of 7%. Based on the highest educational qualification gotten by the respondents, it was shown that respondents with a bachelor's degree made up 42% of the respondents, those with an honour's degree made up 32% of the total respondents, while those having a master's degree made up 21% of the total respondents. Based on the respondents' years of professional experience, those having 1-5 years made up 42% of the total respondents, those having 6-10 years made up 15%, and those having 11-15 years made up 9%. Based on the number of projects handled in other African countries, those with 3-4 projects made up 47% of the total respondents, those with 5-6 projects comprised 28% of the total respondents, while those with more than 8 projects made up 18% of the total respondents.

4.2 CHALLENGES OF SOUTH AFRICAN CONTRACTORS COMPETING IN AFRICAN COUNTRIES

A review of extant literature identified thirteen challenges plaguing the competitiveness of South African construction contractors in competing in the business environment of other African countries. These challenges were presented to the target respondents of the study using a questionnaire for rating using a Likert scale. The retrieved data were analysed with the aid of MIS for ranking the challenges, while the Kruskal Wallis *h*-test was used to determine the discrepancy in opinions given by the respondents based on their professional affiliation. The result of the mean rating of the challenges faced by South African contractors in vying for business opportunities in other African countries is outlined in Table 1. The result portrays that the mean score of all the challenges is above 3.50, which underscores the significance of the challenges. The most rated challenges are collusive acts, high cost of financing, lack of technical skills, and difficulties in obtaining loans, with mean scores of 4.43, 4.40, 4.39, and 4.32, respectively. The least ranked challenges are the unavailability of materials, lack of support from the government, and unstable exchange rates, with mean scores of 3.61, 3.68, and 3.70, respectively. Furthermore, with the use of the *K-W* test, the difference in opinion of the respondents was evaluated based on their professional designation. The findings of the analysis show that the respondents have differing opinions on three of the challenges facing South African construction contractors in exploring the business environment of other African countries. These three challenges have a *p*-value less than 0.05, indicating a departure in the aggregate views provided by the respondents. Also, for the other ten challenges, a *p*-value greater than 0.05 indicates a convergence of the respondents' views.

Table 1: Challenges of Contractors' Competitiveness

Challenges	$\bar{X}$	**R**	***K-W***	
			X^2	**Sig.**
Collusive acts	4.42	1	1.385	0.218
High cost of financing	4.40	2	4.811	0.083
Lack of technical skills	4.39	3	2.840	0.611
Difficulties of obtaining loans	4.32	4	1.986	0.293
Delay in payments	4.25	5	1.337	0.012**
Cultural differences	4.10	6	3.795	0.492
Lack of managerial skills	4.03	7	2.006	0.253
Hostile tax regime	3.92	8	1.293	0.571
Unavailability of equipment	3.86	9	3.841	0.128
Volatility of local currency	3.77	10	3.986	0.462
Unstable exchange rates	3.70	11	1.442	0.339
Lack of support from government	3.68	12	3.748	0.038**
Unavailability of materials	3.61	13	2.584	0.002**

N.B: $\bar{X}$ = Mean Item Score; *K-W* = Kruskal Wallis *h*-test

The result of the SNK post hoc test is presented in Table 2. It outlines the multiple comparisons of the opinions given by the study's respondents based on their professional designation. The findings indicate that there is a difference in the viewpoints provided by the professionals on the challenges faced by South African construction contractors in seeking business opportunities in other African countries. These opinions are given in three broad categories. The first category comprises of engineers and architects with values of 2.735 and 2.512, respectively. The second category comprises of construction managers and construction project managers with values of 2.884 and 2.751, respectively. In comparison, the third category is comprised of quantity surveyors with a value of 3.323.

Table 2: SNK Post Hoc Test

Groups	N	Subset for alpha=0.05		
		1	2	3
Engineers	13	2.735		
Architects	13	2.518		
Construction Managers	13		2.884	
Construction Project Managers	13		2.751	
Quantity surveyors	13			3.323
Sig.		1.000	.241	

5. DISCUSSION OF FINDINGS

The analysis conducted on the retrieved data from the respondents of the study shows the significance of the identified challenges posed to construction contractors from South Africa in exploring the business environment in other African countries. The findings indicate that the collusive acts deployed by government officials and other stakeholders are a significant stumbling block to contractors from other climes seeking opportunities in African countries. This is corroborated by Chan and Owusu (2017), who stated that some government officials use their access and positions to influence the award of contracts to preferred contractors in anticipation of receiving 'kickbacks'. These acts distorts contractual arrangement and relegates deserving and competent contractors. Also, it is shown that the high cost of financing and lack of technical skills are significant challenges. According to Araya (2021), most African nations constantly have a shortage of requisite managerial and technical skills for construction project delivery. The lack of these skills hinders the smooth conceptualisation, execution, and delivery of construction projects. Moreover, economic policies bothering high taxation and volatile exchange rate hinders the prospect of construction organisation in seeking prospects in other African countries. Moreover, the delay in payment for construction projects executed is seen as a challenge to competing for projects in African countries. This is supported by Ogbeifun and Pretorius (2022), who noted that non-payment of completed works from clients is a major source of cash flow problems for contractors, leading to project delays, tighter profit margins, and lower productivity and abandonment of projects.

