SYMPOSIUM

PROCEEDINGS

The 10th World Construction Symposium

Sustainability and Resilience in the Built Environment: Changed Perspectives

24th - 26th June 2022

Online

Organized by

CEYLON INSTITUTE OF BUILDERS (CIOB) SRI LANKA

DEPARTMENT OF BUILDING ECONOMICS UNIVERSITY OF MORATUWA

PROCEEDINGS

of

THE 10TH WORLD CONSTRUCTION SYMPOSIUM 2022

ON

SUSTAINABILITY AND RESILIENCE IN THE BUILT ENVIRONMENT: CHANGED PERSPECTIVES

24-26 June 2022

EDITORS

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Dr. K.G.A.S. Waidyasekara
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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.

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/

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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/

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 1 of 3 Journals recognised by CIB, recognised by the Australian Business Deans' Council, and indexed in SCOPUS, EBSCO, INSPEC and the Emerging Sources Citation Index (ESCI). BEPAM Journal is ranked Q1 in Architecture category under the Scimago Journal & Country Ranking 2021.

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 10th World Construction Symposium (WCS) on the pertinent theme, “Sustainability and resilience in the built environment: Changed perspectives”. This marks the 10th milestone of this WCS series, which was initiated back in 2012. This year’s event is held amidst numerous hardships that Sri Lanka is facing due to the current political and economic crisis. 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; 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 10th 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 10th World Construction Symposium 2022 a success.

Editors

The 10th World Construction Symposium
Colombo, Sri Lanka
June 2022

PREFACE

The 10th World Construction Symposium (WCS 2022) 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 virtually from 24-26 June 2022. The symposium was held in partnership with Western Sydney University, Australia; The University of Newcastle, 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 10th milestone of this 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. Amidst the political and economic crisis prevailing in Sri Lanka that has critically impacted many industries including construction, this year's symposium was organized around the theme "Sustainability and resilience in the built environment: Changed perspectives". The crisis meant that this was the second year in a row that we are holding this symposium as a mainly digital event.

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, 76 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, Malaysia, New Zealand, Nigeria, Sri Lanka, Turkey, United Kingdom and USA. The papers cover a wide spectrum of areas such as sustainable urban development and infrastructure, knowledge management and lessons learned, cost management in construction, innovative procurement approaches, Building Information Modelling, contract administration and dispute resolution, health, safety and wellbeing, pandemic resilient construction, waste management, energy and retrofitting, green building systems, disaster resilient built environments, enhancing construction performance, innovative technologies for sustainability, circular built environment, and sustainable operation and management of facilities.

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 WCS2022 virtual symposium, please pay special attention to the instructions below. If you have any questions or difficulties following the guidelines, please contact the WCS2022 Secretariat (info@ciobwcs.com) who will be happy to help.

How will WCS2022 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 WCS2022 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 WCS2022 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 22 June 2022** and the secretariat will manage the requests.

Preparing for your Virtual Session - Instructions for Presenters:

Use the instructions below when presenting your paper at WCS2022 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 WCS2022 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 WCS2022 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 10th World Construction Symposium 2022

It is a great pleasure to welcome all the participants for this 10th milestone of the World Construction Symposium series on behalf of the organising committee. The 10th World Construction Symposium is jointly organised by the Ceylon Institute of Builders (CIOB) and Building Economics and Management Research Unit (BEMRU), Department of Building Economics, University of Moratuwa, Sri Lanka. The theme of the symposium is "Sustainability and resilience in the built environment: Changed perspectives". Due to the prevailing context in Sri Lanka, this year's symposium is held mainly as a digital event with virtual paper presentations and only a few onsite participants for the inauguration and sum-up events.

The construction industry, as a unique field, faces several challenges as a result of climatic change, technological change, and, in some cases, changes in human aspirations. In addition to that, currently the Sri Lankan construction industry is in a critical situation due to severe challenges resulting from the current political and economic crises as well as the COVID-19 pandemic. Therefore, all stakeholders in the construction industry should look for new ways to tackle challenges while also protecting the environment and supporting sustainable practices. This annual symposium will offer a unique opportunity for researchers and practitioners working in the built environment and construction industry to share their expertise, experiences, and research findings with others from across the world. "Sustainability and resilience in the built environment: Changed perspectives" is the selected theme for this year's symposium. I am certain the discussions under this theme and the associated sub-themes can contribute to insights and solutions towards a sustainable and resilient construction sector in the present climate in Sri Lanka.

I hope that all the participants join us for these two days and keep track of all of the important information that are shared throughout the symposium. I would like to thank all the researchers and paper presenters and congratulate our committees and all others who have contributed to the symposium.

MESSAGE FROM THE PRESIDENT, CIOB

Dr. Rohan Karunaratne

President
The Ceylon Institute of Builders (CIOB)

I am pleased to welcome you to the 10th World Construction Symposium, 2022 on the theme "Sustainability and Resilience in the built environment: Changed Perspectives" for the symposium this year. 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. We are also thankful to the Associate Partners of the Symposium.

As in the previous Symposiums, we have received great support from 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 contributions 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 HONY. SECRETARY, CIOB

Eng. Saliya Kaluarachchi

Hony. Secretary
The Ceylon Institute of Builders (CIOB)

I am pleased to welcome you to the 10th World Construction Symposium 2022 to be held during 24th and 25th June 2022 as a hybrid event. 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 this year is “Sustainability and resilience in the built environment: Changed perspectives” 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 this 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 that the traditional systems with crisp boundaries to achieve the desired results.

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, I wish the WCS2022 every success in its endeavors.

MESSAGE FROM THE SYMPOSIUM CO-CHAIRPERSONS

Mr. Sagara Gunawardena

Mr. Kalana Alwis

Co-Chairpersons
The 10th World Construction Symposium


We take great pleasure in welcoming all the delegates to the 10th World Construction Symposium 2022 to be held as a hybrid event on the 24th and 25th June 2022. This 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 like-minded individuals on one 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.

We are 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 four concurrent papers/presentation tracks. The event gives an opportunity for the professionals in the construction industry to achieve targets on their Continued Professional Development.

We appreciate your commitment and the participation and wish the symposium to be a great success.

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

Ch. QS. Suranga Jayasena

Head
Department of Building Economics
University of Moratuwa

It is a great pleasure and honour to send this message to express my warmest wishes for the 10th World Construction Symposium 2022. This is a remarkable venture jointly organized by the Ceylon Institute of Builders (CIOB) and the Building Economics and Management Research Unit (BEMRU), Department of Building Economics, University of Moratuwa, Sri Lanka for the tenth consecutive year successfully.

For this time Western Sydney University, Australia; The University of Newcastle, Australia; Colombo School of Construction Technology (CSCT), Sri Lanka and the Built Environment Project and Asset Management (BEPAM): Journal, published by Emerald Group Publishing join as associate partners to make this year's symposium successful.

The Sri Lankan construction industry is facing a steep decline in construction projects due to price hikes of raw materials, paired with a fuel and electricity crisis. Subsequently, a key sector that has been boosted the country's overall economic growth has collapsed and the sector has identified the need for sustainability and resilience for those situations in the built environment. Within this context 10th World Construction Symposium focuses on "Sustainability and resilience in the built environment: Changed perspective" as a timely setting.

The 10th World Construction Symposium 2022 affords a platform for both local and international delegates to showcase their knowledge, experiences, innovative ideas, and research findings with related to sustainability and resilience in the built environment: Changed perspective. Accordingly, I expect all delegates would yield this opportunity to share their knowledge and perceptions on the theme of the year.

I wish all the success for the 10th World Construction Symposium 2022.

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FRIDAY, 24 JUNE 2022 - DAY ONE

02.00 pm - 02.15 pm	Symposium Inauguration
02.15 pm - 02.25 pm	Welcome address by President, CIOB
	Dr. Rohan Karunaratne
02.25 pm - 02.35 pm	Address by Conference Chairperson
	Prof. Chitra Weddikkara
02.35 pm - 02.45 pm	Address by Head, Department of Building Economics
	Ch QS Suranga Jayasena
02.45 pm - 03.15 pm	Keynote Address 1 by Chief Guest - CEO CIB
	Mr. Don Ward
03.15 pm - 03.25 pm	Sponsors Video
03.25 pm - 03.55 pm	Keynote Address 2 by Guest of Honour - Emeritus Professor, Former Dean, Faculty of Architecture, University of Moratuwa
	Prof. Lalith de Silva
03.55 pm - 04.15 pm	Address by Editor-in-Chief, Journal of Built Environment Project and Asset Management (BEPAM)
	Prof. Mohan Kumaraswamy
04.15 pm - 04.25 pm	Sponsors Video
04.25 pm - 04.35 pm	Symposium Participants Screenshot Photo
04.35 pm - 04.45 pm	Vote of Thanks by Hony. Secretary, CIOB
	Eng. Saliya Kaluarachchi
04.45 pm - 05.00 pm	Break
05.00 pm - 06.30 pm	Parallel Sessions 1
06.30 pm	End of Day 1

SATURDAY, 25 JUNE 2022 - DAY TWO

09.00 am - 10.30 am	Parallel Sessions 2
10.30 am - 11.00 am	Break
11.00 am - 12.30 pm	Parallel Sessions 3
12.30 pm - 01.30 pm	Break
01.30 pm - 03.00 pm	Parallel Sessions 4
03.00 pm - 03.30 pm	Break
03.30 pm - 05.00 pm	Panel Discussion: "Rebooting to a resilient construction industry - Bouncing back better from multiple crises" ***Panellists:*** Prof. Mohan Kumaraswamy Eng. Nissanka Wijeratne Prof. Asanga Gunawansa Ch QS Upul Shantha Dr. Rohan Karunaratne ***Moderator*** - Ch QS Lalith Rathnayake
05.00 pm - 05.15 pm	Break
05.15 pm - 05.35 pm	Rapporteur's Report
05.35 pm - 05.45 pm	Announcing the Award Winners
05.45 pm - 06.00 pm	Vote of Thanks by Scientific Committee Co-Chairperson
06.00 pm	End of Day 2

SYMPOSIUM SESSION PLAN AT-A-GLANCE

FRIDAY, 24 JUNE 2022				
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
	S14089	S14016	S14075	S14034
	S14093	S14082	S14005	S14055
	T14007	S14020	T14063	S14085
	T14032	S14090	S14091	S14088
	S14086	S14048	S14040	S14078
	Q&A	Q&A	Q&A	Q&A
06.30 pm	End of Day 1			
SATURDAY, 25 JUNE 2022				
09.00 am - 10.30 am	Session 2A	Session 2B	Session 2C	Session 2D
	S14049	S14058	S14073	T14041
	S14077	T14056	S14021	S14061
	S14010	S14043	S14018	S14031
	S14068	S14076	S14029	S14024
		S14059	S14064	S14025
	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
	S14096	S14008	S14080	S14083
	S14006	S14070	S14087	S14084
	S14042	S14071	S14022	S14081
	S14023	S14003	S14054	S14067
	S14037			S14050
	Q&A	Q&A	Q&A	Q&A
12.30 pm - 01.30 pm	Break			
01.30 pm - 03.00 pm	Session 4A	Session 4B	Session 4C	Session 4D
	S14030	S14001	S14097	S14028
	S14072	S14095	S14033	S14066
	S14045	S14009	S14044	S14092
	S14027	T14038	S14036	S14074
	S14046	S14053		S14004
	Q&A	Q&A	Q&A	Q&A
03.00 pm – 03.30 pm	Break			
03.30 pm - 05.00 pm	Panel Discussion			
05.00 pm - 05.15 pm	Break			
05.15 pm – 06.00 pm	Symposium Sum-Up			
06.00 pm	End of Day 2			

DETAILED SESSION PLAN

FRIDAY, 24 JUNE 2022

SESSION 1A

Theme	**Sustainable Urban Development and Infrastructure**
Session Chair	**Prof. Udayangani Kulatunga**
Session Duration	**05.00 PM - 06.30 PM**
Time	**Paper ID, Title and Author(s)**
05.00 PM - 05.15 PM	**S14089: State of the art in risk sensitive urban development: A systematic literature review** *A.G.U. Damsari, M. Thayaparan and T. Fernando*
05.15 PM - 05.30 PM	**S14093: A review of drivers of sustainability in mega infrastructure projects: An institutional approach** *Nicola Thounaojam, Ganesh Devkar and Boeing Laishram*
05.30 PM - 05.45 PM	**T14007: Sustainable challenges and strategies for managing stakeholders in megaprojects: Review of cases from Australia** *Sepani Senaratne and Siryana Rai*
05.45 PM - 06.00 PM	**T14032: Value engineering for the selection of a suitable type of foundation in metro rail projects: A case study from India** *Aneetha Vilventhan, R. Rajadurai and Prateek Vishwakarma*
06.00 PM - 06.15 PM	**S14086: Analysis of the current housing market in Colombo metro region to enhance the prospective consumer satisfaction** *S.R. Dunuwila and K.A.K. Devapriya*
06.15 PM - 06.30 PM	**Q&A**

Session Coordinator: Ms. Agana Parameswaran

FRIDAY, 24 JUNE 2022

<u>SESSION 1B</u>	
Theme	**Knowledge Management and Lessons Learned**
Session Chair	**Dr. Menaha Thayaparan**
Session Duration	**05.00 PM - 06.30 PM**
Time	**Paper ID, Title and Author(s)**
05.00 PM - 05.15 PM	**S14016: The impact of professionals' knowledge on innovation adoption in the construction industry: A critical literature review** *Umesha Weerapperuma, Suranga Jayasena, Akila Rathnasinghe and Niraj Thurairajah*
05.15 PM - 05.30 PM	**S14082: Safety in the maritime construction site: Capturing lessons learned** *Jose Rocha and Anoop Sattineni*
05.30 PM - 05.45 PM	**S14020: Level of risk management knowledge among construction project managers in Sri Lanka** *D.H.N. Welikala, H.S. Jayasena and B.K.C. Perera*
05.45 PM - 06.00 PM	**S14090: Knowledge management practices to minimize the impact of staff turnover** *K.P.A.N. Karunanayake, M.L.S.S. Fernando and U. Kulatunga*
06.00 PM - 06.15 PM	**S14048: Defining a 'maturity model' in the construction context: A systematic review** *J.K.D.D.T. Jayanetti, B.A.K.S. Perera and K.G.A.S. Waidyasekara*
06.15 PM - 06.30 PM	**Q&A**

Session Coordinator: Mr. Sasanka Gallge

FRIDAY, 24 JUNE 2022

SESSION 1C

Theme	**Cost Management in Construction**
Session Chairs	**Prof. B.A.K.S. Perera**
Session Duration	**05.00 PM - 06.30 PM**
Time	**Paper ID, Title and Author(s)**
05.00 PM - 05.15 PM	**S14075: An assessment of maintenance cost of residential apartments in Sri Lanka** *P. Kajavathani and T. Ramachandra*
05.15 PM - 05.30 PM	**S14005: Availability of reliable cost data for whole life costing in the Tanzania building construction industry** *Sylvester L. Manege and Craig J. Kennedy*
05.30 PM - 05.45 PM	**T14063: The impact of material and labour cost variables on contactors' budgeted cost** *R.D.W.W. Jayathilaka, K.G.A.S. Waidyasekara and D.C. Sirimewan*
05.45 PM - 06.00 PM	**S14091: Cost overrun factors in pre-contract and post-contract stages: A critical analysis** *Chanuka Ariyawansha and Mathusha Francis*
06.00 PM - 06.15 PM	**S14040: Beyond the iron-triangle: Accommodating sustainable construction in the new-normal conditions** *L.R.V.N. Rathnakumara and H. Chandanie*
06.15 PM - 06.30 PM	**Q&A**

Session Coordinator: Ms. Kalindu Mendis

FRIDAY, 24 JUNE 2022

SESSION 1D

Theme	**Innovative Procurement Approaches**
Session Chairs	**Dr. Tharusha Ranadewa** **Dr. Ashan Asmone**
Session Duration	**05.00 PM - 06.30 PM**
Time	**Paper ID, Title and Author(s)**
05.00 PM - 05.15 PM	**S14034: Successful delivery of Public-Private Partnership (PPP) in the construction projects of Sri Lankan higher education sector** *Neranja Kandawinna, Harshini Mallawaarachchi and Dimuthu Vijerathne*
05.15 PM - 05.30 PM	**S14055: Applicability of public-private partnership to overcome the challenges encountered by public sector building projects in Sri Lanka** *D.M.D.D. Dissanayake and K.A.K. Devapriya*
05.30 PM - 05.45 PM	**S14085: Adaptability of blockchain-based E-Procurement system in Sri Lankan construction projects** *N. Nitharsan and Mathusha Francis*
05.45 PM - 06.00 PM	**S14088: Strategies adopted by design and build contractors to enhance the implementation of sustainable construction practices** *B.K.M. Nadeetharu and U. Kulatunga*
06.00 PM - 06.15 PM	**S14078: Exploring the lesson learnt by implementing e-tendering - A review of literature** *Kavitha Kajendran*
06.15 PM - 06.30 PM	**Q&A**

Session Coordinator: Mr. Buddhika Arsekularathne

SATURDAY, 25 JUNE 2022

SESSION 2A

Theme	**Building Information Modelling**
Session Chairs	**Ch QS Suranga Jayasena**
Session Duration	**09.00 AM - 10.30 AM**
Time	**Paper ID, Title and Author(s)**
09.00 AM - 09.15 AM	**S14049: Establishing the role of BIM towards mitigating critical project risks assessed using a fuzzy inference system** *Sulakshya Gaur and Abhay Tawalare*
09.15 AM - 09.30 AM	**S14077: A review on unexploited features of n-dimensional BIM: An Indian construction scenario** *Rhijul Sood and Boeing Laishram*
09.30 AM - 09.45 AM	**S14010: BIM-Lean relationship assessment framework: A conceptual establishment** *Mohammad Afjalur Rahman and Sheila Belayutham*
09.45 AM - 10.00 AM	**S14068: Enhance the collaborative involvement of stakeholders through cloud-based BIM in the Sri Lankan construction industry** *R. Mohanaraj, P. Ganeshu and M. Gowsiga*
10.00 AM - 10.30 AM	**Q&A**

Session Coordinator: Ms. Agana Parameswaran

SATURDAY, 25 JUNE 2022

<u>SESSION 2B</u>

Theme	**Contract Administration and Dispute Resolution**
Session Chairs	**Prof. Kanchana Perera**
Session Duration	**09.00 AM - 10.30 AM**
Time	**Paper ID, Title and Author(s)**
09.00 AM - 09.15 AM	**S14058: Deficiencies in bespoke labour subcontract agreements: The case of large-scale contractors in the Sri Lankan construction industry** *A.M.N.N Arampath, Roshani Palliyaguru and G. Karunasena*
09.15 AM - 09.30 AM	**T14056: Challenges on bonds and guarantees under the payment security regime in the construction industry of Sri Lanka** *P.W.V. Manohara and M.D.T.E. Abeynayake*
09.30 AM - 09.45 AM	**S14043: Selection approaches and methods of construction industry consultant: A systematic literature review** *Mohammed Ahmed Hummadi, Srinath Perera, Xiao-Hua Jin and Ali Alashwal*
09.45 AM - 10.00 AM	**S14076: Cultural basic assumptions of consultants and contractors during negotiations: The case of South Australian construction industry** *Sonali Alankarage, Aparna Samaraweera, Joseph Royle, Adrian Macolino, Steven Robertson and A.D. Palihakkara*
10.00 AM - 10.15 AM	**S14059: Opportunities and challenges in conducting virtual Alternative Dispute Resolution (ADR) methods in the Sri Lankan construction industry** *Vithusha Lingasabesan and Mahesh Abenayake*
10.15 AM - 10.30 AM	**Q&A**

Session Coordinator: Ms. Umesha Weerapperuma

SATURDAY, 25 JUNE 2022

SESSION 2C

Theme	**Health, Safety and Wellbeing**
Session Chairs	**Dr. H. Chandanie**
Session Duration	**09.00 AM - 10.30 AM**
Time	**Paper ID, Title and Author(s)**
09.00 AM - 09.15 AM	**S14073: Stressors of quantity surveyors working on-site: Female vs male** *K.A. Gunasekara and B.A.K.S. Perera*
09.15 AM - 09.30 AM	**S14021: Evaluation of construction workers mental health during COVID-19 pandemic in Nigeria** *Oni Olatoyese Zaccheus, Olanrewaju AbdulLateef, Khor Soo Cheen and Akinbile Bolatito Folasade*
09.30 AM - 09.45 AM	**S14018: Implementing Safe Working Cycle (SWC) concept amidst the COVID-19 crisis in Sri Lanka** *H.P. Rasanjana and Chamari Allis*
09.45 AM - 10.00 AM	**S14029: Quantity surveyors working from home during COVID-19 pandemic: Does place matter?** *G.H.A.H.N. De Silva and Y.G. Sandanayake*
10.00 AM - 10.15 AM	**S14064: The role of quantity surveyors for the success of small-scale construction projects in Sri Lanka** *G.C. Rathnayake, K.P.S.P.K. Bandara and K.T. Withanage*
10.15 AM - 10.30 AM	**Q&A**

Session Coordinator: Mr. Dulshan Costa

SATURDAY, 25 JUNE 2022

SESSION 2D

Theme	**Pandemic Resilient Construction**
Session Chairs	**Ch QS Vijitha Disaratne**
Session Duration	**09.00 AM - 10.30 AM**
Time	**Paper ID, Title and Author(s)**
09.00 AM - 09.15 AM	**T14041: Contractual implications related to the construction industry in pandemic situations: A review of case laws** *R.D.W.W. Jayathilaka and K.G.A.S. Waidyasekara*
09.15 AM - 09.30 AM	**S14061: Adapting the standard forms of contract to minimize the contractual effects of COVID-19 on construction projects** *Chathuranga Perera and Roshani Palliyaguru*
09.30 AM - 09.45 AM	**S14031: The impact of COVID-19 pandemic on the demand and supply of apartment projects in Sri Lanka** *J.R. Koonkaduwa and Y.G. Sandanayake*
09.45 AM - 10.00 AM	**S14024: Delays and disruptions in the construction industry during the global pandemic** *Sithum Hansaka Gammanage and Nishanthi Gunarathna*
10.00 AM - 10.15 AM	**S14025: Effect of COVID-19 on the small-scale construction companies: The case of Colombo district, Sri Lanka** *Chamodi Piumika Namarathna and Nishanthi Gunarathna*
10.15 AM - 10.30 AM	**Q&A**

Session Coordinator: Ms. Shashini Jayakody

SATURDAY, 25 JUNE 2022

SESSION 3A

Theme	**Waste 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	**S14096: Enablers to facilitate industrial symbiosis for better waste management of industrial zones in Sri Lanka** *Pubudu Herath, Piumi Dissanayake and Binashi Kumarasiri*
11.15 AM - 11.30 AM	**S14006: Reusing and repurposing of glass waste: A literature review** *Tushar Sood and Argaw Gurmu*
11.30 AM - 11.45 AM	**S14042: A study of liquid waste management practices in construction projects in Australia** *Shiyamini Ratnasabapathy, Srinath Perera and Mary Hardie*
11.45 AM - 12.00 NOON	**S14023: The applicability of regulations for the disposal of construction and demolition waste in Sri Lanka** *Warnakulasuriya Dinu Ashen Chanaka Tissera, Rangamal Dahanayake and Vajira Edirisinghe*
12.00 NOON - 12.15 PM	**S14037: The impact of procurement method on construction time waste** *Kavishka Hewamulla, Himal Suranga Jayasena and Kavini Guruge*
12.15 PM - 12.30 PM	**Q&A**

Session Coordinator: Ms. Agana Parameswaran

SATURDAY, 25 JUNE 2022

<u>SESSION 3B</u>

Theme	**Energy and Retrofitting**
Session Chairs	**Dr. D.P. Chandrasekara**
Session Duration	**11.00 AM - 12.30 PM**
Time	**Paper ID, Title and Author(s)**
11.00 AM - 11.15 AM	**S14008: Strategies to enhance the applicability of grid power solar net metering concept in Sri Lanka** *M.G.W.U. Abeywickrama, P. Sridarran, M. Gowsigaand R.A.A. Dilogini*
11.15 AM - 11.30 AM	**S14070: Developing a decision-making model for selecting smart retrofits** *G.H.T.D. Jayarathne and Nayanthara De Silva*
11.30 AM - 11.45 AM	**S14071: Investigating the sustainable use of energy on construction sites in Sri Lanka** *S.A.U.M. Athukorala and K.G.A.S. Waidyasekara*
11.45 AM - 12.00 NOON	**S14003: Electricity generation through municipal solid waste in Sri Lanka: Drivers and barriers** *T.A.D.C.D. Karunarathna, P. Sridarran and M. Gowsiga*
12.00 NOON - 12.30 PM	**Q&A**

Session Coordinator: Ms. Umesha Weerapperuma

SATURDAY, 25 JUNE 2022

SESSION 3C

Theme	**Green Building Systems**
Session Chairs	**A/Prof. Nirodha Fernando**
Session Duration	**11.00 AM - 12.30 PM**
Time	**Paper ID, Title and Author(s)**
11.00 AM - 11.15 AM	**S14080: Economic performance of green walls: A systematic review** *U.G.D. Madushika, T. Ramachandra and D. Geekiyanage*
11.15 AM - 11.30 AM	**S14087: Green roof as a technology towards sustainability: A perspective of benefits offered** *K.A.L. Dasuni, Thanuja Ramachandra and M.N. Zainudeen*
11.30 AM - 11.45 AM	**S14022: The effect of orientation and plant type on the thermal behaviour of living wall systems in buildings** *H. Merve Yanardag Erdener and Ecem Edis*
11.45 AM - 12.00 NOON	**S14054: Drivers and barriers to implement the green building practices in higher education institutes in Sri Lanka** *I.E. Illeperuma, and M.D.T.E. Abeynayake*
12.00 NOON - 12.30 PM	**Q&A**

Session Coordinator: Mr. Dulshan Costa

SATURDAY, 25 JUNE 2022

SESSION 3D

Theme	**Disaster Resilient Built Environments**
Session Chairs	**Prof. Thayaparan Gajendran**
Session Duration	**11.00 AM - 12.30 PM**
Time	**Paper ID, Title and Author(s)**
11.00 AM - 11.15 AM	**S14083: Development of post-disaster resettlement strategies for Sri Lanka** *H.L.J.M. Lunuvila and U. Kulatunga*
11.15 AM - 11.30 AM	**S14084: Functional characteristics of an early warning system to minimise the risks of dam breaks in Sri Lanka** *L.N.K. Weerasinghe, M. Thayaparan and T. Fernando*
11.30 AM - 11.45 AM	**S14081: Policy-level considerations on marginalised communities in the post-disaster context: A desk study** *A.P.K.D. Mendis, P.A.P.V.D.S. Disaratna, Menaha Thayaparan and Yamuna Kaluarachchi*
11.45 AM - 12.00 NOON	**S14067: Lean iceberg model for post disaster reconstruction projects** *B.A.I. Eranga, K.A.T.O. Ranadewa, A.P. Rathnasinghe and P.A.D. Rajini*
12.00 NOON - 12.15 PM	**S14050: Defining critical infrastructure for Sri Lanka** *Maheshi Randeniya, Roshani Palliyaguru and Dilanthi Amaratunga*
12.15 PM - 12.30 PM	**Q&A**

Session Coordinator: Ms. Shashini Jayakody

SATURDAY, 25 JUNE 2022

<u>SESSION 4A</u>

Theme	**Enhancing Construction Performance**
Session Chairs	**Ch QS Indunil Seneviratne**
Session Duration	**01.30 PM - 03.00 PM**
Time	**Paper ID, Title and Author(s)**
01.30 PM - 01.45 PM	**S14030: Factors affecting construction time performance in high-rise building projects in Sri Lanka** *K. Kilintan, B.A.K.S Perera and P. Kajavathani*
01.45 PM - 02.00 PM	**S14072: A methodology to study the complexity of buildability in construction projects: Phenomenological research perspective** *P.L.I. Wimalaratne and U. Kulatunga*
02.00 PM - 02.15 PM	**S14045: Housing quality indicators: A systematic review** *Nipuni Nilakshini Wimalasena, Alice Chang-Richards, Kevin I-Kai Wang and Kim Dirks*
02.15 PM - 02.30 PM	**S14027: The effect of labour productivity on successful completion of major contracts during the COVID pandemic in Sri Lanka** *B.M.H.D. Bandaranayake and M.D. Rathnayake*
02.30 PM - 02.45 PM	**S14046: Construction industry on the brink: The COVID-19 impact** *Agana Parameswaran and K.A.T.O. Ranadewa*
02.45 PM - 03.00 PM	**Q&A**

Session Coordinator: Ms. Kalindu Mendis

SATURDAY, 25 JUNE 2022

<u>SESSION 4B</u>

Theme	**Innovative Technologies for Sustainability**
Session Chairs	**Prof. Nayanthara de Silva**
Session Duration	**01.30 PM - 03.00 PM**
Time	**Paper ID, Title and Author(s)**
01.30 PM - 01.45 PM	**S14001: A deep learning-based building defects detection tool for sustainability monitoring** *Biyanka Ekanayake*
01.45 PM - 02.00 PM	**S14095: As-built data acquisition for vision-based construction progress monitoring: A qualitative evaluation of factors** *Varun Kumar Reja, Koshy Varghese and Quang Phuc Ha*
02.00 PM - 02.15 PM	**S14009: Application of computer vision for construction progress monitoring** *H.P.M.N.L.B. Moragane, B.A.K.S. Perera and A.D. Palihakkara*
02.15 PM - 02.30 PM	**T14038: Offsite construction skills prediction: A conceptual model** *Buddhini Ginigaddara, Srinath Perera, Yingbin Feng and Payam Rahnamayiezekavat*
02.30 PM - 02.45 PM	**S14053: Container-based relocatable modular buildings for construction site offices in Sri Lanka: Contractors' perspective** *K.Y. Sandamini and K.G.A.S. Waidyasekara*
02.45 PM - 03.00 PM	**Q&A**

Session Coordinator: Ms. Umesha Weerapperuma

SATURDAY, 25 JUNE 2022

<u>**SESSION 4C**</u>

Theme	**Circular Built Environment**
Session Chairs	**Dr. Thanuja Ramachandra**
Session Duration	**01.30 PM - 03.00 PM**
Time	**Paper ID, Title and Author(s)**
01.30 PM - 01.45 PM	**S14097: Importance of a value assessment tool in regenerating a circular built environment in Sri Lanka** *A.M.D.S. Atapattu, H. Chandanie and R. Dilakshan*
01.45 PM - 02.00 PM	**S14033: The role of the quantity surveyor in achieving circular built environment at the design stage** *H.C. Victar, B.A.K.S. Perera and A.D. Palihakkara*
02.00 PM - 02.15 PM	**S14044: Circular Economy (CE) based material selection: Development of a CE-based '10R' evaluation framework for building construction projects in Sri Lanka** *Koshalee Wanaguru, Harshini Mallawaarachchi and Dimuthu Vijerathne*
02.15 PM - 02.30 PM	**S14036: Beyond the reuse: Potentials and barriers for exchanging treated wastewater among the industries in Sri Lanka** *Harshini Mallawaarachchi, Y.G. Sandanayake, Gayani Karunasena and Chunlu Liu*
02.30 PM - 03.00 PM	**Q&A**

Session Coordinator: Mr. Dulshan Costa

SATURDAY, 25 JUNE 2022

SESSION 4D

Theme	**Sustainable Operation and Management of Facilities**
Session Chairs	**Dr. Pournima Sridarran** **Dr. Uthpala Rathnayake**
Session Duration	**01.30 PM – 03.00 PM**
Time	**Paper ID, Title and Author(s)**
01.30 PM – 01.45 PM	**S14028: Industry 4.0 enabled predictive maintenance of facilities: A study on applicability, benefits and challenges** *T. Sivanuja and Y.G. Sandanayake*
01.45 PM – 02.00 PM	**S14066: Sustainable facilities management practice and its perception in health care organisations: A Delphi survey** *F.S. Nazeer, T. Ramachandra and Sachie Gunatilake*
02.00 PM – 02.15 PM	**S14092: Efficient workplace planning and designing strategies to reduce waiting time in the outpatient departments (OPD) of government hospitals in Sri Lanka** *D.P.I.M. Pathirana and Nayanthara De Silva*
02.15 PM – 02.30 PM	**S14074: Industry 4.0 based sustainable manufacturing model for apparel industry in Sri Lanka** *A.M.L De Alwis and Nayanthara De Silva*
02.30 PM – 02.45 PM	**S14004: The impact of COVID-19 on the business continuity of the Sri Lankan apparel industry: Human resource management (HRM)** *M. Gowsiga and T. Kartheepan*
02.45 PM – 03.00 PM	**Q&A**

Session Coordinator: Mr. Buddhika Arsekularathne

KEYNOTE SPEAKERS

Mr. Don Ward

Chief Executive
International Council for Research and Innovation in Building and Construction (CIB)

Keynote on 'Innovations and Global Trends in our Sector'

In March 2020, Mr. Don Ward took up the role of Chief Executive of the International Council for Research and Innovation in Building and Construction (CIB), which is a worldwide network of building and construction experts who enhance their performance through international cooperation and information exchange with their peers to improve the quality and impact of research and innovation activities in the sector. He is a highly experienced and globally recognized CEO of not-for-profit organizations in the construction and built environment sector. Between the period of 1991-2022, Mr. Ward was positioned as the Managing Director, CE International; Chief Executive, Constructing Excellence; Chief Executive, European Construction Institute; Chief Executive, Design Build Foundation; Chief Executive, Construction Industry Board and Head of Energy Efficiency in Housing, Building Research Establishment (BRE). He is a fellow Member of the Chartered Institute of Building (CIOB).

Mr. Ward is renowned as an international expert in industry change, innovation, supply chain integration, collaborative working, benchmarking, and sustainability, with 35 years' experience of in studying, implementing and learning from best practices and change programmes in the housing, construction and infrastructure sectors in the UK and overseas.

Further, he was an advisor to the UK Government's Cabinet Office, Secretary to the British Standards Institution's committee on construction procurement, and a Simon Industrial Fellow at Manchester Business school. He has undertaken speaking engagements and advisory roles in over 30 countries including Australia, Hong Kong, Japan, Korea, Netherlands, Scandinavia, USA and across the Middle East region.

KEYNOTE SPEAKERS

Prof. Lalith De Silva

Emeritus Professor
Former Dean, Faculty of Architecture
University of Moratuwa
Sri Lanka

Keynote on 'Revitalising the Debt Structure Strategy of National Economy using the Resilience of the Built Environment'

Prof. Lalith De Silva is an Emeritus Professor attached to the Department of Building Economics, University of Moratuwa, Sri Lanka. He was the former Dean of the Faculty of Architecture. Prof. De Silva obtained his Bachelor of Science in Built Environment and Master of Science in Architecture from the University of Moratuwa and Post Graduate certificate from James Cook University, Australia. He is affiliated with the Royal Institute of British Architects (RIBA), and he is a fellow Member of The Institute of Architects Sri Lanka. He was the past President of the Sri Lanka Institute of Architects from 2003 to 2005.

Prof. Lalith De Silva has published several peer reviewed research papers in leading journals and conferences in green and sustainable construction, water management and urban planning and development. His research interests are green buildings, occupants' productivity, water management, sustainable/green procurement, risk management, procurement and property development. Prof. De Silva was awarded the BEPAM Highly Commended Paper award at the World Construction Symposium in 2016, CIOB Best Paper Award at the World Construction Symposium in 2015 and Outstanding Research Performances Awards by the University of Moratuwa from 2013 to 2019.

With over 30 years of experience as an academic and of 40 years of experience as a professional, Prof. Lalith De Silva remains a renowned personality in both academia and the architectural profession in Sri Lanka and internationally.

PANEL DISCUSSION

Panel Discussion on "Rebooting to a resilient construction industry - Bouncing back better from multiple crises"

Panellists: Prof. Mohan Kumaraswamy
Eng. Nissanka Wijeratne
Prof. Asanga Gunawansa
Ch QS Upul Shantha
Dr. Rohan Karunaratne

Moderator: Ch QS Lalith Rathnayake

Panel Discussion Moderator

Ch QS Lalith Ratnayake

MSc (PM), BSc (Hons) QS, FIQSSL

Contract Management Consultant

Director, VFORM Consultants Private Ltd and PROMA Private Ltd.

Immediate Past President of Institute of Quantity Surveyors Sri Lanka

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

Panel Member

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Honorary Professor at the University of Hong Kong & the University of Moratuwa

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Mohan Kumaraswamy is an Honorary Professor at the University of Hong Kong and the University of Moratuwa, Sri Lanka. He has been a Visiting Professor at Universities in Singapore, Australia and India and also a Consultant to the World Bank. Before joining academia, he worked on designs, construction and project management, including as a Construction Manager of a 5-star hotel in Colombo and a Director of the pioneering construction project management company in Sri Lanka.

His contributions to academia-industry-link bodies include those as Sri Lanka representative of CIOB (UK) until 1992; Vice-Chairman of CIOB Hong Kong in 1996-97; Chairman of the Civil Division of Hong Kong Institution of Engineers in 1997-98; and as a member of the Institution of Engineers Sri Lanka Accreditation Board from 2014. Prof. Kumaraswamy is also the Founding Director of the Centre for Innovation in Construction & Infrastructure Development, Hong Kong and the Editor-in-Chief of one of the three CIB recognised journals, the Journal of Built Environment Project and Asset Management (BEPAM. Besides, he is the Editor-in-Chief of the Book Series on Domain-Specific Bodies of Knowledge in Project Management under World Scientific Publishing, Singapore.

Furthermore, Prof. Kumaraswamy is a Joint Co-ordinator of the international CIB Working Commission TG72 from 2008 and W122 from 2017, on 'Public-Private Partnership' at the International Council for Research & Innovation in Building and Construction. He also serves as an Arbitrator and Adjudicator in several construction project disputes.

Panel Member

Eng. Nissanka Wijeratne

MSc (UK), BSc (Hons) Civil Eng., MICEUK

Secretary General/CEO of the Chamber of Construction Industry, Sri Lanka

Eng. Nissanka Wijeratne graduated from the University of Peradeniya, Sri Lanka, which is the legacy of the University of Ceylon, with a BSc Honours in Civil Engineering and obtained an MSc in Construction Management from the University of Technology, Loughborough, United Kingdom. Moreover, he is a member of the Institution of Civil Engineers, UK.

Eng. Wijeratne is the Secretary General/CEO of the Chamber of Construction Industry, Sri Lanka, which is the apex representative organisation of all construction industry stakeholders recognised by the Government of Sri Lanka. He was the former CEO and Chief Accounting Officer of the Ministry of Foreign Employment Promotion & Welfare and the Ministry of Construction and Engineering Services. In addition, he was the former Chairman/CEO of the Institute for Construction Training & Development.

Eng. Wijeratne has authored several journal publications on capital budgeting, in addition to his enormous contribution to industry practice.

Panel Member

Dr. Asanga Gunawansa

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Prof. Asanga Gunawansa was called to the Bar as an Attorney-at-Law of the Supreme Court of Sri Lanka in 1993 and has over 28 years of experience as a Legal Counsel. He holds a PhD in Law from the National University of Singapore (NUS) and an LLM in International Economic Law from the University of Warwick, England. He is also a fellow of Brown International Advanced Research Institute (BIARI), Brown University. In addition to being engaged in private legal practice, Prof. Gunawansa served as a Legal Consultant to the Asian Development Bank on public-private partnerships and as a Legal Consultant to the Independent Redress Mechanism of the Green Climate Fund in Songdo, South Korea. He provides his service as a Honorary Legal Consultant to the Ministry of Justice of Sri Lanka and was instrumental in establishing the Colombo International Arbitration Centre. He provides his expertise on the law relating to arbitration in Sri Lanka to the Justice Sector Reforms Program of the Ministry of Justice in Sri Lanka.

Prof. Gunawansa is also an Associate Member of the Executive Committee of the Asia Pacific Centre of Environmental Law, NUS, and an International Research Associate of the Institute of Water Policy of the Lee Kuan Yew School of Public Policy, NUS. He is also an Adjunct Professor at the University of Moratuwa, Sri Lanka.

Outside his legal practice and academic activities, Prof. Gunawansa is a non-resident Associate of the Asia Society and a member of the Editorial Review Board of the International Journal of Law in the Built Environment and the Journal of Built Environment Project and Asset Management. Prof. Gunawansa has authored several books including the ‘Asia Pacific Construction Law Case Book Series’ published by LexisNexis and ‘Water Governance: Evaluation of Alternative Architectures’ published by Edward Elgar Publishing House. He has also authored over 25 Articles published in international journals on construction law, environmental law and arbitration.

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 the Director of Cost Management Services (Pvt.) Ltd. and a past president of the Institute of Quantity Surveyors (IQSSL), Sri Lanka. He obtained a BSc (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 in 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

Dr. Rohan Karunaratne

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Dr. Rohan Karunaratne is the incumbent president of the Ceylon Institute of Builders (CIOB), engaged in developing the construction industry and construction builders in Sri Lanka. He holds a PhD in Management and an MBA from Sussex University (UK). Dr. Karunaratne is an Engineering Graduate of the University of Hindustan and an advanced Diploma holder in HIET (Chennai - India). He is a Fellow of the International Institute of Management and a Fellow of the Ceylon Institute of Builders. He has over 30 years of experience in Civil Engineering, Building Construction, Engineering Consultancy, Construction Training, and lecturing in Civil Construction, Designing, and Planning.

Dr. Karunaratne is the Chairman of AKK Engineers (Pvt) Ltd, Master Builders International (Pvt) Ltd, and Hybrid Airport (Pvt) Ltd, as well as the President of South Asia Lean Construction Association, the former President of the National Construction Association of Sri Lanka, and an Ex-Co Member of the Construction Preservation Forum. Further, he is the Chairman of Arpico Finance, Association Motor Finance and Director of Hatton National Bank.

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A DEEP LEARNING-BASED BUILDING DEFECTS DETECTION TOOL FOR SUSTAINABILITY MONITORING

Biyanka Ekanayake[1]

ABSTRACT

To ensure sustainability of buildings, detection of building defects is crucial. Conventional practices of defects detection from building inspection data are mostly manual and error prone. With the advancements in computer vision, imaging technology and machine learning-based tools have been developed for real-time, accurate and efficient defects detection. Deep learning (DL), which is a branch of ML is more robust in automatically retrieving elements' semantics to detect building defects. Although DL algorithms are robust in object detection, the computational complexities and configurations of these models are high. Therefore, this study presents a process of developing a computationally inexpensive and less complicated DL model using transfer learning and Google Colab virtual machine to improve automation in building defects detection. Cracks is one of the major building defects that constraint the safety and durability of buildings thus hindering building sustainability. Building cracks images were sourced from the Internet to train the model, which was built upon You Only Look Once (YOLO) DL algorithm. To test the DL model, inspection images of five (05) buildings collected by the Facilities Management department of a University in Sydney city were used. The DL model developed using this process offers a monitoring tool to ensure the sustainability of buildings with its' ability of detecting cracks from building inspection data in real time accurately and efficiently. Although the current model is built to detect cracks, this process can be employed to automated detection of any building defect upon providing the training images of defects.

Keywords: *Computer Vision; Deep Learning; Defects; Google Colab; Sustainability.*

1. INTRODUCTION

Since the performance of buildings degrades over time, monitoring of defects is imperative to ensure sustainability of buildings (Mishra, et al., 2022). Crack formation, deformation, dampness, staining, settlement, and rebar corrosion are the most common building defects (Hauashdh, et al., 2021; Mishra, et al., 2022). In the operational stage of a building, the major share of the maintenance budget is allocated for preventing or repairing building defects (Ekanayake, et al., 2018; Hauashdh, et al., 2021).

Conventional approaches of detecting defects typically require facility managers or maintenance engineers conducting manual inspections of the building (Kong, et al., 2018). When the building is a mid to high-rise structure, collecting inspection data becomes cumbersome and can even pose safety hazards (Kung, et al., 2021). With the

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advancements in computer vision (CV), unreliable access to inspection data and the time-consuming, labourious, erroneous manual methods of detecting defects have been improved (Lundkvist, et al., 2014; Şimşek, 2022). Computer vision involves acquiring, processing, and understanding image data with the use of high-definition cameras and machine learning (ML) algorithms (Szeliski, 2010) to replicate human vision for object detection.

The automated visual recognition ability of ML has been leveraged for defects detection in some pioneering studies such as Kwon, Park and Lim (2014); Lundkvist, Meiling and Sandberg (2014); Sankarasrinivasan, et al. (2015). However, traditional ML algorithms relying on manual feature extraction for object detection and classification are sensitive to input images, background noise and visual quality (Ying and Lee, 2019; Ekanayake, et al., 2021). Among the advances in CV, the use of deep learning (DL), which is a branch of ML is notable (Wang, et al., 2021). DL models automatically learn features by training data (Nanni , et al., 2017). Although the DL-based defects detection studies such as Chen and Jahanshahi (2017); Dizaji and Harris (2019); Kung, et al. (2021); Munawar et al. (2022) are emerging, the computational difficulties associated with developing and training DL models have not been fully addressed (Ekanayake, et al., 2021; Wang, et al., 2021).

Although DL performs far better than traditional ML algorithms, expensive hardware requirements, DL model training and configurations are constraining the application of DL models to their full potential (O'Mahony, et al., 2019; Wang, et al., 2021). Transfer learning is a solution to develop DL models using pre-trained networks without having to build the DL algorithm from the scratch (Pan and Yang, 2009; Liu, et al., 2021). With the proliferation of cloud computing, cloud providers offer inexpensive services for cloud enabled virtual machines (VM) such as Google Colab for training DL models (Pal and Hsieh, 2021). Therefore, this study presents a process of developing a computationally inexpensive and less complicated DL model using transfer learning and Google Colab virtual machine to improve automation in building defects detection. The DL models require a large amount of training images. Since this paper only intends to provide guidance on the process, it is not practical to train the DL model for all the defects. Among the defects, cracks are prominent (Mishra, et al., 2022). If the cracks are not properly detected at early stages, they can hinder the safety and durability of buildings thus threatening the building sustainability (Şimşek, 2022). Therefore, to demonstrate the process of the DL-based tool, building cracks images sourced from the Internet were used to train the DL model and inspection images of 5 buildings collected by the Facilities Management department of a University in Sydney city were used to test the model.

2. LITERATURE REVIEW

Understanding the impacts of defects on building sustainability, nature of cracks and the application of CV to enable automated visual recognition of defects are discussed in the subsequent subsections.

2.1 BUILDING DEFECTS AND THEIR IMPACTS ON SUSTAINABILITY

A building defect is characterised as a "failing or shortcoming in the function, performance, statutory or user requirements of a building and might manifest itself within the structure, fabric, services or other facilities of the affected building" (Watt, 2009). The growth of aged buildings has caused a surge in repair costs associated with building defects (Park, et al., 2019). While the old buildings with defects are typically unsustainable, in major cities, some newly built high-rise buildings have also proved to be unsustainable. Evidently, in early 2019, occupants were evacuated from two (02) newly built apartment complexes in Sydney due to building collapse risk caused by structural cracks (Crommelin, et al., 2021).

Explaining the relationship between the defects and building sustainability, Hauashdh, et al. (2021) pointed out that defects prevent the buildings from performing their functions, reducing the building life span, and impacting the building occupants' health and safety. Therefore, the social aspect of sustainability is immensely affected. On the other hand, the costs allocated for detecting, repairing, and preventing defects are escalating to create a negative impact on economic sustainability (Park, et al., 2019). The degradation of structural elements because of defects, generates waste and emissions making the buildings environmentally unsustainable (Lee, et al., 2018). Therefore, defects have a vast impact on the sustainability of buildings.

2.2 BUILDING CRACKS

Building cracks can be divided in to structural and non-structural cracks. The cracks in columns, beams, slabs, and footing are considered as structural cracks and may endanger the safety of a building over time (Mishra, et al., 2022). Structural cracks occur due to incorrect design and defective construction of structural elements. They can also be a result of overloading (Kunal and Killemsetty, 2014). Non-structural cracks mostly result from internally induced stresses in building material due to moisture variations and temperature variations. Cracks on walls and parapet walls are some examples. Even though non-structural cracks usually do not compromise safety of the building, they are not aesthetically appealing and can create impression of instability (Thagunna, 2014; Nama, et al., 2015). According to IS: 456 2000 Code of practice on plain and reinforced concrete, cracks are classified based on their width as follows (BIS, 2000).

- Thin cracks - less than 1mm in width
- Medium cracks - 1mm to 2mm in width
- Wide cracks - more than 2mm in width

Figure 1 illustrates the types of cracks.

a) b) c)

Figure 1: Types of cracks - a) thin crack, b) medium crack and c) wide crack

Source: Kunal and Killemsetty (2014)

There have been some studies related to defects analysis, which focussed on visual inspection of defects using the automated visual recognition ability of algorithmic approaches in CV.

2.3 AUTOMATED VISUAL RECOGNITION

Visual recognition by traditional ML approaches encompasses performing object detection in images by manual feature extraction, which is also referred to as handcrafted feature extraction (Ekanayake, et al., 2021). A feature extraction algorithm like Canny edge detector extracts edges that can be used to classify objects detected using edges. The inspection of a wall crack using Canny edge detector, which is further processed by hyperbolic tangent detector is displayed in Figure 2.

a) b) c)

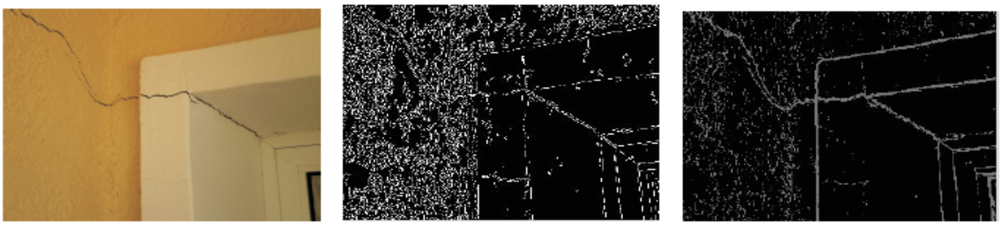

Figure 2: Detection of a crack - a) original image, b) Canny edge detector and c) Hyperbolic tangent detector

Source: Sankarasrinivasan, et al. (2015)

The main drawback of this traditional approach is that it is necessary for the programmer to decide which features are important in each image (O'Mahony, et al., 2019). For example, as in Figure 2, edge is the important feature to be extracted when detecting cracks. In addition to the information on shape, texture and edges of objects, a substantial level of manual pre-processing using algorithms is necessary to remove background noise such as unnecessary data in the image and to enhance visual quality. Instead of applying a single object detection algorithm, the handcrafted feature extraction necessitates conducting additional steps of pre-processing to make the region of interest in the image easily detectable (Ying and Lee, 2019). In recent years, CV-based DL, which is a branch of ML has been evolving rapidly and adopted in the facility inspection and defect analysis context (Marzouk and Zaher, 2020; Liu, et al., 2021). DL models, which are referred to as deep neural networks leverage input-to-target mapping by means of a deep sequence of layers to extract features from input data (LeCun, et al., 2015; Chollet, 2017). While the traditional ML algorithms use a shallow structure, DL network architecture learns the features of an image using a cascade of hidden layers and weights (Slaton, et al., 2020).

In supervised DL, a large amount of annotated data is trained so that the DL model can automatically learn features reducing the manual feature extraction. Objects are detected with rectangular bounding boxes (Wang, et al., 2018). The convolution neural networks (CNNs) are the widespread type of DL neural networks used for image processing (LeCun, et al., 2015; Chollet, 2017). The frameworks of DL-based CNN object recognition methods can mainly be categorised into two types. In one type, region proposals are generated initially, and each proposal is classified into different object categories. Region-based convolutional neural networks (R-CNN) belong to this category (Zhao, et al., 2019). The other type treats object detection as a regression problem, adopting a unified framework to achieve the outcomes. You Only Look Once (YOLO) (Redmon, et al., 2016) algorithm is the best example. Because of the unified framework approach, YOLO models are relatively fast, accurate and simple (Redmon, et al., 2016; Zhao, et al., 2019).

There have been few studies on CNN-based building defects detection. Lin, et al. (2017) built a CNN-based structural damage locations identification system. To facilitate crack detection in nuclear power plant components, Chen and Jahanshahi (2017) presented a CNN framework. Dizaji and Harris (2019) launched a CNN model for detecting surface cracks in concrete columns. In Kung, et al. (2021) and Munawar, et al. (2022), unmanned aerial vehicles (UAVs) were used to capture the defects in mid to high-rise buildings and CNN frameworks were developed for cracks detection.

3. RESEARCH METHODS

The aim of this study is to present a process to develop a computationally inexpensive and less complicated DL model using transfer learning and Google Colab VM for defects detection. This solution is built upon YOLO DL model and tested on cracks images. The subsequent sub sections provide details on preparing the training image database and mechanism behind transfer learning and Google Colab VM.

3.1 PREPARING THE IMAGE DATASET

Since this paper focusses on presenting a process, images were only required to train the DL model. When the number of diversified images is higher, DL model has sufficient features to learn and the accuracy increases (Wang, et al,. 2018). To create a diverse and large dataset of building cracks, publicly available 2000 online images were sourced. The label used was "crack" to annotate each image containing a building crack. To test the DL model developed using the process, inspection images of five (05) buildings collected by the Facilities Management department of a University in Sydney city were used.

3.2 TRANSFER LEARNING

There are two methods to build a DL model. It can either be developed from the scratch or a pretrained model which uses existing networks such as GoogleNet, AlexNet, ResNet (Simonyan and Zisserman, 2014) can be used. In this second approach, a mechanism called transfer learning is adopted to refine the pre-trained model to introduce previously unknown object classes and train the custom model (Torrey and Shavlik, 2010). A DL model can be pre-trained on large dataset of object classes such as Common Objects in Context (COCO) dataset. Using transfer learning, a new model with custom parameters is introduced to produce new weights corresponding to the new object classes. Transfer learning approach is not as much as prolonged and manually intervened as creating a model from the scratch (O'Mahony, et al., 2019). Programmers employ transfer learning to reuse many pre-trained DL models because of the competitive advantages in speed and accuracy (Nalini and Radhika, 2020).

3.3 VIRTUAL MACHINES: GOOGLE COLAB

High computational resources such as graphical processing units (GPUs), high performing memory, processors, and storage are essential for training DL models (O'Mahony, et al., 2019; Wang, et al., 2021). In addition to the hardware requirements, compute unified device architecture (CUDA), and CUDA-based deep neural networks (cuDNN) should be configured for GPU enabled DL model training (Jian, et al., 2013; Jorda, et al., 2019). With the advancements in modern computing systems, GPU-enabled gaming computers, embedded edge computing devices of single board have been used as training platforms for DL models (Pal and Hsieh, 2021). However, the hardware requirements are still expensive, and the configurations are complicated and time consuming. Generally, a functional computer with such hardware requirements costs approximately USD 2000.

With the proliferation of cloud computing and virtualisation, dedicated ML platforms and development environments are available to overcome the hardware and configuration issues (Carneiro, et al., 2018; Canesche, et al., 2021). Among them, Colaboratory (Colab) by Google, Azure Machine Learning by Microsoft and Watson Studio by IBM are prominent. Virtualisation using cloud computing creates a virtual version of the physical computer with a dedicated amount of processer, memory and GPU borrowed from a cloud providers' server. As a result of this, VMs remain independent of the local physical host computer (Rahman, et al., 2022). Colab is the most popular and cost-effective solution to be used as a VM (Pal and Hsieh, 2021). The working mechanism of Colab is illustrated in Figure 3.

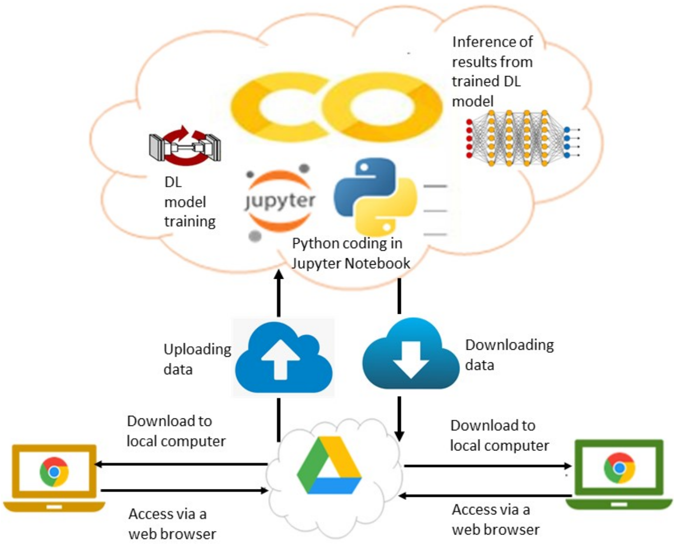

Figure 3: Working mechanism of Colab

Colab is a free-of-charge web-based Jupyter notebook accessed using a Google account to run Python codes. Colab notebooks are stored in Google Drive. Therefore, Google Drive acts as the storage unit accessed from any web browser (Ohkawara, et al., 2021). Colab enables setting up VM as runtime by connecting to GPUs hosted by Google or through Google cloud platform services (Google Research, 2022). Since zero configuration is required and most of the ML libraries are already installed, DL models can be trained in Colab with a few lines of code. Data can be uploaded from the local computer and downloaded to the local computers' hard drive through Google Drive (Pal and Hsieh, 2021).

3.4 THE YOLO VERSION 4 (YOLOV4) ALGORITHM

At the time this paper was written, YOLOv4 (Bochkovskiy, et al., 2020), which was introduced in 2020 has been the most stable and accurate version of YOLO with the optimal speed of detection. Since transfer learning was employed to build the DL model, understanding the mechanism of the YOLOv4 is important to identify the parameters to customise using transfer learning and training in Colab. In YOLOv4, the CNN backbone for object detection is Darknet53 (Bochkovskiy, et al., 2020). The original YOLOv4 model was trained on COCO dataset which comprises of day-to-day general objects of 80 different classes and weights were generated to detect and classify images containing those objects. In the current study, using transfer learning, new weights were trained in Colab for the object class of "crack".

4. PROCESS OF DEVELOPING THE DEEP LEARNING - BASED TOOL

An overview of the process is demonstrated in Figure 4. Initially, the annotated image dataset was prepared with the class label "crack". Next, YOLOv4 were customised using transfer learning followed by DL model training implemented in Colab. To test the cracks detection solution built upon a DL model, test images of building inspection data obtained from a University in Sydney were introduced.

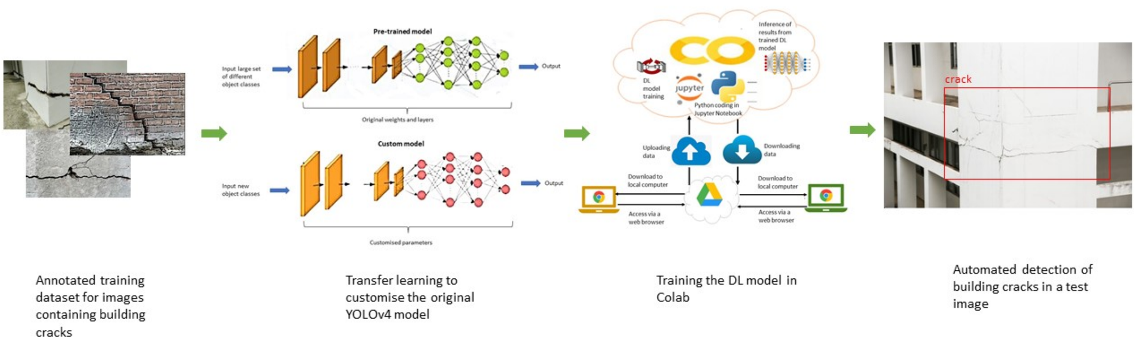

Figure 4: Steps of developing the DL-based solution to detect building cracks

Following are the detailed steps involved in the process of developing the DL-based solution.

- Step 1: Annotating the training images

To annotate the images of building cracks sourced from the Internet, an online annotation tool called *"Makes sense"* was used. The label used was "crack". As per the requirements of the YOLO model, a text file was generated with the details of the annotation for each of the image. Accordingly, 2000 images have corresponding 2000 text files in the training dataset.

- Step 2: Configuring Darknet architecture

To customise the detector backbone of the original YOLOv4 model, the yolov4 configuration file "*yolov4-custom.cfg*" was downloaded from the GitHub repository for YOLOv4, AlexeyAB (Bochkovskiy, et al., 2020). The batch size was changed to 64 images for one iteration and subdivisions were changed to 16, indicating the splitting of batch into 4 mini-batches, such that 64/4 = 16 images per mini-batch. The resolution size chosen for the current model is 416x416 such that the training images were resized to 416x416 pixel resolution. The maximum number of batches was set to 6000.

The parameters of the YOLO layers and the convolutional layers were modified to match the number of object classes. Before each of the YOLO layers, there are three (03) convolutional layers in Darknet architecture. The original Darknet used 255 filters depending on the number of classes of 80. The number of filters were calculated using the formula: (number of classes + 5) x 3. The number of classes were changed to 1 and number of filters were adjusted as 18.

- Step 3: Uploading files to Google Drive

Google Drive was connected to Colab and uploaded with data files needed for transfer learning-based customisation. The customised "*yolov4-custom.cfg"* file and a zip folder containing the images and their corresponding text files with annotation details were uploaded. The Python script containing the instructions to split the dataset into two (02) parts as 90% for training and 10% for validation was uploaded. The names file with the instructions on the class name "crack" and the data file with the instructions on the paths were also uploaded.

- Step 4: Linking the Google Drive and Colab notebook

A Colab notebook was created from the same Google account and was saved in the Google Drive. The runtime was set to GPU and high memory capacity. The *"mount drive"* command was executed to link the Colab notebook and Google Drive.

- Step 5: Cloning Darknet and enabling GPU

Darknet was cloned to Colab from the GitHub repository AlexeyAB followed by GPU enabled in Colab environment.

- Step 6: Building and customising the Darknet

Through transfer learning Darknet was customised using the instructions in the files that were uploaded in Step 3. To facilitate this, the files were copied to the current Darknet directory.

- Step 7: Training the customised DL model

YOLOv4 weights pre-trained on COCO dataset were downloaded from AlexeyAB GitHub. Upon executing the *"train custom detector"* command, as per the changes made in Step 6, weights of the custom YOLOv4 model were generated in every 1000 iteration, until 6000 iterations.

- Step 8: Testing the DL model

After the training was completed, the DL model was tested with building inspection images. Figures 5a and 5b depict how the cracks in the building inspection images were automatically detected by the DL model.

The robustness of the DL model was tested using mean average precision (mAP) and average loss. The metric, mAP is widely used to evaluate the detection accuracy of DL models. The loss value indicates how well a DL model behaves after each iteration. The reduction of loss after each or several iterations is an indication of the higher accuracy of the DL model (O'Mahony, et al., 2019). The mAP is portrayed in red colour and average loss is displayed in blue in Figure 6. The best weight of the DL model has a mAP of 76% and the average loss of the model is 1.14.

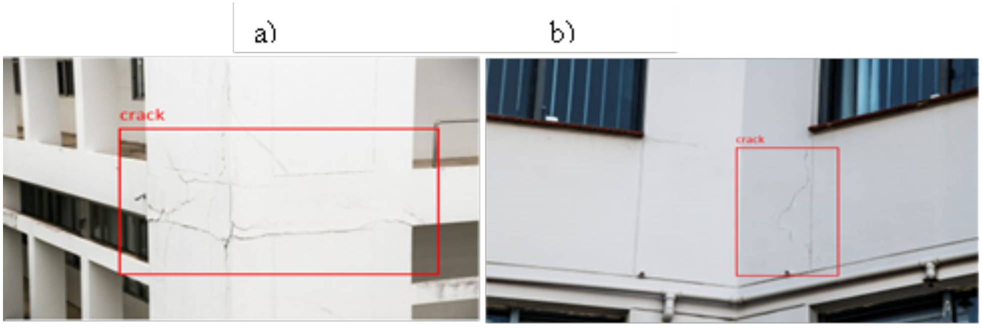

Figure 5: Test images of building inspection data

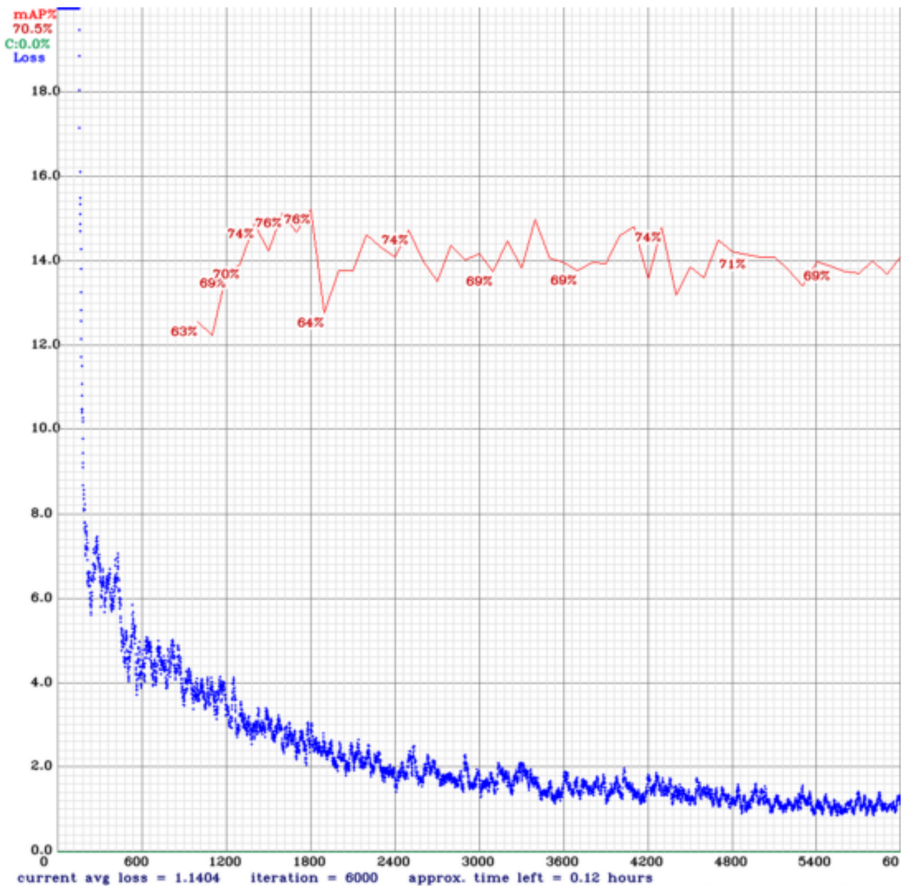

Figure 6: Performance evaluation of the deep learning model

It is noteworthy that these values are subjected to the visual quality of the images, which were sourced from the Internet. If the images are of high visual quality with less background noise, the mAP could be improved, and average loss could be reduced. On the other hand, this model was only trained and tested on images containing cracks to demonstrate the process. Since the process harnesses the DL model's ability in detecting objects, it can be extended to automated detection of any building defect upon providing the training images of the defects.

5. CONCLUSIONS AND RECOMENDATIONS

This paper presents a process of developing a DL-based tool for automated building defects detection. This solution exploits the DL model's ability in detecting objects in images using automated feature learning through training images. Compared to traditional ML algorithms, which use manual feature extraction, DL models proved to be more robust and reduce the manual intervention of pre-processing images. YOLOv4 was used to develop the DL model. Since it was not practical to train the DL model for all types of building defects, this model was only trained on building cracks images. The steps in the process provide guidance on using transfer learning to build DL models from pre-trained networks and training DL models in Google Colab VM platform. Both transfer learning and Colab-based training ensure reducing the computational complexities and expensive hardware requirements associated with DL models.

If defects are not properly detected at early stages, they can hinder the safety and durability of buildings. The DL model developed using this process offers an automated monitoring tool to ensure the sustainability of buildings. To improve automation, building inspection data can be captured using UAVs in mid to high-rise buildings. In terms of sustainable buildings, a step beyond defects detection would be to calculate the width and area of the defects to assess the damages using instance segmentation techniques. There is room for improving the performance of the current DL solution by introducing more training images and optimising the hyperparameters of the YOLOv4 algorithm in future studies.

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A METHODOLOGY TO STUDY THE COMPLEXITY OF BUILDABILITY IN CONSTRUCTION PROJECTS: PHENOMENOLOGICAL RESEARCH PERSPECTIVE

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ABSTRACT

The construction industry is crucial to the economic development of any nation. However, the achievement of the project objectives has become challenging in the construction industry. Thus, research on improving the construction project performance is often appealed. One of the reasons for poor performance in the construction industry has been identified as lack of buildability. Buildability is expected to give a boost to construction project performance throughout the entire project life cycle. Even though the existing knowledge domain suggests various buildability guidelines, appraisal systems, and concepts targeting different phases or different elements of construction, there is no established set of practices or directives that can be incorporated into a construction project throughout its various stages to improve construction project performance. This is mainly due to the absence of clear identification of the deep meaning of the key drivers of the buildability concept. Therefore, it is important to obtain a clear picture of the key drivers of this concept.

This challenge may be handled by obtaining perception from the industry experts with regard to their lived experience concerning buildability. This paper utilises works of literature related to research methodology to design a suitable research framework for this study. The research onion model was adopted for the framework development and phenomenological philosophy was proposed with Interpretative Phenomenological Analysis (IPA). The paper highlights the importance of adherence to micro-interactions and a systematic approach to research work throughout the research process to maintain the quality of the study.

Keywords: *Buildability; Lived Experiences; Phenomenology; Phenomenological Research.*

1. INTRODUCTION

The construction sector plays an important role in the socio-economic development of any country. Thus, the construction industry is undeniably essential to the growth of a nation and a key sector in the nation's economy (Ibrahim, et al., 2010). In addition to

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economic considerations, the impact of the success rate of constructions spread across various other societal goals such as sustainability, carbon reduction, risk reduction too. Therefore, the successful achievement of project objectives in the construction industry is paramount. A construction project is commonly acknowledged as a successful project when the aim of the project is achieved in terms of predetermined objectives of completing the project on time, within budget, and to the required quality standard (Kesavan, et al., 2015; Naoum and Egbu, 2015). To achieve this goal, construction companies should complete the projects within their anticipated budgets, durations and expected quality targets (Polat, et al., 2014). However, in most construction projects severe time and cost overruns occur due to various factors (Venkateswaran and Murugasan, 2017; Habibi and Kermanshachi, 2018; Ogbu and Adindu, 2019; Johnson and Babu 2020). Poor quality in construction projects has also become a common phenomenon in the world (Ali and Wen, 2011; Buba, et al., 2020).

The root causes of these issues have been identified as poor cost estimation, lack of design integration, extensive number of change orders (Rosayuru, et al., 2019; Johnson and Babu 2020), lack of effective communication (Johnson and Babu, 2020; Kwofie, et al., 2020), poor selection of procurement method (Farrell and Sunindijo, 2020; Johnson and Babu, 2020), and lack of buildability (Jergeas and Put, 2001; Farrell and Sunindijo, 2020; Johnson and Babu 2020). Among these causes, lack of buildability has been identified as a key factor that even directly or indirectly impacts on the other issues as well (Nascimento, et al., 2017; Ansyorie, 2019; Al-Fadhli, 2020; Khatib, et al., 2020). This is because buildability impacts throughout the construction projects, starting from conceptual planning, throughout the procurement processes, construction methods, and also involving stakeholders in the decision-making to achieve their satisfaction (Ansyorie, 2019; Al-Fadhli, 2020; Samimpey and Saghatforoush, 2020). The framework shown in Figure 1, which was named "the wider framework of buildability", illustrates the impact of buildability throughout the entire project work stages.

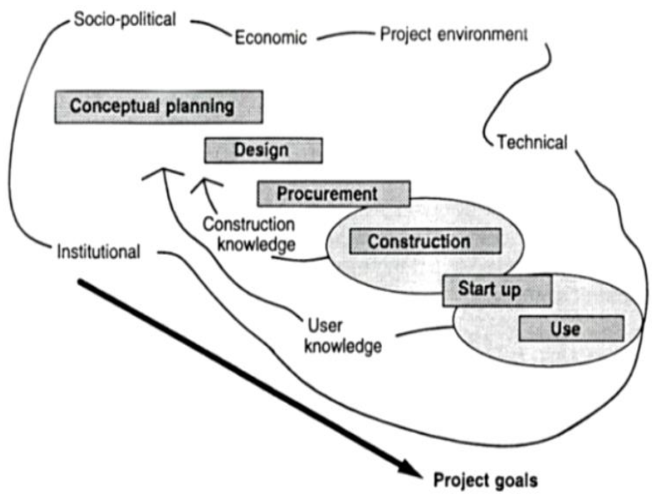

Figure 1: The wider framework of buildability

Source: Construction Industry Institute Australia - CIIA (1993)

The benefits of implementing buildability were multi-faceted. Research performed in this field have shown that buildability is effective in reducing time and cost and improving projects' quality throughout the various phases of the construction project cycle (Jergeas and Put, 2001; Lam and Wong, 2009). Agreeing to this, Samimpey and Saghatforoush (2020) stated that buildability has reduced additional processes and prevented duplications, and thereby has reduced final costs of projects and their delivery time. Therefore, integrating buildability into construction projects can lead construction projects to fruitful outcomes not only in every aspect but also throughout their work stages.

Buildability is a concept deals with the optimal integration of construction knowledge and experience at various project stages to achieve the overall project goals (Naoum and Egbu, 2016). Interestingly, a significant contribution in relation to buildability research is made by various industry research institutes such as Construction Industry Research and Information Association (CIRIA) in the UK, Construction Industry Institute Australia (CIIA) and Construction Industry Institute in United States (CIIUS). CIRIA in 1983 first defined buildability as "the extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building". Since then, numerous studies have been conducted targeting various phases and aspects of construction projects to strive for better project performance through improving buildability. For example, buildability assessment model by Building and Construction Authority (BCA) in Singapore, guidelines for improving the buildability of building designs by CIRIA, concepts to improve buildability introduced by CIIUS have provided guidelines for designers to use at the early design stage to improve buildability in construction projects. Adding to these, buildability principles introduced by Adams (1989), CIIA (1996) and buildability concepts introduced by Nima, Abdul-Kadir, Jaafar and Alghulami (2001) have attempted to cover beyond the design phase of a construction project.

It has to be noted that these generic explanations, guidelines, concepts, and various definitions that have been emerged over time have fostered the concept of buildability towards better construction performance. Our previous study conducted specifically on various definitions of buildability and its key constructs has illustrated the numerous definitions that emerged over three decades. This study concluded that the key constructs of buildability include "integrate construction knowledge and experience", "throughout the project delivery process" to "achieve overall project objectives" (Wimalaratne, et al., 2021). However, a detailed interpretation of these constructs as to what it means in-depth and what to be practically done in each work stage to benefit from it is not adequately explored. Hence, much deeper insight is necessary in relation to these key constructs for further investigating this concept and to develop a practical application that was found profoundly missing in the existing knowledge domain. Therefore, the aim of this study is to investigate the deeper meaning behind the key constructs of buildability leading to its practical application to enhance construction project performance.

Provided that buildability is a concept born and brought up within the construction industry and continues to serve the industry itself, obtaining an industry point of view on this concept to understand the driving principles that come under each key construct is needed. Thereby a clear mechanism could be derived that can practically implement to improve construction project performance throughout the entire project duration. Therefore, it is worth researching to establish the industry point of view on buildability before exploring ways of integrating buildability into construction projects. Accordingly, the aim of this paper is to design the research methodology for understanding the deeper meaning of the key constructs of buildability by understanding the practical experience of the industry experts. This paper addresses the research methodology which is required to obtain an in-depth view of the buildability concept based on the research aim.

2. THE RESEARCH METHODOLOGY

Research is a well-coordinated activity aiming to contribute more knowledge to the existing body of knowledge (Fellows and Liu, 2008). Therefore, the construction of new knowledge and explorations of the existence of realities require a specific method of inquiry (Collins and Hussey, 2014). In this regard, there are different frameworks proposed by various researchers to decide upon a research methodology. These frameworks are comprised of different components to be included in a research design. For instance, Kagioglou, et al., (2000), introduced a framework comprising research philosophy, research approach, and research techniques. (Creswell and David Creswell, 2018) introduced a framework interconnecting philosophical worldviews, strategies of inquiry, and research methods. Saunders, Lewis, and Thornhill (2019) introduced another popular framework comprising six (06) components as research philosophy, research approach, research methodological choice, research strategy, research time horizon and research techniques and procedures. According to these popular frameworks, philosophies (Saunders, et al. 2019), philosophical worldviews (Creswell and David Creswell 2018) and research philosophy (Kagioglou, et al., 2000) represent similar meanings, which basically described the fundamental assumptions in relation to the "reality". Guba and Lincoln (1994) and Healy and Perry (2000) introduced these as "research paradigms" and stated that they can be used to position the relationship between the world and the researcher. Likewise, strategies (Saunders, et al., 2019) strategies of inquiry (Creswell and David Creswell, 2018) and research approach (Kagioglou, et al., 2000) carried similar meanings. (Yin, 2018) explained this "research strategy" as the way of doing research. Further, Research techniques and procedures (Saunders, et al., 2019) research methods (Creswell and David Creswell, 2018) and research techniques (Kagioglou, et al., 2000) carried similar meanings. Each of these authors have described a range of options under these research techniques.

Therefore, the above frameworks contain similar steps required for effective research. In order to design the research methodology for this study, Saunder's research onion (see Figure 2) was used as it was found more comprehensive compared to the other two frameworks.

The Saunders Research Onion illustrates the stages involved in the development of research work as a step-by-step process that can be adopted for almost any type of research methodology and can be used in a variety of contexts (Saunders, et al., 2019). Saunders, et al. (2019) recommend that their "Research Onion" be unwrapped starting from the outer layer towards the most inner layer and the right step from each layer to be selected based on the research. The research onion includes six main stages as below:

1. Research philosophy
2. Research approach
3. Research methodological choice
4. Research strategy

5. Research time horizon
6. Research techniques and procedures (data collection and analysis)

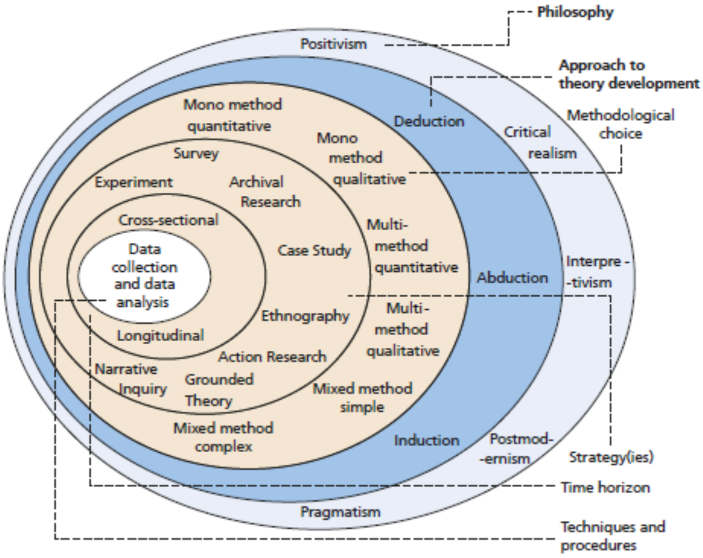

Figure 2: Research onion

Source: Saunders, Lewis, and Thornhill (2019)

Described herein are the detailed procedure designed to be followed in achieving the aim of this study.

2.1 RESEARCH PHILOSOPHY

The research philosophy term refers to a system of beliefs and assumptions about the development of knowledge (Saunders, et al., 2019). The researchers must be aware of the philosophical commitments they make through a research design, and failure to adhere to philosophical concerns can affect the quality of the research negatively (Easterby-Smith, et al., 2015). There are three (03) types of research philosophies/ beliefs and assumptions as axiology, ontology, and epistemology.

Axiology refers to the role of values and ethics (Saunders, et al. 2019). In axiology assumptions, the researcher will need to decide how they maintain both researcher's own values and those of the people who have researched in a particular area (Saunders, et al. 2019). Ontology refers to assumptions about being an existence or the nature of reality (Saunders, et al., 2019). Ontology embodies understanding "what is" (Gray, 2014) and the ontological assumptions researchers make throughout their study will shape how the researcher sees and study the research objectives (Saunders, et al., 2019). There are two approaches come under ontological assumptions. That is objectivism and constructivism. Epistemology on the other hand refers to the assumptions about the best way to study the world (Bhattacherjee, 2012). Epistemology embodies understanding "how to know the reality?". Epistemology helps to relate to and understand the research of others and the choices that were made and build up the relationship between the researcher and the reality (Uma and Roger, 2016). There are two approaches that come under epistemological research. That is positivism and interpretivism. Positivism suggests that "reality" exists external to the researcher and can be explored through the rigorous process of scientific inquiry. Interpretivism underlines that humans are different from physical phenomena for the reason that humans create meanings (Saunders, et al., 2019). Phenomenology is another research philosophy introduced by Edmund Husserl in the 19th century to study the experiences of humans. The founding principle of phenomenological inquiry is that experience should be examined in the way that it occurs, and in its own terms (Smith, Flowers and Larkin, 2009). Therefore, phenomenology has common features to interpretivism which highlights the human intervention in creating knowledge and supports enquiring epistemological problems in a new, fresh, and exciting manner (Moran, 2002). However, phenomenology goes deeper into human experience and studies what the experience of being human is like, in all of its various aspects, but especially in terms of the things which matter to our lived world (Smith, et al., 2009) and evokes in consciousness with reference to a specific experience (Moustakas, 1994). Therefore, major differences in phenomenological research can be identified as engagement in disciplined and systematic efforts to set aside prejudgments regarding the phenomenon being investigated in order to launch the study as far as possible free of preconceptions, beliefs, and knowledge of the phenomenon from prior experience and professional studies - to be completely open, receptive, and naive in listening to and hearing research participants describe their experience of the phenomenon being investigated (Moustakas, 1994).

Choosing the right methodology for a given research project can be an enormous challenge (Masadeh, 2012). Although there is no one best research philosophy, Philliber, Schwab, and Samsloss (1980) stated that research designs deal with what questions to study, what data are relevant, what data to collect, and how to analyse the results. Agreeing to this (Blessing and Chakrabarti, 2009) stated that the research methodology should be selected depending on the specific research question.

The purpose of this research is to create new, richer understandings and interpretations of social worlds and contexts on buildability within construction projects. Therefore, in this study, success is mainly dependent on human contribution and the study demands to understand and interpret deeper meanings of human experiences on buildability. Industry experts are considered as social actors in this study. The study attempts to interpret the world from these social actors' points of view by adopting suitable methods of inquiry rather than observing their behaviour. Phenomenology research philosophy sees social phenomena as socially constructed and is particularly concerned with generating meanings and gaining insights into those phenomena (Moustakas, 1994; Saunders, et al., 2009). The key value of phenomenological philosophy is that it provides us with a rich source of ideas about how to examine and comprehend lived experience (Smith, et al., 2009). The phenomenon studied in this study is buildability. Buildability concept has clearly identified key constructs that seem generic but demand a further investigation referring to knowledge as it appears to the consciousness of experts, which can be interpreted following the science of describing what one perceives, senses, and knows in one's immediate awareness and experience (Moustakas, 1994). Therefore, although this study bears the epistemological stance that humans are different from physical phenomena and create knowledge, this study goes beyond a general interpretivist's inquiry as it attempts a careful examination of human experience to find means by which someone might come to accurately know their own experience of a given phenomenon, and would do so with a depth and rigour which might allow them to identify the essential qualities of that experience (Smith, et al., 2009). Therefore, the research philosophy in this study is phenomenology.

2.2 RESEARCH APPROACH

There are three (03) research approaches as deduction, induction, and abduction. Deductive approach refers to the studies that start with a theory, often developed from reading the academic literature, and the researcher designs a research strategy to test that theory through the research (Saunders, et al., 2019). The inductive approach refers to the studies that start by collecting data to explore a phenomenon and generate or build theory such as conceptual framework (Saunders, et al., 2019). Abductive approach refers to collecting data to explore a phenomenon, identify themes and explain patterns, to generate a new or modify an existing theory (Saunders, et al., 2019).

In this study, literature survey identified the key constructs of the phenomena being studied (buildability). However, further investigation is required through data collection to further explore buildability. A deep identification and interpretation of the lived experiences gathered from the data collection will facilitate the construction of new knowledge. Even though each construction project is different in terms of the procurement process, contractual aspects, and nature of the construction itself, the sense of phenomenon being studied in relation to various construction project stages would be principally applicable and useful to be used in different circumstances of similar context. Therefore, this research will take abductive approach.

2.3 RESEARCH METHODOLOGICAL CHOICE

There are six (06) methodological choices discussed in Saunders research onion. They are, Mono method Quantitative, Mono method qualitative, Multi-method quantitative, Multi-method qualitative, Mixed method simple, and Mixed method complex.

First of all, the methodological choice for research should be whether to follow a quantitative method, qualitative method or mixed-method. Each element in research design should be based on the research question, objectives and show consistency with the research philosophy adopted (Saunders, et al., 2019). Saunders, et al. (2019) explained that one way of differentiating quantitative research from qualitative research is to distinguish between numeric data (numbers) and non-numeric data (words, images, audio recordings, video clips, and other similar material). This research requires in-depth inquiry on the studied phenomenon (buildability), which get the opinions of different people through their lived experiences in relation to the phenomenon being studied. Hence this study falls under qualitative methodological choice. A qualitative research design which use a single data collection technique, is known as a mono method qualitative study and a qualitative research design that uses more than one qualitative data collection technique is known as a multi-method qualitative study (Saunders, et al., 2019). This study will collect data using more than one qualitative data collection technique and corresponding analytical procedure. The selected data collection techniques in this research include expert interviews and case studies using a phenomenological approach. Therefore, the methodological choice of this research is multi-method qualitative.

2.4 RESEARCH STRATEGY

Qualitative research is associated with a range of strategies. Some of the principal strategies used with qualitative research are Action Research, Case Study Research, Exploratory Surveys, Ethnography, Grounded Theory, and Narrative Inquiry. The suitability of these methods depends on the research objective and the philosophy which has been adopted for the investigation.

In this study, first in-depth expert interviews (Stage 1) will be used to collect data and establish conclusions in relation to buildability. Case studies (Stage 2) will use thereafter to further investigate the phenomena (buildability) and identify the gaps in the practice. Sample for the first stage of data collection will be individuals /industry practitioners who have extensive expertise around the world. Data related to the theoretical propositions will be collected at this stage considering the lived experience of the experts of all the phases of construction projects and throughout various orientations of their practice (i.e: contractor's practice, consultant's practice, project manager's practice). Therefore, research strategy is exploratory surveys.

Research strategy for Stage 2 will comprise case studies. Cases are the sources that lead the study into the identification of data to be collected. As per Yin (2018), there are two different steps to be considered when the cases are introduced to the research as (1) defining the case and (2) bounding the case. The "case" can be an individual, some event or entity other than a single person. The cases for this study shall be selected within Sri Lankan geography due to limitations of the research. Once the cases are defined, other clarifications such as bounding of the case is required. The bounding is expected to tighten the connection between the selected case, research questions and theoretical propositions (Yin, 2018).

As per Yin (2018), it is also important to define the specific time boundaries to define the estimated beginning and end of the case (i.e., whether to include the entire or only some part of the life cycle of the entity that will become the case). In this study, the cases will be selected from the nearly completed are recently completed building construction projects as this will facilitate the maximum exposure for the interviewers to explain their lived experiences.

The next step is defining the criteria for interpreting the findings. This criterion shall aid analysis of the data collected and guide the researcher suggesting what to be done after collection of the data. Yin (2018) stated that it is vital for the researcher to be aware of the choices available and how the choices might suit the selected case study which shall then create a more solid foundation for the later analysis. More details on the data analysis technique of the research are discussed under section 2.6 "Research techniques and procedures".

2.5 Research Time Horizon

Before data collection, it is important to determine whether the objective of the research is to study a phenomenon in a snapshot of time (cross-sectional) or study an ongoing phenomenon (longitudinal) (Saunders, et al., 2019). This research involves a particular phenomenon at a particular time. Therefore, the time horizon of the research is identified as cross-sectional method.

2.6 Research Techniques and Procedures

Data collection and analysis will be carried out following the phenomenological interview approach. Phenomenology is concerned with the systematic reflection and analysis of phenomena associated with conscious experiences, such as human judgment, perceptions, and actions, with the goal of; (1) appreciating and describing social reality from the diverse subjective perspectives of the participants involved, and (2) understanding the symbolic meanings ("deep structure") underlying these subjective Experiences (Bhattacherjee, 2012). The phenomenon used in this study is buildability. A comprehensive literature survey will be carried out concerning the academic literature and industry reports to understand the symbolic meaning of buildability and derive theoretical propositions.

Data collection and analysis will be carried out in two stages where stage 1 will be the in-depth expert interviews with experienced experts practicing in the construction industry. Stage 1 shall establish a deeper understanding of the expert's opinion on buildability. Main data source is in-depth conversations with a small number of participants. Stage 2 will be based on the selected case studies using phenomenological interview approach. Stakeholders of the selected construction projects who are responsible for designing buildings, architects & engineers, and specialised experienced contractors will be the participants for the semi-structured interviews under stage 2.

There are two types of phenomenological interviews. They are 1. Descriptive and 2. Interpretive. This study will follow interpretive phenomenological approach where the researcher attempts to understand the hidden deeper meanings behind the phenomenon and interpret it using a suitable analytical technique (IPA) to explain the phenomena being studied. Researcher will bracket herself up to a greater extent in collecting rich insights and digging deeper into the meanings while preserving the authenticity of the lived experiences of the participants. Interpretive phenomenological interviews will facilitate active listening and non-interruption of participants while gathering data around two broad questions "what have the participant experienced in terms of the phenomenon" and "what contacts or situations have influenced the participant's experiences of the phenomena".

There are popular qualitative data analysis methods such as qualitative content analysis, narrative analysis, discourse analysis, thematic analysis, grounded theory and interpretive phenomenological analysis. Among these, Interpretive phenomenological analysis (IPA) is designed to understand the personal experiences of a subject (for example, a person or group of people) concerning a major life event, an experience, or a situation (Kerryn, 2020). Therefore, IPA will be used to analyse the data collected and to identify the gaps in the current practice and thereby reach the conclusions for this study.

2.7 RESEARCH METHODOLOGY FRAMEWORK

In the sections above the research philosophies and underlying assumptions, research approaches and research strategies are discussed in detail with reference to their mutual relationship. In the section below authors formulate an appropriate methodology to fulfil the aim of the research on obtaining the interpretations of the key constructs of the concept of buildability and thereby derive a practical framework to integrate buildability into construction projects.

In order to ensure the effectiveness of the methodological tool introduced below, a pilot study was carried out with an expert who had 16 years of experience in the construction industry. The objective of this pilot study was mainly to test the methodological tool so that the desired outcomes can be achieved under the main study. A semi-structured phenomenological interview was conducted. It was found that the emerging themes were in agreement with the literature findings, and several new themes suggesting integrating buildability into construction project. The new themes were identified as new knowledge and therefore an original contribution to existing knowledge can be made.

Refer Figure 3 for the conceptual research methodology framework derived for this study.

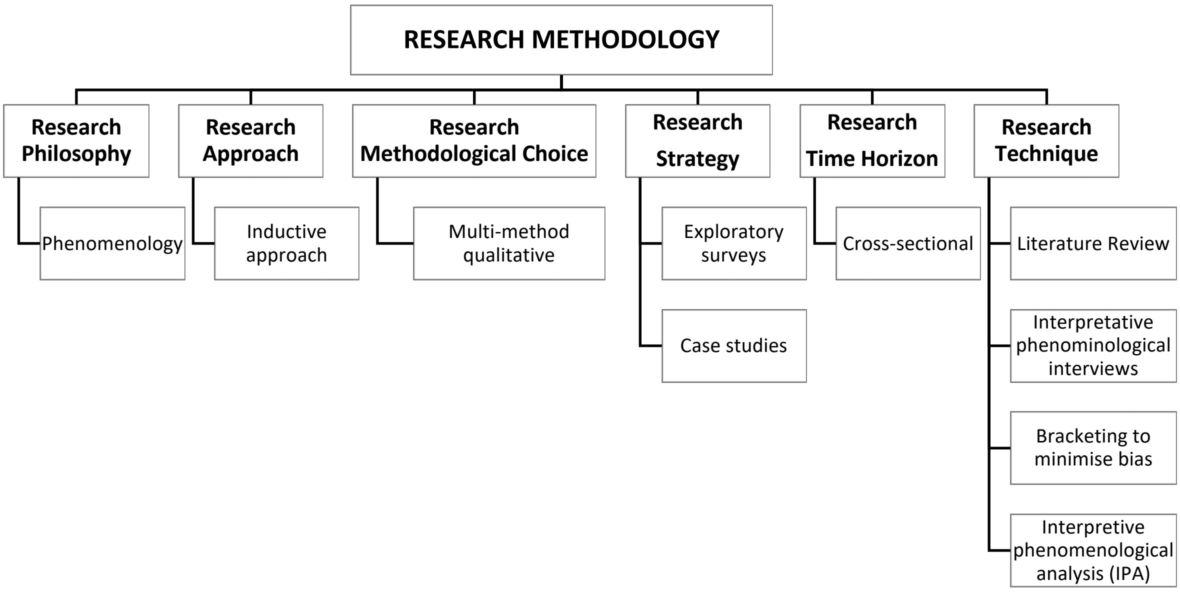

Figure 3: Conceptual research methodology framework

3. CONCLUSIONS

Buildability is a concept that enhances the construction project performance and significantly contributes towards better value for money of a construction project. Against this background, it is surprising that very little thought or energy is given on incorporating buildability into construction projects' works stages which is expected to have the potential to significantly improve outcomes. Therefore, this study is designed to explore ways of integrating buildability in construction projects by making sense of deeper meanings of the key constructs buildability concept.

In this paper, the authors have made an effort to discuss the existing literature related to research methodology. Following a systematic approach from the research philosophies to the Research Approach, Research Methodological Choice, Research Strategy, Research Time Horizon, and Research Techniques and Procedures, a suitable research framework has been designed for this study. This is illustrated in Figure 3 above.

Through the discussion, the authors have argued that this particular research on obtaining a deeper understanding on buildability takes the phenomenological philosophical stance. Case study method as the most suitable research strategy. As way forward, it is envisaged to develop a detailed case study design for the research including particular micro-interactions and specific procedures to follow during data collection to grasp rich insights to the inquiry.

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A REVIEW OF DRIVERS OF SUSTAINABILITY IN MEGA INFRASTRUCTURE PROJECTS: AN INSTITUTIONAL APPROACH

Nicola Thounaojam[1], Ganesh Devkar[2] and Boeing Laishram[3]

ABSTRACT

The need for sustainable practices in megaproject implementation is becoming acute. With the ongoing progress and expansion of mega infrastructure projects (MIPs), a lot of attention has been attracted among policymakers and researchers due to their enormous impacts on the economy, society, and the environment. Given the complexity of MIPs and the sustainability-related challenges it faces; the successful management of sustainability-related targets requires influence from the institutional forces (regulative, normative and cultural-cognitive). However, existing research on the institutional drivers that can effectively promote the sustainability of megaprojects has been largely unexplored and calls for attention. Therefore, this study aims to present a review of what drives the adoption of sustainable practices in MIPs. A systematic literature review was conducted based on a combination of keyword search in the Scopus database. Using the lens of institutional theory and deductive approach, 11 drivers for sustainability in MIPs were identified from reviewing 33 selected peer-reviewed articles. This study would enhance project stakeholders' and policymakers' understanding of drivers for sustainability and help further improve policies, strategies, norms and culture to support MIPs in contributing to sustainable development goals.

Keywords: *Drivers; Infrastructure Projects; Institutional Theory; Megaproject; Sustainability.*

1. INTRODUCTION

The rapid pace of urbanisation has led to an increase in the construction of mega infrastructure projects (MIPs) across the world. In addition to the time and cost overrun of these projects, many policymakers and researchers have criticised the implementation of megaprojects given their enormous economic, social and environmental impacts. Megaprojects generate significant impact across all three "bottom-line" sustainability indicators: economic, financial, and social (Hosseini, et al., 2018). Consequently, they exhibit and trigger far-reaching, long-term effects, thus, creating an environment unable

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to foster sustainability (Brookes and Locatelli, 2015). They are widely denounced for lack of public participation, forced displacement, flaws in CBA (Cost-Benefit analysis), procedural loopholes in EIA (Environmental Impact Assessment) and environmental destruction (Thounaojam and Laishram, 2021). The scale of such projects is so huge that the project activities consume large amount of resources and cause sustainability issues due to carbon emissions. In addition, these projects expend immense budgets, draw serious economic and political attention, and often lead to conflicts between project stakeholders over white elephant projects. Therefore, it is necessary to look beyond the “iron triangle” of fulfilled schedule, budget, and specifications in analysing megaprojects (del Cerro Santamaría, 2021). The need for sustainable practices in megaproject implementation is becoming acute. However, integrating these principles to project processes depend immensely on many triggering factors or drivers that lead a project organisation to promulgate sustainable development in their projects.

Many scholars have recognised the importance of acquiring knowledge of institutional driver for sustainability and have been examining them in the manufacturing sector (Wijethilake, et al., 2017; Misopoulos, et al., 2018), supply chain (Kauppi and Hannibal, 2017) and mining industry (Famiyeh, et al., 2021). Studies have also analysed institutional factors related to sustainability reporting (Rosati and Faria, 2019). However, existing research on the institutional drivers that can effectively promote the sustainability of megaprojects has been largely unexplored and calls for attention. To better understand how megaprojects’ decision-makers and policymakers can accelerate and direct sustainable practices, insight is needed into the drivers for sustainability in the practices of megaprojects. Drawing upon institutional theory, this study aims to identify various forms of institutional pressures (regulative, normative and cultural-cognitive) that are potentially related to the sustainability of MIPs. With the research question in mind, the study reviews the existing literature on drivers for sustainability in megaprojects through the lens of institutional theory. The study can be helpful for project actors and policy-makers to develop and improve policies, strategies, norms and culture to support MIPs in contributing to the sustainable development goals.

2. THEORETICAL APPROACH

Institutional theory sets the foundation for analysing factors that drive survival and legitimacy of organisational practices. The three forms of drivers, regulative, normative and cultural-cognitive structures and activities, provide stability and meaning to social behaviour (Scott, 1995). These structures become the ‘social facts’ that describe the organisation's reality: “explanation of what is and what is not, what can be acted and what cannot” (Hoffman, 2001). Institutional theory is useful in this study to provide more understanding of the connection between institutional drivers and sustainability in megaprojects.