6. CONCLUSION AND RECOMMENDATIONS

The study explored the challenges South African construction contractors face in seeking business opportunities in other African countries. From the review of extant literature, the challenges were identified and presented to the study's respondents for rating based on their significance using a Likert scale. The result of the analysed data obtained from the target respondent shows that the most significant challenges are collusive acts, high cost of financing, lack of technical skills, and difficulties in obtaining loans. In contrast, the least significant challenges are the unavailability of materials, lack of support from the government, and unstable exchange. Furthermore, it is revealed that there is no statistical deviation in the viewpoints of the respondents based on their professional designation on ten of the challenges. While there is a differing viewpoint of the professionals making up the target respondent of the study on three of the challenges:

delay in payments, lack of support from the government, and unavailability of materials. Based on the results of the study, it is recommended that policies and regulations should be formulated by African nations that would propagate the engagement of construction organisations from other African nations. The encouragement of cross-border business penetration in the construction sector would yield attendant benefits such as upscaling employment opportunities, improved economic activities, and technology transfer. Moreover, construction organisations in South Africa should adopt organisational culture that gravitates towards the exploration of the business environment of other African countries.

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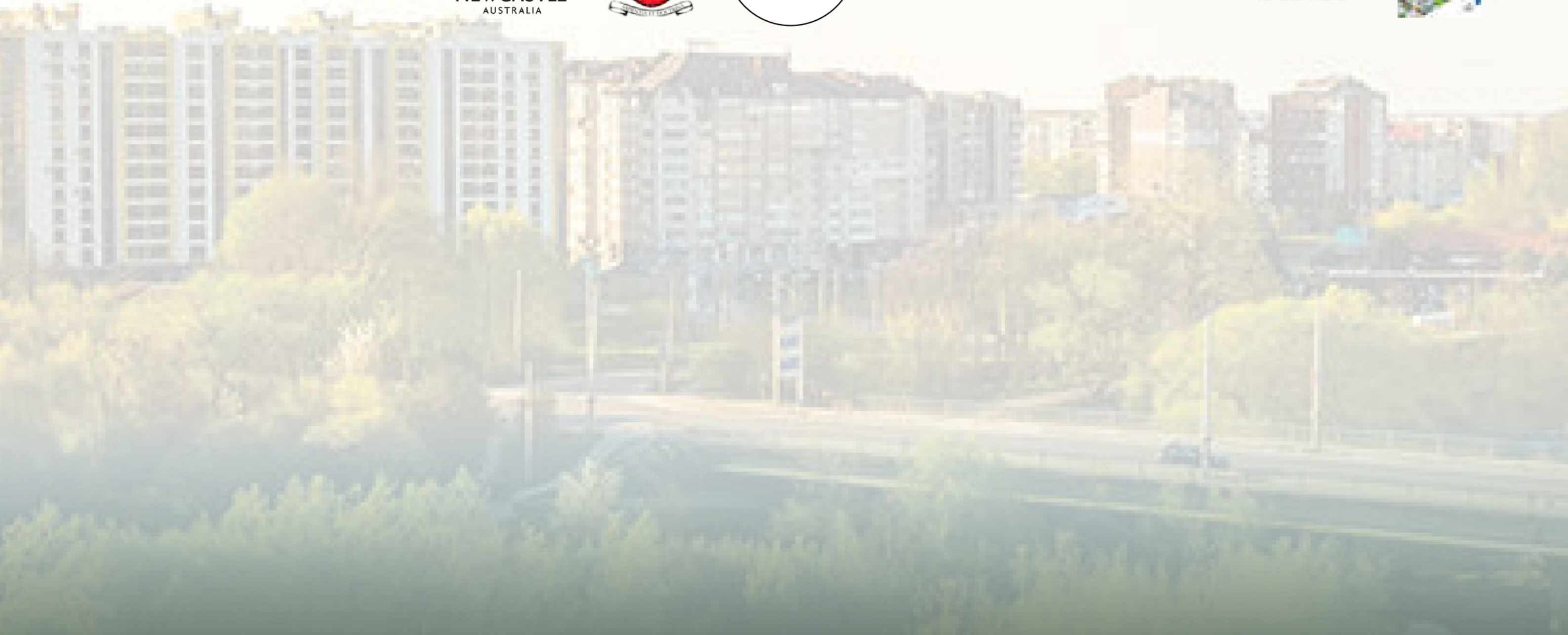

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