Organisations are likely to develop structures and policies that align with the institutional pressures they face. For instance, organisations in supply chain often adopt information technology due to institutional isomorphism, namely coercion, mimesis, and norms (Lai, et al., 2006). Likewise, institutional characteristics, such as political and legal systems, regulatory frameworks and socio-cultural norms, can influence the integration of sustainability in megaproject management. The institutional supports, including government aid, green incentives and training programmes, play a crucial role in promoting sustainability in MIPs (Thounaojam and Laishram, 2021). According to a study conducted among megaproject experts, it was found that different incentive policies from the government can positively influence sustainable construction in megaprojects (Wu, et al., 2018). Given the complexity of megaprojects and the sustainability-related challenges, the successful management of sustainability-related targets requires influence from three institutions- regulative, normative and cultural-cognitive. These projects must be regarded as "socio-technical endeavours" set in complex institutional systems (Biesenthal, et al., 2018), and theoretical frameworks incorporating institutional theory can be a promising domain for future megaprojects research (Hu, et al., 2015). Understanding these projects from the lens of institutional theory may explain how some institutional systems may drive megaproject sustainability. The institutional-environmental elements play a crucial role in promoting the sustainability of megaprojects (Xie, et al., 2021).

Regulative elements use explicit rules and surveillance activities originating from government departments, state agencies or the judiciary. Normative elements look at prescriptive and obligatory dimensions, originating from professional bodies and industry or trade standards bodies, suppliers and consulting organisations; and cultural-cognitive elements rely on shared beliefs (culture) and are dependent on individual cognition (Butler, 2011; Biesenthal, et al., 2018). Each element differs in the degree to which it is visible and ranges from the directly coercive to the "taken-for-granted" (Hoffman, 2001).

3. RESEARCH METHODOLOGY

A systematic literature review was carried out for reviewing the existing literature on drivers for sustainability of megaprojects. Unlike traditional reviews, systematic literature reviews are explicit, rigorous and transparent, and researchers in the area of built environment research have been employing to establish an evidence-based practice (Parida and Brown, 2018). This study followed three phases of review methodology modified from Chelliah, et al. (2021).

The Scopus database was employed for literature search under the first phase of review (planning the review). The search was conducted based on building blocks, further divided into facets (variants/synonyms of each facet). Booth (2008) recommended adopting a "building blocks" strategy in conducting a search query. According to this strategy, the topic of study is broken into facets/blocks. Then, variants and synonyms for each facet are added together using Boolean operators to form a final search query. Likewise, the keywords used for the literature search are shown in Table 1. These keywords were identified using trial-and-error and snowballing techniques.

In the second phase (*conducting the review*), publications were first filtered that are English, peer-reviewed and journal articles. In the next step, papers pertinent to the research question are selected based on title, abstract, and full manuscript analysis (refer Figure 1). These papers were critically assessed based on the inclusion criteria defined in Table 1. In total, 33 papers were selected for literature review to identify critical institutional drivers for sustainability in megaprojects.

In the third phase (*analysing and reporting review*), content analysis was carried out using a deductive approach with categories informed by the institutional theory (regulative, normative and cultural-cognitive). Deductive analysis that explicitly draws from existing theory or frameworks, as opposed to inductive analysis, can be especially useful in attempts to contextualise and complicate existing knowledge (Love and Corr, 2022).

Table 1: Search strings and filtering criteria

	Building Block 1/ Facets	Building Block 2/ Facets	Inclusion criteria	Filter
Search string 1	"Regulative", "normative", "cultural cognitive", "institutional theory", "mimetic", "coercive"	Sustainab*	Articles that use words analogous to sustainability-institutional elements in project management or construction projects.	Language: English Peer reviewed Type: Journal papers
Search string 2	"megaproject", "large infrastructure", "large construction", "large project", "mega-infrastructure"	Sustainab*	Articles that has critiqued institutional drivers, motivation or pressure for sustainability in large infrastructure projects.	

Full-text of the manuscripts was taken as the unit of analysis and necessary data was extracted using QSR NVivo. All the 45 papers were reviewed for content and coded for aspects that fit the categorisation frame or are exemplification of the categories (Polit and Beck, 2004). Some example text coded for each category are provided in Table 2.

After a categorization matrix has been developed, all the data are reviewed for content and coded for correspondence with or exemplification of the identified categories (Polit and Beck, 2004).

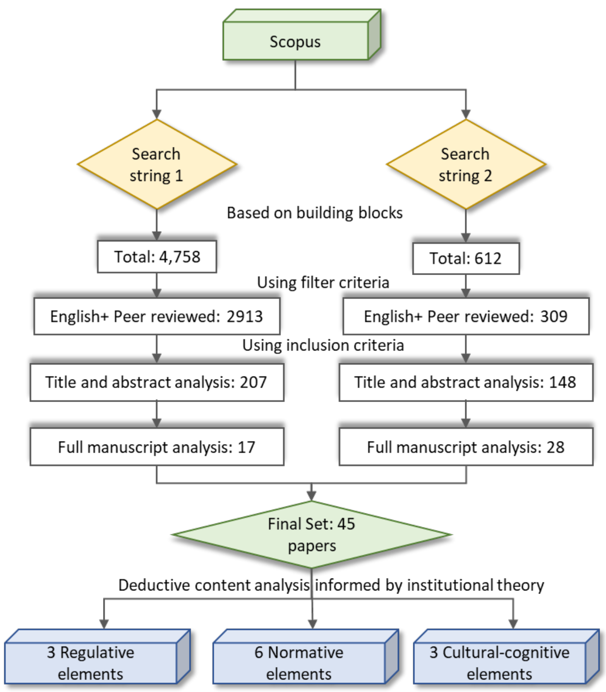

Figure 1: Literature search and selection process

4. RESULTS AND DISCUSSIONS

The findings of the analysis showed three regulative, five normative and three cultural-cognitive elements (as shown in Table 2) that can drive sustainability in mega infrastructure projects. Therefore, the following section discusses the findings from the content analysis.

Table 1: Sustainability-institutional drivers in megaprojects

Sustainability institutional drivers		Description	Example text	Sources
Regulative	Environmental and Social Legislative and Regulatory mechanisms (R1)	Drives through compliance with various environmental and social laws and regulations and monitoring by their respective institution (s)/organisation (s).	"The new regulations for having sustainable production processes place more emphasis on the environmental aspect of TBL."	[1] [2] [3] [4] [6] [9] [10] [13] [14] [18] [20] [21] [22] [23] [24] [27] [28] [29] [33]
	Incentives and penalties (R2)	Incentives from the government as a tool to promote sustainable activities.	"Project managers could be rewarded incentives mechanisms for implementing social and environmental improvement [..]."	[4] [18] [20] [21] [22]
	Contractual contents (R3)	Contractual contents regarding impact assessment; economic, social and environmental obligations; grievances and dispute resolution mechanisms; stabilisation clause; transparency, reporting and public engagement; and penalties and termination.	"Contract documents contain clear requirements for project quality and safety, handling public social events, and ecological environmental protection."	[2] [12] [18] [27] [28] [30] [33]
Normative	Standards and certifications (N1)	Worksites certifications such as ISO 9001, 45001 and 14001, and project green awards such as LEED certification.	"[…] pointed out about self-regulation, […] obtained Environmental Management System certification (ISO 14001) release an environmental balance and policy report annually […]."	[3] [4] [7] [8] [10] [13] [14] [16] [17] [21] [23] [28] [29]
	Vocational training and meetings (N2)	Training programs and meetings for sustainability-related activities.	"Introduce training programs associated with sustainable construction and project management practices."	[5] [8] [10] [11] [17] [19] [20] [23] [30]
	Standardised templates and norms (N3)	Standardised templates and norms for green practices and performance monitoring mechanism.	"The Project Design Documents [….] provide management plans and explanations on how projects will reduce emissions and provide SD benefits."	[13] [17] [20] [25] [31]
	Influence from consultants/ professional bodies (N4)	Participation and support from multiple consultants and professional bodies in the project with a good	"Industry professional bodies play a crucial role in disseminating information on innovative	[2] [4] [9] [11] [20] [26] [31]

	Sustainability institutional drivers	Description	Example text	Sources
		history of implementing sustainable infrastructures.	environmental measures and in advocating cutting-edge green technologies."	
	Influence of multilateral/ international agencies (N5)	Presence of multiple multilateral/ international agencies with a solid environmental and social safeguard framework.	"PFIs [public funding institutions] under consideration here are not only catalysts for private finance but also trendsetters on the sustainability front."	[1] [19] [29] [30]
Cultural-cognitive	Sustainability knowledge and competence among employees (C1)	Knowledge and competence among the employees understand the need to rethink the project activities by incorporating sustainability practices.	"[…] firms' sustainable capabilities and competence as important commitments towards reducing impacts on the environment."	[14] [15] [27] [28] [29] [32]
	Project company's goals and commitments towards sustainability (C2)	The existence of energy, environmental and social sustainability policies in the company positively impacts their commitment and involvement in the sustainable transformation of the projects.	"Project management plan without sustainable principles will fundamentally result in a lack of safeguards to achieve the sustainable development of the MIP."	[6] [9] [14] [15] [17] [23] [27] [28]
	Established sustainable practices/ Peer project participants (C3)	The exchange of knowledge and experiences from peer projects brings positive reinforcement for the project to implement sustainable practices and models. Participation and support from information exchanges on successful models through industrial and government section events.	"Top managers influence the final green innovation choices by learning and comparing the decisions of peers regarding green innovation."	[6] [9] [11] [13] [19] [20] [24] [26] [28] [31] [32]

[1] Caspary (2009); **[2]** Javernick-Will and Levitt (2010); **[3]** Butler (2011); **[4]** Caprar and Neville (2012); **[5]** (Othman, 2013); **[6]** Glover, et al. (2014); **[7]** Brookes and Locatelli (2015); **[8]** Zeng, et al. (2015); **[9]** Dubey, et al. (2017); **[10]** Lin, et al. (2017); **[11]** Hosseini, et al. (2018); **[12]** Li, et al. (2018); **[13]** Misopoulos, et al. (2018); **[14]** Zhang, et al. (2018); **[15]** Alotaibi, et al. (2019); **[16]** Dushenko, et al. (2019); **[17]** Qin, et al. (2019); **[18]** Xie, et al. (2019); **[19]** Yang, et al. (2019); **[20]** Ajibike, et al. (2020); **[21]** He, et al. (2020); **[22]** Jaber and Oftedal (2020); **[23]** Khan, et al. (2020); **[24]** Ma, et al. (2020); **[25]** Mensah, et al. (2020); **[26]** Ullah, et al. (2020); **[27]** Li, et al. (2021); **[28]** Lingegård, et al. (2021); **[29]** Qi, et al. (2021); **[30]** Sidhu and Gibbon (2021); **[31]** Xie, et al. (2021); **[32]** Bamgbade, et al. (2022); **[33]** Ma and Fu (2022).

4.1 REGULATIVE ELEMENTS

Studies have emphasised that regulatory pressure is a significant driver of environmental commitment (Huang and Yang, 2014). Regulative drivers mainly come from formal pressures exerted on organisations by other organisations upon which they are dependent.

They are evident and primarily coercive. For instance, project organisations are under pressure from stakeholders, such as the government, to incorporate social, environmental and economic considerations into their projects through *environmental and social legislative and regulatory mechanisms* (R1) (Xie, et al., 2021). As a result, stimulating project organisations to devote to environmental and social causes (He, et al., 2020). Therefore, it is important that the project organisations and governments make effective and efficient policies and regulation and take appropriate consequent actions to improve sustainability of megaprojects (Ma, et al., 2020). Some of these regulatory mechanisms in the context of India applicable to megaprojects are compiled and shown in Table 3.

Table 2: Environmental and social legislation to address impacts of infrastructure projects in India - compiled from Planning Commission (2007) and Centre for Policy Research (2016)

	Act	**Rules and notifications**	**Organization/ Institution**
1	Environment Protection Act, 1986	EIA notification 2006	MoEFCC/ SEIAA/ DEIAA
		CRZ Notification 2011	State CZMA to MoEFCC/ SEIAA
		Hazardous and other waste rules, 2016	SPCB
		Solid waste management rules, 2016	SPCB/ Local Body
2	Water (Prevention and Control of Pollution) Act, 1974		CPCB/SPCB
3	Air (Prevention and Control of Pollution) Act, 1981		CPCB/SPCB
4	Ground water guidelines, 2015		Authorised officers of notified areas
5	Wildlife Protection Act, 1972		Chief Wildlife Warden/ Wildlife advisory boards
6	Forest Conservation Act, 1980		Regional Office of MoEFCC
7	Land Acquisition Act, 1894		Ministry of Rural Development
8	National Rehabilitation and Resettlement Policy 2007		Ministry of Rural Development
9	Various Labour Laws		Central and State Government.

MoEFCC- *Ministry of Environmental, Forest and Climate Change*; **SEIAA-** *State Environment Impact Assessment Authority*; **DEIAA-** *District Environment Impact Assessment Authority*; **CZMA-** *Coastal Zone Management Authority*; **SPCB-** *State Pollution Control Board*; **CPCB-** *Central Pollution Control Board*.

Furthermore, *legal penalties and incentives* (R2) also serve as drivers for promoting sustainability in megaprojects (He, et al., 2020). For instance, in India, the Ministry of Environment & Forest (2011) has issued a memorandum highlighting that the projects that obtained green building rating under GRIHA, IGBC, including LEED India, shall prioritise environmental clearance. On the other hand, penalty is often used as a routine regulatory strategy to govern poor environmental performance, imposing coercive pressures on organizations (He, et al., 2020).

In addition, Ma and Fu (2022) highlighted that sustainability of megaprojects is mainly dependent on the implementation of contracts. Therefore, *contractual contents* (R3) that highlight environmental protection, occupational health, green construction and other related clauses serve as crucial drivers for sustainability in megaprojects (Sidhu and Gibbon, 2021). Brauch (2017) emphasised the importance of integration of sustainability in infrastructure contracts and highlighted eight approaches to incentivise investment in sustainable infrastructure.

4.2 NORMATIVE ELEMENTS

Normative pressures stem from shared norms within the organisation that are usually informal and latent. Government regulations are not the only driver to practice sustainable management. Self-regulation through obtaining Environmental Management System (EMS) *certification* (N1), such as ISO 14001, has become a clear driver for adopting sustainable management practices. Organisations also attain sustainability compliance by acquiring some of the most tangible, visible and widely adopted approaches, such as voluntary certifications (such as IGBC certification) and eco-labelling (Zhang, et al., 2018) and by GRI or sustainability reporting (Zuo, et al., 2012). These components can also provide source or reference for governments and industry partners to use as they promote targeted industrial standards and regulations (Ma, et al., 2020). In addition, such acts are believed to promote attaining sustainability in projects and enhance the reputation of the organisation and the confidence of the client or end-users (Brooks and Rich, 2016). Having such standards and certification makes the projects more adept at supporting sustainability actions (Thounaojam, et al., 2022).

In addition, *training* (N2) received by the project employees is expected to drive the practices they adopt. Therefore, normative pressure to drive sustainable practices can also be wielded through prescribed training (Lin, et al., 2017). Through systematic training programs and regular meetings associated with sustainable construction and project management practices, project actors can accumulate professional knowledge, build a sense of responsibility toward the environment, and demonstrate their willingness to engage in pro environmental behaviours (Hosseini, et al., 2018; Wang, et al., 2018).

Furthermore, Bamgbade, et al. (2022) accentuated that organisations emphasise sustainability performance because they are obligated to observe specific stringent international- *standardised codes of practice* (N3). Dubey, et al. (2017) also emphasised that these associations can encourage organisations to become more environmentally responsible, and the leading organisations set an example for environmentally and socially responsible conduct. They create environmental standards and mechanisms to ensure environmentally responsible associations in the industry. In addition, *International and national professional associations* (N4), industry-standard bodies and consultants also play an essential role (Caspary, 2009; Butler, 2011). They drive sustainability in projects through standard-setting, awards, training, and regular workshops. In addition, *international or multilateral funding agencies* (N5) are considered "trendsetters on the sustainability front" (Caspary, 2009). They have strict environmental safeguard policies drawn from SDGs, enabling the project to attain sustainability in most aspects.

4.3 CULTURAL-COGNITIVE ELEMENTS

According to Biesenthal, et al. (2018), cultural-cognitive structures have received little attention, and there is a need for looking at megaprojects research from this perspective. Cultural-cognitive elements stem from *sustainability knowledge and competence* (C1) among the employees (Jaber and Oftedal, 2020). Li, et al. (2021) highlighted that the project team exhibits lower sustainable awareness when the professional knowledge of team personnel is not complementary and lacks experience or professional ability. Therefore, specialised sustainability units with competence of specific individuals can help better manage the integration and development of sustainability practices in the project (Lingegård, et al., 2021).

In addition, it is also essential that organisations themselves advocate the importance of sustainability practices and voluntarily measure and disclose their sustainability strategies through the company's *goals and commitments* (C2) (Butler, 2011). Project organisations' willingness to innovate in sustainable models can also drive sustainability in megaprojects (Bamgbade, et al., 2022). Shared vision and organisational culture towards sustainable development goals help promote sustainability in megaprojects (Lingegård, et al., 2021). In addition, organisations also maintain the legitimacy of sustainable practices by *imitating successful strategies of peer projects* (C3) (Li, et al., 2021). In particular, the organisation ascribes its competitor's success to their strategic choices and imitate successful sustainable practices by adopting the same practices. Furthermore, ongoing dialogue and learning between government clients and market actors related to successful and sustainable models or technologies are central for driving long-term change and the development of sustainability in the infrastructure projects (Lingegård, et al., 2021).

5. CONCLUSIONS AND THE WAY FORWARD

This study provides a systematic review of drivers for sustainability in megaprojects, which was lacking in the existing body of knowledge. Using the lens of institutional theory, a deductive analysis of 33 peer-reviewed journals was conducted to identify 11 drivers for sustainability in megaprojects. This review identified three regulative drivers, namely, *environmental and social legislative and regulatory mechanisms*, *incentives and penalties*, and *contractual contents*. Project organisations and governments need to make effective and efficient policies, regulation and contractual clauses and take appropriate consequent actions to improve sustainability of megaprojects. In addition, this study identified five normative drivers, namely, *standards and certifications*, *vocational training and meetings*, *standardised templates and codes*, and *influence from consultants, multilateral and international agencies*. Self-regulation by the project organisations through acquiring international standards and certification can drive the projects more adept at supporting sustainability actions. In addition, training programs and regular meetings associated with sustainable development can accumulate professional knowledge and build a willingness to engage in pro environmental behaviour. Presence of multiple consultants and multi-lateral funding agencies also drive sustainability in megaprojects because of their strict environmental safeguard policies. Furthermore, cultural-cognitive elements that can drive sustainability in MIPs include *sustainability knowledge and competence*, *project company's goals and commitments*, and *learning and comparing decisions of peers* regarding sustainability practices. Professional knowledge along with specialised sustainability units, sustainable goals and commitment from project companies, and mimicking of successful models from peer-projects can drive sustainability in megaprojects.

This study provides valuable insights for improving the understanding of project stakeholders and policymakers' understanding of drivers for sustainability and can help further improve policies, strategies, and norms to support MIPs in contributing to sustainable development goals. This study also imparts project managers the right balance between the three institutional drivers, thus creating a path to promote sustainable culture for addressing sustainable practices in managing megaprojects. In addition, this study lays a solid foundation for researchers to further probe into why some institutional systems drive megaproject sustainability while others are not.

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A REVIEW ON UNEXPLOITED FEATURES OF N-DIMENSIONAL BIM: AN INDIAN CONSTRUCTION SCENARIO

Rhijul Sood[1] and Boeing Laishram[2]

ABSTRACT

Infrastructure sector is a backbone of economic development for most of the countries worldwide. Indian AEC (Architecture, Engineering and Construction) industry is one of the leading sectors in terms of Gross Domestic Product (GDP) and employment. With the increasing demand for infrastructure and continuous development in field of technology, the speed of construction has been improved in various countries. But most of the projects still face the issues of cost and time overruns due to un-exploitation of digital tools and technology. Building Information Modeling (BIM) is one such promising technology that spans several levels of maturity (Level 0, 1, 2, and 3) and dimensions (3D, 4D, 5D, 6D and 7D). Many studies have shown that the construction industry is still lagging behind the rate with which technology should have been adapted, particularly in developing countries including India. This paper, therefore aims to answer systematically about various dimensions and level of maturity and its current status in Indian construction industry and the key factors responsible for un-exploitation of BIM's features due to low maturity. Finally, the paper presented some future research agendas. The study's findings may be of significant value to the practitioners and policy-makers in incorporating mandatory BIM based framework for Indian construction industry and also in other developing nations.

Keywords: *AEC; BIM; Dimensions; India; Level of Maturity.*

1. INTRODUCTION

Infrastructure is generally referred to all physical assets, equipment, and facilities of interconnected systems, as well as the key service providers who deliver linked commodities and services to the general public with the objective of enabling, sustaining, or improving social living circumstances (Weber, et al. 2016). Infrastructure that is of high quality not only attracts new investment and allows existing enterprises to expand for long-term economic growth, but it also improves people's living standards by easing access to crucial health and safety supplies. Projects under construction typically experience a high level of uncertainty at various stages of construction, resulting in an increase in risk in terms of construction cost estimates, handover delays, and poor project quality. Notably, since the outbreak of the pandemic of COVID-19, numerous construction enterprises have attempted to implement innovative techniques to accelerate production recovery and enhance the ability to cope with the crisis. The construction

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industry has moved from a 2D to a 3D environment, and then from a 3D to a design environment using building information modeling (BIM) to boost productivity. BIM is one such technology that spans several levels of maturity (Level 0, 1, 2, and 3) and dimensions (2D, 3D, 4D, 5D, 6D and 7D). BIM is a generic word that refers to the process of digitally producing, representing, and managing buildings and related information using modern 3D computer-aided design software (CAD) (Ikediashi and Uyanga, 2016). BIM helps in applying and maintaining an integral digital representation of all building information for different phases of a project lifecycle (Gu and London, 2010). This is only possible by utilizing various dimensions of BIM. The models created using BIM are used not only to design the building geometry, but also to include information that allows for various types of analysis to be undertaken (structural, schedule, cost estimate, energy analysis) (Kota, et al., 2014). It facilitates in the decision making process of an asset throughout its lifecycle, i.e., from conception till demolition (Won, et al., 2013).

As a result, BIM can be thought of as a collection of software applications with distinct characteristics that are linked together to improve infrastructure design, visualization, operation, and management. BIM has been used to replace traditional computer-aided design and drawing (CADD) for a wide range of infrastructure design and development projects since the early twenty-first century (Lin, et al, 2021). Despite the fact that it is still called "Building Information Modelling", it is increasingly being thought of as a service rather than a software solution or a single product (Isikdag, 2012). The emergence and evolution of the concept of BIM has resulted in the development of a technology platform for exchanging technical information at all stages of construction, as well as enhanced data collection, transmission, and feedback management (Akcamete, et al., 2010). Another benefit of BIM is that data may be prepared once and reused many times, resulting in fewer errors, increased uniformity, clarity, and clear authorship responsibilities (Kelly, et al., 2013). Even though there are many advantages of using BIM in construction but the acceptance and implementation rate is very slow. Each of the BIM dimension has its own characteristics and advantages which are discussed in subsequent sections. Most of the projects worldwide still face the issues of cost and time overruns due to un-exploitation of digital tools and technology. Apart from the United Kingdom (UK) and the United States of America (USA), which have seen increased acceptance and implementation of BIM, the majority of other countries including India are still lagging behind

The current study therefore aims to shed some light on the existing body of knowledge in BIM by studying the research in employing BIM for infrastructure construction industry in India and the key factors responsible for not exploiting the technology in India. In addition, the study aims to provide information on current research trends and identify future research agendas.

The paper is organized as follows in this regard. Firstly, the paper describes the methodology of the systematic review. Secondly, it summarizes the findings of descriptive and content analysis. The study discusses various dimensions and level of maturity of BIM along-with understanding the maturity stage reached in India, what are the unexploited features that still needs to be exploited by Indian construction stakeholders (Clients, Contractors, Engineers, Architects, etc.). In the end, the study summarizes the list of key factors for such trends in India and conclusions are presented with a pathway to future agenda.

2. METHODOLOGY

The current study's research approach was based on a comprehensive review of existing literature. This is due to the fact that systematic review is an important scientific study strategy that can be utilized to assess, synthesize, and communicate the findings and consequences of a large number of research publications on a certain issue (Green, 2005), as has previously been done in various research works. The definition, refining, and evaluation of raw data are all required processes in the data collection process. To retrieve the correct data set for the study, the collected data sets must be articulately stated using the query string. The data must be refined using the relevant parameters, which include, among other things, the year, country, and type of publishing (depending on the study objective). Following that, the data is evaluated to ensure that the information obtained meets all of the search criteria. The process for the review was divided into three stages, as discussed below.

2.1 PLANNING THE REVIEW

The first stage is to define the research problem and then formulate it. This was followed by a SCOPUS database literature search to identify the papers to be included in the review. The database was chosen for its breadth of coverage, as it includes the bulk of peer-reviewed journals in project management and megaprojects (de Araújo, et al, 2017) (Zhou and Mi, 2017). Before beginning a database search, it is critical to identify a list of keywords and other relevant terms connected to the study subject. As a result, the search was conducted using building blocks, which is one of the most commonly utilized search strategies among literature reviewers (Booth, 2008). As a result, the research topic/ problem is divided into discrete phrases that are linked together using Boolean operators such as "AND" and "OR". The terms *"BIM, Building Information Modeling, India*" have been discovered to be relevant to the current study problem. These probable phrases were discovered through a combination of snowballing and trial-and-error searching.

2.2 CONDUCTING THE REVIEW

Following the definition of keywords in the preceding section, the subsequent stage entails searching for and selecting relevant papers, which also comprises of 3 steps. The first step was to conduct a keyword search in SCOPUS. The initial publication date for the research publications was not provided so that a comprehensive collection of papers could be compiled. The list of papers to December 2021 was covered, yielding a total of 485 publications. Only English language publications were retained, and duplicate papers were also eliminated, reducing the list to 126 papers. In the second step, titles and abstracts of publications were critically evaluated based on pre-defined filtering and selection criteria in the databases.

The criteria involved the inclusion and rejection of publications, which included: (a) studies that focused on BIM other than Building Information Modeling, (b) articles that did not focus on the Indian construction sector, were excluded. Following this regressive screening, 61 papers were chosen for further consideration. After exporting the previously filtered articles, a full-text manual analysis was undertaken in the third phase, and a list of 40 papers was determined for the systematic review analysis, as stated in later sections of this paper (refer to Figure 1).

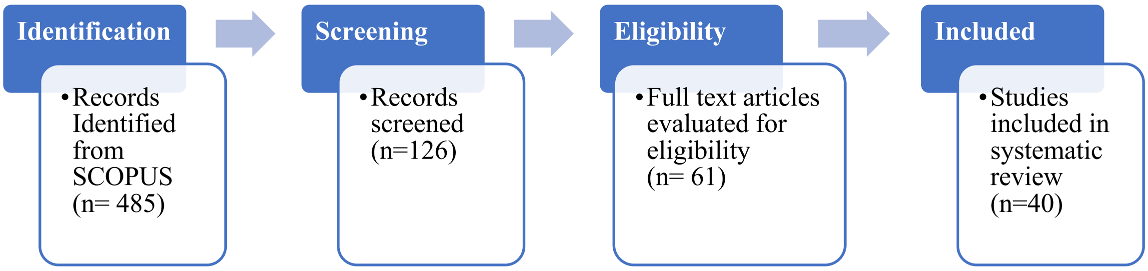

Figure 1: Flow diagram of selection of studies for systematic review of published research

2.3 ANALYZING AND REPORTING REVIEW

At this stage, a descriptive analysis of the papers was carried out in order to provide year-specific and infrastructure sector-specific publications. In the following section, charts and tables are used to illustrate these findings. Inductive content analysis was also performed to categorise the various stages of construction and how BIM is utilised throughout the many lifespan stages of an infrastructure project, as well as distinct levels of maturity. Each document was read several times back and forth in order to extract and group codes, and then categorise them.

3. ANALYSIS AND RESULTS

3.1 DESCRIPTIVE ANALYSIS

As shown in Figure 2, the descriptive analysis includes the publication distributions in various years beginning in 2006. The number of publications was limited in the beginning since digital technology in infrastructure operations and maintenance was still in its infancy considering Indian construction sector. However, as technology advances, the frequency of publications has grown as well. The list of articles is also divided into fields where the majority of the research has been conducted (refer Figure 3). Highways and bridges are regarded as the most vital infrastructure assets, and significant case studies are based on them. As can be observed, following 2016, there was a significant increase of publications, suggesting the usage and more research on BIM technology in Indian construction industry.

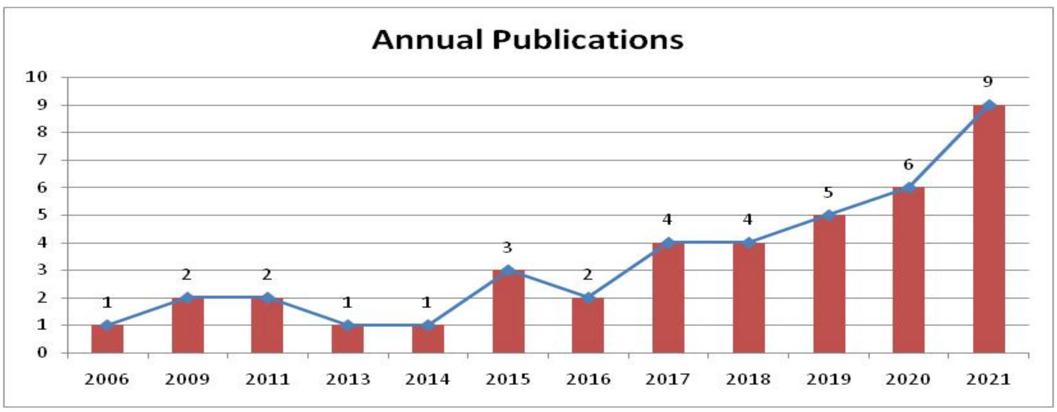

Figure 2: List of annual publications

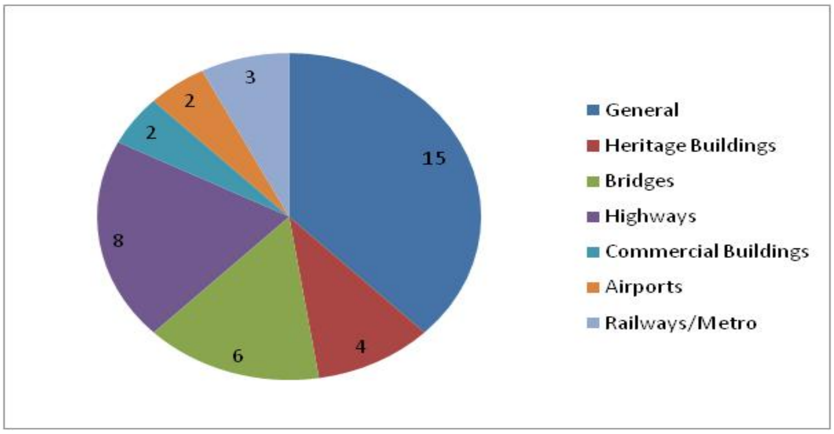

Figure 3: Sector wise distribution of papers

3.2 CONTENT ANALYSIS

The conclusions of the content analysis are presented in this section, which includes the evaluation of all research publications. Section 3.2.1 covers the benefits of various BIM dimensions along with the level of maturity of BIM while Section 3.2.2 highlights the current level of BIM implementation in India along with the key factors that affects high maturity level BIM implementation in the Indian construction industry.

3.2.1 BIM Dimensions

BIM is more than just creating a 3D model of a structure. It also entails adding information about the phases of design, construction, and maintenance. BIM dimensions are defined as the additions of pre-specified used cases to existing models. BIM dimensions includes 3D, 4D, 5D, 6D, and even 7D so as to improve the data connected with the model and allowing for a better understanding of the construction project to be shared. In fact, supplementing data with other information allows the stakeholders to learn how the project will be delivered, how much it will cost, and how it should be maintained. Specific parameters are added to the existing information in BIM, based on project stage needs and project complexity.

3D BIM: Visualization Phase

As we all know, 3D symbolizes the three geographical dimensions (x, y, and z) of a building construction. These dimensions include geometrical and graphical information of the components designed. Even before the project begins, stakeholders can visualize the construction of a building in three dimensions because to geographical capabilities. 3D BIM enables all stakeholders to successfully collaborate for modeling and solving fundamental structural problems. Furthermore, because everything is saved in a centralized area, namely the BIM model, it becomes easier to fix concerns at a later time. Some of the benefits of 3D BIM include improved visualization, streamlined communications, simplified collaborations between multiple teams (civil, mechanical, electrical, and plumbing), clash detection, and reduced instances of rework and revisions due to complete transparency from project's beginning.

4D BIM: Time Phase

4D BIM is the integration of the 'TIME' element to a simple 3D BIM model. Scheduling data aids in determining how much time will be required to complete the project and how the project will grow over time. The data can provide elaboration on the time required for installation or construction, the time required to complete the project, the sequence of installation of various components, and other scheduling information. The advantages of 4D BIM include improved site planning and scheduling efficiency, streamlined coordination among architects, contractors, and on-site teams, improved information sharing regarding project timelines, obtaining accurate project visualizations, and anticipating potential schedule delays.

5D BIM: Quantity and Cost Phase

5D creates a project using a simple 3D geometry and adding the 'COST' element to it. This enables participants to visualize the progress of their actions as well as estimate the overall costs associated with it, resulting in increased accuracy and feasibility of any given project. 5D BIM is useful when budget analysis and cost estimation are necessary right from the start of a project. It helps project promoters and owners to assess the expenditures that will be incurred in the course of the project's activities over time. It offers numerous benefits, including real-time cost visualization with notification of changes in costs, simplified cost analysis and budgetary analysis with predicted and actual spends over time, minimization of budgetary offshoot due to regular cost reporting and budgeting, and the ability to analyze cost and time overruns using earned value analysis.

6D BIM: Sustainability and Energy Analysis Phase

6D BIM aids in the analysis of a building's energy consumption and the generation of energy estimates during the early stages of design. Analyzing energy performance early in the design process allows the designer to choose the best technological solutions for lowering energy consumption, improving quality, and ensuring the project's long-term viability. This method aids in determining the total cost of an asset and how money should be spent to achieve long-term sustainability and cost-effectiveness. 6D BIM is also referred to as integrated BIM since it includes detailed information that can aid facility management and operations in the future. Reduced long-term energy consumption, complete study and impact of a decision on economic and operational aspects over the whole lifecycle (Life cycle analysis), and better operational management of the building or structure after handover are just a few of the benefits.

7D BIM: Operations and Maintenance Phase

7D BIM is a novel concept in which all information about the facility/asset management process is gathered in one location within the model. Building managers and owners use 7D BIM to manage operations and facilities. This dimension is used to keep track of key asset data, such as its status, maintenance/operation manuals, warranty information, technical specs, and so on, for later use. The primary benefits of 7D BIM include improved asset and facility management from design to demolition, simpler and easy replacement of parts and repairs at any time during the life of a structure, and a streamlined maintenance process for contractors and subcontractors.

BIM is utilized in a variety of ways in various nations, depending on the type of project and the level of maturity. BIM maturity levels range from 0 to 3, as indicated in Figure 4. Level 0 BIM shows a lack of collaboration. Working with 2D CAD designs demonstrates Level 0 BIM. Level 1 BIM is demonstrated by using 3D CAD for concept work but 2D for drafting production data and other documents. Level 2 BIM encourages collaboration among all parties involved in building projects. Level 2 makes use of 3D CAD or software models, and information about the design of a built environment is exchanged among the parties involved using a common file format. As a result, it can save time and money, as well as eliminate the need for rework (Lat, et al., 2021) .

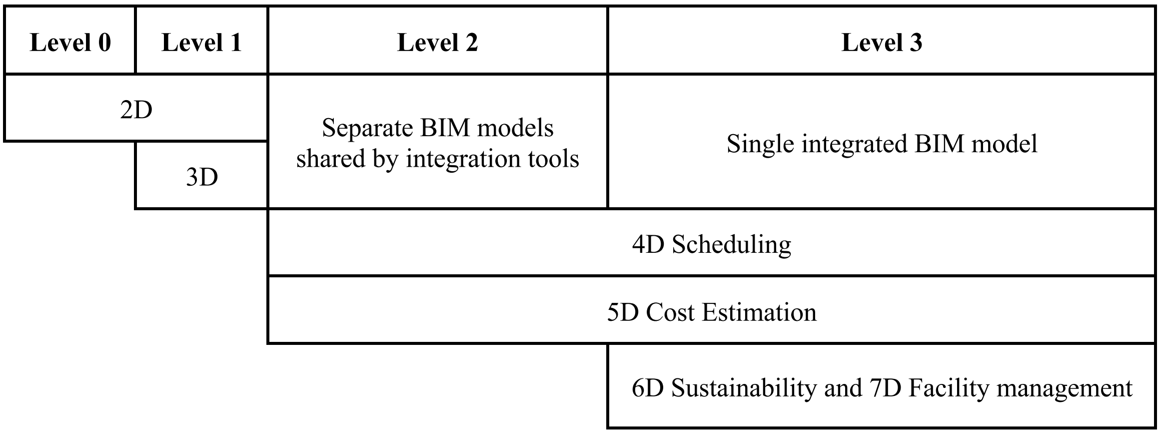

Figure 4: Level of development of BIM maturity

3.2.2 BIM in India

The AEC industry is the largest in the world, and it is the second largest employer in India after agriculture, contributing significantly to the country's GDP (Charlesraj and Dinesh, 2020). India is a developing country that necessitates the construction of all forms of infrastructure. With the COVID-19 problem putting an unprecedented toll on the country's economic activities, significantly increased infrastructure investment is necessary for recovering the country's growth (Wang and Tian, 2020). BIM technology acceptance in the construction sector has lately expanded, with the UK, the USA, and other countries, such as Finland and Norway, displaying a high level of adoption and implementation(Adekunle, et al., 2021). Like UK, USA and all other developed countries the Indian government does not take an initiative to encourage the practice of BIM in the AEC industry (Ahuja, et al., 2020). In India, however, BIM has yet to gain widespread acceptance among building professionals (architects to contractors).

Despite being new to the Indian construction scenario, BIM has shown strong acceptance potential here but implementation rate is very low. India has a booming market for large-scale residential and commercial development. The real estate industry has skilled, trained, and experienced BIM professionals who are using this technology, however in comparison to the worldwide scenario; the proportion of acceptance is not as high. Evidence from literature reveals that developing countries struggle with BIM adoption. Furthermore, the percentage of BIM acceptance differs widely, with India ranking among the lowest, with only 10-18% BIM adoption compared to 71% BIM users in the USA alone (Sawhney, 2014). In India, BIM is most commonly used for visualization, i.e. for 3D modeling and brief client presentations, followed by concept design and asset management (Mohanta and Das, 2022), implying that BIM’s maturity level in the Indian construction sector is at the early stages of Level 2.

The key factors for low level of maturity of BIM in Indian construction industry are studied by many researchers among which the most common includes: lack of defined/contractual guidelines and regulations/BIM standards (Azhar, 2011; Kassem, et al., 2013; Naghshbandi, 2016), lack of BIM Knowledge/Expertise (Gu and London, 2010; Kassem, et al., 2013; Ramilo and Embi, 2014; McArthur, 2015), complexity of BIM tools (Kassem, et al., 2013; Mahalingam, et al., 2015; Ahuja, et al., 2020), resistance for new technology (Azhar, 2011; Naghshbandi, 2016; Sreelakshmi, et al., 2017; T. Patel, et al., 2021), lack of support from owners and other trade partners (Azhar, 2011; Kassem, et al., 2013; Sawhney, 2014; R. P. Patel, et al., 2021), interoperability issues among various BIM Tools (Kassem, et al., 2013; Jagadeesh and Jagadisan, 2019; Ahuja, et al., 2020; Mehedi and Shochchho, 2021; R. P. Patel, et al., 2021), high cost of Implementation (Azhar, 2011; Kassem, et al., 2013; Ramilo and Embi, 2014; R. P. Patel, et al., 2021), low awareness of BIM benefits, risks involved in implementing BIM, doubts about Return on investment (ROI) (Sreelakshmi, et al., 2017; Isac and Anoop, 2019; Ahuja, et al., 2020; Charlesraj and Dinesh, 2020), mindset of construction stakeholders, lack of demand from the client side and insufficient government support (Ramilo and Embi, 2014; Charlesraj and Dinesh, 2020; T. Patel, et al., 2021). These factors can be broadly categorized among several groups such as technical, cost related, managerial, organization culture and others.

4. DISCUSSION

The preceding sections mostly demonstrated the application of BIM in the Indian AEC industry. It also highlights the un-exploited dimensions, levels of maturity of BIM in the Indian sector, as well as the challenges that construction owners and other various stakeholders face while using BIM. Some research gaps have been found in order to help this industry handle the two main difficulties of cost and time overruns by correctly integrating digital technologies such as BIM in all phases of an asset's lifecycle procedures. The COVID-19 event should be viewed as an opportunity rather than a threat by stakeholders seeking to maximise the use of BIM software, particularly the higher dimensions specified in the paper. Overall, the study contributes to a complete and systematic analysis of the demand for BIM in the construction sector, as well as the need for further research on integration with lean management tools and practises.

5. FUTURE RESEARCH AGENDAS

The observations from the current shows some future research areas in the current domain of maturity of BIM and need to enhance the implementation of BIM in Indian construction sector. The analysis of research methods shows that the majority of study in this domain is done on basis of surveys and lacks real world cases on BIM application (Becerik-Gerber, et al., 2012).

Secondly, there is lack of study on the way how COVID-19 has brought the change in the working of AEC industry people. The impact of this pandemic was worldwide and construction being one of the labor- intensive industry with slow technology adapter was impacted the most.

Thirdly, there have been discussions about new dimensions of BIM such as 8D, 9D and 10D which corresponds to safety management, lean management and construction industrialization respectively. These dimensions are still at the initial stage of development and not been mentioned or researched upon yet. But, there have been mention about the integration of lean tools with BIM but the study is very rare (Sood and Laishram, 2021).

Hence, the current study would be helpful to develop new frameworks and methodologies that take a multidisciplinary approach, such as integrating social science theories to analyze the interdependencies of institutions and factors affecting higher level BIM implementation in India. Such studies can help policy-makers understand the key effective institutional structures or strategies to strengthen the Indian construction industry (Favari and Cantoni, 2020).

6. CONCLUSION

According to the current study, the infrastructure construction sector is continually evolving, delivering worldwide economic development as well as continuous improvement through the use of technology at various stages of an infrastructure asset's life cycle. However, digital technology such as BIM is still not extensively adopted in the Indian AEC business. There are numerous fundamental issues associated with the employment of technology and are discussed briefly. However, a comprehensive analysis of the research contribution is required to provide an overview of the issues faced by stakeholders in the efficient use of BIM. In this context, the purpose of this study was to comprehensively investigate existing research on BIM, its different dimensions, and its level of maturity in the Indian setting. The literature search was performed in SCOPUS database. The study adopted a three-step methodology including title analysis, abstract analysis, and full text analysis for filtering and finalising 40 articles for final review. The articles were organised by year of publications and infrastructure sectors.

There has been very less study in understanding the implementation of higher dimension/ maturity level of BIM in India due to less case studies. The COVID-19 outbreak has served as a catalyst for informing stakeholders about the significance of using more technology-based tools and approaches, as well as allowing researchers to gain insight into its impact, particularly the potential gains. By building and examining frameworks through Indian construction case studies, the research paves the way for future research into the usage of lean approaches that have applications in effective BIM utilisation.

Overall, the review provides a comprehensive and systematic review of various dimensions and maturity level of BIM, implementation of BIM in Indian construction scenario as well as the key factors which are responsible for such low implementation. The results obtained contributes to the study of knowledge of BIM in India. Nevertheless, some limitations are present in the review but the practitioners and policy makers in field of Digital construction in India can prepare a future road map for Indian construction based on this study.

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A STUDY OF LIQUID WASTE MANAGEMENT PRACTICES IN CONSTRUCTION PROJECTS IN AUSTRALIA

Shiyamini Ratnasabapathy[1], Srinath Perera[2] and Mary Hardie[3]

ABSTRACT

The construction industry is increasingly under pressure to improve environmental performance and reduce environmental degradation, which often results from carbon emissions and a high volume of waste generated from unprecedented levels of development associated with urbanisation and industrialisation. Construction projects consume a significant amount of water at the same time; they generate liquid waste (LW) from several wet processes during construction on-site, which is often unmetered. At the same time, LW or wastewater generated from construction projects is detrimental to the environment and human health, adversely polluting the surface and groundwater as well as the ground soil. It is, therefore, indispensable to manage LW appropriately while utilising the water efficiently. Limited studies have paid attention to explore the importance of effective liquid waste management (LWM) practices in construction projects and their implications on environmental sustainability. This study aimed to investigate the current practices of LWM in construction projects through the analysis of expert user views and quantitative data analysis while providing an account of LWM related legislative requirements. Moreover, this study estimated the average volume of water consumed for tool washing and water saving for different types of projects and compared it against the use of sustainable LWM systems, notably a closed-loop washout system employed in construction projects. The outcome of this study has the potential to add new and under-measured factors to the current LWM systems and to promote sustainable LWM practices in construction projects. While it highlights issues related to LWM, it provides criteria that can be considered for the green rating of buildings.

Keywords: *Construction Projects; Closed Loop System; Liquid Waste Management; Trade Wastewater; Water Usage and Saving.*

1. INTRODUCTION

The construction industry is increasingly concerned with improving its environmental performance and reducing environmental destruction, which often results from unprecedented levels of rapid development in the sector. The depletion of natural resources, increased global warming and pollution are stimulating the construction industry to pay more attention and be responsive to the issues related to environmental, social and economic sustainability (Park and Tucker, 2017). As such, the future reputation of the industry depends on the careful and responsible use of finite resources as well as how well the industry addresses and responds to the potential unintended damage made

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to the natural environment. The main resources from the natural environment, which are considered as the inputs for sustainable management practices as well as the environmental performance assessment of a construction project include water, fossil fuels and land consumption (Xing, et al., 2009).

Being a water-intensive industry, water becomes a key resource component in any construction project due to the diverse nature of the typology of buildings, involving several wet trades and processes associated with the application of different construction materials and technologies (Nový, et al., 2019). While a large volume of water (technological water) is consumed for production, a considerable amount of liquid waste (LW)/wastewater (resulting from operational water) is generated from construction sites. The sources of which generally include construction runoff, stormwater/groundwater collected on-site, spray water from dust suppression, wastewater generated from cleaning of heavy equipment/vehicles and some construction activities, such as airlifting processes of bored piling (Wong, 2002; Nový, et al., 2019). At the same time, LW generated from various processes needs to be properly managed either on-site or off-site as it may contain toxic substances or gases and hazardous solid materials which are harmful to the environment and human health and have a high potential to pollute the groundwater and the ground soil (Wong, 2002). The concentration of suspended solids in LW generated from cleaning of equipment/vehicles and tool washing varies with the construction process and is one of the major pollutants to the environment (Fan, et al., 2013).

The solids in LW also can cause blockages, resulting in overflows and strong odours released to the environment and problems in downstream wastewater treatment plants as well (CleanaWater, 2020, Icon Water, 2020). Subsequently, it will result in heavy fines for construction companies and affect the progress of construction activities (Wong, 2002). Therefore, each construction site requires proper on-site washing out facilities to treat LW/wastewater appropriately before it is discharged. Some past research studies have focused on water efficiency during the construction stage and captured various measures to improve the efficiency of water use during the operational stage of a building (Carragher, et al., 2012) and water-saving measures in different phases of a construction project (Wu, et al., 2020). Limited studies have paid attention to the necessity of appropriate liquid waste management (LWM) practices in the construction sector. The construction sites have a high potential to achieve water savings by improving the efficiency of operational water use during the construction stage (Waidyasekara, et al., 2016). However, water saving by enhancing on-site washout facilities has received less attention among academics and practitioners. There are knowledge gaps around the amount of water consumed for the washing and cleaning processes on-site during the construction stage. In particular, the benefits of using proper and sustainable LWM systems are under-recognised and rarely studied. This study is an attempt to investigate the current status of LWM practices in construction projects in Australia through the following set objectives:

- To identify the legal obligations and regulations related to on-site LWM for the construction projects;
- To identify the sources of LW generated from construction projects;
- To identify the current management methods practised on-site and possible pathways of managing LW on-site;
- To evaluate the volume of water used for the tools washing process on-site;

- To estimate the volume of water-saving when personalised washout systems are implemented on-site for LWM and
- To identify barriers for implementing effective LWM practices/systems on-site.

2. LITERATURE REVIEW

2.1 POSITIONING LIQUID WASTE IN THE CONSTRUCTION SECTOR

An appropriate definition of LW is important to provide a consistent means to determine whether LW generated on-site is suitable for treatment and disposal at landfill sites or into public sewerage networks. According to Environmental Protection Authority, New South Wales - EPA NSW (2014), waste is classified as LW (with no requirement for further assessment for classification), if the waste (other than special waste) meets the following criteria: (1) has an angle of repose of less than 5 degrees above horizontal; (2) becomes free-flowing at or below 60 degrees Celsius or when it is transported; (3) is generally not capable of being picked up by a spade or shovel and (4) is classified as LW under an EPA gazettal notice. In Australia, LW is divided into three main streams: sewage, trade waste, and hazardous liquid waste (Randell, 2012). The waste classification system in Australia varies across jurisdictions and there are considerable inconsistencies in the classification and definition of waste across the states and territories. However, LW classifications and definitions for sewage and trade waste were found to be reasonably consistent at the national level. At the same time, trade waste has not been included as an LW stream for the construction sector consistently across the jurisdictions. Despite, the fact that construction falls under the industrial sector, LW generated by this sector has not been included either under the category of industrial trade wastewater or commercial trade wastewater in NSW. As such, there is no waste category available to include LW/wastewater generated particularly from construction activities. However, wastewater generated by building and construction activities has been classified as ‘Liquid trade Waste’ in the Australian Capital Territory (ACT) (Icon Water, 2020). According to Liquid Trade Waste Regulation Guidelines 2009 (NSW Office of Water), liquid trade waste includes all LW other than sewage of a domestic nature.

Besides, some basic construction materials such as cement, stone and abrasives have been included under the category of discharging industrial trade wastewater. Similarly, some of the processes associated with the construction developments (which include medium/high-density developments, mixed developments, commercial and industrial developments) have been included as the ‘deemed process’ for the requirements to meet pre-treatment, backflow prevention and other requirements under the category of commercial trade wastewater in NSW. Those deemed processes include slab formation (no discharge from this process to the sewer is allowed) and wash water generated by the washing of painting and plastering tools such as brushes, trays and spatulas (Sydney Water, 2020). Considering the requirement for approval to discharge the trade wastewater as a deemed process, wastewater generated during the construction stage can be included under the category of ‘Commercial Trade Waste’ as the construction industry falls under the category of secondary manufacturing industries. However, the construction industry is one of the industries, which largely fails to recognise that the industry is responsible for managing LW to comply with the relevant legislation (Perera, et al., 2021).

2.2 LEGAL REQUIREMENTS FOR LIQUID WASTE/WASTEWATER DISCHARGE FROM THE CONSTRUCTION SECTOR

Many developed countries have established local and national regulations that define the quality of the water that is permitted to discharge into the public sewer. Those regulations set some limitations for the values of some of the properties of water such as suspended solids (SS), acidity (pH), biological oxygen demand (BOD) and chemical oxygen demand (COD) (Nihon Kasetsu Corporation, 2020). According to the Environment Protection (Water Quality) Policy 2015, South Australia (SA) and hence by law, certain types of pollutants that are likely to be generated from the building and construction industry should not be discharged into the stormwater system from any construction sites. The Code of Practice for the Building and Construction Industry (SA) strongly recommends that all construction sites need to follow erosion, sediment and drainage control management practices at sites. Such practices are required to ensure the pollutants do not enter the stormwater system and the construction sites fulfil the legal obligations and general environmental duties related to the Water Quality Policy. In order to comply with these water quality-related regulations, most jurisdictions require pre-treatment and approvals from relevant authorities prior to the discharge of trade waste to the sewerage network. Pre-treatment is the process of treating trade wastewater appropriately using suitable items of equipment before discharging it to the sewer.

The review found that not all the EPAs across the nation have inclusions in the trade waste related aspects that are specifically associated with construction activities. EPAs of Victoria (VIC), Queensland (QLD) and SA and the Department of Water & Energy of NSW Government have only addressed some of the legal requirements, procedures and guidelines relevant to sediment control and discharge of contaminated water from construction sites. The review of legal requirements, policies and guidelines revealed that not all the jurisdictions have established regulations related to stormwater water pollution prevention and approval for the discharge of trade wastewater generated particularly from construction sites. While the LW classification system in Australia varies across jurisdictions, there are considerable inconsistencies in regulations related to LW generated from the construction sector across the states and territories. However, general requirements and guidelines have been established for all the businesses and/or other industries that intend to install a wash down area connecting to the sewer. The construction industry is one of kind to follow those general requirements and guidelines as there has been a lack of specific requirements and guidelines established for the construction industry and those need to be consistent across the jurisdictions.

3. RESEARCH METHODOLOGY

This research primarily employed a mixed-method approach comprising quantitative and qualitative methods of data collection and analysis to achieve its objectives. The approach combines a comprehensive literature review, expert interviews with industry professionals; a review of LWM related documents and a quantitative analysis of raw data. Initially, a comprehensive literature review was carried out to understand the definition of LW/wastewater, the main sources of LW, and the classification and characteristics of LW in general. The review also assisted to find the key LWM pathways, guidance for LWM and relevant regulations/legislation stipulated for LWM across the different states and territories in Australia and currently practised in the construction industry.

Following the literature review, three semi-structured interviews were conducted with industry professionals to identify and understand the current LWM practices in construction projects. The purposive sampling method was used to select the interviewees for the interviews by targeting professionals based on their knowledge, experience and involvement with a minimum of five years of experience in on-site construction project management. The purposive sampling method is considered appropriate for this type of study related to LWM, to which a limited number of experts, who can contribute to the study are available as the primary data sources (Dudovskiy, 2022). The interviewees included top-level managers with more than 20 years of industry experience in project management and represented their working experience in different types of construction projects. The profile of the participants who were interviewed for this study is presented in Table 1.

Table 1: Profile of the interview participants

Interviewee Code	Experience (years)	Position	Size of the Organization
IW 1	20	Director	Medium
IW 2	28	Project Manager	Large
IW 3	30	Construction Manager	Large

The interview participants were asked to provide their opinion and comments on the current status of LWM practices followed in construction projects. The interviews, which were semi-structured with some guide questions mainly focused on identifying the main sources of LW, on-site LWM practices/procedures, pre-treatment requirements, regulations established for managing LW on-site and the barriers for implementing proper on-site LWM services. Qualitative data collected through the interviews were analysed using content analysis methods and the analysed data were used to assess the current status of LW/wastewater management practices and related issues.

The quantitative data were collected from an organisation that provides a fully automated closed-loop washout solution for construction and maintenance sites that require on-site washout facilities for wet trades. The organisation uses a stand-alone, mobile system (hereinafter named Washbox) that does not consume water from the water main, hence requiring no plumbing connections and discharging wastewater into the main sewer/stormwater drain after tool washing. As a closed-loop system, it processes and recycles the wastewater (including the required treatment) once the tank is filled and thus wastage of water is kept very minimal. Possible water wastage is expected from the process of evaporation and spillages only. Solids from LW are allowed to settle at the bottom of the tank after the wastewater is stirred and it is then extracted and sent to the solid waste recycling facility. No shovel is required to remove the solid waste as used in traditional washing facilities, which use either a drum or plastic wheelie bins for tools washing. Figure 1 illustrates a typical Washbox system used for tools washing on-site. The Washbox system was selected because of its specific features that provide a holistic washout solution for on-site tools washing.

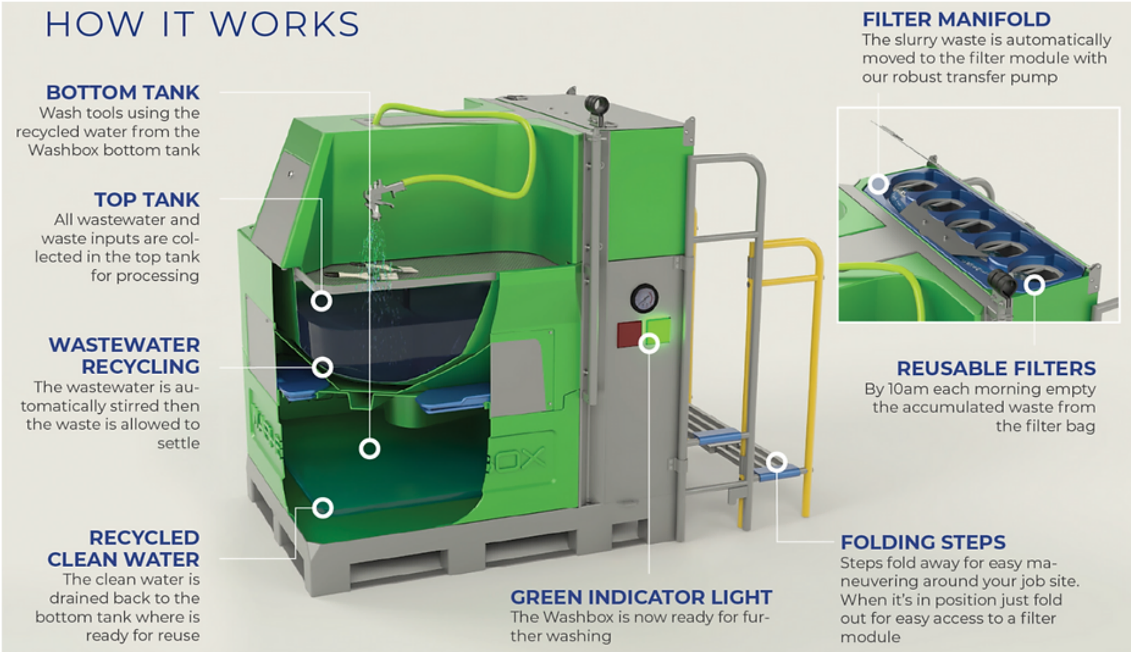

Figure 1: Structure and functioning of a closed-loop Washbox system

Source: Washbox (2022)

Altogether, data from 29 projects, which employed Washbox system for tool washing were considered for the final analysis. These projects were categorised into 8 groups based on their functions. Raw data collected for the analysis include the gross floor area (GFA) of the projects, the volume of water usage when the Washbox is used for tool washing and the volume of water from the water main during the time the Washbox system was functioning on-site. These figures were then used to estimate several data points related to the study such as possible water usage if Washbox system was not used on-site. It enabled the calculation of the possible volume of water savings that can be achieved in tool washing with the use of Washbox system for different types of projects handled by different sizes of builders/developers. GFA of the projects was used to calculate the water usage per square meter of a building for cross-comparison purposes. The following formula (Eq. 01) was used to estimate the water saving by the closed-loop Washbox system.

$$\textit{Total water saving} = M - T \qquad (Eq.\ 01)$$

$$M = (T / f) * F$$

Where, T - Total water usage when Washbox is used

M - Total water usage when Washbox is not used

F - The average flow rate of the water mains (20 litre/minute)

f - The flow rate of the nozzles of the Washbox system (4.7 litre/minute)

The flow rates of the water main and the Washbox system were collected from the organisation, which provided the washout facilities. It should be noted that due to limitations in data availability for different types of projects, it is difficult to generalise the conclusions. As such, the analysis provided is indicative and preliminary. The following section summarises the analysis of the expert interviews and the data collected from the Washbox system.

4. FINDINGS AND DISCUSSIONS

This section summarises the findings from interviews and analysis of the water usage and water saving in different types of construction projects using the data collected from a series of projects where the closed-loop Washbox system was employed on-site by large and medium-sized builders. It is worth mentioning that all project types except Defence projects have used alternative LWM methods in addition to Washbox system. As such, water usage and saving per m² data may not be accurate. Still, the single data point reflecting a Defence project exclusively used Washbox system as the method of LWM on site.

4.1 LIQUID WASTE MANAGEMENT PRACTICES: ANALYSIS OF USER VIEWS

This section presents the findings from interviews, particularly the current status of the LWM practices in the construction sector based on the views of top-level industry professionals and project-related document reviews. The interview analysis highlighted some important aspects of LWM that could help to reveal the under-measured factors, and inefficiency in legislation and act as indicators for measuring environmental performance. These aspects are briefly discussed with some high points with the reference to the interviewees' code.

Planning for LWM: Planning for managing LW on-site is not specifically considered at the development application stage of a project and planning is carried out during the construction stage only (IW2, IW3). Hence, there is generally no separate section included for LWM either in the general Waste Management Plan (WMP), Environment Management Plan (EMP) or Construction Environment Management Plan (CEMP) unless it is specified as a client's requirement in the conditions of the contract (IW1, IW2, IW3).

Sources of LW: Table 2 presents the sources of LW identified from the interview. The Washbox system has been mostly employed for tool washing for some trades that generated LW mixed with chemicals, powders, dyes and solids from tool washing, in the middle or latter part of the construction phase.

Table 2: Sources of liquid waste generated from construction projects

Trades	Source/Activity	Interview Code
Excavation	Sediment slurry runoff from rock excavation/piling, cleaning and cooling of machinery by water after or while operating	IW2, IW3
Concreting	Classic concrete washout, curing of concrete elements, cooling concrete cutting and machines	IW1, IW2, IW3
Painting/staining	Washing of tools such as brushes, rollers, trays, tins, etc.	IW1, IW2, IW3
Tiling	Washing tools used for grouting, bedding	IW1, IW2, IW3
Rendering/plastering	Washing tools used for mixing materials and rendering	IW1, IW2, IW3
Plasterboard-gyprock	Washing tools used for joining	IW1, IW2, IW3

Trades	Source/Activity	Interview Code
Brickwork/blockwork	Washing tools used for bonding and cleaning - acid washing	IW1, IW2, IW3
Others	Runoff from hydraulic and mechanical sprinklers during testing	IW2, IW3

LWM Methods and Data Reporting: Managing LW on-site is generally handled by the principal contractor (PC) of the project. Typically, the PC hires wheelie bins or 44-gallon drums and installs them on-site for tool washing (IW1, IW2, IW3). In a project site where there is no proper washout service employed to manage the LW, the LW generated from tool washing and washouts from concrete and brick/blockwork are discharged into the main sewer once the solids have settled at the bottom of the drum/sediment bin (which includes filters) and extracted. Yet, the wastewater is not treated before discharging and inspected by any authorities unless it is reported by third parties/public (IW1, IW2, IW3). Often it is common practice that discharging happens even before solids are completely settled. No water is allowed to run off the street or storm waterlines (IW2). The LW removed from the project site by a specialised LMW service contractor is managed (transporting, recycling, treatment and disposal) off-site. However, some PCs, who are concerned with environmental sustainability used to employ personalised washout systems like Washbox to facilitate LWM on-site (IW1, IW3).

There has been no formal reporting involved with LW generated from the trades such as painting, tiling, plastering/rendering, plasterboard and acid washing, except for the LW which is managed off-site by a specialised contractor (who holds the licence to manage LW) (IW1, IW2, IW3).

Cost of LWM: Generally, there is no cost specifically allocated in the budget to employ any washout facilities, like Washbox system on-site. Hence the cost of employing a washout facility becomes a burden to the PC as the cost is not covered under the contract. However, the cost involved in the managing of LW off-site by a specialised contractor is generally estimated and included in the budget (IW2). For some wet trades, such as concreting, painting and plastering, the trade cost will generally include the cost associated with tool washing and cleaning (IW1, IW2, IW3). The interviewees suggested that the cost for LWM services should be allocated in the budget and the PC should not be disadvantaged by bearing that cost. The cost can be paid by the developer or client as an allowance (IW1, IW2, IW3). There is a potential for saving in the cost of LWM services by sharing the services among the wet trades involved on-site (IW1).

Legal Requirements: Compared to solid waste management, following legal compliance in handling, processing and discharging LW is still in its infancy. The PC is required to make sure that they fulfil the compliance and comply with the auditors and inspectors from relevant authorities (IW2). Besides, the local council or relevant authorities such as EPA is responsible to investigate, inspect and fining the contractors who fail to comply with the requirements/conditions of a development application (non-compliance). Application to discharge the trade waste is required at the stage of a development application (DA) and it is the responsibility of the builder/developer to get approval or inform the local authority about their plan to manage the LW during the construction stage (IW1, IW2, IW3).

Barriers for LWM: The major barriers for implementing proper LWM methods in construction projects are found to be as follows;

1. Perceptions of the higher cost involved in employing a washout facility like Washbox and low margin of contractors (IW1, IW2, IW3).
2. The developers are not required to account for measures in managing LW in their sustainability goals and as such, there is no allowance provided in tender conditions (IW1, IW2).
3. Lack of strong sustainability and/or environmental policies followed by some builders' organizations that encourage inefficient LWM or apathy in implementation of such policies where these do exist (IW1, IW2, IW3).
4. Lack of standard procedures for LMW, systematic inspection procedures and fines for not fulfilling compliance specifically for the construction industry (IW2, IW3).
5. Lack of education or training in the tertiary education sector to improve the awareness or knowledge on the impact of LW generated in particular from construction projects and the benefits of implementing effective LWM systems on-site (IW1).
6. Lack of demand from the client to initiate personalised LWM services and pay for the services (IW1, IW2).

4.2 Analysis of Water Usage and Water Saving by Project Type and System User

4.2.1 Water Usage by Project Type

Figure 2 indicates the average total amount of water used for different types of projects when Washbox systems were used. Compared to other types of projects, residential projects indicate a very low usage of water when Washbox systems are used despite the greater involvement of wet finishing trades in residential buildings. Defence indicates a very high (almost 4 times as residential) usage because the data are based on data from a single project.

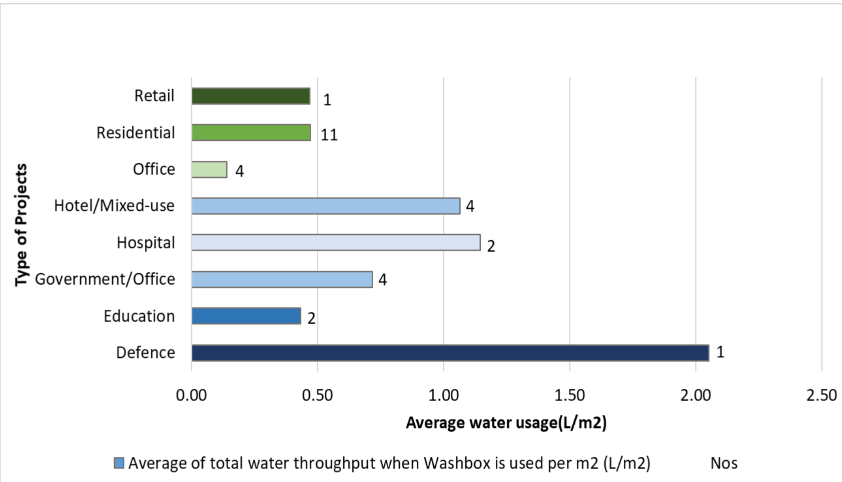

Figure 2: Average water usage per m^2 of gross floor area by project type (when Washbox system was utilised)

Source: Perera, et al. (2021)

4.2.2 Comparison of Water-saving by Project Type

Figure 3 indicates the average water saving for different types of building projects analysed per m^2 of building gross floor area. Data collected from Defence projects can be disregarded as it is based on one data point, which may represent an outlier. However, its inclusion is justified because evidently in this particular project, the Washbox system was the sole LWM system used. On the other hand, the water savings per square meter of buildings for residential type projects represented over 10 datasets, which is much more indicative of true savings. The average across all types of projects indicates a saving of 2.1 litres per m^2 and this is significant and would potentially have a significant impact on water usage in projects across the construction sector.

The water saving that can be achieved for Class 2 type of buildings (multi-storey residential type) is around 2 litres per m^2. When this figure is extrapolated to the 53,000 apartments constructed in the 2017-18 period in Australia, it is estimated that there will be around 10 million litres of water saved in a year. This is considerable and it is only just the saving from the Class 2 type of construction in NSW.

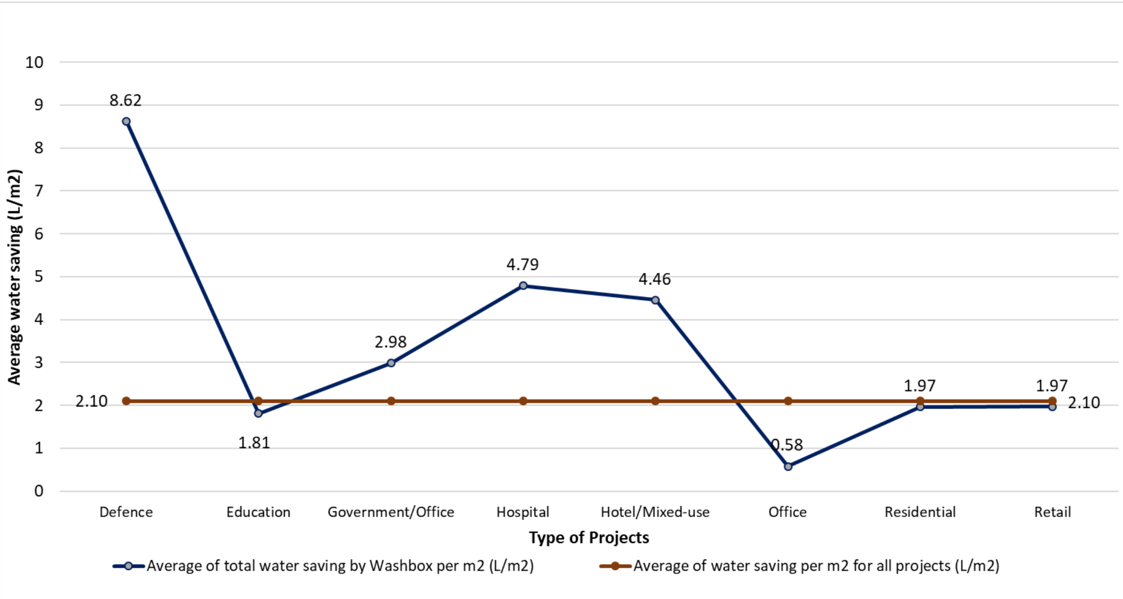

Figure 3: Comparison of average water saving by Washbox per m^2 of gross floor area by project type

Source: Perera, et al. (2021)

4.2.3 Comparison of Water Usage and Water Saving by Project Type

Here again, it is prudent to compare data for types of buildings where there are many data points. Figure 4 clearly indicates the amount of water saving that can be achieved across many building types. In all cases, it indicated over 95% water saving except for Education buildings (85%). The savings varied from 85% to 99% indicating a significant benefit due to water savings. Further, the use of such technologies means that wastewater from tool washing, site cleaning and related activities are not reaching the main sewer system or waterways, which, in turn, keeps the environment away from contamination.

Moreover, a greater level of water efficiency is indicated in the Hotel/Mixed-use category compared to the residential category may also indicate that there is greater scope for improvement of water efficiency in residential projects. However, this may have been a product of Residential buildings involving a greater number of wet trades related to finishes compared to Hotel/Mixed-use that adversely affect efficiency.

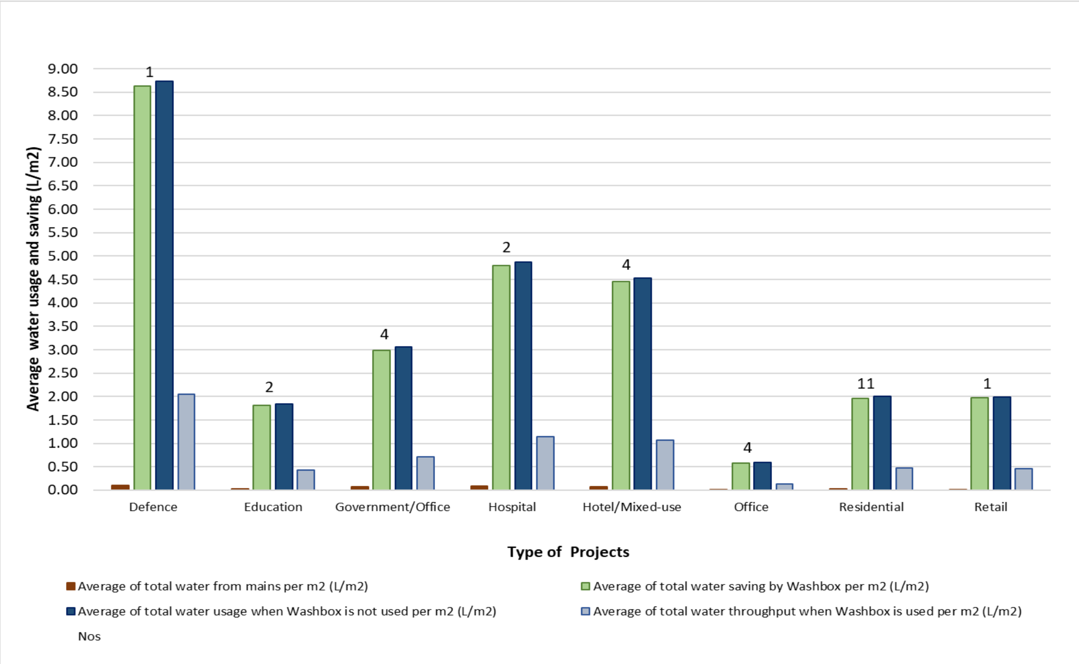

Figure 4: Comparison of average water usage saving per m^2 of gross floor area by project type

Source: Perera, et al. (2021)

4.2.4 Comparison of Water Usage and Water Saving by the System User (Size of the Organisation

Alternatively, the average water usage and water saving were compared against the size of the system users, which are categorised as large and medium-sized organisations. As revealed in Figure 5, there is not much difference shown in water usage when Washbox is used by both users. However, there is slightly greater water usage in projects delivered by large builders compared to medium-sized builders across all types of projects when Washbox is not used.

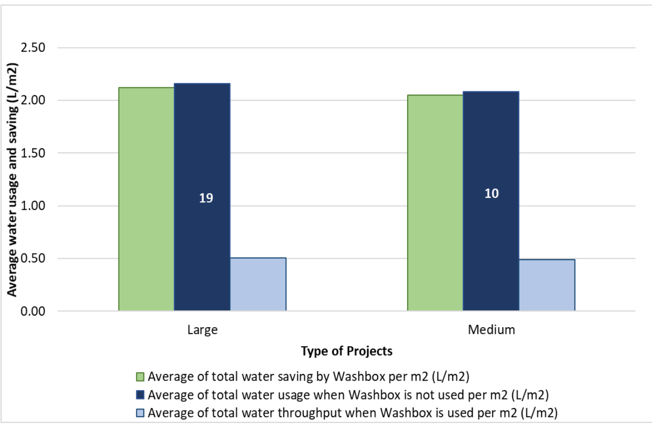

Figure 5: Average water usage and saving per m^2 of gross floor area by the system users

Source: Perera, et al. (2021)

In terms of water saving, greater water saving by large builders has been observed. This is an interesting outcome that could be resulted from the employment of Washbox systems as a sole LWM system and the use of appropriate LWM procedures. However, it needs further investigation to identify whether the systems and procedures adopted in these two situations are different for this result to manifest. In smaller projects, it is often difficult to have alternative methods and a smaller number of wet trades involved on-site provide greater control.

5. CONCLUSIONS AND RECOMMENDATIONS

This research investigated the current practice of LWM in construction projects, followed by a data analysis using the data collected from 29 different types of building projects. It was estimated that Residential buildings use 0.03 L/m^2 of water for tool washing when Washbox system is used. This is indicative of a 1.97 L/m^2 saving which is a comparatively significant amount. The average water saving for all projects stands around 2.1 L/m^2. When the water savings are extrapolated for multi-storey residential projects (Class 2) across NSW, the total annual saving is estimated at 10 million litres. Large builders seem to be slightly more efficient in water saving than small to medium-sized builders. Since the Washbox system is a closed-loop system that recycles the wastewater within the system, 98% of the water is saved through the Washbox system, proving its efficiency in water saving. Water reclamation, recycling and reuse are being recognised as key components of water and wastewater management (Po, et al., 2004). As such, commissioning an LWM system like Washbox at the construction sites not only enables the construction organisations to comply with the environmental requirements but also helps to achieve economic benefits and enhance the organisation's commercial reputation by reducing the wastewater footprint, conserving water and thus contributing to environmental safety and sustainability.

It is recommended that the efficiency of washout facilities employed on-site should be continuously measured and data of that type should be utilised to create acceptable efficiency benchmarks for construction sites. Water-saving measures used and the amount of waste saved in construction projects are not reported to local authorities (e.g., council) and therefore not acknowledged. There will be no management required if the LW is not measured, reported and inspected. Therefore, reporting of LW managed on-site and off-site needs to be mandated. It is desirable to incorporate the LWM process as a recognised component in Green Star evaluations and introduce rewards such as Green Star credit points for projects which save water through the development and implementation of water-saving plans. Because rating tools such as green star can be considered as a valuable reference to implement water-saving measures in construction projects (Wu, et al., 2020). In terms of legal compliance, there should be a step-change with revisions in working towards full legal compliance related to LWM in construction projects. Legislation governing LWM should specifically state the requirements for and impact of discharging partially or untreated LW from construction sites. The inclusion of an LWM plan that could form a part of either WMP, EMP or CEMP should be mandated for all construction projects. Further research needs to be carried out to evaluate in detail the state of legislation with respect to LWM in construction projects and the environmental consequences of LW generated from construction projects.

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ADAPTABILITY OF BLOCKCHAIN-BASED E-PROCUREMENT SYSTEM IN SRI LANKAN CONSTRUCTION PROJECTS

N. Nitharsan[1] and Mathusha Francis[2]

ABSTRACT

E-procurement and Blockchain are relatively new technologies that have the potential to provide a variety of benefits due to their unique features such as transparency, decentralized approach, immutability, and consensus. The Sri Lankan construction industry is corrupted and that drives up construction costs, which are then passed on to the general public. Procurement plays a major role in construction projects as it is the basis of any transaction. E-Procurement is one of the recent technologies used by modern businesses to save time, money, and effort. Therefore, the current research aims to investigate the adaptability of e-procurement using Blockchain technology in the Sri Lankan construction industry. A mixed research approach was adopted including a questionnaire survey and semi-structured interview. A total of 55 questionnaires were distributed among experienced professionals, and 37 responses were received. The data collected from the questionnaire survey were analysed using Relative Important Index (RII) and Gap analysis. For the interview, total of 5 professionals who have experience in procurement and tender management were drawn through the snowball sampling technique to identify the strategies for the adoption of Blockchain based E-procurement. The survey found that there is a gap between the desirability and readiness for Blockchain adoption. In addition, the eight important drivers and barriers to the adoption have been identified. As a result, from an organizational and governmental perspective, measures must be designed and implemented to overcome barriers and enhance readiness levels, so closing the gap between desirability and readiness. Finally, based on the findings, strategies for improving the readiness of Blockchain-based E-Procurement practices in the Sri Lankan construction industry were identified.

Keywords: *Blockchain; E-Procurement; Payment Management; Smart Contracts; Supply Chain Management.*

1. INTRODUCTION

As a result of the rapid uptake of ICT in Sri Lanka which is fuelled by the COVID-19 pandemic, its impact on the construction industry also cannot be neglected. The research problem arises from the fact, people in the construction business are of the opinion that the Sri Lankan construction industry is complexed and that drives up construction costs, which are then passed on to the public (Hadiwattege, et al., 2010). The works of Eadie, et al. (2011) revealed that the involvement of different parties and less defined specifications with unknowns makes construction procurement more complex and unique than the general types of goods and services procurement. The digitization of public

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procurement is gaining traction around the world, and the reason has been attributed to how procurement is handled by various public institutions, which has led to corrupt practices in which funds set aside for development initiatives end up in the pockets of public officers (Ogunlela Oyebanjo, et al., 2021). Algama (2017) quoted that "Some of the contracts appear to have been awarded without observing the fundamental principles of governance in procurement such as transparency and accountability.

Nicoletti (2020) noted that it is critical to improving the procurement sector's effectiveness, efficiency, and economics to satisfy the rising need for adding value and delighting consumers by using all an industry's operations. A blockchain is a digital record of transactions that are replicated and disseminated throughout the whole network of computer systems on the blockchain, making it difficult or impossible to modify, hack, or defraud the system (Christidis and Devetsikiotis, 2016). Blockchain technology is very reliable because of its six major components such as decentralized, transparent, open-source, autonomous, immutable, and anonymous. Because of blockchain's immense potential, every agreement, process, task, and payment in the world would have a digital record and signature that could be recognized, validated, stored, and shared, eliminating the need for intermediaries like lawyers, brokers, and bankers and allowing individuals, organizations, machines, and algorithms to easily transact and interact with one another (Marco and Lakhani, 2017). As a result, the introduction of blockchain technology has a beneficial influence on how businesses conduct procurement, resulting in greater opportunities for worldwide development and expansion (Akaba, et al., 2020).

Management of government money and budget clearances used to be a nightmare in traditional public institutions, making it a time-consuming endeavour to secure the necessary approvals from the many government departments (Ogunlela Oyebanjo, et al., 2021). Further, they argued that these issues, however, can be overcome by creating a blockchain system, in which funds can be allocated practically instantaneously following approval by the appropriate authorization levels. The businesses are adaptive, dynamic, and will collaboratively operate in an open and free environment globally soon and the question is whether the participation of the Sri Lankan construction industry is guaranteed? Change in procurement must become faster in responding to organizational needs, more networked, more agile because of the effort stemming from the fourth industrial revolution (Nicoletti, 2017). There were few studies conducted in terms of EP in Sri Lanka. Therefore, to improve the transparency, traceability, and security of electronic procurement using blockchain technology, the current study aims to investigate the adaptability of EP using Blockchain technology in the Sri Lankan construction industry.

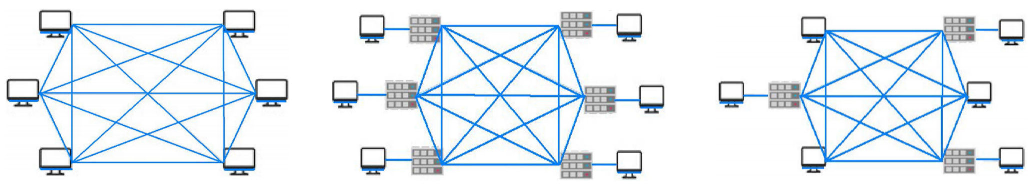
2. LITERATURE REVIEW

2.1 INTRODUCTION TO BLOCKCHAIN

The blockchain is a safe and efficient distributed ledger system for sharing data across multiple geographical locations without a single point of control, eliminating intermediaries, and ensuring trust in an untrustworthy environment (Guegan, 2017). Blockchain is a technology that allows you to copy, distribute, synchronize, and analyse data that is scattered over various sites, countries, or companies (Nanayakkara, et al., 2019). In his research, Gaikwad (2020) identified six properties of Blockchain, which are described below:

- Immutability - The block that is created in blockchain cannot be updated or altered at any time. Every block has a different hash value. To change a single block on the blockchain, a person would have to change every single block after it.
- Anonymity - One of the most critical aspects of blockchain security is anonymity. The identity of the user conducting the transaction is unknown. Although the user will be linked to a public address, no one will know the user's real identity or address.
- Decentralization - Decentralization allows transactions to be done directly between users without the involvement of a third party. This increases financial efficiency and reduces people's reliance on banks and other financial institutions.
- Transparency - The transparency of blockchain technology is one of its major advantages. The foundation of blockchain transparency is having the same records dispersed across a broad network for everybody to see.
- Persistence - As agreed by consensus, blockchain will not produce or maintain incorrect transactions. The blocks created are cryptographically locked in the chain, making it difficult to delete, change, or copy previously created blocks and place them on the network. This results in the creation of digital assets, as well as a high level of reliability and trust.
- Auditability - Blockchain can be used as a distributed ledger to record and verify transactions between two parties. Auditors can immediately verify transactions on publicly accessible blockchain ledgers instead of requesting bank statements from clients or submitting requests to third parties.

According to Niranjanamurthy, et al. (2019), blockchain technologies can be divided into three types namely; public, private and consortium as described in Figure 1.



Public Blockchain	**Private Blockchain**	**Consortium Blockchain**
Anyone can go through the transaction and verify it, as well as participate in the consensus process. Bitcoin and Ethereum, for example, are both Public Blockchains	Node participation will be restricted; not every node will be able to join in this Blockchain, which will have rigorous authority management over data access.	This indicates that the node with authority can be chosen ahead of time, usually has business-to-business connections, and the data in Blockchain can be open or private, making it partially decentralized.

Figure 1: Different types of blockchain

Source: Niranjanamurthy, et al. (2019)

At its inception, blockchain was conceived as a public ledger that allowed everyone access to the ledger network's history and the ability to check the history of transactions (Kwak, et al., 2019). It is more dependable and preserves a modest level of privacy when compared to the private blockchain (Venkateswara, et al., 2018). Private Blockchain technology can be used to transcend these constraints and set up a distributed network only for authorized members (Kwak, et al., 2019). Through a simple application program interface (API), any private blockchain may be connected to a block bench and benchmarked against workloads based on real and synthetic smart contracts (Dinh, et al., 2017). A consortium blockchain is a type of blockchain that includes features from both public and private blockchains. Rather than an open system in which everyone can access the ledger or a closed system in which only authorized parties are allowed, the consortium blockchain relies on a small number of equally strong parties serving as validators (Zhong, et al., 2020).

2.2 Overview of Blockchain-Based E-Procurement

Many countries throughout the world have profited from government EP (Electronic Procurement) because it allows the government to provide more convenient and widely available government services in a more efficient, cost-effective, and sustained way (Premathilaka and Fernando, 2018). Batenburg, (2007) elaborated that EP is one of the most recent technologies used by modern businesses to save time, money, and effort. The blockchain is a safe and efficient distributed ledger system for sharing data across multiple geographical locations without a single point of control, eliminating intermediaries, and ensuring trust in an untrustworthy environment (Guegan, 2017). There are various applications and services linked with blockchains and distributed ledgers that contribute to their use, such as applications that operate over blockchain networks and allow users to interact with them easily (Lemieux, 2017).

2.2.1 Smart Contracts

Smart contracts, which are self-executing contracts written into a blockchain network, enable confidence in a trustless internet environment without the need for an intermediary (Alharbyet al., 2018). Lemieux (2017) stated that smart contract code governs which transactions and what information is stored in the blockchain. Furthermore, many types of contractual conditions can be made partially or entirely self-executing and self-enforcing with smart contracts. Smart contracts are programmed to commence payments based on the number of hours worked and the timely delivery of deliverables, resolving late payment and cash flow difficulties (Penzes, 2018).

2.2.2 Payment Management

Incorporating a blockchain-based platform into the project execution process, which can begin payments based on digitally approved work, contractual terms, and smart contract activities, is one of the most appropriate uses of blockchain in the construction industry (Penzes, 2018). Implementation of smart contract-enabled blockchain payment applications can provide greater trust in transactions with automation and effective operation to mitigate payment-related issues in the procurement process (Samudaya, et al., 2019). As there is no involvement of a third party in the transactions, the procedure is considerably easier and faster than the traditional method, which will increase the construction organization's productivity in terms of cash flow management (Hewavitharana, et al., 2019).

2.2.3 Supply Chain Management

With many internal and external suppliers connected through dynamic and lengthy supply chains, the construction industry produces one of the most complex and largest objects (Perera, et al., 2017). A supply chain is a network of numerous organizations' activities that are linked as upstream (suppliers) and downstream (customers) to deliver items or services to the ultimate consumer (Mentzer, et al., 2001).

3. RESEARCH METHODOLOGY

A mixed-method was adopted to the current research as it requires to collect qualitative data and quantitative data from the professionals who have knowledge in blockchain and its application. However, the professionals with such profile are limited in Sri Lankan construction industry. Initially, a questionnaire survey was carried out to identify significant drivers and barriers for the adoption and to identify the readiness and desirability of the Sri Lankan construction industry. Survey provides a relatively quick and efficient method of assessing information about the population (Kelley, et al., 2003). Surveys allow the collection of a large amount of data from a significant population in a highly economical way. Often obtained by using a questionnaire administered to respondents. Further semi-structured interviews were carried out to investigate the strategies to overcome the barriers to adoption and to reduce the gap between desirability and readiness. Semi-structured interviews helped to collect in depth views of professionals regarding the implementation of Blockchain application in Sri Lankan construction industry. Table 2 provides the relevant work experience of the respondents and the response rate of the respondents to the questionnaire survey results.

Table 2: Experience and response rate of respondents for the questionnaire

Relevant Experience in years	Distributed	Received	Response rate
0-5 years	25	17	68%
6-10 years	25	17	68%
Over 10 years	5	3	60%
Total	**55**	**37**	**67.27%**

For the questionnaire survey, a total of 37 responses were received out of 55. Survey results of barriers and drivers were analysed using RII and gap analysis between readiness and desirability of the adoption. Subsequently, five experienced professionals were interviews and their profile is given in Table 3.

Table 3: Profile of the interview respondents

Respondent Code	Designation	Years of Experience	Scope of work
A	Tendering Section Head	7	Estimation; Tender management; Procurement management
B	Assistant General Manager	10	Estimation; Contract management; Procurement management; Tendering
C	DGM of Contract Management	15	Precontract management and overall scope of contract organizing
D	Project Manager	10	Project Management; Contract Management
E	Senior Quantity Surveyor	8	Tendering; Cost estimating; Claim management

In terms of years of experience, all the interviewees were possessed with adequate industrial experience in pre and post contract phases to contribute to the study with their technical and professional know-how. Moreover, all the interviewees are chartered quantity surveyors and had exposure to the fields of project management, procurement management, and contract administration, so they were able to enlighten the study with their peculiar expertise. Thus, this profile of information of research participants indicates that the collected data are reliable.

4. RESEARCH FINDINGS

4.1 SIGNIFICANT DRIVERS AND BARRIERS FOR ADOPTING BLOCKCHAIN-BASED E-PROCUREMENT

A questionnaire was created to discover the most important drivers and barriers for the Sri Lankan construction sector to adopt Blockchain-based EP. Respondents were given a Likert scale ranging from 1 to 3, denoting great importance for each driver and barrier. Table 4 presents the significant drivers to adopting Blockchain-based EP.

Table 4: Significant drivers to adopting Blockchain-based E-procurement

No.	Drivers	RII
1	Administration cost savings	0.838
2	Enhanced (automated) decision making and market intelligence	0.829
3	Improved inventory management and contract management	0.829
4	More transparency throughout the process	0.820
5	Competitive edge in procurement	0.811
6	Cost and time savings in the entire procurement process	0.811
7	Better utilization of all parties	0.802
8	Increased efficiency and enhanced quality of outputs	0.802
9	Errorless process flow	0.802
10	Improved management and control of procurement system	0.784
11	Improved dispute resolution	0.784
12	Communication and collaboration effectiveness and enhancement	0.775
13	Simplified and streamlined process flow	0.766

All the drivers in Table 4 have a level of significance of RII value of 0.75 or above. According to the questionnaire survey, administration cost savings is the biggest driver for adoption. Because in construction organizations, administration cost is attached to every procurement which increases the bid price and creates ineffective expenses. Contractors unnecessarily suffer different types of administration costs during a construction project which include a huge part in the procurement. According to (Golosova and Romanovs, 2018), Blockchain technology minimizes costs as well as legal and bureaucratic barriers, which require a long time to process and begin transactions in a banking company. The second most selected driver is Enhanced(automated) decision making and market intelligence. The enhanced and automated decision-making will improve the efficiency and accuracy of the construction procurement process in a greater sense. And it is essential to create a feedback loop that constantly analyses the rules against the results they create to build a self-learning, self-correcting system. Each action is recorded on the Blockchain, and the data of records are accessible to all Blockchain participants and cannot be modified or deleted, providing transparency, immutability, and trustworthiness to the Blockchain (Bahga and Madisetti, 2016). Transparency is another important driver which will greatly contribute the Blockchain adoption. With Blockchain decentralization, the transparency of the transactions can be heavily improved without any fraud activities in the procurement process. Along with that, cost and time savings in the procurement process will be another major driver in adapting Blockchain-based EP.

Along with that, cost and time savings in the procurement process will be another major driver in adapting Blockchain-based EP. The time taken by a construction project is far higher than the general industrial procurement. Therefore, many different professionals involved in the procurement process will make the procurement process very time-consuming. If the procurement process time increase, it is natural that the cost of the procurement process also will increase. In most construction procurements, the client and consultants suffer more time and cost in the procurement process even before the construction projects start. And during the bidding process, different contractors who bid on the project also will go through the time extensions and other costs related to procurement. By simplifying the procurement process by adopting Blockchain technology the actual time and cost can reduce to the minimum level which is beneficial to all main parties of procurement such as the client, consultant, and contractor.

Improved management and control of the procurement system, improved dispute resolution, communication, and collaboration effectiveness and enhancement, and simplified and streamlined process flow does not have much significance as drivers in adopting Blockchain-based EP. Since construction procurement is complicated and can't be simplified into a single streamlined process due to the involvement of various factors. Respondents have stated that the effectiveness of communication and collaboration won't be a significant driver due to the reason that, Blockchain technology does not directly improve the communication and collaboration in the procurement process. When considering the dispute resolution in the construction process, even though the Blockchain process can help to reduce disputes it is not enough significant driver to adopt Blockchain technology. In adopting any new technology, the drivers must surpass the barriers of the adoption. In adopting Blockchain technology, the advantages of Blockchain will be the main drivers and according to the survey, it is clear there are the most significant drivers of adopting Blockchain-based EP in the Sri Lankan construction industry.

Table 5 shows the barriers in adopting Blockchain based EP in Sri Lanka.

Table 5: Significant barriers to adopt Blockchain-based E-procurement

No.	Barriers	RII
1	IT infrastructure	0.757
2	Software capabilities of integrating internal and external issues related to Blockchain and EP	0.748
3	Absence of an accepted standard	0.748
4	Lack technical expertise	0.730
5	Issues in collaboration, communication, and coordination in the supply	0.721
6	Security of transactions	0.694

No.	Barriers	RII
7	Lack of training of the staff	0.685
8	No absolute business benefit	0.685
9	Unreliability and lack of confidence on new technologies	0.676
10	Cost concerns are associated with the system implementation, internet services, and initial cost	0.667
11	The legal position of Blockchain and EP	0.667
12	Lack of support from the upper management or authorities	0.658
13	Resistance to change	0.631
14	Interoperability concerns	0.514

Although the Sri Lankan construction industry is knowledgeable about Blockchain and EP, the numerous benefits it can provide, the adoption and use of Blockchain-based EP are hampered by several obstacles. It is necessary to research the importance of these stumbling blocks. Table 5 shows the RII values for the key impediments found through the questionnaire survey.

According to the survey, the most significant barrier is the IT infrastructure necessary for Blockchain-based EP. To use Blockchain technology, an IT infrastructure is required. Although Blockchain offers considerable cost and time advantages, the high initial capital cost may be a deterrent (Niranjanamurthy, et al. 2019). The country's present information technology infrastructure does not satisfy the standards for implementing new information technology-based technologies. The government urgently must establish a strong information technology infrastructure in general, and it must achieve a particular degree of maturity before implementing a complicated and sophisticated technology like Blockchain. Because Blockchain code is publicly available and they become autonomous entities once they are created, smart contracts can be vulnerable to hackers (Gatteschi, et al. 2018). Sri Lanka's IT industry is now through new stages of development, most notably in the construction sector. Governments and other private entities have also initiated the move to electronic procurement and the implementation of new electronic procurement capabilities. Even if there is a barrier, it can be overcome rather quickly. Sri Lanka's government must provide standard IT knowledge and embrace and practice more technological features to increase IT infrastructure standards. Another important significant hurdle is software capabilities for merging internal and external issues related to Blockchain and EP. Even while certain industrial procurements have been converted to EP using basic software, Blockchain requires sophisticated cryptography software to implement any Blockchain-based procurement application. The lack of an acknowledged standard is the next big stumbling block. The Sri Lankan construction sector has developed some fundamental norms for electronic procurement for government projects, but none for Blockchain technology. If the construction industry is to accept new technologies, it is critical to have well-defined standards in place, at the very least for government construction projects. Another stumbling block for Blockchain-based applications is a lack of technical expertise. Due to the absence of technical understanding of construction professionals and technical practice in Sri Lanka, the construction sector lacks technical experience in Blockchain. The other five barriers, such as cost concerns related to system implementation, internet services and initial cost, the legal position of Blockchain and EP, lack of support from upper management or authorities, resistance to change, and interoperability concerns, are considered minor barriers due to their lower RII value survey score. Nonetheless, these considerations must be considered for the adoption of Blockchain technology.

4.2 Gap Analysis Between the Level of Readiness and Desirability of Blockchain-Based E-Procurement Applications in the Sri Lankan Construction Industry

To enhance Blockchain-based EP procedures in the Sri Lankan construction sector, it is critical to assess if the construction industry is willing to use Blockchain-based EP. Even though generally construction business is desirable to adopt new technologies, there is a need to explore the readiness in terms of financial, legal, organizational, and technological competence for improved acceptance and usage of Blockchain-based EP applications by these Sri Lankan construction organizations.

As a result, the respondents were asked to indicate their preparedness by considering their technological, legal, organizational, and financial capabilities, as well as their desirability by considering their willingness to use Blockchain applications that relate to procurement. A Likert scale was created, with values ranging from 1 to 3, with 1 denoting low level, 2 denoting medium level, and 3 denoting high level. The arithmetic average was used to calculate the spread of respondents' readiness and desirability scores for each application of Blockchain-based EP. For a better understanding of the gap between readiness and desirability, the quantitative data acquired for readiness and desirability were evaluated separately. The desirability and readiness of Blockchain-based EP applications are depicted in Figure 2.

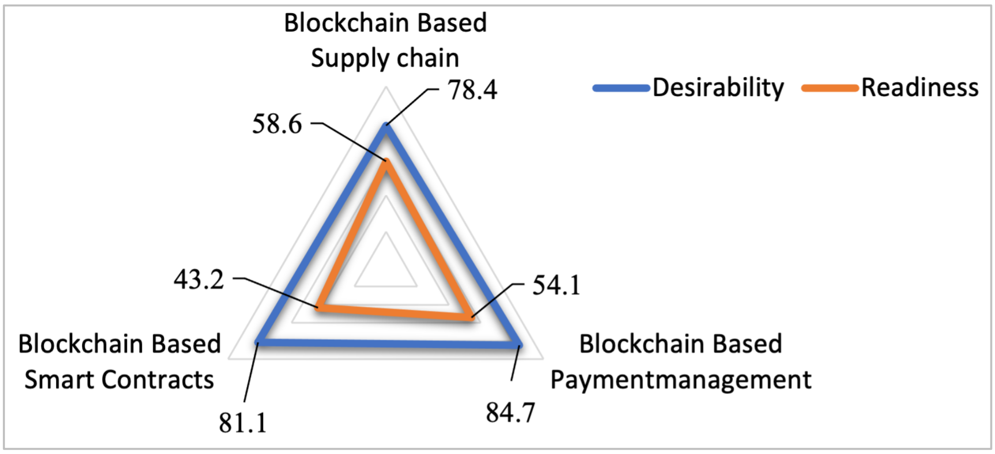


Figure 2: Gap analysis between the level of readiness and desirability of Blockchain-based E-procurement applications in the Sri Lankan construction industry

According to the survey results, respondents believe that the desire to use Blockchain applications is greater than their readiness to do so. Blockchain-based payment management is more desirable than the other two applications in terms of desirability. The increased awareness of payment management systems, which was also highlighted in the last data collection, is the cause of this desirability. According to the survey, the Blockchain-based supply chain system is the least popular of the three applications. In terms of construction sector readiness, the survey shows that the supply chain is the readiest for adoption. The payment management application is the next application with the readiest. Blockchain-based smart contracts have the lowest adoption readiness.

A deeper understanding of Figures 2 reveals that the gap between desirability and readiness of the Sri Lankan industry is lesser across all tools of Blockchain. The supply chain management application has the smallest gap between readiness and desirability among these three applications, but it is also the least desired. As a result, it is hard to conclude that supply chain management has a higher likelihood of adoption than the other two applications. As a result of study findings, payment management appears to have the next smallest gap, making it a preferable alternative for initial adoption when comparing other applications. Smart contracts based on blockchain have the largest gap in all three applications, indicating the least likelihood of adoption in the Sri Lankan construction industry.

4.3 SUGGESTIONS FOR THE SRI LANKAN CONSTRUCTION INDUSTRY TO OVERCOME THE SIGNIFICANT BARRIERS ASSOCIATED WITH THE ADOPTION OF BLOCKCHAIN-BASED EP

The list of barriers impeding the adoption of Blockchain-based EP in the Sri Lankan construction industry was determined using the survey. Interviewees were asked to summarize their reactions to the findings on key hurdles and to provide suggestions on how to decrease such barriers. All significant challenges and ideas raised by interviewees are compiled and presented in a tabular manner below for simple comprehension.

Table 6: Summary of strategies to weaken the barriers to adoption

Barriers	Strategies to overcome the barriers
IT infrastructure and Software capabilities for integrating internal and external issues related to Blockchain and EP	• EP to all government projects • More research and education on new technology developments • Backend-as-a-Service (BaaS) • Awareness programs regarding new technologies
Absence of an accepted standard	• Borrow from other countries and customize • Creating and testing new standards for government projects • Collaborating with international construction organizations
Lack of training of staff, lack of technical expertise, and lack of knowledge	• Top management accountability and support • Recruitment of skilled and technically sound people • Training and knowledge sharing from system providers • Continuous professional development • Incorporation to curriculum
Absence of a nationwide framework and policies for collaboration, communication, and coordination	• Policies to ensure continuous project flow • Centralized EP portal or framework for all Government projects • An effort from Private construction organizations
Security of transactions and system	• Complex passwords and usernames • System suppliers' built-in security system • Security features embedded into the system must be made aware of and updated regularly. • Regulation by the Central bank in the transaction history

Barriers	Strategies to overcome the barriers
No Absolute business benefit and lack of confidence in new technologies	• Creating awareness programs through CIDA • Actual project implementation and use as a model to attract more private businesses

5. CONCLUSIONS AND RECOMMENDATION

As detailed in the introduction, the underutilization of Blockchain technology and EP by the construction industry has been identified, as the need for initiatives to improve Blockchain-based EP practices in Sri Lanka's construction industry. As a result, the goal of this research study was to improve the construction sector of Sri Lanka's Blockchain-based EP practices. The literature review has highlighted Blockchain-based EP applications which include smart contracts, payment management, and supply chain. The survey was used to identify nine important drivers and barriers to adoption. The survey was also employed to determine the readiness and desirability of three applications in the Sri Lankan construction industry. The results showed that the Sri Lankan construction industry has higher overall desirability and low readiness to adopt Blockchain-based EP. Further, it demonstrated the gap between desirability and readiness was comparatively high across all three Blockchain applications. Due to this reason semi-structured interviews were conducted with construction industry experts to identify the strategies for weakening the barriers for adopting Blockchain-based EP. Experts believe that bridging the gap between the desire for Blockchain-based EP and the preparedness of the Sri Lankan construction sector is necessary for its effective implementation. Expert views were used to develop ways to decrease important hurdles and close the gap between readiness and desire, and it was discovered that they must be complemented by government-led and organizational actions. Furthermore, it has been stated that gap closing is linked to the decrease of obstacles to adoption. The strategies shown in Table 6 were developed using the results of expert interviews. The Sri Lankan construction industry will need to do more research and development, and the government will need to raise awareness of Blockchain applications. Further, the industry needs to try standardized and regulated common platforms from the government which provide an easy way to use and costs much lesser than customized systems for each different organization. Government Authorities and Regulatory Bodies need to set future goals and support the Sri Lankan construction industry to enhance Blockchain and EP.

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ADAPTING THE STANDARD FORMS OF CONTRACT TO MINIMIZE THE CONTRACTUAL EFFECTS OF COVID-19 ON CONSTRUCTION PROJECTS

Chathuranga Perera[1] and Roshani Palliyaguru[2]

ABSTRACT

The construction industry is a major economic driver in Sri Lanka. However, the construction industry was significantly affected by the responses made by the Sri Lankan government to prevent the spread of the COVID-19 pandemic. The effects of those government responses on construction projects are diverse as time, cost, and quality-related impacts. These effects resulted in numerous contractual effects that were mostly to be dealt with reference to the provisions made in the standard forms of contracts such as ICTAD/SBD/02 and FIDIC 1999 in Sri Lanka. Since no similar pandemic has affected Sri Lanka at this magnitude before, neither ICTAD/SBD/02 nor FIDIC 1999 have been drafted giving due consideration to such exceptional circumstances. Furthermore, no studies that researched these kinds of aspects can be found in the existing literature. Hence, this research aims to explore the effects of the responses made by the Sri Lankan government to prevent the spread of the COVID-19 pandemic on the construction industry and the possible adaptations of standard forms of contracts to address the contractual implications of those effects to mitigate the effects on the contractual parties in both building and civil engineering projects. A desk review was carried out to identify the existing provisions of ICTAD/SBD/02 and FIDIC 1999 to overcome the effects of pandemic situations, and three case studies, including two building projects and one civil engineering project, were used for the empirical data collection. Representing contractors, consultants, and employers, twelve semi-structured interviews were conducted within the three case studies. The research findings reveal that a collaborative approach with cost and time-sharing is the best approach to address the effects of a pandemic situation. Furthermore, defining terminologies, developing transparency in contractual relationships, and establishing an equal assessment basis can all aid in the contractual development of the ICTAD/SBD/02. As a result, the study suggests improving documentation practices, developing guidelines for amicable settlement, and eliminating the adversarial effects of ICTAD/SBD/02 through an equal assessment process. Thus, this research contributes to the further development of ICTAD/SBD/02 while also improving Sri Lankan building and civil engineering projects by reducing contractual issues in future pandemics.

Keywords: *Contractual Implications; COVID-19; FIDIC 1999; ICTAD/SBD/02.*

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1. INTRODUCTION

An outbreak of pneumonia of unknown origin was first reported in Wuhan City in Hubei Province, China on 31st of December 2019. Subsequently, World Health Organization named the disease as COVID-19 and on 11th of March 2020, it declared the outbreak a pandemic (Central Bank of Sri Lanka, 2020). Sri Lanka is one of the countries hardest hit by the disease. Zin and Ahnuar (2022) elaborated that "*this pandemic was a new phenomenon, and there were limited legal references to refer to when deciding on the best way to deal with that contractual effect*". The COVID-19 pandemic has devastated the working world. Its impact, which varies by sector, is significant in the construction sector because construction is sensitive to economic cycles and construction companies and workers, in particular, were vulnerable to the sharp drop-in economic activity caused by the pandemic (International Labour Organization, 2021). Renukappa, et al. (2021) have pointed out a range of issues such as office closures and lockdowns, construction site closures, changes to progress meetings, changes in quality and health and safety procedures, etc. that have arisen due to COVID-19 in the United Kingdom. In addition to that, Gan and Koh (2021) revealed that the setting up of an interagency task force, temporary closure of construction worksites, systematic testing of every worker, management of infected workers at an appropriate care facility, and prioritization of COVID-19 vaccination in the construction sector are government interventions in Singapore, and such interventions lead to many contractual effects for the construction work (Gan and Koh, 2021).

In the same way, the government of Sri Lanka and public authorities imposed various rules, regulations, and guidelines such as "Guidance for Workplace Preparedness for COVID-19", "Health & Immunity Enhancement Guidelines for COVID-19 & Dengue" published by CIDA, and the "Coronavirus Disease 2019 (COVID-19)" Act to prevent the spread and control the COVID-19 pandemic. These regulations and guidelines imposed by the legally constituted public authorities have had serious effects on the contractual aspects of construction projects. Consequently, events such as payment delays, expiry of securities, suspension of work, terminations, etc., keep occurring and resulting in a chain of other issues. In summary, COVID-19 has led to the implementation of new rules to prevent the spread of the virus and the consequences of them are the inability to fulfil contractual obligations by the parties, which results in disruptions, delays, additional costs to the contractor, sub-contractors, suppliers, consultants, and employers, and some contracts being subject to impossibility where further performance becomes impossible (Kawmudi, et al., 2020; Vithana, et al., 2020; Pathirana 2021). Overall, because of the epidemic, Sri Lanka experienced an overall economic downturn (Roshana, et al., 2020).

2. LITERATURE REVIEW

2.1 OVERVIEW OF COVID-19

The COVID-19 disease, formally known as the ‘Coronavirus disease’ can be easily understood as the deadliest pandemic the world has faced so far in the 21st century. In parallel to the spread of the pandemic, the major economic activities of all trades and industries faced a severe blow to their normal functions. Both economies, on a global and individual scale, have severely been affected by complications from the combination of the above-mentioned pandemic situation and the relative economic downfalls (Kandewatta, et al., 2021).

The continuous spread across Sri Lanka of the COVID-19 pandemic started with the very first case, which was reported on the 10th of March 2020. The initial restrictive measure was to place a police curfew throughout the island to prevent all travel among citizens. The responsibility of containing and dealing with the virus was vested in a collection of government institutions and organizations, namely the Ministry of Health, Sri Lanka Medical Council, Tri-forces, and other essential services personnel (Roshana, et al., 2020).

2.2 SRI LANKAN GOVERNMENT'S RESPONSE TO COVID-19

A key factor that is crucial in facing uncertain times such as this pandemic lies within the strength of the government's stability to ensure a firm grip on the imposed regulations. Furthermore, the tracking of all suspected patients was successfully carried out with the help of the national intelligence network, which was based on an integrated plan with the aid of the Special Task Force (Pathirana, 2021).

The Government of Sri Lanka (GOSL) introduced various actions which helped to prevent, detect and respond to the COVID-19 pandemic in Sri Lanka. Aggressive "social distancing" measures were implemented in the entire country, including issuing travel bans to other affected countries and closing ports and airports, an island-wide strict curfew, imposing travel restrictions between provinces and districts, emergency health and economic measures, including several economic relief measures for the poorest segments of society and the most vulnerable sectors of business, an increase in government spending on healthcare and public safety measures, and the establishment of the Coronavirus Task Force, which effectively coordinated the health and containment measures. Quarantining also be identified as some key actions (COVID-19 Outbreak Impact on Sri Lanka and Recommendations, 2020). A summary of government actions to prevent the spread of COVID-19 in Sri Lanka is listed below:

1. Implement social distancing,
2. Imposed curfew and travel restrictions on the whole country and parts of the country,
3. Initiate quarantine centres around Sri Lanka,
4. Establishment of a Coronavirus Task Force and taking necessary economic relief measures, and
5. Issuing travel bans to other affected countries and the closing of ports and airports.

Since March 2020, several regulations and guidelines, such as ***Guidance for Workplace Preparedness for COVID-19*** (Epidemiology Unit-Ministry of Health & Indigenous Medical Services, 2020), and ***Health and Immunity Enhancement Guidelines for COVID-19 & Dengue***, were issued by the CIDA to control the pandemic situation (Construction Industry Development Authority, 2021). In addition to that, currently, the government has published the draft act titled "***Coronavirus Disease 2019 (COVID-19) (Temporary Provisions) Act, No. 2021*** to make temporary provisions to proceed with a judicial proceeding under the COVID-19 pandemic situation (The Democratic Socialist Republic of Sri Lanka, 2021). These guidelines/Acts are briefly described below:

2.2.1 Guidance for Workplace Preparedness for COVID-19

As per the Epidemiology Unit of the Sri Lankan Ministry of Health and Indigenous Medical Services (2020), the Guidance for Workplace Preparedness for COVID-19 was issued for making arrangements for the workplace and work force, which are listed below.

1. Regulations for compulsory hand sanitizing stations to all and stations at critical locations throughout the facility, including the main entrance,
2. Regular inspection of hand sanitizing stations, including refilling of hand sanitizing liquids and inspection of water availability at hand washing stations,
3. Strict enforcement on social distancing and compulsory usage of masks and face shields to all,
4. Discourage the touching of eyes and noses as it can easily be a reason for the spread of disease, and
5. Provide means to conduct possible work through an online platform.

2.2.2 Health and Immunity Enhancement Guidelines for COVID-19 and Dengue

This guideline was published by the CIDA to specify the responsibilities of or actions to be taken by employers and contractors to prevent the spread of COVID-19 and dengue, and a few of those actions mentioned there are summarised in Table 1:

Table 1: Duties of employers and contractors

Duties of Employers	Duties of Contractor
• Conduct thorough meetings with critical health officials and other main stakeholders in the project.	• Conducting of regular health care checks, including temperature checks, using infrared thermometers.
• Properly pre-planning all strategies & precautions to be used by administrative & contract provisions.	• The entrance is to be provided with a proper hand sanitizing facility.
• Providing all required PPE, including surgical masks and face shields, to all workers without any additional cost.	• The entrance security guard is to maintain a daily record of visitors.
• Provide financial allocations for safety precautions and PPEs required for both parties' workers against COVID- 19.	• Provision of living quarters to all workers present for the project with strict covid-19 protocols.

2.2.3 Coronavirus Disease 2019 (COVID - 19) (Temporary Provisions) Act

The Minister of Justice on 8th of June 2021 presented the Coronavirus Disease 2019 (COVID-19) (Temporary Provisions) Bill. The emergence of the new COVID -19 virus variant and the surge in the spread of the virus since March 2020 have resulted in cyclical lockdowns, curfews, and/or travel restrictions being imposed in Sri Lanka. The COVID-19 Bill is to make temporary provisions/provide certain legal facilities for the following situations where people are unable to perform certain actions due to COVID-19:

- To grant relief concerning parties to certain contracts who were unable to perform contractual obligations due to COVID-19. To assign alternative courts where a court cannot function due to COVID-19 circumstances.
- To conduct court proceedings using remote communication technology to facilitate the control of coronavirus disease 2019 (COVID-19).
- To grant relief concerning parties to certain contracts who were unable to perform contractual obligations due to COVID–19. If the times prescribed by law are not complied with because of a COVID-19 circumstance, inter alia, the instituting of action, filing of appeals, or performing any time-sensitive act, a further prescribed time will be permitted as described in the Act.

- If the party to a "scheduled contract' is unable to perform any obligations and/or exercise any rights under such a contract, an application may be made to a court, tribunal, or other authority established and empowered by law to hear and determine matters concerning the scheduled contract (The First Schedule of the Bill provides a non-exhaustive list of what is considered a "scheduled contract").

According to part IV (Temporary Relief in Respect of Contract) of this Act, it will provide temporary relief for the parties who cannot fulfil their rights and obligations due to the COVID-19 pandemic. Therefore, if any party fails to perform contractual obligations and rights due to the COVID-19, such party can request relief under this part of the Act to the court, tribunal, or any other respective authority established by or under any law which would otherwise have jurisdiction, authority, or power to adjudicate in respect of such contract under any applicable law. However, if a party has already claimed the relief according to the contractual provisions, but that party is unsatisfied with the given relief, they can seek further relief based on the provision (Part IV, Sub Section 30) stipulated in this Act.

2.3 EFFECTS OF GOVERNMENT RESPONSES TO THE COVID-19 PANDEMIC SITUATIONS ON THE CONSTRUCTION INDUSTRY

Construction industry members, including owners, developers, contractors, sub-contractors, and supply chain vendors, have experienced varying degrees of effects as a result of the COVID-19 pandemic. Every government in the world has been implementing various rules and regulations to prevent the spread of COVID-19 since January 2020. By adapting to those rules and regulations, the construction industry has been more challenged. Direct effects have ranged from decreases in goods and labour to project suspensions and, in some instances, terminations of parties or entire projects. Construction activities remain in flux in some parts of the world depending upon whether construction is classified as an essential business.

Kawmudi, et al. (2020) have reported that the key challenges the industry currently faces are delays in completion of the final project, for which the parties agreed to contractually while signing the contract, disturbances in the main supply chains, uncertainty in global markets, new economic challenges, poor experience in handling the current situation due to a lack of experience regarding a pandemic, financing difficulties for a smooth project flow, issues under legal aspects and a lack of sound experienced professionals to deal with the situation, suspensions of contracts for temporary timeframes, labour shortages due to travel restrictions, etc. The significant factor that contributed to the disruption of supply chains can be identified as the travel restrictions imposed by the government on an area basis. With travel restrictions, both labour and materials were significantly disrupted in their particular supply chain channels (Pathirana, 2021).

The additional requirements to strengthen health and safety controls (including COVID-19 testing for workers, temperature monitoring, and regular cleaning and disinfection of work areas and surfaces) have also had a significant impact on time, cost, and quality constraints while performing on a project. However, due to the pandemic situation, the contractors are required to continue to adhere to the government regulations that are published due to pandemic situations, and this will lead to rescheduling the original program. This may have delayed the progress of such work and increased the cost of completion (Kramer and Thadani, 2020).

2.4 Desk Review on the Existing Provisions in Standard Forms of Contracts to Overcome the Effects of Pandemic Situations

2.4.1 ICTAD/SBD/02 (Standard Bidding Document - Procurement of Works Major Contracts)

In the Sri Lankan construction industry, most of the construction contracts are governed by the Standard Bidding Documents (SBD) published by the Construction Industry Development Authority (CIDA). Every effect of a pandemic has a correlation to time and cost. After a thorough desk review conducted within the study, several clauses that are related to time and cost constraints and help address the effects of pandemic situations were identified. The relevant causes given in ICTAD/SBD/02 are presented in Table 2.

Table 2: The relevant ICTAD/SBD/02 clauses

Clause	Description
8.4	Extension of Time for Completion
8.5	Delays Caused by Authorities
13.6	Adjustment for Changes in Legislation
17.3	Employer's Risks
17.4	Consequences of Employer's Risks
19.1	Contractor's Claims
20.1	Force Majeure
20.2	Notice of Force Majeure
20.4	Consequences of Force Majeure
20.6	Optional Termination, Payment and Release

2.4.2 FIDIC 1999 Red Book

As SBD/02, FIDIC 1999 is also a popular standard form of contract in the construction industry of Sri Lanka. If the funding for the project is foreign, most of the governing standards documents will be foreign ones like JCT, FIDIC, etc. As with ICTAD/SBD/02, FIDIC 1999 also has several clauses that are related to time and cost constraints and help address the effects of pandemic situations. They are given in Table 3.

Table 3: Relevant FIDIC clauses

Clause	Description
8.4	Extension of Time for Completion
8.5	Delays Caused by Authorities
13.7	Adjustment for Changes in Legislation
19.1	Force Majeure
19.2	Notice of Force Majeure
19.4	Consequences of Force Majeure
20.1	Contractor's Claims

3. METHODOLOGY

According to Creswell (2014), there are three research approaches: quantitative, qualitative, and mixed-method approaches. The qualitative approach to the research was identified as the best-suited approach for this study. The first part of the study used existing literature to identify the responses of the government of Sri Lanka to the COVID-19 pandemic situation, the effects of those responses on the Sri Lankan construction industry, and the contractual provisions already available in the ICTAD/SBD/02 and FIDIC 1999. The second part of the study used an empirical data collection that was qualitative in nature to further explore the above factors and determine suitable improvements to the ICTAD/SBD/02 to minimize the contractual effects of such future pandemic situations. The data was collected through twelve semi-structured interviews conducted among three case studies, of which two are building projects and one is a civil engineering project, which is a road. Experts from the contractor, employer, and consultant sides who had been involved with the project since its inception were all interviewed via the Zoom platform in the three case studies. The empirical data was highly useful in validating the literature findings and assessing new facts. Table 4 lists the interviewees' and the project's profiles. The empirical data obtained from the interviews was analysed using the manual content analysis technique.

Table 4: General information of interviewees and case studies

	Case Study A				**Case Study B**				**Case Study C**			
Project Type	Building Project				Building Project				Infrastructure Project			
Client	Private-sector client				Public-sector client				Public-sector client			
Duration	42 months				650 days				730 days			
Approx. value	Rs.11.5 Bn				Rs.2.45 Bn				Rs.3.8 Bn			
Location	Colombo District				Colombo District				Vavuniya District			
Nature	35 Floors				14 Floors				95.48 km			
Interviewee	**A1**	**A2**	**A3**	**A4**	**B1**	**B2**	**B3**	**B4**	**C1**	**C2**	**C3**	**C4**
Profession	QS	QS	Senior QS	QS	QS	QS	QS	Contract Administrator	Planning Engineer	QS	QS	QS
Industry exp. (years)	7	10	18	6	8	5	9	7	8	12	10	3

4. DATA ANALYSIS AND FINDINGS

4.1 POSITIVE EFFECTS OF COVID 19 ON THE SRI LANKAN CONSTRUCTION INDUSTRY

As the literature suggests, the COVID-19 pandemic had a huge impact on the Sri Lankan construction industry. Similarly, the data obtained from the interviews suggests that this outbreak has had both positive and negative effects on the same. The positive effects identified by the interviewees include the incorporation of technology into the construction industry at somewhat higher levels than before, which was lacking previously. Most interviewees mentioned that "digitalization of work, to a certain extent," has supported the construction industry positively in improving communication while combating the impact of COVID-19. It was found that through the adherence to health and safety aspects, workers' risk of contracting other illnesses such as the common cold and cough was significantly reduced.

4.2 NEGATIVE EFFECTS OF GOVERNMENT RESPONSES TO THE COVID-19 PANDEMIC ON CONSTRUCTION PROJECTS

The negative effects of government responses to the COVID-19 pandemic are four-fold: time, cost, quality and other aspects of construction projects. Table 5 below presents a summary of those negative effects of COVID-19.

Table 5: Negative effects of COVID 19 on the construction industry

Type of Effect	Negative Effects
Time-Related	Delay in construction programmes
	Authority delays (delay in approvals)
Cost-Related	Additional cost for health and safety
	Prolongation cost & Price escalation
	The additional cost in the resumption of work
Quality-Related	Material & labour scarcity
	Rectification work
Other	Unemployment & Sociological effects
	Less functioning supply chain

As far as the time-related effects are concerned, several categories were evident from the semi-structured interviews, which are, namely, travel delays, workforce limitations, site shutdowns, work disruption, material delays, which affected directly the construction program, and authority delays, where delays happened in approvals due to COVID 19. Therefore, these implications have negatively affected all three case study projects (i.e., the two building projects and the road project). One case study project was found to have a little reduction in productivity due to a lack of familiarity with personal protective equipment. As stated in the guidelines, the mandatory hand sanitizing process delayed the start time of one case study project on a daily basis, resulting in a significant delay in terms of a cumulative delay of one month.

When considering the cost-related effects of government responses, most interviewees agreed and explained that there was some sort of cost incurrence while adhering to them. Sometimes they were direct costs, and sometimes they were indirect costs. There were some direct costs associated with providing hand sanitization stations, promoting hand sanitizing techniques, providing personal protective equipment, and providing other additional health and safety measures stated in the new guidelines. Due to EOT, prolongation costs for site staff and contractor’s facilities were also a considerable amount. Also, costs have been indirectly affected in different ways, such as rectification work on resuming the work, unexpected price escalation in resources, additional guards, food and drink for them, care for the plant nursery plants, etc. during the curfew periods. Also, there had been sort of cost incurrence while taking actions to mitigate such negatives effects of government responses to the COVID-19 on your construction project. Geo bubble arrangement is a one method that has been used by contractors to mitigate the negative effects come from government responses.

It was found that very limited government responses have created quality-based effects on the building and civil engineering projects studied in this research. Accordingly, rectification work when resuming the work, such as removing formworks and scarcity of skilled labour, has led to a lack of workmanship. Similarly, conducting meetings adhering to health guidelines with a minimum number of participants has led to disturbances in communication. Referring to the government's temporary relief based on the Act and referring to monetary relief measures led parties to adopt alternative materials and solutions, which have affected the quality of the construction project in one or the other way. Apart from that, every interviewee's perspective was that achieving the expected quality in the project was their ultimate goal, and thus the quality should be intact for any reason.

Thus, the majority of interviewees confirmed the key challenges the industry faces are: delays in completion of the final project; disruptions in the main supply chains; uncertainty in global markets; new economic challenges; and financing difficulties for a smooth project flow, as identified by Kawmudi, et al. (2020), and they also emphasized that the contractor will incur further losses as projects are further delayed because there is no positive reaction to the cost incurrence from the employer. Thus, the data analysis confirmed that the challenges faced by the UAE construction industry due to the COVID-19 pandemic, as found by Rehman, et al. (2021), are also similarly applicable to the Sri Lanka construction industry.

4.3 APPLICATION OF EXISTING PROVISIONS OF STANDARD FORMS OF CONTRACTS TO ADDRESS THE CONTRACTUAL EFFECTS OF GOVERNMENT RESPONSES TO COVID-19 ON SRI LANKAN CONSTRUCTION PROJECTS

4.3.1 ICTAD/SBD/02 (Standard Bidding Document - Procurement of Works Major Contracts)

Almost all the clauses identified from the desk review on ICTAD/SBD/02 are applicable in addressing the effects of a pandemic situation, except for sub clauses 13.6, 17.3, and 17.4 because most interviewees stated that 17.3 and 17.4 are not applicable as the "pandemic" or "epidemic" has not been listed in the employer's risk list. As per the interviewees' understanding, the sub-clauses 20.1, 20.2 and 20.4 are applicable due to the phrase "*may include, but not limited to exceptional events*" stated **in the 2nd paragraph of** sub-clause 20.1 **of ICTAD/SBD/02**. As all the interviewees except one emphasized, "*there are no legislative changes, only the existing legislative implications are initiated.*" Therefore, sub-clause 13.6 in ICTAD/SBD/02 is found to be not applicable in addressing the contractual effects of COVID-19 responses on construction projects. As a result, the new guidelines imposed by the government cannot be regarded as an adjustment to legislative changes, despite the fact that those new guidelines have impacted construction projects in terms of time, cost, and quality, as well as both contractor and employer in a variety of ways in both civil engineering and building projects. It confirmed literature findings and the utterance of Ratnayake (2020), in a webinar conducted by the Sri-Lanka Branch of International Chapter of Australian Institute of Quantity Surveyors (AIQS) in association with the Contractors Preservation Forum, "*Imposition of new regulations under existing laws, but no changes to Acts in Sri Lanka, but new regulations.*" However, the "Coronavirus Disease 2019 (COVID 19) (Temporary Provisions) Act" does not fall under this as it is a new bill passed in parliament.

According to the interviewees, the contractor can raise claims when he considers himself entitled to any EOT or cost in connection with the contract under sub-clause 19.1 in ICTAD/SBD/02 in both civil and building projects, but they have to give proper notice and justify the claim with supporting documents. Nevertheless, it was found that, in some cases, the contractor has not been able to prove the actual time impact of COVID-19 on the project through their construction programme because of errors in the use of programming techniques in the initial programme submission, and thus delay analysis does not show the actual delay in the projects. That is a reason why some EOT claims remain unevaluated.

4.3.2 FIDIC Red Book 1999 1st Edition

Similar to ICTAD/SBD/02, FIDIC 1999 addresses the effects of the pandemic, and interviewees emphasized that the FIDIC 1999 clauses are very similar to the ICTAD/SBD/02 clauses and that most clauses have the same provisions. Accordingly, all the interviewees agreed that the sub-clauses 8.4, 19.1, 19.2, 19.4, and 20.1 apply. As per industry experts' perspective and elaborated in the desk review, FIDIC 1999 and ICTAD/SBD/02 have addressed the construction industry's related aspects and the pandemic situations to some extent. However, the implications and practice of these clauses are limited, as revealed by the interview findings. According to them, the "Force Majeure" clause is not applicable to the current "new normal condition" as per the definitions of clauses 19.1.b[3] and 19.1.c[4] sub clause which do not fulfil the conditions of the "new normal condition". "A new normal" is a state in which the economy, society, etc. settles down after a crisis, if it is different from the situation before the crisis began. It is confirmed that the bids called after the 1st wave and entered into a Contract cannot go for claims under "Force Majeure" because clauses 19.1.b and 19.1.c are not fulfilled.

Accordingly, it is clear that the impact of the Force Majeure clause in both ICTAD/SBD/02 and FIDIC 1999 has been able to address the time impact only and not the cost overruns. Accordingly, the implications of the Force Majeure clause have had a distinct approach during the first wave and after the first wave. So, all case study projects have been able to have Extensions of Time for Completion (EOT), but not the cost. Therefore, the contractors had to absorb all the risks of these additional costs, and they were not in a position to claim all the costs that occurred during the pandemic. Therefore, certain costs had to be covered under the contractor's site overhead. But there have been some instances where both parties have agreed and gone for amicable solutions to share the cost equally, and in some situations, contractors have not gone for claims; because that might harmfully affect their future contractual relationship with the employer.

4.4 POSSIBLE IMPROVEMENTS TO THE CLAUSES IN THE STANDARD BIDDING DOCUMENT (ICTAD/SBD/02) TO MANAGE UNFORESEEABLE SITUATIONS LIKE PANDEMIC SITUATIONS (COVID-19)

Interviewees suggested the following methods under three categories to address the project-related contractual effects of government responses to pandemics or similar situations in the future and deliver a quality outcome: collaborative measures, BOQ-

[3] Which (event) such party could not reasonably have provided against before entering into the Contract.
[4] Which (event), having arisen, such Party could not reasonably have avoided or overcome

related measures, and measures for the better conceptualisation of unforeseeable situations as shown in Figure 1.

Collaborative Measures	BOQ-related Measures	Measures for better conceptualization of unforeseeable situations
•Providing a guideline for implementing amicable solutions where the standard document cannot address the situation. •Appoint an impartial mediator to a contract as a dispute avoidance strategy. •Develop a mechanism to distribute time, cost and quality damages equally among parties.	•Pandemic and epidemic should be defined and included in the employer's risk sub-clause 17.3 so the burden can be passed to an insurance company. •Introducing a provisional sum in the BOQ should be defensive for both contractor and employer.	•Clauses should support cost implications as well without limiting them to time aspects. •Implement a mechanism in force majeure clause to share the cost between contractor and employer •Interpret "pandemic" and "epidemic" terms in details and stipulating under which sub-clause it should be considerd.

Figure 1: Possible improvements for the ICTAD/SBD/02

Accordingly, defining the epidemic and pandemic terms clearly and transferring the risk to an insuring company is essential to address the current issues. Finally, the data analysis suggests implementing a dispute avoidance and transparent mechanism to address pandemic and epidemic situations. It has to be developed with a risk-sharing perspective in terms of time and cost. Likewise, the implications of ICTAD/SBD/02 could finally lead to several changes in the industry.

5. CONCLUSIONS

The literature review was the main method used to identify the responses of the government of Sri Lanka to the COVID-19 pandemic situation and the effects of those responses on the Sri Lankan construction industry. Accordingly, several government responses, legislation, and acts were referred to that were trying to address the construction sector irrespective of whether they were building or civil engineering projects. The government's responses include both legal and health and safety concerns. However, among those several responses, CIDA had played a major role in the preparation of supplementary documents to support the construction industry, and the epidemiology unit and other health institutions had made those supplementary documents available to the public. Furthermore, a desk review was adopted to identify the existing provisions of ICTAD/SBD/02 and FIDIC 1999 to overcome the effects of pandemic situations.

The effects of the government's responses to the COVID-19 pandemic were further identified through an empirical data collection concerning three real-life contemporary projects (case studies) covering both building and civil engineering. Accordingly, it was identified that the major effects were recorded with respect to the time and cost-related aspects, and only a very limited number of effects were found on the quality aspects. Among several types of cost implications, prolongation cost, arrangement cost, price fluctuations, and hygiene cost were the main costs that were affecting both building and civil engineering projects.

Through the literature review, semi-structured interviews, and desk review, it was found that ICTAD/SBD/02 has more time and cost-related clauses that can be applied to deal with the effects of a pandemic situation compared to FIDIC 1999. Furthermore, the contractor has experienced significant effects from the pandemic situation, whereas the client has experienced fewer. Moreover, it was found that most of the clauses identified from the literature review and the desk review have been applied by both contracting and consulting parties in building and civil engineering construction projects, but they were not effective in addressing the whole set of effects. However, a major loophole identified in ICTAD/SBD/02 and FIDIC 1999 is the lack of provisions to address pandemic situations.

Semi-structured interviews within the three case study projects reveal key improvements needed for the ICTAD/SBD/02 under three headings: collaborative-type developments, BOQ-related developments, and measures for better conceptualization of unforeseeable situations-related developments. Accordingly, enhancing collaboration among contractors, clients, and consultants is an effective measure to mitigate the current issues in the construction sector where the standard book cannot give a specific guide. Furthermore, distinguishing between a pandemic and an epidemic is critical to dealing with the situation in a more precise manner, and the construction document-related developments were found to be essential for that. Also, research findings revealed that adaptation to the "new normal conditions" and providing facilities to the project staff, such as residential engineers, contractors' personnel, and laborers, is essential.

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AN ASSESSMENT OF MAINTENANCE COST OF RESIDENTIAL APARTMENTS IN SRI LANKA

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ABSTRACT

Buildings require maintenance for their continuous operation at a higher level through their extended life. Early prediction of maintenance costs (MC) would enable efficient maintenance and smooth operations of the buildings and thereby ensure achieving value for the investment. The effects of factors on MC provide a chance to refine the design to ensure the optimisation of MC during early design development. Thus, this study aims to analyse the MC of high-rise residential apartments along with the effects of factors influencing MC in Sri Lanka. Initially, a questionnaire survey was conducted to assess the factors' impact on the MC elements based on a 1-5 Likert scale. Then, a case study approach was employed using three high-rise residential apartments with above 30 floors located in Colombo to analyse the costs of MC elements. The data collected from semi-structured interviews and document review were analysed manually as a percentage of MC. The findings revealed that MC accounts for 30% of running costs (RC). According to Pareto analysis, 11 out of 29 sub-elements including lifts and escalators, maintenance management, repairs and replacement, and electric power and lighting contribute to 80% of MC. Further, most of the building design factors and technical factors highly affect the MC. The annual MC per GFA is about Rs. 350.00. It is expected that these findings would enable the designers to forecast the MC and focus on the relevant design and technical factors to optimise the maintenance costs of high-rise residential buildings at the early design stages.

Keywords: *Cost Components; High-rise Residential Apartments; Maintenance Costs; Maintenance Phase.*

1. INTRODUCTION

The traditional costing approach for building projects predominantly focuses on minimising initial capital cost at the expense of future costs (Kishk, et al., 2003). Despite the importance of initial capital costs, the running cost (RC) of most of the buildings exceeds 50% of the total Life Cycle Cost (LCC) (Alqahtani and Whyte, 2016). According to Alqahtani and Whyte (2016), the RC of commercial buildings account for 60-74% of LCC, whereas the RC of residential buildings accounts for 40-55% next to commercial buildings. On a slightly different note, Weerasighe, et al., (2016) indicated that the RC of Sri Lankan office buildings account for 75% and 25% of RC respectively. As Chua et al. (2018) stated, all buildings require maintenance for their continuous operation at a higher level through their extended life. The building maintenance can be considered as the

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combination of technical and administrative actions associated with ensuring the elements are in a position to perform and function in an acceptable and suitable standard (Chanter and Swallow, 2007; Pelzeter, 2007; Lateef, et al., 2010; Ali, et al., 2010). The quality of maintenance assures minimum interruption during the operation of the system (Lai and Yik, 2008). Due to higher Maintenance Costs (MC), the public ignores building maintenance value without focusing its effects on the operational phase (Lateef, et al., 2010). It is undeniable that routine maintenance plays an essential role in high-rise residential buildings (Au-Yong, et al., 2019).

During the last decade, Colombo's skyline has been dominated by a great number of high-rise apartment structures (Jayalath, 2016). In typical buildings, 80% of the RC are influenced by 20% of initial costs (as cited Weerasighe, et al., 2016). Therefore, early prediction of MC can assist in cost-related decisions and minimising subsequent future costs (Chan, et al., 2003). Masshender and Finch (1998) identified factors including building characteristics and political factors that affect MC. Subsequently, Ali et al., (2010) identified five factors influencing the MC, including the building characteristics, tenant, maintenance factors, political and other factors. Increased MC are a significant concern for the building industry (Lai and Yik, 2008). Besides every building having its unique characteristics, it requires a different degree of cost allocation and distribution for maintenance (Ali et al., 2010). Perera et al. (2016) believe that placing dominant factors influencing would assist the building managers in the budget allocation with optimum MC on each task from the early stage. Thus, this study aims to analyse the significance of MC in high-rise residential apartments in Sri Lanka.

2. LITERATURE REVIEW

2.1 FACTORS AFFECTING MAINTENANCE COSTS

MC contributes significantly to the total building cost (Boussabaine, et al., 1999). The quality of maintenance assures minimum interruption during the operation of the system (Lai and Yik, 2008). Futher to authors, 15% of the total number of elements of the Building MC Information System (BMCIS) account for 85% of total RC. Perera, et al. (2016) indicated that factors affecting MC should be recognised initially to reduce their impacts. Similarly, Ihsan and Alshibani (2018) stressed that factors should be identified to develop strategies and methods to regulate the cost, to increase its intended benefits, and enable maintenance managers to distribute limited resources efficiently. Maintenance strategy should be selected carefully considering the users' standard, budget, function, and building size (Elhag, et al., 2005).

Building characteristics are the essential operation and maintenance expense determinants (Perera, et al., 2016). The nature of the site refers to location, physical condition, services availability, resources availability and climate condition of the site affects the building MC (Cunningham, 2013). Technical factors also impact building MC (Nyayiemi, 2013). According to Nyayiemi (2009), poor workmanship leads to an increase in the cost of maintenance. Function of the building is another parameter that directly influences MC as factors including the design of the building and technology used vary depending on this (Bari, et al., 2012). A higher number of occupants will cost more to the client (Cunningham, 2013). Table 1 presents the factors affecting MC elements.

Table 1: Factors affecting MC elements

	Factors	**Maintenance Management**	**Services Management**	**Repairs and replacement**	**Cleaning**	**External works**	**Fabric cost**	**Decorations & Finishes**
Design of the building	Life time	✓	✓	✓	✓	✓	✓	✓
	Plan shape	✓	✓	✓		✓	✓	✓
	Size of the building (GFA)	✓	✓	✓		✓		✓
	Wall to floor ratio	✓	✓	✓				✓
	Degree of circulation space		✓			✓		✓
	Storey heights		✓			✓	✓	✓
	Total height of the building		✓			✓		✓
	Grouping of buildings	✓		✓				✓
	Ecstatically appearance				✓	✓	✓	✓
Nature of the site	Location							✓
	Physical condition							
	Services availability							
	Resources availability				✓			✓
	Climate condition	✓	✓	✓		✓	✓	✓
Technical factors	Technology used	✓	✓	✓	✓	✓		✓
	Workmanship	✓	✓	✓	✓	✓		✓
	Quality of materials & equipment used	✓	✓	✓				
	The durability of materials & equipment used	✓	✓	✓				✓
Tenant factors	Expectation of tenant	✓		✓	✓	✓	✓	✓
	Use of the property							
	Vandalism by the tenants							
	Delay and failure in reporting problem	✓	✓	✓			✓	✓
	Accessibility to the property							
Other factors	The function of the building	✓	✓	✓	✓	✓	✓	✓
	Number of Occupants	✓	✓	✓				
	Legislative constraints							

Adapted from: (Meng, et al., 2009; Bari, et al., 2012; Krstić and Marenjak, 2012; Nyayiemi, 2013; Cunningham, 2013; Islam, et al., 2015; Che-Ghani, et al., 2016; Shabniya, 2017).

During the early stage of the construction projects, the initial cost estimates are highly focused on the early decision-making process (Ji and Ahn, 2019). At the design stage, critical activity forecasts cost for services elements and evaluate alternative designs proposals (Aibinu, et al., 2015). It has been reported that between 70-85 % of the building which is a significant part of the total building life cycle costs, can be influenced during the design stage (Krstic and Marenjak, 2012).

3. RESEARCH METHODOLOGY

Initially, a questionnaire survey was conducted using a Likert scale to assess the impacts of factors on the MC elements. Respondents were asked to weigh the factors identified through literature review on a 5-point scale representing 1-Not at all affected, 2-Slightly affected, 3-Neutral, 4-Affected and 5-Highly affected. Then a case study approach was adopted to analyse the MC of the high-rise residential apartments in detail. Three high-rise residential apartments of above 30 floors located in Colombo were selected for the study considering different factors impacting the MC of residential apartments. Documents such as annual budget estimates, maintenance budgets, utility bills, drawings, manuals, and other cost documents were reviewed to obtain the MC details of the selected apartments. Along with this, semi-structured interviews were conducted to obtain other cost-related details and building characteristics. The interviewees included professionals who were involved in the maintenance of the selected apartments including the Project Manager, Facilities Engineer and Facilities Manager. The unique characteristics and features of the buildings were also noted. Details of MC elements were derived from New Rules of Measurement (NRM) 1 and Building Cost Information Service (BCIS) standards. The obtained data were tabulated in Microsoft excel and manually analysed in terms of cost per GIFA (m^2), cost per person, cost per unit and cost of maintenance elements as a percentage of total MC. Further, cross-case analysis was carried out considering the MC of the apartments. Weighted Mean Rate (WMR) was calculated to evaluate the factors affecting the MC. The WMR was calculated according to the formula given in Eq. 01.

$$WMR = \frac{\sum_{i=1}^{5}(x_i \times f_i)}{\sum R} \qquad \textit{(Eq. 01)}$$

Where: WMR= Mean Rating for an attribute; f_i = Frequency of responses for an attribute, x_i= Likert scale for an attribute (ranging 1 to five), $\sum R$= Total number of respondents.

In addition, Pareto analysis was selected because it reflects on potential issues and attempts to recognize areas of improvement (Tembo Silungwe and Khatleli, 2020). Typically, the results of a Pareto analysis are represented by a Pareto chart, and in ranked order, the chart represents the different variables under consideration (Talib, et al., 2010). The theory of Pareto is a mathematical approach based on the Pareto Theory that approximately 80% of the consequences arise from 20% of the reasons for certain cases (Tembo Silungwe and Khatleli, 2020). In this study, Pareto analysis identifies the significant elements that contribute to 80% of the MC in the residential apartments.

4. RESEARCH FINDINGS

4.1 QUESTIONNAIRE ANALYSIS

The questionnaire survey was administered to a sample of 37 professionals who involved in the maintenance of high-rise residential apartments and were aware of MC. Table 3 provides the basic characteristics of the respondents. As seen from Table, a total of 34 professionals with a fair distribution of professional category of Architects, Facilities Managers, Engineers, Quantity Surveyors and Project Managers responded to the survey.

Further, 50% of the sample respondents have over 10 years of experience, while remaining 50% was with less than 50%.

Table 2: Basic characteristics of respondents

Professionals	No. of Participants	Years of experience	No. of Participants
Architect	4	Less than 5 years	8
Facilities Manager	7	5 – 10 years	9
Engineer	9	10 - 15 years	5
Quantity Surveyor	10	15 - 20 years	8
Project Manager	4	20 - 25 years	4

The questionnaire responses were tabulated and WMR was calculated. The WMRs were further categorised using another scale to decide the degree of affected level. Table 3 provides the scale used to represent the affected level.

Table 3: Affected criteria based on weighted mean

Mean Value	Degree of Affected Level
$4.75 \leq x \leq 5.00$	Highly Affected factor (HA)
$3.50 \leq x < 4.75$	Affected factor (A)
$2.00 \leq x < 3.50$	Slightly Affected factor (SA)
$1.00 \leq x < 2.00$	Not Affected factor (NA)

Respondents were asked to scale the factor based on its impacts on the respective building MC elements. Factors were scaled based on a Likert scale from 1-5. The weighted mean value of each factor was used to determine its rank. The weighted mean of each factor is used to decide the affected type based on Table 3. Table 4 shows the link between the selected parameters and the MC aspects gleaned from the questionnaire survey.

Table 4: The relationship between the selected factors and the MC elements

	Factors	Maintenance Management	Service Management	Repairs and Replacement	Cleaning	External Works	Fabric Cost	Decoration Cost
Design of the building	Life time	HA	HA	HA	SA	A	A	A
	Plan shape	SA	HA	A	HA	A	HA	HA
	Size of the building (GFA)	HA	HA	A	HA	NA	A	SA
	Wall to floor ratio	HA	A	A	NA	NA	NA	NA
	Degree of circulation space	HA	HA	A	A	A	HA	HA
	Storey heights	HA	HA	HA	SA	A	NA	A
	Total height of the building	HA	HA	SA	A	A	A	A
	Grouping of buildings	A	NA	SA	SA	A	SA	A
	Aesthetical appearance	A	SA	A	HA	A	HA	HA

	Factors	Maintenance Management	Service Management	Repairs and Replacement	Cleaning	External Works	Fabric Cost	Decoration Cost
Nature of the site	Location	A	A	NA	NA	A	SA	A
	Physical Condition	SA	A	SA	NA	NA	NA	SA
	Services availability	HA	A	A	SA	A	A	A
	Resources availability	HA	SA	NA	NA	SA	A	NA
	Climate condition	SA	HA	A	A	HA	HA	HA
Technical factors	Technology used	SA	HA	HA	A	SA	SA	NA
	Workmanship	A	HA	HA	HA	A	A	NA
	Quality of material and equipment used	HA	HA	HA	A	A	A	SA
	Durability of material and equipment used	HA	HA	HA	A	NA	NA	NA
Tenant factors	Expectation of tenant	A	SA	A	A	HA	A	A
	Use of the property	HA	HA	SA	NA	SA	HA	NA
	Delay and failure in reporting problem	HA	A	HA	A	SA	NA	NA
Other factors	Number of occupants	HA	SA	HA	HA	A	NA	A
	Function of the building	HA	HA	HA	HA	HA	NA	NA
	Legislative constraints	SA	NA	A	A	NA	NA	NA

As observed from the table, most of the design variants affect MC of the building. In particular, building lifetime and plan shape were identified as highly affecting the MC while wall to floor ratio has the least impact. Similarly, nature of the site has less impact on MC compared to other factors. All the technical factors including technology used, workmanship, quality of material and equipment used and durability of material and equipment used have a high impact on services management, and repairs and replacement. Tenant factors affect most of the MC elements. Number of occupants and functionality of the building highly affect most of the MC elements. However, they have less influence on the fabric and decoration costs. Compared to other factors, legislative constraints have the least influence on MC elements. The maintenance management cost was mostly affected by most of the factors as stated in the table. The services management is highly affected by building design factors and technical factors. The repairs and replacement costs are highly affected by the total height of the building, technical factors, delay and failure in reporting problems, number of occupants and function of the building. Cleaning cost, external works, fabric cost and decoration cost were impacted by a few factors. Fabric cost and decoration cost were impacted by plan shape, degree of circulation space and aesthetic appearance.

4.2 CASE STUDY ANALYSIS

The high-rise buildings selected for the study were named AP1, AP2 and AP3 and the RC data were obtained for one year period of April 2019 to March 2020 to analyse the significance of MC elements. Table 5 presents the profile of the selected three buildings.

Table 5: Profile of the selected buildings

Details	AP1	AP2		AP3
		Tower - I	Tower - II	
Size (GIFA - m^2)	44,528	25,620	28,698	42,300
Circulation space (m^2)	3,670	2,760	3,090	4,243
Number of floors	47	33	37	45
Number of units	152	48	56	115
Total height (m)	160.9	142	131	146
Number of occupants (Nr)	600	180	220	448
Operated years	03	11		10
Orientation	North	North		South
Grouping of buildings	Detached	Attached		Detached
Type of structure	Tubular structure	Tubular structure		Tubular structure
Location	Colombo	Colombo		Colombo
Specific feature	Green certified	Twin tower		-

As all three buildings were situated in a given location, Colombo where the political, social, and environmental set-up are similar, hence, it is expected the effects of those factors; political, social, and environmental are minimal. Similarly, the impact of tenant characteristics on the cost is considered to be minimal when considering the tenants' income and affordability in luxury apartments. The operational phase maintenance management of three apartments was outsourced to specialised facilities management companies. Two of the apartments are managed by the same company while the third apartment is managed by a similar type of organisation. Therefore, almost similar maintenance procedures and standards are followed in all three apartments. Further, the impact of design and construction defects can be considered a minimum based on fewer operating years and the construction uniqueness of the apartments. The AP1 residential apartment tower consists of 152 units. AP2 has only two apartment units on each floor. AP3 includes one to four-bedroom apartment units and penthouses. Each floor includes only four apartments. All three apartments have incorporated amenities with unique features for comfortable residence in high-rise apartments.

As evidenced in Table 6, the average operating costs of apartments is 70% of the RC, while MC accounts for 30%. Table 6 presents the distribution of major MC elements as a percentage of RC in all three residential apartments. In terms of major elements of MC, services and maintenance management are the significant contributors with 14% and 5% contribution respectively. Further, the annual MC per GFA is about Rs. 350.00.

Table 6: Distribution of major MC elements as a percentage of running cost in all three residential

Cost Elements	AP1 (Rs.)	%	AP2 (Rs.)	%	AP3 (Rs.)	%
Running costs	49,693,684.00		60,019,320.00		53,820,659.34	
Operational costs	32,906,119.00	66.22%	41,898,279.00	69.81%	39,677,153.91	73.72%
Maintenance costs	16,787,565.00	33.78%	18,121,041.00	30.19%	14,143,505.43	26.28%
Services maintenance	6,587,837.00	13.26%	9,690,581.00	16.15%	6,872,505.43	12.77%
Maintenance management	2,883,000.00	5.80%	2,950,000.00	4.92%	2,571,000.00	4.78%
External works	5,047,288.00	10.16%	1,216,460.00	2.03%	1,130,000.00	2.10%
Fabric	1,119,440.00	2.25%	1,544,000.00	2.58%	1,675,000.00	3.11%
Repairs & replacement	500,000.00	1.01%	1,870,000.00	3.12%	1,000,000.00	1.86%
Cleaning	480,000.00	0.97%	680,000.00	1.13%	750,000.00	1.39%
Decoration	170,000.00	0.34%	170,000.00	0.28%	145,000.00	0.27%
Cost per m^2 of GFA		377.01	333.61		334.36	
Cost per occupant (per month)		2,331.61	3791.74		2,630.86	

4.3 PARETO ANALYSIS

The Pareto analysis was conducted on the major and sub-elements of MC represented in Table 7. According to Pareto analysis, 11 of 21 sub-elements contribute to 80% of MC. Of them, lifts and escalators account for 30% of MC while maintenance management accounts for 17% of MC. The remaining elements (9 out of 11) contribute 2% to 7% as seen from Table 7. The remaining individual elements which contribute less than 2% on average were merged and represented as other elements in the table. The other elements include other structural items, heating and ventilation, windows, plumbing and internal drainage, external finishes, fittings and fixtures, internal decoration, telecommunication and data, gas installations and external decorations. The average cost of the elements of landscaping and repairs and decoration was derived ignoring AP1 as the contribution of the respective elements is abnormally higher than in other two buildings.

According to Table 7, services maintenance accounts for approximately 47% of MC. The lifts and escalators are the primary cost accounting sub-element in-service maintenance. More than 55% of services MC is spent on lifts and escalators. The regenerative drive technology utilised in apartment AP1 generates its electricity in elevators and uses the least amount of power from the main grid. Elevators in AP1 are more cost-effective to run than conventional elevators. The intelligent sorting system incorporated into the lift programming also increases its efficiency. The regenerative drive technology and PORT have helped to reduce the building's total energy use and contribute to achieving the building's sustainability targets. AP2 includes two elevators and one service elevator in each tower. The lift access control service is outsourced to a specialised organisation. AP3 includes two elevators and one service elevator. All three elevators have been equipped with the group controller system to reduce energy consumption and waiting time.

Table 7: Distribution of MC elements

No	Cost components (Rs.)	AP1		AP2		AP3		Average cost	As % of MC	Cumulative %
		(Rs.)	%	(Rs.)	%	(Rs.)	%	(Rs.)		
	Maintenance Cost	16,787,565.00		18,121,041.00		14,143,505.43		16,350,703.81		
1	Lifts and escalators	4,016,318.00	23.92%	6,738,056.00	37.18%	3,795,500.00	26.84%	4,849,958.00	29.66%	29.66%
2	Maintenance management	2,883,000.00	17.17%	2,950,000.00	16.28%	2,571,000.00	18.18%	2,801,333.33	17.13%	46.79%
3	Repairs and replacement	500,000.00	2.98%	1,870,000.00	10.32%	1,000,000.00	7.07%	1,123,333.33	6.87%	53.67%
4	Electric power and lighting	833,126.00	4.96%	967,590.00	5.34%	1,059,500.00	7.49%	953,405.33	5.83%	59.50%
5	Repairs and decoration	1,547,288.00	9.22%	736,460.00	4.06%	630,000.00	4.45%	683,230.00	4.18%	63.67%
6	Fire detection and protection system	565,440.00	3.37%	720,200.00	3.97%	650,000.00	4.60%	645,213.33	3.95%	67.62%
7	Landscaping	3,500,000.00	20.85%	480,000.00	2.65%	500,000.00	3.54%	490,000.00	3.00%	70.62%
8	Other M&E services	415,484.00	2.47%	490,000.00	2.70%	490,505.43	3.47%	465,329.81	2.85%	73.46%
9	Internal finishes	325,000.00	1.94%	504,500.00	2.78%	540,000.00	3.82%	456,500.00	2.79%	76.26%
10	Roof structures	318,440.00	1.90%	450,000.00	2.48%	480,000.00	3.39%	416,146.67	2.55%	78.80%
11	Internal/external surfaces	250,000.00	1.49%	400,000.00	2.21%	500,000.00	3.54%	383,333.33	2.34%	81.15%
12	Other elements	1,433,469.00	8.54%	1,605,500.00	8.86%	1,677,000.00	11.86%	1,571,989.67	9.61%	

The maintenance management of all three apartments accounts for nearly 16-18% of MC and 5-6% of RC. Repairs and replacement are another critical element that contributes significantly to MC. Repairs and replacement cost in AP1 account for 3% whereas an average cost of 9% in the other two apartments. Compared to AP1, increased spending is observed in AP2 and AP3. Apartments AP2 and AP3 have nearly ten years of operational period, whereas AP1 has three years of operation. With the increased operational period, the spending on repairs and replacement works has increased. Also, from Table 4, it is noted lifetime is a highly affecting factor for repairs and replacement. Electric power and lighting cost approximately 5-8% of MC while fire detection and protection system cost 3-5% of MC. All three apartments have integrated smoke, heat and gas detector, and fire safety systems, including an automated fire sprinkler device, a firefighting hose reel wet riser system, and fire extinguishers on each floor.

As evidenced in the profile of the selected buildings, AP1 is a green-certified building. Compared to other two apartments, a significant increase is observed in the MC of external works of AP1. External works contribute approximately 10% to RC in AP1 while an average of 2% in the other two apartments. The increased percentage is observed as the result of increased expenditure for landscaping and repairs and decoration. The landscaping costs of apartments AP2 and AP3 are 3-4% whereas AP1 accounts for 21%. Repairs and decoration in AP1 account for 9% whereas the other two apartments have only 4% of the MC. Repairs and decoration consist pest control services, drains and road pavements. As the AP1 is a green-certified residential vertical garden, more cost is spent on maintaining the garden and drip irrigation system and pest control. The management has assigned a specialist landscape architect to carry out the ongoing maintenance of the green terraces of the apartments.

The maintenance of other M&E services costs nearly 2-3% of MC. All three apartments do not have records related to the expenditure of refrigeration equipment and loose appliances. Internal finishes account for 2-4% of MC. The internal finishes include three major sub-elements including wall finishes, floor finishes and ceilings. Roof structures are considered as one of the critical elements of fabric maintenance. It includes three further sub-elements covering flat, covering pitched and gutters and rainwater pipes accounting for 2-4% of MC. The cleaning cost maintenance for internal and external surfaces are more significant than the cleaning cost for windows accounting for 2-4% of MC. Figure 1 illustrates the Pareto analysis for the MC elements derived from Table 7.

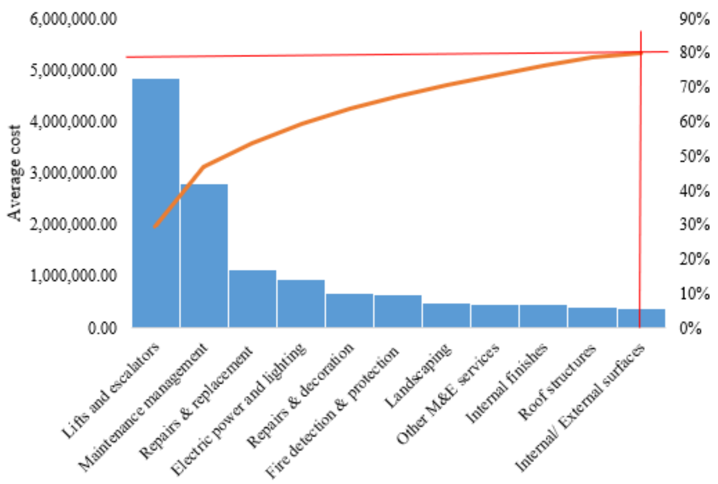

Figure 1: Pareto analysis for the MC elements

According to Figure 1, the first five elements of lifts and escalators (30%), maintenance management (17%), repairs and replacement (7%), electric power and lighting (6%) and other elements including repairs and decoration, fire detection and protection system, landscaping, other M&E services, internal finishes, roof structures and internal/external surfaces contribute to 80% of the MC.

5. DISCUSSIONS

The operating costs range from 65% to 70% of RC in the selected apartments, while MC accounts for between 30%-35% of the RC. The operational costs include insurance, utilities, administrative costs, and taxes. The service MC accounts for approximately 47% of MC and this is highly affected by the design of the building except the grouping of elements, technical factors, climatic condition, use of property and function of the building. The legislative constraints and grouping of buildings do not seem to influence the service maintenance. Maintenance management is another critical element that accounts for approximately 16-18% of RC. The factors such as plan shape, degree of circulation shape, climatic condition and lifetime of the building highly affect the MC, whereas physical condition, legislative constraints, resource availability and wall to floor ratio seem to have a slight impact. The external work is an item that has a minimal impact on the MC with nearly 7-8% contribution in a typical building whereas, the same in a green building account for about 30% of the MC. The external works are highly affected by climate conditions, expectation of tenants and function of the building. Size of the building, wall to floor ratio, physical condition, the durability of material and equipment used and legislative constraints have least or no impact on external works. The MC of repairs and replacement accounts for 7-10% in buildings with more than 10 years of occupancy and just 3% in building with 3 years of occupancy. Also, it is noted that lifetime is a highly affecting factor of repairs and replacement. Cleaning and fabric also take a small share of nearly 3-7% of MC. Further, the cost of these elements is highly dependent on plan shape and aesthetical appearance of the building.

6. CONCLUSIONS AND RECOMMENDATIONS

Maintenance is one of the significant concerns in buildings throughout the life cycle, thus the cost of it is not to be oversighted. Thus, this research has analysed the MC of high-rise residential apartments in Sri Lanka and concluded that the annual MC per GFA is about Rs. 350.00. According to the analysis, this is account for 30-35% of the RC. Services maintenance, maintenance management, external works and repairs and replacement are the critical major elements contributing over 80% of the MC in these high-rise buildings. Over 55% of services maintenance is spent on lifts and escalators. It is noted repairs and replacement costs have increased with the building lifetime. Similarly, the maintenance cost of external works is significantly higher in the green building with the increased cost for landscaping and repairs and decoration. Of the factors influencing the maintenance cost of elements, building design factors and technical factors are significant.

Service management and maintenance management are highly affected by the design of the building. Similarly, technical factors critically affect services management and repairs and replacement. In addition, climatic condition, use of the property, number of occupants and function of the building highly affects most of the MC elements. Thus, a careful focus on these factors would enable designers and investors and occupants to optimise the maintenance costs of high-rise residential buildings in the early design stages as well as during the operational stage.

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ANALYSIS OF THE CURRENT HOUSING MARKET IN COLOMBO METRO REGION TO ENHANCE THE PROSPECTIVE CONSUMER SATISFACTION

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ABSTRACT

Housing is an essential element of social development. One consumer may purchase such a house once for his/her entire lifetime. Therefore, when making a housing purchasing decision, it is intensively explored more than it is considered in purchasing other consumable products. Property developer has the responsibility of understanding the consumer behaviour. The main research problem is the lack of attention towards the analysis of the current housing market of the Colombo Metro region from the consumer perspective. An extensive literature synthesis was carried out to gather information on the general attributes of the housing market and determinants of housing supply. Furthermore, investigation on the housing demand and consumer behaviour reference to Colombo Metro region were conducted through the literature synthesis. Subsequently, case studies and a survey have been adopted to proceed with the study following the mixed research approach. Semi-structured interviews for case studies and questionnaire survey were employed as the primary data collection. The primary data analysis was conducted through manual content analysis, Relative Important Index (RII) techniques and elementary statistical analysis. The findings revealed, how the prospective consumers are considering Person, Product, Place, Price related factors when purchasing a residential property. For an example this research discovered that quick access to Colombo is the highly considered fact by the consumers. It revealed that the consumer behaviour in Colombo Metro region is different from other contexts. Therefore, carrying out a study to analyse the current housing will be very important to maximize the consumer satisfaction in house purchasing.

Keywords: *Consumer Behaviour; Consumer Satisfaction; Housing Market.*

1. INTRODUCTION

Housing is an essential element of social development, not only providing shelter and space but also leading to other material and social resources. Mainly, it impacts consumption patterns and household incomes and the future expectations of consumers (Niriellage, 2011). According to Nastaran and Ranaei (2010) housing has been an essential human necessity throughout history. Further, after the Universal Declaration of Human Rights 1948, they expressed that an essential factor of people's standard of living is measured through housing necessity. Nevertheless, internal (and international)

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migration, poverty, shortage building lands, improper infrastructure planning, and increasing urbanization led to housing, an acute problem in developing countries. Housing is considered as a normal good, and it denotes if the incomes of the household rise, the household will tend to purchase a more expensive house comprised of more facilities than the prior residence (Waddell, 2000). Niriellage (2011) expressed that the Sri Lankan government participates in taxation, expenditure, regulation amending to capital market gain while improving housing facilities for the low-income households. Housing price is impacted due to public policy law and regulations, and the government has several building codes, housing codes and zoning ordinances as main determinants of house costs (McDonald, 2012). Niriellage (2011) further explained Banking facilities are highly influenced by people to gain interest in private housing, and it lifts the housing market to a high level.

There are several researches done on consumer satisfaction of house purchasing. In the research called "Housing tenure status and housing satisfaction" (Lane and Kinesy, 1980) express the relationship between demographic factors of the tenure and house purchasing satisfaction. In that research author identified people live in different types of dwellings but the satisfaction is comparatively based on the quality of the structure of house. Research done by Muellbauer and Murphy (2008) determined that house prices are highly impact the satisfaction of the consumer. Further author stated that equilibrium of housing supply and demand will lead to affordable house price.

Kenn, et al., (2021) done research about the house quality, financial capabilities, and government policies influence on the purchasing decision of a property consumers. That research concluded that environmental factor and subjective norm factor have positive influence as well as financial factor has a negative influence on the purchasing decision. Since the consumer behaviour in Colombo Metro region is different from other contexts, carrying out a study to analyse the current housing market from the consumers perspective will be very important to maximize the consumer satisfaction in house purchasing. The aim of the study is to investigate the current housing market in the Colombo Metro region while reviewing the consumer behaviour in the housing market to suggest strategies to maximize the prospective consumer satisfaction.

2. LITERATURE REVIEW

2.1 GENERAL ATTRIBUTES OF THE HOUSING MARKET

McDonald (2012) states that housing could be identified as a consumer good and an economic asset. Therefore, it relevant to the fundamental economic analysis of consumer behaviour. Furthermore, housing comes to peoples' main achievement in their lives based on several factors. Housing is a category in the real estate field. Real estate is comprised of two main components, which are housing and commercial. The above categorization is based on the functional purpose of real estate (Vasiliene, et al., 2019). The housing market depends on several factors, and McDonald (2012) identified them as the choice of residential location, housing prices and land values, quality of life from the consumers' perspective. Location is a mandatory factor that the consumer considers due to the neighbourhood surrounding, schools, employment location, shopping, and access to transport. According to Niriellage (2011), growth of a city is measured equally by the growth of population and new buildings constructed. Due to the rapid urbanization and frequent change in the economy, people cannot achieve their housing requirements.

Furthermore, Niriellage (2011) has elaborate that the government has a massive responsibility to develop the housing market for the nation. Not only the government, both public and private stakeholders should play an important role to fulfil the requirement mentioned above.

2.2 DETERMINANTS OF HOUSING SUPPLY

Determinants of housing supply could be identified as population growth, land component and government policies. The housing market trend is always going parallel with the demographic trends. Compared to other data statistics, population data is the most reliable and high level of certainty, and the minimum assumptions have consisted of it. Research is done by Reed (2016) focused on the population trend directly impacted by the housing market. The land is a significant factor that determines the housing market (Martinuzzi, et al., 2007). Government impact in the housing market is specified in several kinds of research. In 1977, the government introduced a complete package of economic developments that changed the economic condition in Sri Lanka according to Liyanage (1997) stating that the government had planned to move with the market despite acting against it. Medagedara (1988) has indicated several factors had a direct impact on the price increase of the lands.

2.3 HOUSING DEMAND AND CONSUMER BEHAVIOUR

Consumers of real estate consider a wide range of elements. Individuals' standards, attitudes, and ambitions, as well as those of their families, businesses, government officials, and others, all influence demand for real estate (Mothersbaugh, et al., 2020). Demand for housing in the economy varies depending on consumer income, the price of other items, and, most importantly, household preferences. As a result, a consumer's decision to purchase a certain house is a critical aspect in determining housing market demand. The consumer behaviour has been elaborated as the purchasing decision of a particular product or service (Morden, 1991). Consumer as a living creature, it has very subjective desires, expectations, and attitudes. Therefore, it is mandatory to have a clear perception of consumers' characteristics and purchasing behaviours. In any housing supply firm marketing strategies is the best solution to identify it properly. Marketing strategies is basically created through marketing mix i.e., product, place, price, and promotion (4Ps). Indeed, this is a combination of elements that meets the consumer's needs providing certain values. Therefore, it can be pointed out that the consumer should be the focal point of such marketing strategy. Thus, in view of the fact, the marketing strategy should be formulated based on the consumer behaviours. Deriving from the above marketing strategy, consumer behaviour of housing market could be discussed as Person, Product, Place and Price.

2.4 IMPORTANCE OF IDENTIFYING THE HOUSING MARKET AND CONSUMER BEHAVIOUR

The ineffectual plan of land development has resulted in an uncontrolled urban sprawl. Urbanization is a central challenge in different regions of the world, and it is highly affected in densely populated regions. Smart growth and conservation efforts are important for identifying the ecosystem impacts on human activities (Martinuzzi, et al., 2007). Every individual's main intention is to obtain better houses for their living. To achieve the best status of living, the housing market trend should be identified to better the whole society. The author examined that the material living standards, health, education, personal activities, and social connection could be considered as main factors (McDonald, 2012). Consumer as a living creature it has very subjective desires, expectations, and attitudes (Mothersbaugh, et al., 2020). Therefore, it is mandatory to have a clear perception of consumers' characteristics and purchasing behaviours in housing market.

3. METHODOLOGY

Since the research problem is "how the consumers' perspective on determining factors of housing market changes from person to person?", it is putting the research in assessing opinions and behaviour perspectives, answering the questions that begins with "how". So, the most relevant approach for the first phase is the qualitative method. In the first phase, it discovers what supply and demand side determining factors are considered. Two cases in the housing market in Colombo Metro region are referred from the consumers' perspective. The housing suppliers were selected using purposive sampling since one represents as a government entity and other one as the highest market share in middle income housing supplier. This study is limited to two major housing suppliers mainly due to accessibility constraints.

In the second phase a quantitative approach based on the collected records and evidence is carried out to find the highest impacting determinant out of the above discussed factors in the first phase. Hence, this method was used to analyse the factors considered before purchasing a housing in Colombo Metro region of the prospective housing consumers. It is suitable to elaborate the consumers behaviour while focusing to an appropriate sample size. Finally, it can be determined that this research applied the mixed approach to enrich the quality of the analysis and findings while progressing with this research.

At final phase a with the data collected from the questionnaire survey a relationship study was carried out to determine relation between each determinant factors and income levels.

4. FINDINGS AND ANALYSIS

4.1 CASE STUDY ANALYSIS

Table 1 presents the stakeholders that were interviewed using a semi-structured interview method to identify the supply and demand side factors of housing market from two cases.

Table 1: Profiles of selected organizations under cases

Organization	Respondent	Experience	Description
A	C1R1	5 years	Project Architect in Middle income housing program
	CIR2	20 years	Assistant Director - Real Estate Development Division
	C1R3	16 years	Assistant Director - Colombo Metro region planning Division
B	C2R1	6 years	Assistant Architect
	C2R2	5 years	Assistant Marketing Manager
	C2R3	6 years	Quantity Surveyor

In the case study analysis, it is summarized that, both cases are not much concern about the population growth rates. Further, private sector housing developer mentioned that it changes due to externalities. Under land component, government housing supplier said that they select most commercially viable location they are vesting the lands and centrality is considered. Private sector housing supplier said that context analysis is done and "New City Concept" which provides all the facilities within the boundary of the housing complex. They also considered the high future value of a particular land. Regarding the government policies, government sector housing supplier stated that PPP projects are in practice. Most of the projects are BOI projects. Abide by Condominium act; EIA, PPC adhering to the building regulations enacted by UDA; Less time for approvals. Even private sector housing supplier stated same, and they mentioned that time is higher for approvals for their projects.

4.2 QUESTIONNAIRE SURVEY ANALYSIS

The questionnaire survey was distributed among 120 prospective housing consumers in Colombo Metro region. The collected data was analysed using SPSS version 20 to derive the primary objective of the research. All the respondents were asked to rank the consideration scale while purchasing a built residential property (refer Table 2).

Table 2: Ranking of determinants according to the RII values

Determinant of house purchasing decision	Category	RII	Rank
Quick access to Colombo city	Place Related	0.832565284	1
Price of property	Price Related	0.814132104	2
Recreational facilities (gym, swimming pools, garden area)	Product Related	0.807987711	3
Proximity to shopping malls	Place Related	0.806451613	4
In-built amenities (central Gas system, Solar PV, Electrical vehicle charging)	Product Related	0.795698925	5
Proximity to hospital	Place Related	0.795698925	6
Quality of construction	Product Related	0.78801	7
Size of living room, bedrooms, kitchen, and dining	Product Related	0.746543779	8
Proximity to leading schools	Place Related	0.740399386	9
Safety/crime rate	Place Related	0.715821813	10
Design	Product Related	0.700460829	11
Flexibility of agreements by the developer	Product Related	0.668202765	12
Easiness of taking loans from banks	Price Related	0.657450077	13
The time is taken to pay back the loan	Price Related	0.657450077	14
The status level of neighbours	Place Related	0.655913978	15
Legal environment	Product Related	0.649769585	16
Increment of property value in future	Price Related	0.606758833	17
Astrological aspects of a house	Product Related	0.360983103	18

People who are willing to purchase a property with the main intention of quick access to Colombo Business District. Next in order, the proximity to hospital, quality of construction, size of living room, bedrooms, kitchen, and dining, proximity to leading schools, safety/crime rate, design of the property, flexibility of agreements by the developer and easiness to take bank loans are considered before a purchase of a house in Colombo metro region. Least considered determent of house purchasing is the astrological aspects of a house. It shows the least RII value comparing to other determinants. Most of the respondents are not much considered in astrological aspect in already built properties before purchasing them as residential properties.

4.3 RELATIONSHIP BETWEEN PRODUCT, PRICE AND PLACE RELATED FACTORS AND PROSPECTIVE CONSUMER'S CONSIDERATION

Consideration of the Product, Price, and Place related factors before purchasing a residential property is varying according to the respondents' demographic attributes such as income, age, experience on the housing market, etc. According to the questionnaire survey results, relationship between product related factor vs the prospective consumers' income is investigated using elementary statistical analysis method. Because income is a crucial factor for prospective consumers' housing decision. For the analysis, following statements are considered. The main three factors; "Product, Price & Place" are considered on the perspective of a fourth factor of "Person". Table 3 presents the house purchasing facts derived through literature review.

Table 3: House purchasing facts derived through literature review

		Statement
Product related	01	I would consider the design before I purchase a residential property
	02	I would consider the in-built amenities (central Gas system, Solar PV, Electrical vehicle charging) before I purchase a residential property
	03	I would consider recreational facilities (gym, swimming pools, garden area) before I purchase a residential property
	04	I would consider astrological aspects of a house before I purchase a residential property
Place related	05	I would consider the quick access to Colombo city before I purchase a residential property
	06	I would consider the status level of neighbours before I purchase a residential property
	07	I would consider the Safety/crime rate before I purchase a residential property before I purchase a residential property
Price related	08	I would consider the easiness of taking loans from banks before I purchase a residential property
	09	I would consider the increment of property value in future before I purchase a residential property

Figure 1 represents the people's agreement towards whether the design is considered or not before a housing purchase. Considering the portion, who strongly and averagely agreed that housing design matters, the bar chart is created showing their income levels. So, Figure 1 explains, that with the increase of the income, people tend to consider the design of the house more before purchasing it.

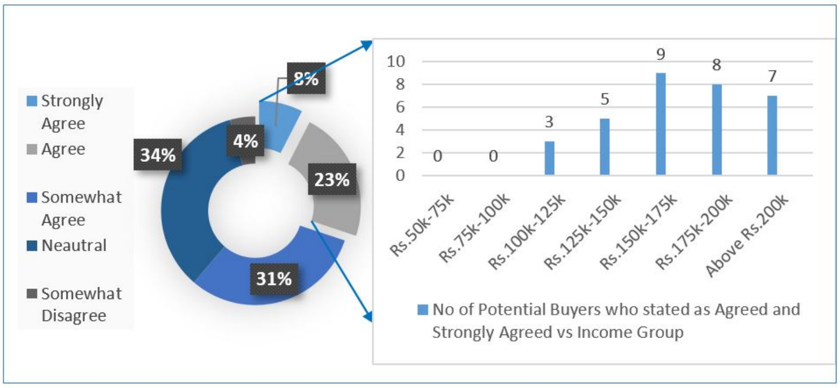

Figure 1: Relationship between the income and consideration of the design before purchasing a residential property

Table 4 presents the percentage of prospective housing consumers who "Agreed" or "Strongly Agreed" on Statement 01.

Table 4: Percentage of prospective housing consumers who "Agreed" or "Strongly Agreed" on Statement 01

Single Family detached House	Single Family detached House in gated Community	Apartment	Apartment in mixed development
40.74%	37.03%	11.11%	11.11%

Significant relationship which shows most of the respondent who strongly agreed or agreed on the above statement are selected their house type as single family detached house or single family detached house in gated community. It's a clear indication that people love to lift their image on their own social circle. Furthermore, people who selected apartments as their resident, are not much concern about it. The reason may be their intention of selecting it as a short-term option.

Figure 2 shows the relationship between the income and quick access to Colombo city before purchasing a residential property.

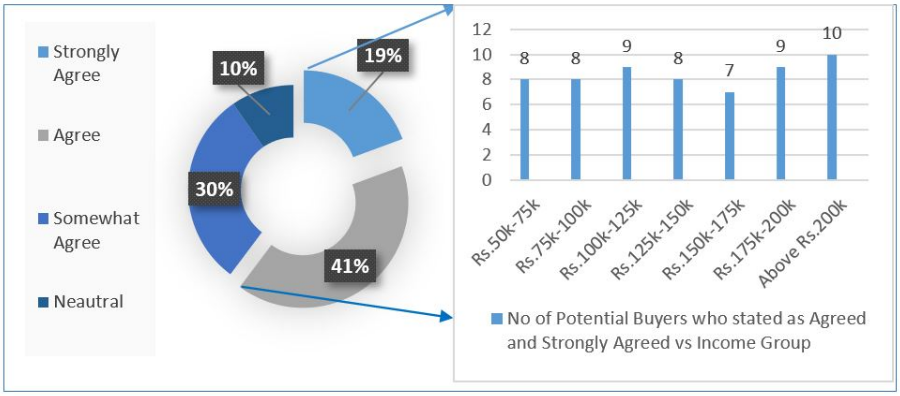

Figure 2: Relationship between the income and quick access to Colombo city before purchasing a residential property.

There is no significant relationship between income and willingness to get quick access to Colombo city. This shows all the respondents are very much need to get quick access to Colombo from their own residence. It is very clear that most of the people are highly concern about the quick access to Colombo city from their resident.

According to Figure 3, when the income is lower, people tend to go for loans. Strongly agreed 36% and agreed 36% people are from the total sample. As it emphasizes according to the bar chart, high number of prospective consumers in the monthly income range between Rs.75,000-100,000 considered highly about the easiness of taking loans. Table 5 shows that nearly 60% from the people who "Agreed" or "Strongly Agreed" on Statement 08, are employed in government sector. It indicates that government sector people mostly looking for housing loans.

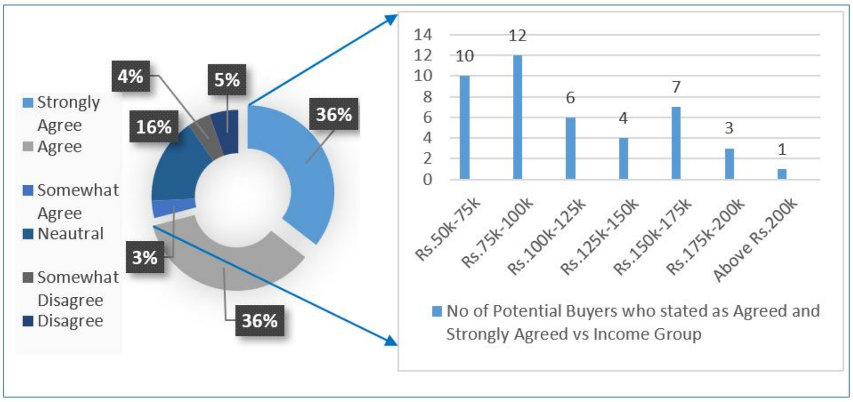

Figure 3: Relationship between the income and consideration of easiness of taking loans before purchasing a residential property.

Table 5: Percentage of prospective housing consumers who "Agreed" or "Strongly Agreed" on Statement 08

Employed in government sector	Employed in private sector	Self employed
59.37%	21.21%	25%

Table 6 shows that strategies to enhance the prospective consumer satisfaction while purchasing a residential property.

Table 6: Strategies to enhance the prospective consumer satisfaction

	Strategies
Product related	In Apartment designing, increasing the usable space while maximizing the building efficiency should be concerned.
	Customization according to the consumer's preferences before constructing detached houses.
	In apartments Cost effective in-built amenities including sustainable energy sources could be used.
	Consider new recreational facilities such as Club house, BBQ area, Kids play area, Spa and viewing decks.
	Due to lack of space in City centre, it's better to find suitable location, that already has the locational advantage of recreational facilities in closer proximity
Place related	Most suitable location for residential property is 5km-10km from the Colombo city centre

	Strategies
	If the location is distance is exceeding 10km from the city centre, it should be near to an express way Consider the status level of the neighbourhood in creating detached houses more than it considered in apartment creation Access control including multi layered commercial access control system with perimeter security CCTV could be used.
Price related	Focused on materials with better quality to increase the life cycle of the property Higher concern on the selection the property location because increment property value is mainly based on the location.

5. DISCUSSION

Housing is a real estate product which is not a homogenous product (Calem, et al., 2010). Hence, housing market is not a perfectly competitive market. Therefore, housing market is imperfect and due to this imperfection real estate market in Sri Lanka prices are distorted and lands comprising with other resources are misallocated. Every individual's main intention is to obtain better houses for their living while satisfying their buying decision. Due to the rapid urbanization and frequent change in the economy, difficulty of fulfilling housing requirement was discussed (Niriellage, 2011). Focusing on the major determinants of housing supply which are population growth, land component and government policies had identified. Achieving this objective at first through the literature review was beneficial, because it leads the path to enhance the consumer satisfaction of buying residential property.

In the economy demand for housing is varying due to level of income of the consumers, price of other goods and specially the taste of households. Therefore, consumers buying decision of a particular property is very important factor which determine the housing market demand (Marthya, et al., 2020). Furthermore, the consumer behaviour of housing market could be discussed as Person, Product, Place and Price (4Ps). impact of the determinants of housing supply in Colombo Metro region is discussed while conducting semi structured interviews with professionals in two leading property developing firms. However, comparing two cases, UDA occupied more lands in Colombo Business District while private developer focused on the sub urban areas. UDA attempts to fulfil the housing requirement of middle-income people rather than totally considering the profit maximization and private developer give main priority to profit maximization. In the analysis, consumer behaviour is discussed as two property developers' perspectives. From the RII analysis, first consideration of the consumers' is quick access to Colombo city while purchasing a residential property. The 2nd highest consideration is price of the property and 3rd one is the recreational facilities. Relationship between income and the house purchasing determinants consideration level were examined through an elementary statistical analysis. In the analysis, it was identified that design consideration is increasing with the consumer's income is increasing and single detached houses have more design consideration than apartment construction. Another current trend identified is prospective consumers almost equally considered in-built amenities despite of their income and it is mainly focused on apartment construction. Consumers who selected city centre as the location highly considered the recreational facilities. Regarding the price related factors, it was proven that prospective consumers who are working in government sector, highly considered on obtaining loan while purchasing a residential property. However, as property developers are not much concern on above facts lead to dissatisfaction of prospective consumers while purchasing a residential property according to the findings.

6. CONCLUSIONS

This study focusses key factors affecting the housing market supply and the demand side represents the determinants of consumer behaviour. Through the literature review, four main determinants of housing supply have been identified: population growth, land, and government policies. Determinants of consumer behaviour has been categorized under four main sections as Person related, Product related, Place related and Price related factors. Moreover, since the impact identification of supply side factors and fulfilling the determinants of consumer behaviour is a necessity to enhance the consumer satisfaction. Therefore, following strategies could be applied to maximize the consumer satisfaction of house purchasing in Colombo Metro region. The contribution to the research direction is the impact it could make on brokers, real estate agents, planners and any stakeholder related to construction field to take informative decision.

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APPLICABILITY OF PUBLIC-PRIVATE PARTNERSHIP TO OVERCOME THE CHALLENGES ENCOUNTERED BY PUBLIC SECTOR BUILDING PROJECTS IN SRI LANKA

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ABSTRACT

Public-Private Partnership (PPP) is a connection between public sector and private sector for a long duration with the aim of producing public services. PPP provides a mechanism for governments to bridge the supply-demand gap by developing new facilities in the construction industry. It is an extensive necessity for the Sri Lankan context due to the declining position in economic growth over the past years. Since PPP is already being practiced in Sri Lankan infrastructural projects, it is essential to investigate the ability of PPP to improve the public sector building projects (PSBP) in Sri Lanka (SL). An extensive literature synthesis was carried out to identify the PPP approaches and challenges encountered by PSBP. The challenges encountered by PSBP were validated and updated by conducting a semi-structured preliminary interview to comply with the Sri Lankan context. A questionnaire survey was conducted to identify the ability of PPP approaches to overcome the challenges in PSBP. Data analysis was done by conducting the Relative Important Index (RII) technique. The findings revealed that PPP has a high ability to overcome the challenges encountered by public sector building projects. Therefore PPP can be recommended as a procurement strategy for PSBP in SL.

Keywords: *Approaches; Building Projects; Challenges; Partnering; Procurement*

1. INTRODUCTION

According to the statistics of the Central Bank of Sri Lanka (2020), the country was in a position of declination in economic growth throughout the past three years. Additionally, Ramachandra, Rotimi and Rameezdeen (2013), stated that the construction industry and the economy of the nation have a considerable relationship. Therefore, it can be concluded that successful construction projects will have an effective impact on Sri Lanka's economy in an effective manner. However, according to Myers (2005), the construction industry is defined by its activities such as supplying building materials,

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manufacturing machinery, manufacturing building product components, operating sites, initiating new projects and assembling. That process of obtaining goods and services was known as procurement (Cartlidge, 2009).

According to Mathonsi (2012), the procurement system is a key factor that determines the success or failure of a project. Therefore, it would be best to apply the procurement method as a strategy to ensure the success of the project. However, a procurement method with transparency and competency will lead to effective project completion (Hardcastle, et al., 2005). The partnering of the public and private sectors for the purpose of designing and managing construction projects for a specified time period was known as PPP (Sharma, Bindal and Cantt, 2014). Additionally, in PPP, the private sector assists the public sector services by providing funds and providing leadership (Macdonald and Cheong, 2014). Patil (2017) reported PPP as an alternative option for public sector infrastructure development. Further, Patil (2017) stated that PPP provides a mechanism for governments to bridge the supply-demand gap by developing new facilities in the construction industry, which is currently the most important factor in the Sri Lankan context. Hence, the most of the resources were reported on improving infra-structure projects through public private partnership, it is important to investigate whether the application of same theory for Public sector building projects will increase the viability of projects. Due to the lack of researches on improving PSBP by applying public private partnership procurement, it is crucial to review ability of public private partnership to overcome the challenges encountered by PSBP prior to the implementation of PPP as a procurement strategy in building projects.

2. LITERATURE REVIEW

2.1 PUBLIC PRIVATE PARTNERSHIP (PPP)

Cartlidge (2009) defined PPP as a connection between the public and private sectors for a long duration with the aim of producing public services or infrastructure. Moreover, Allard and Trabant (2008) defined PPP as a "marriage" between public sector and private sector tasks for a long duration to optimize the use of public funds and enhance the quality of services generally provided by the public sector. In addition to that, according to Macdonald and Cheong (2014), PPP is a contractual arrangement between the private sector and the public sector where the private sector is obliged to deliver a public sector facility or service by funding or operating the project. Similarly, the PPP concept facilitates the public and private sectors' organizing of long-term alliances for producing goods and services (Kang, et al., 2019). The development of PPPs improved resource availability, sustainability, and efficiency in public services such as transportation, water, energy, health, and telecommunication (Babatunde, et al., 2014). Kang, et al. (2019) reported that most governments around the world have adopted PPP. In particular, developing countries such as Asian and African countries have started to believe in the PPP concept to develop infrastructure projects (Kang, et al., 2019). However, as noted by Babatunde, et al. (2014), the PPP projects were designed with attentive consideration within the project implementation.

2.2 CHARACTERISTICS OF PPP

Characteristics of PPP were identified from different sources as stated in Table 1.

Table 1: Characteristics of PPP

Characteristics	1	2	3	4	5	6	7	8	9	10
Private Sector Participation	√	√	√		√		√		√	
Value for Money (VFM)	√	√		√				√		
Certainty of outcomes	√	√					√			√
Innovation	√			√		√	√			√
Work Planning and Organizing		√							√	
Optimisation of life cycle cost				√					√	
Risk sharing		√	√	√	√	√	√		√	
Responsibility Sharing		√	√		√		√			√
Resources Sharing		√			√		√		√	√
Improve Level of delivering the Service	√		√							
Transparency		√	√		√		√			

1; (Akintoye, Liyanage and Renukappa, 2011), 2; (Akintoye, et al., 2003), 3; (Allard and Trabant, 2008), 4; (Boussabaine, 2007), 5; (Cheung, Chan and Kajewski, 2012), 6; (Chinyere and Lin, 2008), 7; (Kang, et al., 2019), 8; (Kurniawan, Mudjanarko and Ogunlana, 2015), 9; (Leiringer, 2006), 10; (Macdonald and Cheong, 2014)

2.2.1 Private Sector Participation

According to Allard and Trabant (2008), one of the main unique characteristics of PPP is the relationship between the private sector and the public sector, which was identified as a "marriage" between both sectors during the project lifetime.

2.2.2 Value for Money (VFM)

Hardcastle, et al. (2005), reported that one of the major aims of PPP is to achieve VFM. Leiringer (2006), stated that PPP motivates actions that facilitate the VFM during the project life cycle. United Nations Economic Commission for Europe - UNECE (2008), mentioned that PPP achieves VFM by delivering the projects at a lower cost, with a higher level of service, and reducing risk. Similarly, according to Leiringer (2006), there is a huge impact on VFM due to the risk transfer.

2.2.3 Certainty of Outcomes

Due to the strong encouragement for on-time and on-budget project completion, private sectors have mostly focused on the successful completion of the projects as soon as possible within the allocated budget (UNECE, 2008). Similarly, Asian Development Bank (2020), stated that PPP projects are highly motivated to achieve desired outcomes.

2.2.4 Innovation

UNECE (2008), explained that PPP has high potential for innovations due to the combination of skills and motivations of the public and private sectors. In particular, technological innovations can be adopted due to the long duration of the projects

(Leiringer, 2006). Moreover, Yuan, Skibniewski and Li (2008), reported that as a result of compatibility and consistency between two parties, it may lead to design innovations.

2.2.5 Work Planning and Organizing

The Public-Private Infrastructure Advisory Facility Organization - PPIAF (2009), argued that projects with long durations have the capability of adopting and maintaining proper planning and organizing procedures. According to Yuan, Skibniewski and Li (2008), proper planning in PPP projects results in improved outputs.

2.2.6 Optimisation of Life Cycle Cost

Due to the involvement of investment, maintenance, and operation tasks in PPP projects, there should be a well-balanced expenditure throughout the project (PPIAF, 2009). According to Hardcastle, et al. (2005), project costs, quality, management, and schedules are the main factors that affect the life cycle cost. Moreover, innovation concepts are mainly occurring to optimise the life cycle cost of projects (Javed, Lam and Chan, 2013).

2.2.7 Risk Sharing

According to the the World Bank (2014), risk should be transferred to the party that is capable of handling it at the highest level. Therefore, the main characteristic of PPP is appropriate risk allocation (Akintoye, et al., 2003). However, according to Kang, et al. (2019), the majority of the risk was allocated to the private sector. Anyhow, the risk allocation differed according to the form of PPP (Sharma, Bindal and Cantt, 2014).

2.2.8 Responsibility Sharing

Macdonald and Cheong (2014), identified that appropriate responsibility sharing in PPP projects may guide to successful project completion over a long period of time. According to Rocco and Plakhotnik (2009), and Irimia-Diéguez and Oliver-Alfonso (2012), the responsibility of design, management, financing, and maintenance varied with the degree of involvement in the public sector and private sector of different PPP models.

2.2.9 Resources Sharing

Akintoye, et al. (2003), argued that both resources and risks were shared among public and private sector parties. Similarly, Akintoye, et al. (2003), stated that within PPP project procedures, public sector and private sector resources were combined. According to Kang, et al. (2019), PPP projects achieve the best skills and human power through the sharing of private sector resources.

2.2.10 Improve Level of Delivering the Service

The PPP concept was improved for the delivery of public services (UNECE, 2008). According to the URT (2009), PPP is one of the main viable methods to deliver a good service to end users. In order to minimize the risks, the private sector leads to improving the services delivered through the public sector (Zhou, et al., 2013).

2.2.11 Transparency

According to Macdonald and Cheong (2014), PPP projects have transparency in the tasks of the partnership and in the roles of each partner. In addition to that, Miranda (as cited in Akintoye, Liyanage and Renukappa, 2011), reported that due to public sector involvement, there is considerable transparency in the PPP process.

2.3 CHALLENGES ENCOUNTERED BY PUBLIC SECTOR BUILDING PROJECTS

Challenges encountered by public sector building projects were identified in Table 2.

Table 2: Challenges encountered by public sector building projects

Root cause	Source
Financial Issues	(Ferdous, et al., 2019)
	(Riazi and Lamari, 2013)
	(Umar, 2018)
	(Silva, Rajakaruna and Bandara, 2008)
	(Kosala, Francis and Sirimewan, 2021)
Changes in Government Policies	(Silva, Rajakaruna and Bandara, 2008)
	(Yap and Cheah, 2020)
	(Riazi and Lamari, 2013)
	(Madanayake, 2015)
	(Staples and Dalrymple, 2007)
Lack of Technology usage	(Yap and Cheah, 2020)
	(Amusan, et al., 2018)
	(Sha'ar, et al., 2017)
Poor Management and Coordination	(Azis, et al., 2012)
	(Mbala, Aigbavboa and Aliu, 2019)
	(Umar, 2018)
Lack of Research and development	(Silva, Rajakaruna and Bandara, 2008)
	(Riazi and Lamari, 2013)
Resources shortage	(Tahir, et al., 2019)
	(Sha'ar, et al., 2017)
	(Issa, 2013 cited in Madanayake, 2015)
	(Silva, Warnakulasuriya and Arachchige, 2018)
Less Safety concerns	(Issa, 2013 cited in Madanayake, 2015)
	(Silva, Rajakaruna and Bandara, 2008)
Lack of Training and development	(Riazi and Lamari, 2013)
	(Ferdous, et al., 2019)
	(Tawalare and Laishram, 2020)
Social issues	(Riazi and Lamari, 2013)
	(Silva, Rajakaruna and Bandara, 2008)
Lack of skill levels	(Umar, 2018)
	(Silva, Warnakulasuriya and Arachchige, 2018)

Since the PPP characteristics and Challenges encountered by the building projects were listed in the Literature, it is essential to validate the challenges according to the Sri Lankan context and investigate the ability of each PPP characteristic to overcome the identified challenges.

3. METHODOLOGY

This research uses the questionnaire survey research strategy to achieve the research aim of reviewing the ability of PPP approaches to overcome the challenges encountered by public sector building projects in Sri Lanka. Thirty-one (31) professionals who had experience in PPP projects and building projects in SL responded to the questionnaire survey. They were reached through the snowball sampling method. In this dissertation, RII value analysis (refer Eq. 01) was mainly used to rank the PPP approaches under each challenge in PSBP in SL according to their contribution to overcoming the challenges.

$$RII = \frac{\sum W}{A\,(N)} \qquad \textit{Eq. 01}$$

Where, W = Weighting is given to each factor by the respondent; A = The highest weight in the research; and N = Total number of respondents.

Challenges encountered by public sector building projects were identified in the literature and validated by conducting a preliminary interview to validate the challenges to comply with Sri Lankan context. Four preliminary interviews were conducted with professional quantity surveyors who have experience in PSBP in Sri Lanka. Experts for preliminary interviews were selected only by representing industry practitioners. The Profile of the Interviewees is concluded in Table 3.

Table 3: Details of the interviewees

Interviewee ID	Designation	Experience	Qualifications
PI1	Quantity Surveyor	10 years	BSc (Hons) Construction Engineering
PI2	Quantity Surveyor	11 years	BSc (Hons) QS, MQSi
PI3	Quantity Surveyor	12 years	BSc (Hons) QS
PI4	Procurement executive	16 years	Charted QS, BSc (Hons) QS, MSc (CPM) MRICS, MAIQS

4. FINDINGS AND DISCUSSION

4.1 CHALLENGES ENCOUNTERED BY PUBLIC SECTOR BUILDING PROJECTS IN SRI LANKA

In the literature synthesis, challenges to the PSBP were identified and they were grouped under their root causes. According to the literature synthesis, financial issues, poor management and coordination, skill shortage, resource shortage, government policies, social issues, lack of research and development, and safety issues were identified as challenges. Identified challenges were validated to comply with the Sri Lankan context using Preliminary Interview. Anyhow, PI1 stated that "*There is an adequate skilled human force in the Sri Lankan construction industry. Therefore, according to my view, there is no skill shortage.*" Therefore, a skills shortage cannot be considered as a significant challenge to PSBP. Further, PI2, PI3 and PI4 also confirmed that Sri Lanka has a strong human force which was skillful in the construction field. Therefore, challenges to the PSBP were concluded to financial issues, poor management and coordination, resource shortages, changes in government policies, social issues, lack of research and development, Lack of Training and development, and safety issues.

4.2 ANALYSIS OF THE ABILITY OF PPP APPROACHES TO OVERCOME THE CHALLENGES IN PSBP IN SRI LANKA

The ability of each PPP approach to overcome the challenges had been assessed in the questionnaire survey. The level of ability to overcome the challenges was tested on the five-point Likert scale, which was indicated as 1 - "Very low," 2 - "Low," 3 - "Medium," 4 - "High," and 5 - "Very high". Since there are five scales, RII value interpretation was done by dividing the 0 - 1 in to five levels (refer Table 4).

Table 4: RII value interpretation

RII Value	Interpretation (level of ability)
0 – 0.200	Very Low
0.200 – 0.400	low
0.400 – 0.600	medium
0.600 – 0.800	High
0.800 – 1.000	Very high

According to the ratings, the RII value was calculated (refer Tables 5 and 6). RII values between 0.6 and 0.8 were interpreted as having high ability, while RII values between 0.8 and 1 were interpreted as having very high ability.

Table 5: Ability of PPP approaches to overcome the challenges encountered by public sector building projects in Sri Lanka (part 1)

Challenges \ PPP Approach	Private Sector Participation	Best Value for Money	Optimisation of LCC	Resource Sharing	Risk Sharing	Certainty of Outcomes
Financial Issues	0.8600	0.8533	0.8400	0.8400	0.7933	0.7800
Changes in Government Policies	0.7533	0.7466	0.7000	0.7533	0.8066	0.7666
Lack of Technology usage	0.7533	0.7600	0.7000	0.7733	0.7000	0.7666
Poor Management and Coordination	0.7000	0.6800	0.6800	0.7866	0.7633	0.6800
Lack of Research and development	0.7333	0.7800	0.6533	0.7333	0.6533	0.6800
Resources shortage	0.7600	0.7200	0.8133	0.9000	0.7200	0.6666
Less Safety concerns	0.6400	0.6733	0.7133	0.6600	0.8600	0.7133
Lack of Training and development	0.7600	0.7333	0.5800	0.6800	0.6600	0.6733
Social issues	0.5733	0.7000	0.7000	0.6800	0.6933	0.7666

Table 6: Ability of PPP approaches to overcome the challenges encountered by public sector building projects in Sri Lanka (part 2)

Challenges \ PPP Approach	Improve Level of Delivery of the Service	Work Planning and Organisation	Responsibility Sharing	Innovation	Transparency
Financial Issues	0.7733	0.7533	0.7400	0.6800	0.6333
Changes in Government Policies	0.7866	0.8136	0.8066	0.7600	0.7000
Lack of Technology usage	0.7866	0.8133	0.7333	0.8066	0.7000
Poor Management and Coordination	0.7933	0.8933	0.8266	0.7466	0.8000
Lack of Research and development	0.8066	0.7333	0.7000	0.8400	0.5933
Resources shortage	0.7533	0.7800	0.7133	0.8066	0.6133
Less Safety concerns	0.7400	0.8600	0.7600	0.7666	0.6733
Lack of Training and development	0.7600	0.8000	0.7533	0.8133	0.6533
Social issues	0.8866	0.7066	0.7066	0.6933	0.8466

Financial issues in PSBP in SL can be overcome mainly by "private sector participation". According to the literature review, the PPP mechanism introduces private sector capital to the government sector, which helps to overcome the capital shortage faced by the Sri Lankan government in the construction industry. Secondly, the "best value for money" contributes to overcoming the financial issues. Value for money is a key factor in measuring the economic effectiveness of a project. Therefore, having the best VFM through PPP will enhance the economic effectiveness of a project. Thirdly, "optimisation of life cycle cost" and "resources sharing" are ranked as the PPP approaches to overcome the financial issues in PSBP in SL. Innovation and investment introduced with the PPP cause well-balanced expenditure on a project. Therefore, it helps optimize the LCC of a project. Furthermore, in the literature review, PPP was formed upon the concept of resources, risk, and reward sharing, which contributed to overcoming the financial issues occurring in a project.

As mentioned in Tables 5 and 6, "work planning and organisation," "risk sharing," and "responsibility sharing" are the three most contributing PPP approaches to overcome the government policy changes in PSBP in SL. According to the literature review, longer-duration projects, such as PPP projects, have a greater capacity for proper work planning and organization. In the event of a government change, the project can be continued according to plan without any interruption. The risk is transferred to the private party who is capable of bearing it. Even though government and policy changes have occurred, due to the risk-bearing of the private party, they can continue the project. Projects with long durations can be survived with responsibility-sharing among the parties. Because even if the government changes, a private party can continue the project by fulfilling their responsibilities. So, the above three approaches have a very high ability to overcome the challenges occurring due to government policy changes. Among the eleven PPP approaches identified under Table 1, two main approaches have a very high ability to improve the usage of technology in PSBP in SL. Those two approaches are "work planning and organization" and "innovation." Work planning and organization are main factors in long-term duration projects, which encourage workers to use more technology to do proper work planning and organization. PPP enables the opportunity for new technological innovation in the project. Therefore, innovation is one of the most contributing approaches to enhancing the technology usage in PSBP.

According to Table 5, poor management and coordination can be overcome mainly by "work planning and organising," "responsibility sharing," and "transparency" provided by the PPP procurement method. Longer-duration projects have a greater capacity for proper planning and organization. With the PPP approach, a project can achieve best work planning and organizing with its long-term duration to overcome the existing poor management and coordination. Secondly, responsibility sharing contributes to overcoming poor management and coordination. It is because of the two parties' involvement that encourages us to improve the management and coordination within the project procedure. Thirdly, the transparency introduced with the PPP may help to improve the management and coordination. Because the transparency enhances the necessity of proper management and coordination between the parties involved in the project. Tables 5 and 6 demonstrated that "innovation" and "improving the level of delivery of the service" are the main contributing factors to overcoming the challenges that occurred due to a lack of research and development. Innovation leads to alternative options within the project process, which will be a main reason for implementing research and development. Improvement of the delivery process may be initiated along with the new research and development. Therefore, while improving the delivery of service, research and development will also be improved. Therefore, the above-mentioned PPP approaches have a high ability to improve research and development in PSBP.

According to Tables 5 and 6, "resource sharing," "optimisation of lifecycle cost," and "innovation" have a high ability to overcome the resource shortage in PSBP in SL. PPP facilitates the ability to share resources between the public and private sectors. When there is a resource shortage, there are two parties to resolve the shortage. Moreover, optimisation of LCC will be done by well-balanced investment, maintenance, and operations where the resource shortage can be identified at the prior stage and the necessary effort put into it to resolve it. As the third approach, innovation will initiate alternatives and new technological solutions to a resource shortage. Therefore, innovation is also one of the main approaches to overcome the resource shortage in PSBP in SL. According to Table 5, "work planning and organisation" and "risk-sharing" have a high ability to overcome the challenges that occur due to fewer safety concerns in a project. PPP is initiated along with work planning and organizing, where the lean principles are applied. Therefore, the planning and organizing have more potential to improve the safety concerns of a project. Furthermore, risk sharing will be another PPP approach to focus on safety concerns when the construction is going on. Because, PPP transfers the risk to the best possible party to bear it. Therefore, each party will be more concerned about safety issues. So that the planning, organizing, and risk sharing will contribute to improving the safety concerns within a PSBP in SL.

Further, "innovation" and "work planning and organisation" have a high ability to overcome a lack of training and development. PPP has an innovative approach where more training and development are needed. Moreover, proper work planning and organizing needed more training and development in relevant areas. Therefore, innovation and work planning and organizing encourage the training and development of a project". Improve the level of delivery of the service" and "Transparency" have a high ability to overcome social issues in PSBP in SL. PPP is one of the most viable methods to deliver a service to the end users. Therefore, it can reduce the social issues that arise against PSBP. Moreover, transparency provides more information about the project. So the transparency approach in PPP also helps to minimize the social issues in SBP in SL.

5. CONCLUSIONS

PPP is a procurement strategy where the public and private parties partner to complete a project with mutual objectives. In Sri Lanka, PPP is mostly used in public sector infrastructure projects to overcome the financial incapacities of the government. However, public sector building projects have different challenges which cause the abandonment of the buildings prior to completion or after completion. Therefore, the research identified the challenges faced by PSBP in SL and measured the ability to overcome them with the PPP approaches, which proved that PPP approaches have a high ability to improve the viability of the PSBP. So PPP has to be implemented in SL building projects as well. The preliminary interviews successfully verified the facts identified in the literature review. Nevertheless, all the respondents rejected the skill shortage in the Sri Lankan context. Therefore, it was removed from the list of challenges faced by PSBP in SL. The verified facts were added to the questionnaire survey for further processing. A sample of 30 experts who have experience in the Sri Lankan construction industry rated the ability of each approach to overcome the challenges encountered by building projects in the Sri Lankan context. Even though the report discusses the approaches with the highest ability, the RII value showed that all the approaches have a high ability to overcome the challenges faced by PSBP in SL (refer Table 05). Therefore, the PPP's ability to overcome the challenges encountered by PSBP in SL was ascertained in this paper.

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APPLICATION OF COMPUTER VISION FOR CONSTRUCTION PROGRESS MONITORING

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ABSTRACT

Progress monitoring of construction work is crucial to identify the discrepancies between the as-built product and as-planned design and take necessary action based on the results. Construction work is time consuming and labour intensive. However, the use of new technologies, such as computer vision (CV), in construction progress monitoring (CPM) can minimise human errors. Thus, the aim of this study was to explore the current applications of CV in the construction industry in general and in the different stages of CPM. A qualitative approach based on the Delphi technique comprising two interview rounds was used to collect the required data. The study findings revealed that CPM has seven stages: initial planning, data acquisition, information retrieval, verification, progress estimation and comparison, results visualisation and schedule updating. During these stages, CV can be used in various CPM activities, such as earthmoving operations, crane operations, formwork and rebar tracking, worker activity tracking, safety assurance, landscape identification, work item monitoring and integrating with other technologies. Familiarisation of the workforce with CV and research on the applications of CV in construction can help the construction industry to move with technology and be on par with other industries. This study would enable construction personnel to explore the possibility of applying CV in CPM. Further research on identifying the synergy between CV and CPM can be based on the study findings.

Keywords: *Construction Work Progress Monitoring; Computer Vision; Stages of Progress Monitoring*

1. INTRODUCTION

The construction industry has a low uptake of modern computer technologies, making the industry to stagnate technologically (Mahami, et al., 2019). Progress Monitoring of construction work is a laborious task, mostly conducted manually during the construction process, resulting in a large number of errors (Braun, et al., 2020). Construction progress monitoring (CPM) includes scheduling, cost and resource management, and change order management (Omar and Nehdi, 2016). Although it can be tedious, CPM can produce timely, comprehensive and most up-to-date data relating to designs, schedules, costs and progress performance and enable a fast and easy decision-making process (Alizadehsalehi and Yitmen, 2018). The use of new technologies can help overcome many challenges (Mahami, et al., 2019). New technologies, such as laser scanning (LS),

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radio frequency identification (RFID), ultra-wideband (UWB), global positioning systems (GPS) and wireless sensor networks have been used in CPM; these technologies, however, have their own drawbacks with regard to delivery time, cost-effectiveness, popularity (Omar and Nehdi, 2016), setting up and implementation, and accuracy in the case of large-scale projects (Park and Brilakis, 2012). Computer vision (CV) can be a cheaper option than any automated technology and could make construction monitoring easy (Zhong, et al., 2019).

When CV is used in CPM, a model would be created using as-planned information, which would be compared with real-time project data obtained using automation techniques (Fard and Peña-Mora, 2007). CV implementation has numerous enablers. It also has several challenges, such as lighting and environmental issues of the visual field (Spencer Jr, Hoskere and Narazaki, 2019), handling and gathering of big datasets with large capacities in the training of artificial intelligence (AI) (Fang, et al., 2020), and the proper selection of camera angles and monitoring of employee stress (Seo, et al., 2015). Many studies have been conducted on CV and CPM separately (Fang, et al., 2020; Park and Brilakis, 2012); the synergy between CV and CPM, however, has not been studied sufficiently, and no studies have been conducted to analyse the synergy between the two in the different stages of CPM. Thus, the aim of this study was to investigate how CV can be applied in the various stages of CPM.

2. LITERATURE REVIEW

2.1 CONSTRUCTION PROGRESS MONITORING

Progress monitoring of construction work, an ongoing task in construction, involves the periodic measurement of the actual project progress and its comparison with expected / as-built progress (Alizadehsalehi and Yitmen, 2018). If construction projects fall behind schedules and if discrepancies exist between as-built and designed baseline plans, many unfavourable events could occur during project implementation (Omar and Nehdi, 2016). Hence, the tracking and monitoring of construction work progress in real-time is a vital part of project management and is important in the achievement of project objectives. According to Ekanayake, et al. (2021), inefficient and inaccurate monitoring and tracking of construction work are two major factors responsible for time and cost inefficiencies in construction projects. CPM requires project schedule updating for which the actual data related to project progress at different project stages have to be obtained from the project sites to obtain processed data (Kazado, Kavgic and Ergen, 2019).

2.2 PROGRESS MONITORING STAGES

According to literature, CPM can be divided into several stages as given in Table 1.

Table 1: Progress monitoring stages

Stages	A	B	C	D	E	F	G	H	I	J	K	L
Initial planning/Scheduling			✓	✓		✓			✓			
Data acquisition	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Information retrieval	✓	✓		✓	✓	✓	✓	✓	✓	✓		
Verification					✓						✓	
Progress estimation and comparison	✓	✓	✓	✓				✓	✓	✓	✓	✓

Stages	A	B	C	D	E	F	G	H	I	J	K	L
Results visualisation /reporting	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
Schedule updating						✓						

Sources: A - Pushkar, Senthilvel, and Varghese (2018), B - Omar and Nehdi (2016), C - Meredith and Mantel (2009), D - Daniel, Kavgic, and Ergen (2019), E - Braun, et al. (2015), F - Kim, Son, and Kim (2013), G - Fard, Mora, and Savarese (2015), H - Alizadehsalehi and Yitmen (2018), I - Fard and Peña-Mora (2007), J - Han and Fard (2017), K - Braun, et al. (2020), L - Wang, et al. (2021)

According to Table 1, CPM has seven basic stages. Planning in CPM includes breaking down project work into various activities and indicating their expected dates of completion to enable the identification of the project stage to which a project activity would belong (Daniel, Kavgic and Ergen, 2019). According to Braun, et al. (2020), data acquisition and information retrieval can be expedited using traditional methods, which require a high level of human intervention and automation. The authors explained that the data and information collected have to be verified manually to ensure accurate verification. Presently, engineers and project managers monitor the working status of a construction labourer by looking at images (Braun, et al., 2015). Progress estimation is the comparison of planned schedules with as-built schedules or models to determine project progress (Pushkar, Senthilvel, and Varghese, 2018). In the stage following project estimation, data visualisation and reporting is performed to make the decision-making process smooth (Han and Fard, 2017). After processing the information using the actual start date, actual finish date, and measurement date, the project schedule will be updated to enable the reallocation of resources (Kim, Son and Kim, 2013).

2.3 COMPUTER VISION AND CONSTRUCTION PROGRESS MONITORING

2.3.1 Integration of Computer Vision with Construction Progress Monitoring

CPM is necessary to determine the differences between the as-built product and as-planned product so that corrective actions could be taken to minimise the differences (Ekanayake, et al., 2021). Project visualisation has an important role to play in construction projects (Wang, et al., 2021). Inefficient and inaccurate CPM contributes to the time and cost overruns of a construction project. Fard and Mora (2007) stated that the inherent complications and dynamic nature of construction projects, which involve outdoor activities, make it difficult to keep up with as-planned progress during project implementation despite the use of improved construction equipment and management strategies. Vision-based tracking, which can track multiple entities present within a camera view, can be used to overcome the aforementioned challenges (Park and Brilakis, 2012). CV, which is cheap and easy to execute, can monitor project progress accurately. Extracting comprehensive information from the images via computer vision-based systems can help automate diverse construction-related activities, such as the progress monitoring, safety management, quality control and productivity tracking of construction projects (Paneru and Jeelani, 2021). Remotely controlled unmanned aerial vehicles (UAV) and unmanned ground vehicles (UGV) can be used in large construction sites to ensure safety at the sites and collect data efficiently (Elena, Vito and Pecce, 2019). CV-based technologies have accelerated the automation of CPM, helping to overcome the challenges faced when using traditional and manual methods, which are labour intensive and error-prone (Ekanayake, et al., 2021).

2.4 IMPORTANCE OF COMPUTER VISION FOR CONSTRUCTION PROGRESS MONITORING

During the past decade, a growing trend of using CV and its applications in the fields of architecture, engineering and construction and facility management could be observed (Xu, et al., 2020). CPM is important because the as-built progress of a construction project has to be constantly monitored and compared /analysed with the planned progress of the project to minimise the discrepancies between the two (Fard and Peña-Mora, 2007). The manual inspection and monitoring of construction progress have many challenges related to cost, time and quality (Braun, et al., 2020). However, the traditional and manual CPM, which requires human interactions, still dominates the construction industry (Braun, et al., 2015). Thus, many studies have been done on the use of advanced technologies, such as LS, GPS, RFID, augmented reality (AR) and UWB, in the construction industry (Omar and Nehdi, 2016). Nonetheless, CV is considered cheaper and more flexible than other automated technologies (Zhong, et al., 2019). In recent years, there has been a dramatic increase in the number of digital photos taken in construction environments, making the development of the required systems feasible, cost-effective and fast (Hamledari, McCabe and Davari, 2017). Because the construction industry is labour intensive, by using CV, companies can reduce their labour requirements and use UAV/UGV to access risky areas while ensuring the safety of the people (Elena, Vito, and Pecce, 2019). Thus, the use of CV in CPM deserves investigation.

3. RESEARCH METHODOLOGY

A purely qualitative approach was used in the study based on its objectives; however, it has limitations because of its subjectiveness and dependency on linguistic variables, leading to inaccurate outcomes (Islam and Nepal, 2016). The Delphi method is a systematic and interactive research technique involving two or more rounds of structured surveys or interviews, which can be used to obtain the views of an independent expert panel (Aghimien, Aigbavboa and Oke, 2020). The literature is not specific about the number of rounds that would be required to achieve a consensus using the technique. Nevertheless, in most construction management-related studies, a consensus can be reached after the second or third Delphi round (Ameyaw, et al., 2016). Thus, a two-round Delphi technique was used in the study to achieve the study objectives. Because the study required personal perspectives and experience-based answers, a qualitative approach was adopted in the Delphi survey (Hammarberg, Kirkman and de Lacey, 2016). Manual content analysis was used to analyse the qualitative findings of the survey.

3.1 RESPONDENT PROFILES

The purposive sampling technique was used in the study to facilitate the intentional selection of those who are best suited to take part in the survey (Etikan, Musa, and Alkassim, 2016). The Delphi technique can be effectively used with a heterogeneous panel consisting of experts coming from different fields (Skulmoski, Hartman and Krahn, 2007). Furthermore, a heterogeneous sample would help obtain a generalised overview of the subject. The selected heterogeneous sample consisted of participants from countries such as Sri Lanka, Australia, the United Kingdom, New Zealand, the United Arab Emirates, Singapore, Malaysia and Oman. Fifteen participants took part in the first round of the survey, while eleven participants took part in the second round. For a Delphi survey, a robust result is possible with a panel of 10–20 experts in the first round (Nashir, Mustapha and Yusoff, 2015). In Table 2, the profiles of the survey respondents are presented.

Table 2: Respondent profiles

Code	Round		Designation	Experience (years)	Industry
	R1	R2			
I1	✓	✓	PhD candidate	5.5	Construction
I2	✓		Contract manager	12	Construction
I3	✓	✓	Senior computer vision developer	10.5	IT
I4	✓	✓	PhD candidate	3	Construction
I5	✓	✓	PhD candidate	5.5	Construction
I6	✓	✓	PhD candidate	7	Construction
I7	✓		Quantity surveyor	8	Construction
I8	✓		Quantity surveyor	4	Construction
I9	✓	✓	Quantity surveyor	3.5	Construction
I10	✓	✓	Quantity surveyor	11	Construction
I11	✓	✓	Senior project manager	28	Construction
I12	✓		Senior cost manager	6	Construction
I13	✓	✓	PhD candidate	4	Construction
I14	✓	✓	Senior project manager	20	Construction
I15	✓	✓	Project manager	15	Construction

4. RESEARCH FINDINGS

4.1 DELPHI ROUND 1

4.1.1 Identification of the Stages of Construction Progress Monitoring (Round 1 Phase 1 Findings)

Seven stages of progress monitoring of projects were identified from the literature. In Phase 1 of Delphi Round 1, the interviewees were requested to validate these stages for CPM and suggest any new stages that need to be included in CPM. Table 3 lists the progress monitoring stages of construction projects agreed upon by the interviewees.

Table 3: Progress monitoring stages

No.	Stage	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	I13	I14	I15
1	Initial planning/ Scheduling	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2	Data acquisition	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3	Information retrieval	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
4	Verification	✓	✓	✓	X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

No.	Stage	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	I13	I14	I15
5	Progress estimation and comparison	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
6	Results visualisation /reporting	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
7	Schedule updating	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

According to Table 3, all the respondents except I4 have validated all the stages of CPM identified from the literature. I4 was of the view that verification could be a part of progress estimation and comparison and said, “Four stages, namely *initial planning*, *data acquisition and processing*, *comparing and results visualising* and *schedule updating* will be sufficient to demonstrate the entire process”. I6 added, “After the 6th stage, a new stage will be required to look back at the previous plan.” However, the interviewees I7, I8, I9, I11 and I3 did not agree on having this additional stage because the work envisaged during this stage could be included under *progress estimation and comparison*. With the agreement of most of the interviewees, all seven stages of progress monitoring mentioned in the literature were considered as applicable to construction projects.

According to I3, the initial plans for the project/section are prepared, and the milestones are determined during the planning stage for the easy and gradual management of the project. I5 stated that data acquisition could be the most time-consuming process in the PM workflow as it takes as much time as the whole construction process so that the information retrieval can be done in parallel with the construction progress. I6 also agreed that data acquisition is time consuming and laborious and that, therefore, in most projects, automated techniques are used in the planning stage more than in other stages. I4 added that the information retrieved from the data has to be verified manually or by using software to ensure the accuracy of the CPM workflow and to improve the reliability of the comparison made between the as-built and as-planned schedules. I1 added that the results visualisation stage is necessary to ease decision making and that it helps schedule updating after comparing the as-planned models with as build models. The seven stages identified were then considered for validation.

4.1.2 Use of Computer Vision in Construction Progress Monitoring (Findings of Delphi Round 1 Phase 2)

Thirteen uses of CV in construction-related activities, such as earthmoving operations, crane operations, formwork and rebar tracking, worker activity tracking and safety assurance, were identified from the extant literature. The interviewees were requested to determine whether these uses could be validated for CPM. Nine new uses of CV in CPM also were identified through the interviews. Most of the interviewees validated for CPM, a majority of the CV uses stated in the literature. The uses such as tracking of worker travelling and their activities, nailing using a hammer and bending, identified using the literature review were rejected by the interviewees I1, I3, I4, I5, I6, I8, I10 and I11, stating that those activities did not require monitoring because they were not related to the progress of site work. I1 and I4 disagreed with most of the items identified from the literature, stating that if a task was not directly related to the completion or partial completion of a work item, its progress did not require monitoring. I4 opined that the monitoring of machinery and labour activities do not come under CPM, although they would be required to evaluate worker efficiency and productivity. I9, I12 and I13 opined that labour productivity and safety measures could be considered during CPM because the data retrieved from those activities can help project managers and other supervisors to track construction work progress. I1, I4, I6, I8 and I11 were of the view that safety did not have to be considered during CPM. I11 stated that safety is not related to CPM but to health, safety and environmental monitoring. However, the other interviewees agreed that safety assurance could be considered during CPM because it exerts a considerable influence on the project timeline.

Nine new uses of CV also were identified at the interviews. I3 added two of the new uses, namely taking crude measurements from the sites and performing aesthetic works with the help of AR, which can help CPM. I3 said, "Most of the technologies recently developed cannot be used independently and have to be integrated with other technologies; CV also can be integrated with other technologies, such as AR and virtual reality (VR), in the planning processes of CPM". I7 agreeing with I3, stated that the integration of CV with building information modelling (BIM) will be effective with BIM also being an emerging technology in construction. I4 also introduced a few new uses of CV in CPM, namely the construction of columns, walls, prefabricated items, installation of HVAC and plumbing systems, and material counting. He was also of the view that if an item/work monitored is required to complete an item in the bill of quantities or an element that is essential to the project, it could be included in CPM.

4.2 DELPHI ROUND 2

4.2.1 Use of Computer Vision in the Various Stages 0f Construction Progress Monitoring

During Phase 2 of Delphi Round I, the uses of CV in general construction applications that were identified from the literature were validated for CPM. During Delphi Round 2, the CV uses in CPM were categorised according to the stages in which they were applied. Table 4 lists under each progress monitoring stage of construction, the CV uses that were validated for CPM by more than 75% of the respondents.

Table 4: Uses of CV in different stages of construction progress monitoring

<table>
<tr><th colspan="2">Use \ Stage</th><th>Initial Planning/ Scheduling</th><th>Data Acquisition</th><th>Information Retrieval</th><th>Verification</th><th>Progress Estimation and comparison</th><th>Results Visualisation</th><th>Schedule Updating</th></tr>
<tr><td rowspan="4">Earthmoving operations</td><td>Excavator: Moving, scooping, rotating, dropping or stopping</td><td rowspan="2"></td><td rowspan="2">✓</td><td rowspan="2"></td><td rowspan="2">✓</td><td rowspan="2"></td><td rowspan="2">✓</td><td rowspan="2"></td></tr>
<tr><td>Dump truck: Moving / static</td></tr>
<tr><td>Loading time analysis of dump truck movements</td><td></td><td>✓</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Tracking of onsite workers engaged in excavation work</td><td></td><td>✓</td><td></td><td>✓</td><td></td><td>✓</td><td></td></tr>
</table>

Use	Stage	Initial Planning/ Scheduling	Data Acquisition	Information Retrieval	Verification	Progress Estimation and comparison	Results Visualisation	Schedule Updating
Crane operations	Loading concrete, moving to and returning from the work zone, unloading concrete and detaching the concrete bucket		✓		✓		✓	
	Moving the hook							
Formwork and rebar tracking	Detection of effective/ineffective work performed by the workmen				✓			
	Measuring, moving, preparing and resting							
	Fixing, placing, taking and transporting formwork					✓	✓	✓
	Connecting, fixing, placing, transporting and welding rebars							
Worker activity tracking	Laying bricks, transporting, cutting plates, drilling, tying rebars, nailing, plastering, shovelling, bolting, welding and sawing				✓			
	Tracking picking up, holding, walking, putting down, measuring and cutting, breaking of gypsum boards and idling		✓		✓			
	Normal climbing, backward-facing climbing, climbing while carrying an object and reaching to a side on the ladder		✓		✓			
Safety assurance	Identifying risky heights and edges at the sites		✓		✓		✓	
	Identifying workers wearing safety vests and other safety gear		✓		✓		✓	
	Ensuring environmental safety by detecting cracks in concrete and steel		✓		✓		✓	
Landscape identification	Identifying hills and valleys in a region		✓		✓			
General	Making crude measurements							
	Counting material, such as rebars							

Use	Stage	Initial Planning/ Scheduling	Data Acquisition	Information Retrieval	Verification	Progress Estimation and comparison	Results Visualisation	Schedule Updating
Work item monitoring	Monitoring construction of columns and walls		✓	✓	✓	✓	✓	✓
	Monitoring installation of services, HVAC and plumbing		✓	✓	✓	✓	✓	✓
	Monitoring prefabricated construction work	✓	✓	✓	✓	✓	✓	✓
	Monitoring, plastering, framing, insulating fit outs and refurbishment work	✓	✓	✓	✓	✓	✓	✓
Integration with other technologies	Conducting aesthetic work using AR systems						✓	
	Using as a tool to feed BIM systems in real time		✓		✓			
	Integrating with digital twin technology		✓		✓		✓	

CV is used mostly in data acquisition, verification and visualisation stages of CPM. In Table 4, the uses of CV endorsed by more than 70% (>= 5) of the respondents as being applicable to CPM are highlighted in green. The new uses of CV identified during Delphi Round 1 are highlighted in grey. According to I9, in a construction site, material counting can be done easily either manually or by using cheap technologies, such as RFID, and rough measurements can be made without using an advanced system. Thus, two uses of CV identified during Delphi Round 1, namely making crude measurements, and counting material, such as rebars had to be removed during the second round because a majority of the respondents did not endorse them.

According to I4, CV *can* be used in all stages of CPM in activities coming under the category of *work item monitoring*. I5 stated that CV-based CPM should be incorporated into a project during its initial stages, especially when CV has to be integrated with other technologies. I13 added that the use of *CV* during data acquisition, verification and results visualisation stages of CPM for activities such as crane operations, safety assurance and landscape identification could overcome many challenges and obstacles faced during construction. I10 opined that CV could be used in data acquisition, verification, and results visualisation stages of CPM than in any other stages of CPM.

The interviewees from the industry believed that all tasks associated with CPM, including worker and productivity-related activities, are performed in the sites; however, the interviewees representing the academia believed that the tasks involve the comparison of as-planned and as-built schedules.

4.3 DISCUSSION

Few past researchers, such as Ioannis Brilakis, Ahmadian Fard, Pena Mora and Johnny Wong, identified the uses of CV in construction projects to optimise and increase the efficiency of construction work monitoring and tracking. Because CPM is costly, time-consuming and error-prone, automation can be more efficient and productive than CPM (Yang, et al., 2015). Construction projects use a significant number of resources such as labour, equipment and materials, and the proper management of these resources would have a positive impact on onsite productivity, which requires constant monitoring (Bügler, et al., 2016). I4, endorsing the literature, stated that the use of CV in CPM can save many resources, including costs and time. Workers actively engaged in work, idling or resting, also could be monitored as a part of CPM (Luo, et al., 2018). However, I1 stated that items relating to workers and recording of their idling times do not come under CPM and that they are related to labour force productivity. I9 did not agree with I1 and endorsed what is reported in the literature by stating that although the monitoring of workers and recording their idling times cannot be considered a part of CPM, they are required to conduct CPM effectively. Thus, the monitoring of workers and recording their idling times are also crucial for CPM. Cost for the workers can also be reduced from 25% - 35% from the construction project costs, which makes it cost-efficient and CV can be applied to promote the reduction of idling of the workers (Luo, et al., 2018). Generally, construction sites can be highly risky because they are dynamic and difficult to access. The use of CV in CPM can also promote safety at construction sites. Because safety monitoring in a construction site is important, it can be automated by using CV and identifying the safety hazards through worker behaviour analysis (Fang, et al., 2020). Although I1 disagreed that monitoring of safety in a construction site is important, most of the other interviewees agreed that monitoring of safety could be useful for CPM. The interviewees introduced a few more uses of CV under *monitoring work items* and *integration with other categories*. Monitoring of individual work items, such as structural framework, walls, prefabricated modules and HVAC installation are directly associated with CPM. Most of the interviewees accepted that these uses of CV could be used in CPM as well.

5. CONCLUSIONS AND RECOMMENDATIONS

The aim of the study was achieved cumulatively via the literature review and two-round Delphi survey. Twenty uses of CV for CPM were identified and categorised into major activities such as earthmoving operations, worker activity tracking, safety assurance, work item monitoring and integration with other technologies. CV can be applied to track the activities of plants and machinery, such as cranes, excavators and dump trucks, to determine their efficiencies and impact on construction progress. Tracking of workers also can be done using CV, and the data obtained can be used in CPM. Worker productivity can be tracked by analysing the idling times of the workers and the number of effective man-hours required for a task. This data can help CPM by providing an overview of the worker standards and providing a reliable plan. CV significantly assists in monitoring the progress of work items, such as structural, brick/block and mechanical, electrical, and plumbing works. Another use of CV in CPM is its use as an automated tool by integrating it with BIM and AR technologies. Because the synergy between CPM and CV has been hardly discussed in the literature, facilitating research in the area can be helpful for the further development of CPM. Promoting methods to implement CV by integrating it with BIM will allow BIM to be further automated and reduce the extent of human intervention required and make CV popular among project management teams. CV can be integrated with virtual reality in various ways, such as VR/AR and mixed reality. Implementation of these technologies in construction will help solve many issues encountered in projects because it will enable the early identification of problems using simulations.

The aim of this study was to identify the applicability of CV in CPM. Thus, the study findings can be used as a reference when conducting further studies on determining the synergy between CV and CPM. The findings will encourage and promote construction automation. Because of the limited applicability of CV in the construction industry, the expert sample selected for the study had to be selected only from a few countries. Thus, the study findings cannot be generalised in the global context.

Moreover, there are several shortcomings in the effectiveness of using CV vision in the construction sector since the construction industry is infamous for being one of the least digitalised sectors. Furthermore, the unavailability of required technology and unavailability of human resources with sound knowledge in computational areas in construction would also become a barrier in implementing CV for construction PM. Although the application of CV for PM is possible in theory but there are several computational issues in practice that still need to be resolved. Thus, this study can be used as a benchmark for further studies on identifying the practicality of adopting CV for PM and how to overcome challenges and barriers in doing so.

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AS-BUILT DATA ACQUISITION FOR VISION-BASED CONSTRUCTION PROGRESS MONITORING: A QUALITATIVE EVALUATION OF FACTORS

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ABSTRACT

The accuracy of computer vision-based progress monitoring of construction projects depends on the quality of data acquired. The data acquisition can be conducted through different vision-based sensors combined with several options for sensor mounting. Several factors affect this combination and considering these factors in selecting the acquisition technology and sensor mounting combination is critical for acquiring accurate vision-based data for the project. Currently, their definition and impact of these factors on the selection of these technologies are both subjective, and there are no formal studies to evaluate the impact. Hence, in this study, we first identify and define twelve key factors affecting data acquisition technology and eight factors affecting sensor mounting. Next, a questionnaire survey was designed, and responses from professionals were used to evaluate the Relative Importance Index (RII) for the individual factors for these technologies and methods. The obtained ratings were compared to the author's initial assessment, and the cause for a few variations obtained was justified. This study provides a clear assessment of these factors and forms a basis for selection based on the factors involved with the project requirements.

Keywords: *As-built modelling; Data Acquisition; Reality Capture; Scan-to-BIM; Technology Selection.*

1. INTRODUCTION

Progress monitoring is critical to the project's success. Computer vision and its subdomains are being explored for effective and real-time progress monitoring (Paneru and Jeelani, 2021). Computer Vision-Based Construction Progress Monitoring (CV-CPM) involves three steps, namely – data acquisition, as-built modelling, and progress estimation (Bhadaniya, et al., 2021; Reja, et al., 2021). Our recent study presented the integrated CV-CPM framework, which defines the three steps in detail while discussing the tools, technologies, algorithms and the methods involved in each step (Reja, et al., 2022).

The fundamental concept is to acquire spatial data and convert it to develop a 3D as-built model. Finally, this model is compared with the equivalent as-planned model at a specific

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time to compute the project's progress. The data acquisition step is critical because the quality of the acquired data affects the next steps involved in the CV-CPM pipeline (Rebolj, et al., 2017). There are two critical components for data acquisition: (a) selection of technology and (b) selection of sensor mounting method. The selection of these two depends on various factors, which can depend upon the characteristic of the project being monitored and the level of progress monitoring to be conducted. Identifying and evaluating these factors is critical for data acquisition and further steps of CV-CPM. In our recent study (Reja, et al., 2022), we identified these factors through an in-depth literature review through the PRISMA methodology. It was found that there is a critical need to evaluate these factors to guide the selection of technology and mounting method for implementation on construction projects. Therefore, this paper aims:

- To identify the factors affecting the selection of data acquisition technology and sensor mounting method for progress monitoring at projects.
- To qualitatively evaluate these factors and provide a basis for selection based on a structured questionnaire survey.

The scope of the work includes data acquisition technologies and sensor mounting methods used specifically for computer vision-based construction progress monitoring.

Section 2 reviews various data acquisition technologies and sensor mounting methods used for CV-CPM. Section 3 shows the methodology adopted for this research study. Section 4 identifies and defines the factors affecting acquisition technologies and sensor mounting methods. Section 5 presents the details of the questionnaire survey. Section 6 presents the results obtained from the survey analysis and compares them with the author's primary assessment. Finally, conclusions are presented in Section 7.

2. DATA ACQUISITION FOR CV-CPM: LITERATURE REVIEW

Table 1 shows the literature summary of the data acquisition step in the existing CV-CPM pipelines. It can be observed that several combinations of acquisition technologies and sensor mounting methods have already been tested.

For acquisition technology, most methods have used photogrammetry/ videogrammetry (based on images/videos) or laser scanning; only a few studies have used RGB-D based data capture. For sensor mounting, it can be noted that most studies have used manual methods of device traversing instead of UAV or UGV. The selection also considers the scope of progress monitoring, which can include interior reconstruction, exterior façade, or both because ongoing construction sites may not be entirely open or closed. Figure 1 shows the available data acquisition technology and sensor mounting methods. These have been discussed in detail in the following sub-section.

2.1 ACQUISITION TECHNOLOGY

As shown in Figure 1, cameras, video cameras, Laser scanners, and Range Imaging (or RGBD cameras) are the vision-based technologies used to collect progress monitoring data. These are discussed in detail below:

2.1.1 Cameras (Images and Videos)

Two camera variants are used to capture images and videos, i.e., monocular and binocular (or stereovision cameras). The monocular camera captures a single frame from a single lens, while a binocular camera has two lenses separated by some distance and captures two frames at an instance. This binocular disparity helps the stereo camera to compute the depth of the corresponding captured points. The videos are first decomposed to separate image frames, and then these frames are selected for further processing. Cameras are cheap, portable, easy to use, and available on almost all mobile devices, making them a preferred alternative over other technologies. However, processing camera images using SfM have a relatively high computational cost if the images are not in sequence and also requires acceptable capturing conditions like lighting, distance, and adequate and obstacle-free field of view for accurate results (Reja, et al., 2022).

Table 1: Literature summary data acquisition for CV-CPM pipelines

Data Acquisition			
Reference	**Acquisition Technology**	**Mounting Method**	**Indoor/ Outdoor**
(Khairadeen Ali, et al., 2021)	Laser Scanning and Photogrammetry	Manual	Indoor
(Pour Rahimian, et al., 2020)	RGBD Camera	Manual	Both
(Braun, et al., 2020)	Digital Images	UAV	Outdoor
(Vincke, et al., 2019)	Laser Scanning or Photogrammetry	Manual	Both
(Han, et al., 2018)	Photogrammetry/Laser Scanning	UAV	Both
(Arif and Khan, 2021)	Videography	Fixed	Both
(Kim, Kim and Lee, 2020)	Laser Scanning and Photogrammetry	UAV	Both
(Wang, et al., 2021)	Video Camera	Fixed	Outdoor
(Kopsida and Brilakis, 2020)	RGBD Camera	Manual	Indoor
(Mahami, et al., 2019)	Photogrammetry	Manual	Both
(Maalek, et al., 2019)	Laser Scanning	Manual	Both
(Bognot, et al., 2018)	Videogrammetry	UAS	Outdoor
(Omar, et al., 2018)	Photogrammetry	Manual	Outdoor
(Pučko, et al., 2018)	RGBD Camera	Manual	Both

2.1.2 Laser Scanners

Laser scanners (or LiDARs: Light detection and ranging) directly capture the 3D cartesian or spherical coordinates of the surrounding points and deliver 3D point cloud data directly with internal processing. They can be controlled by either phase-based or time of flight-based methods. They are best used for automated data retrieval as they do not require much processing and can capture high-resolution spatial data. Their major disadvantage is that they require a clear line of sight requiring a frequent change of scanning positions to capture 3D data, making them tedious to use and having a high purchase cost (Omar and Nehdi, 2016).

2.1.3 Range Imaging Devices

Range imaging cameras (or RGBD cameras) compute the pixel point's depth by calculating the distance of points in a scene concerning a specific point with the help of a sensor. They capture the spatial as well as depth information simultaneously. They generally output a point cloud or surface mesh directly with the help of their in-built algorithm. Their major disadvantage is their low range of capture, but they are easy to use.

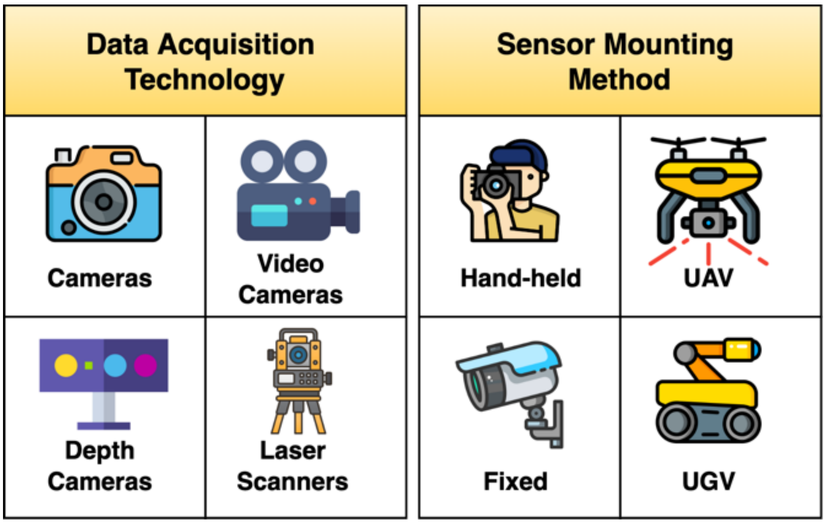

Figure 1: Data acquisition technology and sensor mounting methods

The sensor mounting methods are discussed in the following sub-section.

2.2 SENSOR MOUNTING METHOD

As shown in Figure 1, the acquisition can be by a static device (as in the case of laser scanners), hand-held devices (like mobile cameras and Tablets), UAV or UGV mounted robotic systems (like 2D-Cameras or Range imaging devices) or even a combination of these systems (Asadi et al., 2020). The integration of these robots deployed for manoeuvring with the desired technology creates different acquisition dynamics, including robotic path planning, obstacle avoidance, capture speed, automation, etc. The recent development of light air-borne LiDAR sensors and SPOT by Boston Dynamics (Boston Dynamics, 2019) with high data transmission speed (Reja and Varghese, 2019) has paved the way for unmanned data acquisition in dynamic construction scenes, which can be used in the future pipelines.

2.2.1 Hand-held

The manual method of capturing the data includes holding the acquisition device in hand and traversing along the site to capture the relevant data. These require human effort, are tedious and subject to errors.

2.2.2 Fixed

The fixed method mounting is when the data capturing device location is static on a construction site, and the capture frequency is set. It is mainly in the form of fixed cameras. The major disadvantage of being fixed is that they suffer occlusions due to moving objects and can capture only the specified field of view (FOV). Hence, multiple fixed devices are required to capture the construction site.

2.2.3 UAV

Unmanned Aerial Vehicles (UAVs) include drones that can fly autonomously or manually on the planned path to capture data. Their primary advantage is enabling automatic data capture if the path is planned. They have navigational disadvantages as they require a clear and collision-free route, which is challenging to plan at construction sites. If they are manually operated, an operator with navigation skills is required. It is generally required to meet the statutory laws applied to use them on projects commercially.

2.2.4 UGV

Unmanned Grounded vehicles (UGVs) include robotic vehicles embedded with various sensors to move on the ground. These generally use obstacle avoidance algorithms for autonomous navigation. Their major disadvantage is that they have specific terrain requirements for movements.

This section presented various data acquisition and sensor mounting methods with their strengths and challenges. The following section identifies various factors which affect the selection of these.

3. METHODOLOGY

Figure 2 shows the methodology followed for this research. Since multiple factors affect the selection of these data acquisition technologies and sensor mounting, the factors were identified and documented based on the author's practical experience and supported by the literature. A questionnaire survey-based method was used to calculate the Relative Importance Index (RII) for selection for a qualitative evaluation of the factors.

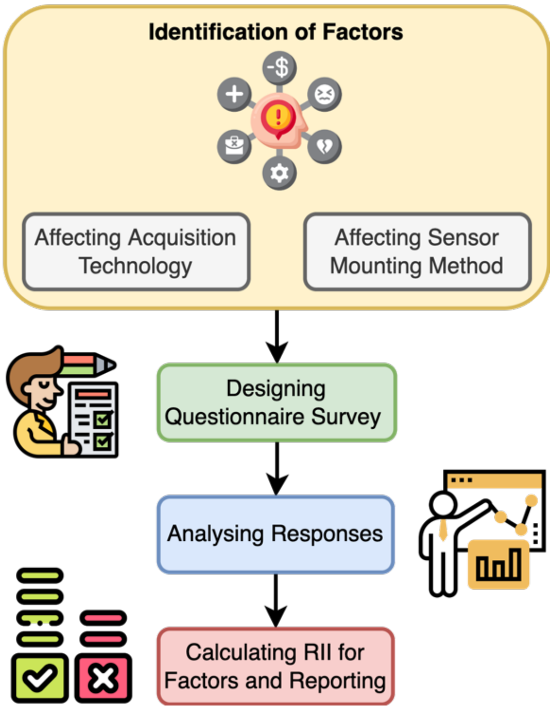

Figure 2: Methodology

4. FACTORS AFFECTING DATA ACQUISITION TECHNOLOGY SELECTION

Evaluating the technology and methods is critical for selecting the combinations for on-site implementation. Several factors govern the selection criteria. Therefore, this study identifies the factors based on their use in literature while choosing the technology and method and the authors' experience in this field. Our recent study identified these factors (Reja, Varghese and Ha, 2022) by a thorough review of the literature using a well-defined PRISMA methodology.

Table 2 shows twelve key factors for data acquisition technology that have been identified. They are equipment cost, equipment portability, automation for data capture, real-time data availability, range of equipment, spatial resolution, spatial accuracy, lightning requirement, user training requirement, time for data capture, preparations for data capture and computation cost for processing.

Likewise, Table 3 shows eight key factors that have been identified for the sensor mounting method. They include accessibility, manoeuvre speed, navigation skills, operator training, statutory requirements, sensor mounting cost, range of operation and preferred use-case.

The initial relative assessment of factors based on the author's perspective supported by field experience and literature has been shown in Tables 4 and 5. The colour codes green, yellow, and red represents low, medium, and high. As this is a subjective evaluation, a questionnaire survey was designed to make it more objective, and responses were analysed. The following section presents the details of the questionnaire statistic and survey results.

Table 2: Definition of various factors that affect data acquisition technology selection

Sl. No	Factors affecting data acquisition technology selection	Definition
1	Equipment Cost	It is the measure of the cost of purchasing the equipment.
2	Equipment Portability	It is the ease of moving the technology (device) around to capture another location.
3	Automation for Data Capture	It is the degree of automation in the process for capturing data like images and depth of the point cloud.
4	Realtime Data Availability	It is the measure of the speed of raw data capture and availability.
5	Range of Equipment	It is the measure of distance up to which the device can be used to capture data.
6	Spatial Resolution	It is a measure of the smallest object that can be resolved by the sensor or the linear dimension on the ground represented by each pixel.
7	Spatial Accuracy	It is the measure of the degree to which information on an image or point cloud matches real-world values.

Sl. No	Factors affecting data acquisition technology selection	Definition
8	Lightning Requirement	It is the measure of the degree of illumination required for data capture.
9	User Training Requirement	It is the degree of training required to use the technology to capture data.
10	Time for Data Capture	It is the measure of time required to capture the data.
11	Preparations for Data Capture	It is the degree of preparation required to capture data.
12	Computational Cost for Processing	It is the time required to process the raw data to point cloud data.

Table 3: Definition of various factors that affect sensor mounting method selection

Sl. No	Factors affecting sensor mounting method selection	Definition
1	Accessibility	It is the ability to reach a place with respect to another place.
2	Manoeuvre Speed	It is the speed at which the device can be manoeuvred to capture data.
3	Navigation Skills	It is an act of directing the course of sensing technology to capture data.
4	Operator Training	It is the amount of training required to operate the mounted technology.
5	Statutory Requirements	It is the number of requirements to be met which are set by the central or state government of a country for the use of these methods.
6	Sensor Mounting Cost	It is the measure of the cost of purchasing the sensor mount.
7	Range of Operation	It is the measure of distance up to which the device can be manoeuvred using the mount
8	Preferred Use-Case	It can be preferred either for interior or exterior data capture.

5. QUESTIONNAIRE SURVEY

A questionnaire survey with project description and factors definition was sent to 40 experienced professionals from the construction industry[4]. The participants were postgraduate engineers working on different construction projects across India in several organisations with at least two years of field experience. The survey participants were selected so that each participant had relevant experience in using and implementing the data acquisition technologies and sensor mountings methods on construction projects. Finally, 33 responses were received from the participants of the survey.

[4] The link to the questionnaire is available at: https://docs.google.com/forms/d/e/1FAIpQLSeh-NoWReaYDBEfBnRd_aY1viumwEo4u8mhWYvQjIcHUaJCyw/viewform

Below are the results after analysing the Relative Importance Index (RII) as calculated from Eq. 01. RII is used to analyse the survey results for factors.

$$RII = \frac{\Sigma(W_n)}{A*N} \qquad \text{(Eq. 01)}$$

Where,

W = Constant expressing the weighting given to each response

A = Highest rating (In our case, A=3)

n = Frequency of responses

N = Total number of responses

Based on the ranks obtained from the analysis, the factors were categorised as high, medium, and low levels with colour codes as red, yellow, and green, respectively. The criteria for the values of 0.55 and 0.75 were set so that the classification best reflects the variation in the factors. For example, for equipment costs, a digital camera costs in the range of $200, a range imaging camera about $1000 and a laser scanner about $15000. Hence the ratings were set so that these are divided into low, medium, and high values to show relative comparison wherever possible.

Low ~ ($RII < 0.55$)

Medium ~ ($0.55 < RII < 0.75$)

High ~ ($RII > 0.75$)

Tables 6 and 7 show the relative ranks of the factors received for the data acquisition technology and sensor mounting method, respectively.

Table 4: Matrix for data acquisition technology selection - Author's perspective

Sl. No	Evaluating Factors	Cameras	Range Imaging	Laser Scanner
1	Equipment Cost	Low	Medium	High
2	Equipment Portability	High	High	Low
3	Level of Automation for Data Capture	Medium	High	High
4	Realtime Data Availability	High	High	Low
5	Range of Equipment	Medium	Low	High
6	Spatial Resolution	Low	Medium	High
7	Spatial Accuracy	Medium	Medium	High
8	Adequate Lightning Required	High	High	Low
9	User Training Requirement for Data Capture	Low	Low	High
10	Time Required for Data Capture	Low	Low	High
11	Pre-Preparations Required for Data Capture	Low	Low	High
12	Computational Cost for Data Processing	High	Low	Low

Table 5: Matrix for sensor mounting - Author's perspective

Sl. No	Evaluating Factors	Fixed	Hand-held	UGV	UAV
1	Accessibility	Low	Medium	Medium	High
2	Manoeuvre Speed	Low	Low	Medium	High
3	Navigation	NA.	User	RC & Automated	RC & Automated
4	Operator Training	Low	Low	Medium	High
5	Statutory Requirements	Medium	Low	Low	High
6	Sensor Mounting Cost	Low	Low	High	High
7	Range of Operation	Low	Medium	Medium	High
8	Preferred Use-Case	Interior and Exterior Scenes	Interior and Exterior Scenes	Interior Scenes	Exterior Scenes

6. RESULTS AND DISCUSSION

It can be observed that there is a slight difference in the survey results of the values in Tables 6 and 7 in comparison to Tables 4 and 5, which were based on the author's perspective. The deviations have been highlighted using bold font and an asterisk symbol. However, most of the factors and their relative importance ratings matched, and that affirms our preliminary assessment. The deviations found are discussed in the following subsections.

Table 6: Matrix for data acquisition technology selection - Survey results

Sl. No	Evaluating Factors	Cameras	Range Imaging	Laser Scanner
1	Equipment Cost	Low	Medium	High
2	Equipment Portability	High	**Medium***	Low
3	Level of Automation for Data Capture	Medium	**Medium***	High
4	Realtime Data Availability	High	High	Low
5	Range of Equipment	**Low***	Low	High
6	Spatial Resolution	Low	Medium	High
7	Spatial Accuracy	Medium	Medium	High
8	Adequate Lightning Required	High	High	Low
9	User Training Requirement for Data Capture	Low	**High***	High
10	Time Required for Data Capture	Low	Low	High
11	Pre-Preparations Required for Data Capture	Low	**Medium***	High
12	Computational Cost for Data Processing	High	Low	Low

Table 7: Matrix for sensor mounting - Survey results

Sl. No	Evaluating Factors	Fixed	Hand-held	UGV	UAV
1	Accessibility	Low	Medium	Medium	High
2	Manoeuvre Speed	Low	Medium*	Medium	High
3	Navigation	NA.	User	RC & Automated	RC & Automated
4	Operator Training	Low	Medium*	Medium	High
5	Statutory Requirements	Medium	Low	Low	High
6	Sensor Mounting Cost	Low	Low	High	High
7	Range of Operation	Low	Medium	Medium	High
8	Preferred Use-Case	Interior and Exterior Scenes	Interior and Exterior Scenes	Interior Scenes	Exterior Scenes

6.1 COMPARATIVE RESULTS FOR DATA ACQUISITION TECHNOLOGY SELECTION

As compared from Tables 4 and 6, slight deviations are realised in the ratings for range imaging technology. Equipment portability is medium in the case of range imaging (compared to low in Table 4). This can be because, compared to digital cameras, RGB-D cameras can be bulky due to additional accessories provided.

The level of automation has been reported as medium for range imaging (in comparison to high in Table 4). This may be because the reconstruction requires manual input compared to laser scanning, which automatically produces a point cloud.

The range of equipment is low in the case of digital cameras (in comparison to the medium in Table 4). This can be because taking images from far may result in lower reconstruction accuracy; therefore, accurate reconstruction can be done if the objects are clear from a specific range.

User training requirements and preparations for data capture for range imaging are found to be high and medium, respectively (in comparison to low and low in Table 4). This may be because of the calibration process required before starting the data capture.

6.2 COMPARATIVE RESULTS FOR SENSOR MOUNTING

The manoeuvring speed and operator training requirements have been reported to be medium (in comparison to low and low in Table 5). This variation can be because it depends on the data capturing skills of the operator and his technical knowledge of using the device.

All the other relative ratings match the author's perspective, affirming that the comparison and the ratings provided are appropriate.

7. CONCLUSION

The paper presented a qualitative evaluation of the factors affecting the data acquisition step of CV-CPM. For achieving the first objective, the factors affecting technology and mounting method selection were first identified and defined. For the second objective in this study, an objective evaluation was conducted based on a questionnaire survey circulated among experienced professionals.

The results were compared with the author's preliminary ratings, and it was noted that few variations were seen. Individual deviations were discussed by providing possible reasons. The ratings obtained through this study can be utilised for technology and mounting method selection, which is a valuable addition to the existing method of selection, which is entirely dependent upon the use case. In addition to these ratings, project-specific requirements should be evaluated against these factors to select an appropriate technology for collecting data for CV-CPM.

The study contributes primarily by comparing the factors for data acquisition and sensor mounting qualitatively, which has not been done before, which adds to the theory of construction progress monitoring. The current limitation of this study is that the comparison shown here is relative to the three technologies and the four mounting methods. Some of the factors can be better evaluated by directly a quantitative comparison of values, which will be a part of future research in this area.

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AVAILABILITY OF RELIABLE COST DATA FOR WHOLE LIFE COSTING IN THE TANZANIA BUILDING CONSTRUCTION INDUSTRY

Sylvester L. Manege[1] and Craig J. Kennedy[2]

ABSTRACT

Whole life costing plays a major role in ensuring that value for money is attained from the inception of a building to its end of life. Availability of reliable cost data is essential ensuring that whole life costing is undertaken with utmost precision. This study explores the availability of reliable cost data for whole life costing in the Tanzania building construction industry. It aims at realising the key sources of cost data as well as analysing their reliability. It will also suggest ways to improve cost data availability in the industry. The research involved the use of questionnaire survey and structured interviews to collect data from quantity surveyors and other industry professionals respectively in Tanzania. The study revealed that in-house and market survey as the most familiar and most used sources of cost data in the Tanzania building construction industry. It also realised that running cost data, which are crucial for undertaking whole life costing, did not have a source in Tanzania which is contrary to other countries. The study also revealed that despite cost data sources being considered reliable, they still lacked credibility as most respondents still had doubts about them. To improve the availability of reliable cost data for whole life costing, the study suggests that the Tanzania building construction industry should adapt to the online information service which will ensure easy and fast access to reliable cost data. The industry should also engage in the collection and sharing of running cost data which is essential for whole life costing.

Keywords: *Building Construction Industry; Cost Data; Tanzania; Whole Life Costing.*

1. INTRODUCTION

Cost data availability is a very important aspect of the building construction industry. The accuracy of cost data plays a major role in ensuring the level of confidence in decision making. Cost data for building construction projects helps to render key decisions on whether to build or not. Additionally, it helps to monitor and meet projects time and budget during execution. The building construction industry faces criticism globally on high construction costs and unpredictability due to inconsistent cost data, challenged to innovate and reduce costs (Robson, et al., 2016). Improving project management performance by reducing project time and cost, Hu (2008) encourages proper reuse of cost data.

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Whole life costing plays a major role in ensuring that value for money is attained from the inception of a building to its end of life. There have been many definitions of whole life costing that have evolved over the years, including BSI (2008), OGC (2007), Boussabaine and Kirkham (2004), Gluch and Baumann (2004) and El-Haram, et al. (2002) but for this study, it will be defined according to Kishk, et al. (2003); it is a tool to assist in assessing the cost performance of construction work, aimed at facilitating choices where there are alternative means of achieving the client's objectives and where alternatives differ, not only in their initial cost but also in their subsequent operational costs. Results of whole life costing are often put into question due to lack of enough cost data (Sterner, 2000), and when they are available, they are usually inconsistent or not relevant for usage (El-Haram, et al., 2002). Manege and Kennedy (2020) and Sandaruwan, et al. (2021) revealed that lack of reliable cost data is one of the key barriers to whole life costing application in the Tanzania building construction industry. According to Munro (2018), a problem in cost data availability in the building construction industry is getting worse. This study is aimed at exploring the availability of reliable cost data for whole life costing in the Tanzania building construction industry. It will investigate the key sources of cost data as well as analyse their reliability and suggest ways to improve cost data availability. The study is important to the Tanzania building construction industry as it will help to re-evaluate its cost data availability and look to improve, therefore ensuring accuracy in cost estimations and thus bringing value for money to projects

Quantity surveyors are cost experts entrusted with keeping building construction projects within budget and ensuring value for money is attained. According to Eke (2007), quantity surveyors are considered encyclopedias of information on all junctures of building costs, thus from inception to end of life. According to Hoar (2007), quantity surveyors should be responsible for undertaking whole life costing, even though Hunter, et al. (2005) believe that it should be undertaken by anyone in the industry so long as they have enough knowledge of it. Therefore, this study will focus primarily on quantity surveyors as they are directly linked to the use and need of cost data as well as undertaking whole life costing and backing up their views with other industry professionals.

2. LITERATURE REVIEW

2.1 COST DATA FOR WHOLE LIFE COSTING

Historical cost data is usually acquired from previous and existing projects. The use of historical cost data should be done with great caution as changes in prices may have significant impacts on construction costs (Atinuke, 2010). According to Sayed, et al. (2020), reliable cost data are needed for accurate cost estimates, which is a key factor for a successful project. Building construction stakeholders, specifically quantity surveyors, use cost data for the following reasons (Ashworth, 2004): approximate estimates for proposed schemes, cost planning during design, contract estimating for tendering purposes, agreement of variations in final accounts, calculation and settlement of contractors' claims, loss adjustment valuations, maintenance management. According to Atinuke (2010), cost data is essential to quantity surveyors for future projects cost forecast, different projects cost comparisons, contractor's unit rates negotiations, monitoring and controlling of construction costs and design cost planning. Agyekum, et al. (2018) portray that the unavailability of cost data is one of the key obstacles to the utilisation of non-traditional cost estimate models. According to Sayed, et al. (2020), reliable cost data is needed to ensure accuracy and success in building construction cost estimates.

The cost of running a facility often surpasses the initial design and construction costs, with estimates that up to 85% of expenditure over the life of a building is associated with running the facility (Edirisinghe, et al., 2017). Thus, to attain value for money it is essential to look at whole life costs of a building rather than focusing on capital cost only. According to Manege and Kennedy (2020), despite most construction professionals being knowledgeable of whole life costing in Tanzania, it is still not widely practised and one of the key reasons being lack of reliable cost data. Thus, for whole life costing to be applied there is a tremendous need for availability of reliable and accurate cost data. Whole life costs consist of the following cost elements (Manege and Kennedy, 2020): non-construction costs, income, externalities and life cycle costs (construction, operation, maintenance and end of life). To implement whole life costing, all the needed cost data need to be readily available. The difficulty in accessing running cost data (operation and maintenance cost data) for buildings makes it difficult for building construction professionals to undertake whole life costing and forecast the financial expenditure of a building (Stride, et al., 2020). However, Ashworth, et al. (2013) encourage the use of facility managers in buildings as the best source for running cost data.

2.1.1 Cost Data Sources

The use of accurate cost data generated from reliable sources ensures that objective, rather than subjective, decisions are made in the industry (Moon, et al., 2007). A reliable source of cost data needs to be accurate, up to date and consist of well-stored records. It is unlikely that a building construction professional can hold sufficient cost data to offer a suitable base for whole life costing and other cost plans covering a wide range of building types. Therefore, collection and storage of cost data for building projects can be done from several sources depending on availability. The following are the most common sources of cost data in the building construction industry.

In-house: This is one of the major sources of cost data in the building construction industry (Ashworth, 2004), based on successful contractors' tenders. It is sometimes referred to as the priced bill of quantities source of data. It is considered the cheapest, fastest and most comprehensive source. Its importance comes from the fact that it is homemade, meaning that owners are familiar with the projects. It is often considered the most accurate and reliable source although it can be disputed that it can be subjected to peculiarities in tendering, like errors from lack of accurate cost data and other human errors in preparing it. Therefore, it is important to treat the cost data from this source with great care, taking into consideration each project in its uniqueness. The following factors are the cause for variations in rates and prices in the building construction industry: the size of the project, type of the project, location of the project, contract conditions of the project, market conditions and contract implications. The more details available in a project the more it will be subjected to variability, making the cost data less reliable (Ashworth, 2004). According to Hu (2008), it can be difficult to collect and store cost data for in-house sources, due to different building construction projects being undertaken by multiple practitioners thus, cost data is scattered and subjected to loss. Therefore, there is a need to be extra vigilant in ensuring that all the cost data is collected and stored to be used for future projects.

Market survey: This entails having a feel or knowledge of what is going around in the current building construction market. The survey involves asking around to get the latest cost data in the building construction industry from different industry stakeholders. This will involve asking other building construction professionals (Architects, Quantity surveyors, project managers, engineers), labour unions, plant hiring and purchasing companies, builders' merchants, subcontractors and suppliers of building components (Atinuke, 2010). Common practice involves asking suppliers and builders merchants their prices and quotations, thus providing cost data to help with estimates for tendering. Material suppliers are also known to produce material price lists from time to time, which come in handy to industry practitioners while undertaking cost estimates. Building construction professionals in the industry act as a source to one another by communicating to enquire on certain cost data they are missing. Even though this is highly practised, data collected from colleagues in the industry may not be reliable as some might decide not to disclose correct cost data and sometimes the cost data might not be relevant or outdated. It is therefore important to treat the information collected from colleagues with the utmost caution.

Technical press: Also known as price books, the technical press is common in developed countries where technical magazines and journals are available in the building construction industry to publish cost information. They normally entail basic material prices, elemental cost analysis, cost indices and labour rates. They are considered a fast point of reference and in some instances, they help with inflation to keep the players aware of price changes. Technical presses are not common in developing countries due to lack of competition in construction projects as compared to developed countries. In some developing countries like Nigeria where it is available (Atinuke, 2010), it is considered the least comprehensive and trusted source because of its inconspicuousness of the source of information. The government in developing countries is the main client who is not money conscious as the private client in developed countries, thus, technical press in developed countries is more common because private clients push for them as they are engaged more in construction projects and are after value for money.

Online information service: This is one of the most reliable and the fastest source of cost data. Also known as cloud-based, this is a source where cost data can be accessed online from electronic devices (phones, tablets, computers), therefore making it the most reliable, easy to access and fastest source of cost data in the modern world. BCIS in the United Kingdom is a major example of an online information service. Formerly known as Building Cost Advisory Service was established in 1962, BCIS is considered the largest disseminator of cost data in the world (Ashworth, 2004). Its main functions include collection, storage, analysis, selection and publishing of data. Even though its focus was on providing reliable cost data for quantity surveyors, it now allows subscriptions from architects, engineers and contractors. The service works on a reciprocal basis whereby it exchanges cost information between members who can supply it with information. Apart from publishing capital costs, BCIS also furnishes its users with running costs which can help perform whole life costing to get the best value for money in the long run. Another current similar online information service is the Building Cost Information Service Malaysia (BCISM) from Malaysia.

3. METHODOLOGY

A literature review was conducted during the initial stages of the study to gain in-depth knowledge from different sources such as journal articles, conference proceedings, books, and electronic sources. This revealed the knowledge gap and existing knowledge on the research problem. This study is descriptive and follows a mixed method research strategy (Creswell, 2014). It's descriptive as it describes the availability of reliable cost data for whole life costing in the Tanzania building construction industry (Kothari, 2004). Sequential explanatory mixed method research strategy was adopted, which involves conducting a quantitative method, followed by a qualitative method to expand on initial findings (Saunders, et al., 2016).

The questionnaire survey was adopted for a quantitative approach, where quantity surveyors were considered, as they are key personnel engaged in cost data and undertaking whole life costing in the building construction industry in Tanzania. The questionnaire survey adopted the use of both web and mobile internet self-completed questionnaires (Saunders, et al., 2016), thus web links to the questions were sent to the respondents. The use of internet questionnaire was adopted to facilitate reaching a large number of respondents in different geographical zones in Tanzania. Stratified probability sampling was used to categorise them into two strata: class one contractors and consulting firms. This technique is considered free from bias as it ensures a sample that accurately reflects the population being studied (Saunders, et al., 2016). Purposive random sampling was then used to select respondents from each category or strata, according to Trochim (2006) a researcher is bound to get information from a sample of the population that one thinks knows most about the subject matter.

According to the Tanzania building construction industry, there are 140 class I contractors registered with the Contractors Registration Board (CRB, 2021) and there are 134 quantity surveying consulting firms registered with the Architect and Quantity surveyors Registration Board (AQRB, 2021). To determine the sample size for the study, Eq. 01 was used as per Saunders, et al. (2016). The study considered a level of confidence of 80% (z = 1.28), a margin of error (e) of 10%, percentage belonging (p) of 50% and percentage not belonging (q) of 50%, which brought a minimum sample size (n) of 40.96. Eq. 02 was then used to attain an adjusted minimum sample size for each group from the minimum sample size as seen in Table 1. A total of forty-two (42) questionnaires were returned out of sixty-three (63) which were distributed, equivalent to 66.67%. In contractors, 22 responded out of 32 which is equivalent to 68.75%, and in consultants, 20 responded out of 31 which is equivalent to 64.52% (Table 1). Golland (2002) depicts that a response rate of 30-40% is good and that over 50% is considered excellent.

$$n = p \times q \times \left[\frac{z}{e}\right]^2 \qquad \textit{(Eq. 01)}$$

Where: n is the minimum sample size required; p is the percentage belonging to the specified category; q is the percentage not belonging to the specified category; z is the z value corresponding to the level of confidence required; e is the margin of error required.

$$n' = \frac{n}{1+\left(\frac{n}{N}\right)} \qquad \textit{(Eq. 02)}$$

Where: n' is the adjusted minimum sample size; n is the minimum sample size; N is the total population.

Table 1: Population, sample size and response rate

Quantity Surveyors	Population	Sample size (n')/ Distributed	Responded	Response percentage (%)
Class I Contractor	140	32	22	68.75%
Consulting Firms	134	31	20	64.52%
Total	274	63	42	66.67%

Upon analysing the questionnaire survey data, a series of structured interviews were carried out as a qualitative approach, to gain a deeper understanding and provide more insight into the same. A structured interview was adopted as its more economical and provides a safe basis for generalisation (Kothari, 2004). The population for this study was limited to quantity surveyors, architects, project managers and engineers still active in the building construction industry in Tanzania.

The interview included a mixture of face-to-face and telephone interviews (Saunders, et al., 2016) in which digital voice recording was used to aid in capturing information upon consent from the interviewees. Convenience random sampling technique was used to select the interviewees. Twenty (20) building construction professionals working in the industry were interviewed to reach data saturation (Saunders, et al., 2016). Table 2 provides the general information of the interviewees.

Table 2: Interviewee background information

Interviewee Code	Designation	Years of Experience
INT 1	Quantity Surveyor, Consultant	4 years
INT 2	Quantity Surveyor, Consultant	6 years
INT 3	Quantity Surveyor, Consultant	7 years
INT 4	Quantity Surveyor, Consultant	10 years
INT 5	Quantity Surveyor, Contractor	6 years
INT 6	Quantity Surveyor, Contractor	6 years
INT 7	Quantity Surveyor, Contractor	8 years
INT 8	Architect, Consultant	5 years
INT 9	Architect, Consultant	6 years
INT 10	Architect, Consultant	6 years
INT 11	Architect, Consultant	11 years
INT 12	Architect, Contractor	5 years
INT 13	Project manager, Consultant	7 years
INT 14	Project manager, Consultant	8 years
INT 15	Project manager, Contractor	3 years
INT 16	Project manager, Contractor	5 years
INT 17	Project manager, Contractor	5 years
INT 18	Engineer, Consultant	5 years
INT 19	Engineer, Consultant	6 years
INT 20	Engineer, Consultant	3 years

Data analysis entails closely related operations, undertaken to summarise the collected data and organise them to address the research objective (Kothari, 2004). Data collected through questionnaires were analysed in frequency and percentage using Statistical Package for Social Sciences (SPSS), in which charts and tables were used to present the interpreted data. The use of thematic analysis was adapted for the interviews, Saunders, et al. (2016) entails that it involves coding qualitative data to identify themes for further analysis related to the research question.

4. ANALYSIS AND DISCUSSION

4.1 FAMILIARITY OF COST DATA SOURCE

This question was focused on identifying the most commonly used sources of cost data and realising the familiarity of other sources in the Tanzania building construction industry. The results, as seen in Figure 1 revealed that for in-house sources 2.4% of the respondents were 'Not familiar' and 97.6% were 'Familiar and used'. For market survey: 2.4% of the respondents were 'Not familiar', 9.5% were 'Familiar but never used' and 88.1% were 'Familiar and used'. For technical press: 33.3% of the respondents were 'Not familiar', 2 52.4% were 'Familiar but never used' and 14.3% were 'Familiar and used'. For online information service: 71.4% of the respondents were 'Not familiar', 23.8% were 'Familiar but never used' and 4.8% were 'Familiar and used'. This response clearly shows that the most familiar and used source of cost data is in-house followed by market survey. It also relays that the online information service source of cost data is the most unfamiliar source followed by the technical press.

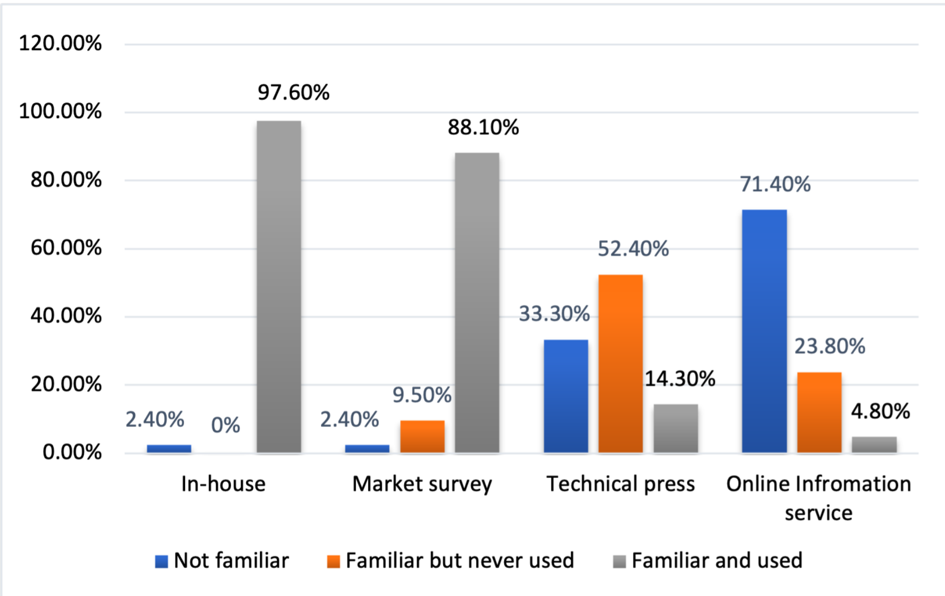

Figure 1: Respondents on familiarity of cost data sources

To generate an in-depth understanding of the source of cost data, the interviewees were asked to name their sources of cost data. Only two sources of cost data were named, in-house and market survey, in which all the interviewees named In-house as their source and several included market survey. According to interviewee INT 1, "*we have our own cost data in the company which we refer to when in need. We also do enquire from our suppliers and other colleagues in the industry for certain costs that we do not have*". And interviewee INT 2 mentioned, "*We are engaged with so many suppliers with different kinds of materials and they have their price lists of the materials they supply so depending on the item that I need, I can ask them, like how much do you sell this cement or this bucket of paint, so I get from suppliers or from people I know but mostly it's from suppliers. We also store all the cost data that we collect for future use*". While interviewee INT 3 responded, "*Our main source is our own records from previous projects, and we get others from our suppliers whom we ask for different prices when we lack them. Also, I use experience quantity surveyors to get information*". The interviewees INT 4, INT 10 and INT 15 mentioned that their cost data comes from the archives that they keep from previous projects and encounters.

Interviewee INT 12 responded, "*We have our database, in which after we purchase let's say a certain material, we will store the information for later projects. In labour, it's the same thing we have our labour rates which we use, and we change them depending on the situation or location. We also consult other people in the industry if we need help*". Interviewee INT 16 went forth and said, "*Mostly I consult experts of different items example for electricity I would consult with them to get the cost data also we have our records that we can check*". And interviewee INT 18 said, "*we have inhouse data that's been collected from previous projects and if we miss any cost data, we usually call other people in other companies to see if they can help*".

The interviewee's responses back up the questionnaire's findings that in-house and market surveys are the most commonly used sources of cost data in the Tanzania building construction industry. They also show that there is no awareness of the other sources of cost data: technical press and online services. The findings above align with Ashworth (2004) that in-house is a major source of cost data in the building construction industry.

4.2 RUNNING COST DATA SOURCE

According to Manege and Kennedy (2020), whole life costing plays a vital role in ensuring long term value in a building is attained but in order to undertake it, there is a need to have reliable running cost data (maintenance and operation cost data). Therefore, this question was aimed at realising whether the respondents had a source for running cost data. The results as seen in Figure 2 revealed that 61.11% of the respondents said no and 38.89 said yes. This shows that the majority of the respondents do not have a source for running cost data.

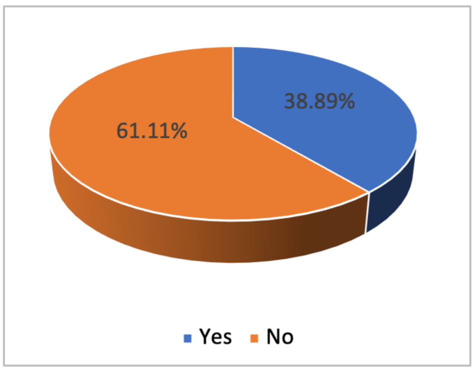

Figure 2: Respondents on having a source for running cost data

Although some of the questionnaire respondents highlighted having sources for running cost data, it was contrary to the interviewees, where all responded to not having a source for it. And according to interviewees INT 6 and INT 17, said that they had no idea how they would even get them. However, interviewee INT 2 went further to say, "*It's very difficult to get those, maybe until I start to use the building for some time then I can start to notice like if I switch so much the AC, this is what the energy consumption will be. But for now, I don't have a source"*. This clearly shows that there lacks a source of running cost data that can help in whole life costing undertakings (Manege and Kennedy, 2020; Sandaruwan, et al., 2021) and other cost estimations needed in the building construction industry.

4.3 RELIABILITY OF COST DATA SOURCES

In order to understand the reliability of cost data sources, the respondents were asked to assess how reliable they thought their cost data sources were. This question was focused on realising how the quantity surveyors in the Tanzania building construction industry were confident in their sources of cost data. The results, as seen in Figure 3 revealed that 28.57% of the respondents were 'Not sure', 66.67% believed they were 'Reliable' and 4.76% believed they were 'Highly reliable'. The response demonstrates that despite the majority believing that their sources are reliable, some are unsure if they are and only a few believe that they are highly reliable.

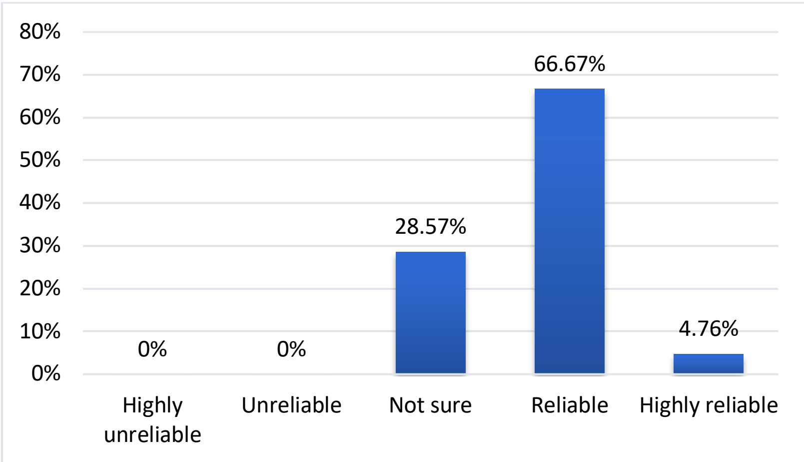

Figure 3: Respondents on reliability of cost data sources

According to the interviewees, the majority responded that they thought their source of cost data was reliable, although many were quick to justify that not all the time, they considered them to be so. The level of reliability according to most interviewees relied much on being successful on tenders and execution of projects. According to interviewee INT 2, they said, "*Yes, I think they are reliable. Because what I plan from the planning stage up to the execution there is no difference, meaning that if am planning to use this much for the construction and when I start executing the work, the final cost that I calculated is almost the same as what I use*". This was further supported by interviewees INT 8, INT 11, INT 13, INT 14 and INT19 who believed that the cost data from their source was reliable as he has used the same sources for years and is yet to find fault in them. Interviewee INT 7 went forth to say, "*Yes, I have gotten several projects by using the data from my sources. But it's fair to say that sometimes the data can be misleading in project types that you have not done before, I end up being either too low or too high*".

Contrary to those who believed that the cost data sources were reliable, interviewee INT 3 responded that "*They are not entirely reliable, but they are the only ones we have. They* *sometimes tend to mislead us in tenders, and we end up losing the tenders*". Interviewee INT 20 responded that they are not very sure as to whether the cost data from their sources are reliable as they can be contradicting from one source to another, a similar response was received from interviewees INT 5 and INT 9. This was further supported by interviewee INT 1 who elucidated that "*If you get from your friend, how can you believe that it's reliable data, you may find that you apply it and you end up getting a loss or the project ends up failing. They are mostly not realistic. And there is not any place you can confirm that it's realistic or not because you don't have a place to benchmark".*

This analysis helped realise why most of the responses from the questionnaire believed that their cost data sources were reliable but not highly reliable, as most believed that the cost data from their sources did get them through successfully in multiple tenders and projects but not all. This can be depicted that the cost data sources in the Tanzania building construction industry are considered reliable, but they lack credibility as the practitioners cannot account for them fully.

5. CONCLUSIONS AND RECOMMENDATIONS

This study looked at exploring the availability of reliable cost data for whole life costing in the Tanzania building construction industry. The study was conducted through a mixture of questionnaires and interviews as means of data collection from quantity surveyors and other building construction professionals respectively. It aimed at revealing what are the key sources of cost data as well as familiarity with other sources among industry professionals. It also went further and looked at the reliability of the cost data sources.

The study revealed that in-house and market survey were the most familiar and used sources of cost data in the Tanzania building construction industry and that online information service was the most unfamiliar source. Running cost data which are crucial for undertaking whole life costing did not have a source according to the findings, therefore making it difficult to undertake whole life costing. The study also revealed that despite cost data sources being considered reliable, they still lacked credibility as most respondents still had doubts about them.

To improve cost data availability in Tanzania there is a need to have improved sources of cost data that will facilitate the availability of reliable cost data for whole life costing undertakings and other estimates. Building construction professional bodies across the country should look at addressing this challenge by moving from reliance on in-house and market survey sources to online information services like the BCIS as this will ensure that quantity surveyors and other industry professionals have a place to benchmark their cost data as well as ensure the reliability of the cost data provided. Also, much emphasis should be given to ensuring there is availability of running cost data, as this will ease and promote whole life costing in the industry.

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BEYOND THE IRON-TRIANGLE: ACCOMMODATING SUSTAINABLE CONSTRUCTION IN THE NEW-NORMAL CONDITIONS

L.R.V.N. Rathnakumara[1] and H. Chandanie[2]

ABSTRACT

As one of the economic stabilisers in Sri Lanka, the construction industry is affected severely due to the Corona Virus Disease (COVID-19) pandemic. Unbalance of the Iron-triangle which refers to key Construction Project Goals (CPG) (i.e., time, cost, and quality) is one of the phenomena that can be addressed while Sustainable Development (SD) (i.e., economic, social, and environmental sustainability) has been streamlined to worse condition. Even though, sustainability must be prioritised in developing countries e.g., Sri Lanka, where significant construction works are currently underway, especially during this situation. Further, the appropriate construction and implementation in a construction project can make a dramatic contribution to the mandate of sustainable development. Hence, this research intends to investigate how the Iron triangle would be unbalanced during the new-normal situation where it has a significant impact on SD simultaneously. A qualitative survey strategy was used to achieve the research aim. A semi-structured interview survey was conducted to solicit the perception of experts. Nine experts were selected purposively, who had experience in both Sustainable Construction (SC) and project management, especially proceedings during the new-normal condition. To analyse the empirical data, the manual content analysis method was used. As the decisive outcome, the 'Iron-star' model was developed by merging the Sustainable triangle and Iron-triangle which pertained to the interrelation between SD and Construction Project Goals (CPG). Initially, interrelations between SD measures and CPG were cogitated by literature findings. Economic depletion, health-related issues, supply chain disruption, and cash flow issues were identified as interventions to achieve CPG through SD measures. Further, it revealed that the Iron-star can implement as the way forward for the construction industry in the Sri Lankan (SL) context.

Keywords: *Construction Project Goals; COVID-19; Sri Lanka; Sustainable Development.*

1. INTRODUCTION

The construction industry has always been different and dynamic, coping with a wide range of risks with inter and various cultural backgrounds (Acharya, Lee and Kim, 2006). Construction work entails interconnected and multi-criteria set of success factors, posing challenges to construction firms (Turkyilmaz, et al., 2019). Osei (2013) stated that the construction sector and its operations have a huge impact on the environment, the

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economic system, and the community. As a result, it is constantly looking for applicable tactics to make construction more sustainable (Abidin, 2010). Realising the major implications of construction activities on SD has contributed to the growth of several management methodologies for project success. Further, Johnson and Babu (2020) stated that project success is mostly measured by its ability to complete projects on schedule and under budget while maintaining top quality as the main goal. Even though, the inability to satisfy the major goals of time, cost, and quality can have a long-term impact on clients, contractors, and all stakeholders, especially during pandemic situations (Assaf and Al-Hejji, 2006; Nega, 2008). Meanwhile, the recent outbreak of COVID-19 had a large influence on the global economy by affecting numerous industries e.g., construction, tourism, and exports (Shibani, Hassan and Shakir, 2020). Besides, Chopra and Nagar (2020) stated that the severity of the effect would be determined by the length of the shutdown and the time required for the economy to return to normal.

Meanwhile, Mahawatta (2021) discussed that there is no assurance that the Sri Lankan economy will return to normal towards sustainable development, where the capability to suppress the intensification of dollars with unsustainable debts and interest for the next few decades. Yet, the sustainability performance of a single construction project throughout its life span is an essential component in accomplishing the objective of SD (Athapaththu and Karunasena, 2018). However, SD is still considered by stakeholders as a 'nice-to-have' practice that reinforces standard practice without being integrated into making decisions (Du Plessis, 2002). Sri Lanka, as a developing country, has a high demand for SC, even though the country lacks sufficient SC practices (Jayalath and Gunawardhana, 2017). Further, Gbahabo and Ajuwon (2017) discussed that poor-quality construction projects, lengthy delays, and budget overruns stymie economic progress, which can be crippling, particularly in most developing countries. Moreover, the Differences-in-Differences model assesses the effect of COVID-19 on performance in organisations through the construction industry along with sustainability and project goals as two dimensions can be used (Shen, et al., 2020). Although different studies had been carried out on SD and CPG which studied the impacts of the COVID-19 Pandemic regarding SL context, none of them covered how CPG are affected by SD measures during the COVID-19 Pandemic unanimously. In this COVID-19 pandemic, the economic, social, and environmental pillars must be combined not late into arguments on developing sustainability to achieve CPG (Eizernberg and Jabareen, 2020). This research aims to investigate the impact of CPG (i.e., time, cost, and quality – Iron triangle) in sustainable projects in new-normal conditions. Critically reviewing the interrelations of SD and CPG to analyse the impact of the COVID-19 Pandemic on SD measures and appraise the new-normal sustainability challenges against the Iron triangle through developing the Iron-star as a conceptual framework was the outcome.

2. LITERATURE REVIEW

In Sri Lanka, Construction Project Goals (CPG) at project success zone, since the recent outbreak of Corona Virus Disease (COVID-19) which had a large influence on the global economy by affecting numerous industries e.g., construction, tourism, and exports (Shibani, Hassan and Shakir, 2020). As illustrated by Kawmudi, et al. (2020), Sri Lanka without reservation is affected by the harmful situation and restricted people to stay home and keep social distance to minimise the exposure and stop the spreading of the virus and subsequently instructed to work from home. During the lockdown, fewer construction workers can be able to pass, and there will be limited access to and supply of inputs, causing CPG (Chopra and Nagar, 2020).Nonetheless, construction projects need naturally everybody at a construction site to be joined with workers to perform several tasks according to the specifications (Okema, 2000). Further, import and export facilities of materials have been obstructed due to a pandemic that will impact on construction industry (Hasanat, et al., 2020). This circumstance will have an impact on construction materials, technical equipment, and electrical equipment, and enterprises will have to pay a higher price to purchase these products in the future, prolonging the process (Kawmudi, et al., 2020).

When it comes to the concept of sustainability i.e., social, economic, and environmental factors represent, as mutually three intersected circles in which the centre has become ubiquitous (Purvis,Mao and Robinson, 2019). Huovila and Koskela (as cited in Durdyev, et al., 2018) defined sustainability as follows:

> *"The balance between the three elements of sustainability plays a significant role in the construction industry compared to other industries, and it is strongly recommended that the industry's success must be considered based on the triple-bottom-line, rather than traditionally used measures focusing on time, cost and quality". (p.04)*

Among three pillars, social sustainability consists of three components, i.e. (i) basic needs, (ii) individual capacity, and (iii) social capacity (Fiorini and Jabbour, 2017). Further, Nidheesh and Kumar (2019) stated that environmental characteristics should be viewed as capital instruments, as natural and social capital. Apart from environmental and social sustainability, Ahmad and Thaheem (2018) explained that although economic sustainability appears to be a simple concept in the construction sector, it is a complex process involving capital and life cycle costs, adaptability, and other factors. However, there is a major positive and long-term impact on economic sustainability, decisions, and policies by social and environmental sustainability especially in developing countries (Ahmadi, Kusi-Sarpong and Rezaei, 2017). Referring to three pillars, various sustainability techniques have been created to assess the success of growth at various phases of the project lifespan in terms of balancing energy and environment while taking social and technological elements into account (Clements-Croome D. e., 2004). In most cases, rigid focus on project budget and schedule management has affected the prejudice of project quality, which tends to project deliverables are not fit for the purpose or without applying the requirements even in SC for project success (Wright and Lawlor-Wright, 2019). Aga, Noorderhaven and Vallejo (2016) suggested that the triangular factors of time, budget, and quality are used to determine the success of a construction project.

Meanwhile, Maqsoom, et al. (2018) stated that the capacity to reduce project time, and cost, and enhance quality may define a construction firm's degree of success referring to the Iron-triangle. According to Atkinson (1999) technically balancing three main project goals in the construction industry refers to the "Iron triangle" that remains in constant tension regarding the successful project. The author further elaborated those traditional measures of project success are time, cost, and quality, also known as the iron triangle. These project success criteria have been adopted in many projects. Denoting the Iron-triangle, once the planned completion date has been exceeded due to both internal and external issues, the time to complete will be extended (Al-Nijjar, 2008). As well as the excess of actual cost over the budget by escalation or increase can be recognised as a cost overrun (Zhu and Lin, 2004). Moreover, Laughlin, et al. (2012) explained that the quality aspect represents the operations and measures a contractor undertakes to manage the project which is expected from end-users in successful projects.

Researchers intend to analyse the project success that is contributing to sustainability which makes a competitive advantage (Rabechini and Carvalho, 2006). Further, Raut, et al. (2018) ascertained the significance of a holistic view and balancing the triple bottom line of sustainability during the implementation process towards project success. Figure 1 shows the evolvement of the emerging two criteria with real-world implications.

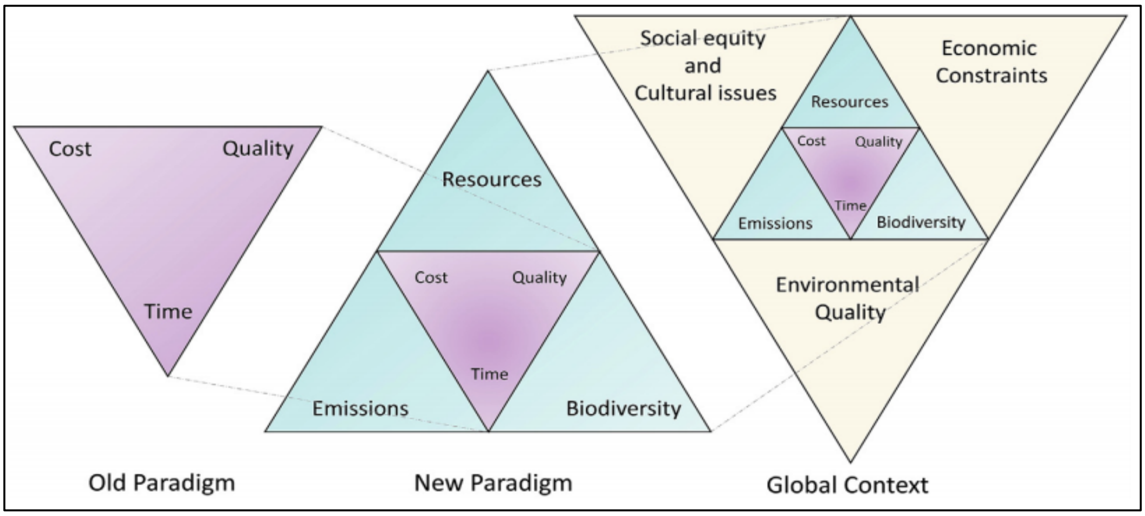

Figure 1: The evolvement of context

Source: Ahmad, et al. (2019)

According to Ahmad, et al. (2019), economic constraints, social equity and cultural issues, and environmental quality are indirectly broadcast around the Iron triangle (refer Figure 1). The authors further explained that cost performance may be impacted by environmental and social sustainability, as well as time and quality performance and vice versa. Meanwhile, Ahmad, et al. (2019) confirmed that in many developing countries, social, economic, and environmental benefits tend to increase the ecological cost. Unstable political and social conditions may result in strikes, and military attacks affect material supply suspensions which further leads to increased market prices (Enshassi, Al-Najjar and Kumaraswamy, 2009). Additionally, Ahmad, et al. (2019) have interpreted time performance may be impacted by economic sustainability while environmental sustainability may be impacted by time performance and vice versa. Nevertheless, when establishing the linkage between sustainability and project management, it is required to transcend beyond an axiological mentality on sustainability associated tools in the triple bottom line in a project viewpoint (Bolis, Morioka and Sznelwar, 2014). Further, the authors discussed that genre of this linkage is better than using those concepts sporadically to overcome issues in construction projects. Therefore, impacts on CPG from each pillar of sustainability make sense on potential all project success factors (Ahmad, et al., 2019).

Ultimately, developing the Iron-star (refer Figure 2) based on the interrelation of SD and CPG would be a worthwhile impression aligned with the following conceptual framework to uplift the SD in the SL context. The Iron-star developed based on each aspect of the Iron triangle is affected by each pillar of sustainability. Two triangles which represent the triple bottom line of sustainability (i.e., economic, social, and environmental sustainability) and the iron triangle (i.e., time, cost, and quality) are merged one to one (refer Figure 2). Each goal has direct impacts from both right and left side sustainable pillars, while the indirect impact from the facing pillar.

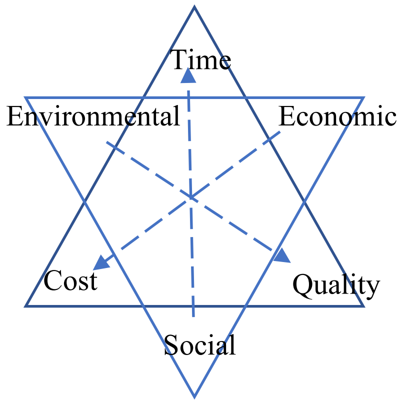

Figure 2: The Iron-star

3. METHODOLOGY

This study aimed to ascertain unbalance in key project goals in SC while new-normal conditions. The qualitative research approach was selected to collect data. Through semi-structured interviews with the invited professionals for their perceptions. There were nine experts with more than ten years of experience with sound knowledge of sustainable development and project management as well as currently working under new-normal conditions placed by the COVID-19 Pandemic. Experts were selected through purposive sampling, including three quantity surveyors, five project managers, and two civil and structural engineers. These interview discussions provide valuable comments on the impacts on SD measures and CPG. Qualitative data obtained from expert interviews were analysed through manual content analysis by tracking the findings within identified themes.

4. RESULTS

Initially, the findings of the expert survey can be elaborated on the impacts of the COVID-19 Pandemic situation based on the interrelation between SD and CPG as identified in the literature review. Through the manual content analysis, the interviewee's opinions were analysed and the obtained summary is presented in Table 1.

Table 1: Impacts on SD and CPF from COVID-19

Sustainable pillar/CPG	Impacts of COVID-19 Pandemic
Time	Suspensions and prolonged suspensions
	Lack of skilled labour and specialised labour
	Reduction of per-day-working hours
	Scarcity of materials and equipment
	Health issues (Coronavirus spread)
	Reworks
	Arrange and manage further health facilities

Sustainable pillar/CPG	Impacts of COVID-19 Pandemic
	Lengthy permission procedures
	Cash flow issues with payment lags
	Various COVID guidelines with Newly enacted laws
	Resource idling
	Resource acquiring process is gone slow manner
	Absenteeism of workers
	Chaos of workflow
Cost	New high prices for materials and equipment
	Additional incentives for staff and labours
	Additional cost for additional PPE, and facilities
	Project acceleration cost
	Cost for reworks
	Various compensations
Quality	Usage of alternative materials
Economic sustainability	Changes in exchange rates (increase)
	Country's Economic depletion
	Disruption of supply chain
	Individual income depletion
	Progress of other industries have been curtailed
	Foreign funds are suspended
Social sustainability	Health and mental well-being are damaged
	Communication and management issues
	Newly enacted laws and regulations
	Social/travel restrictions
Environmental sustainability	Additional wastage

According to developed Iron-star, 21 impacts on CPG are affected by 12 SD measures directly or indirectly. Ascertained new normal sustainability challenges against the construction industry's key project goals are discussed hereupon.

4.1 IMPACT OF CPG FROM SD MEASURES THROUGH ECONOMIC SUSTAINABILITY

While advanced economies are concerned about economic sustainability, developing countries are concerned about economic development rather than sustainability. Besides, during the new-normal conditions, the increasing exchange rate of the Sri Lankan (SL) Rupee is one of the major impacts on the country's economy. Therefore, the inflation rate is going up day by day. Simultaneously, the purchasing power of the SL Rupee is gone down while GDP has fallen. Apart from the COVID-19 restrictions, disrupted importations are arisen due to the increase in the exchange rate. As well, with this scarcity situation, resources are sold at high rates with high demand and a low supply chain. Experts highlighted that especially cement, reinforcement bars, tiles, electrical items, and service items are inadequate day by day and Letter of Credit openings for special importing materials are suspended for most of the contractors these days. Consequently, suspensions occur in many projects since the contractors cannot afford price fluctuations of materials, as well as machinery rates, leading to scarcity within the country. When it comes to the situation where the scarcity of materials and slow acquiring process of materials, time delays generally occur. If the time delays occurred where the critical path is lagged, there is more chaos within the workflows.

As evident through experts, manufacturing, transportation and agriculture sector have been waddled due to scarcity of essentials, broken economy, and spread of coronavirus. Moreover, taxation for numerous goods and services becomes high rate and individual economic status is become a damask due to this economic depletion. The contractor's cash flow led to negative due to these factors, especially the low-rate progress of construction activities. Further, even some contractors face situations where cannot apply for interim payment with inadequate progress. That foreign-funded construction projects are terminated by funding agencies, due to the country's bad economy. As evidenced by experts' depletion of economic sustainability is affected by time and cost overruns while quality factor changes from time to time.

4.2 IMPACTS ON CPG FROM SD MEASURES THROUGH SOCIAL SUSTAINABILITY

The social sustainability concept is related to the long-term survival of the upgrade corporation in the construction sector concerning social issues. When it comes to social sustainability, there are various separate guidelines to follow during the first wave, second wave, and third wave of COVID-19. The maximum volume of workers to be maintained, and some health rules to be followed are included in those guidelines. Due to the inadequacy of labour requirements of the sites maintaining with social distances, low per-day labour productivity, and health regulations lead to suspensions and delays of construction projects. Moreover, low labour productivity due to some of the labours are (skilled, unskilled, and specialised) being infected with viruses and quarantined for long weeks and trapped in hometowns with restrictions. This will lead to time overrun of the projects and then definitely it will affect cost overrun by project acceleration.

Mainly health services, manufacturing industry, transport services, educational services, and other industries are curtailed due to various occurrences during this crisis. When it comes to COVID-19 positive cases, the whole construction site needs to be quarantined and get tested (PCR) by all the persons on the site. Then virus-positive persons are transferred to the quarantine centres and site activities are continued in the usual way. These procedures consume time as well as a cost since the general PCR test is around Rs. 6000 and Rapid Antigen Test is around Rs. 2500 in the country. As well as there are considerable time-consuming procedures viz washing hands, sanitising site premises and equipment, cleaning procedures more than previous days, and COVID-19 prevention seminars to the labours with proper guidance which can be recognised when to consider construction site as a sample of the construction industry, due to pandemic situation and various regulations.

4.3 IMPACT OF CPG FROM SD MEASURES THROUGH ENVIRONMENTAL SUSTAINABILITY

In today's world, social and, especially, environmental sustainability is established indecently within various business lexicons. The situations like COVID-19 Pandemic, there can be considerable delays in schedule aligned with a cost overrun of a budget with these managing and controlling protecting environment by additional wastage within the construction sites as illustrated by all the experts. As a whole, environmental sustainability is not affected harmfully in this pandemic, even though there is additional wastage with health proceedings considering the construction industry. Yet, a construction site as a sample, there can be a considerable amount of additional waste, even though a low percentage of polythene usage, gas emission, etc. These mechanisms lead to additional time and additional cost to the project as well as sometimes contractors have to bear all the additional costs.

Impacts on SD are shown in the red boxes and impacts on CPG are shown in the blue boxes under Figure 3. Besides, literature findings were focused on the global context while expert findings were focused on the Sri Lankan context. Concerning both literature and expert findings, the Iron-star was developed to highlight challenges on CPG against SD measures during these new-normal conditions. Identified challenges were accelerated impact on CPG. When it comes to mitigating and compromising the situation affected, these challenges will be helpful rather than concerning either project management tools or sustainable tools in an ad-hoc manner. Yet, the strategies are born out of challenges against construction operations in the countries in these situations. Therefore, by apprising all the potential impacts, the Iron-star has become a congruent solution for the current construction industry. Figure 3 shows the updated Iron-star after analysing the expert findings.

5. CONCLUSIONS

The COVID-19 disease has the potential to annihilate individual livelihoods and day-to-day lifestyles, business industries, and the whole economy in both developing and developed countries all over the world. For the construction industry, it affects various means by challenging project goals i.e., time, cost, and quality. This paper concludes that the direct challenges on CPG and sustainable impacts in new-normal conditions. Further, the Iron-star developed concerning the direct challenges on CPG by COVID-19 and SD measures indirectly. It was identified that 21 impacts on CPG have been affected by 12 SD measures directly or indirectly. The interrelation between two concepts was the main context under the development of the Iron-triangle. It helped to ascertain all the potential impacts on project success matters. Therefore, strategies can be apprised towards sustainable development. There will be no necessity for conventional project management tools. Altogether 33 impacts were identified that influenced time, cost, and quality based on the Iron-star. However, these findings will be helpful for industry professionals to restrain the intensification of impacts on project goals with unstable conjunctures like the COVID-19 pandemic.

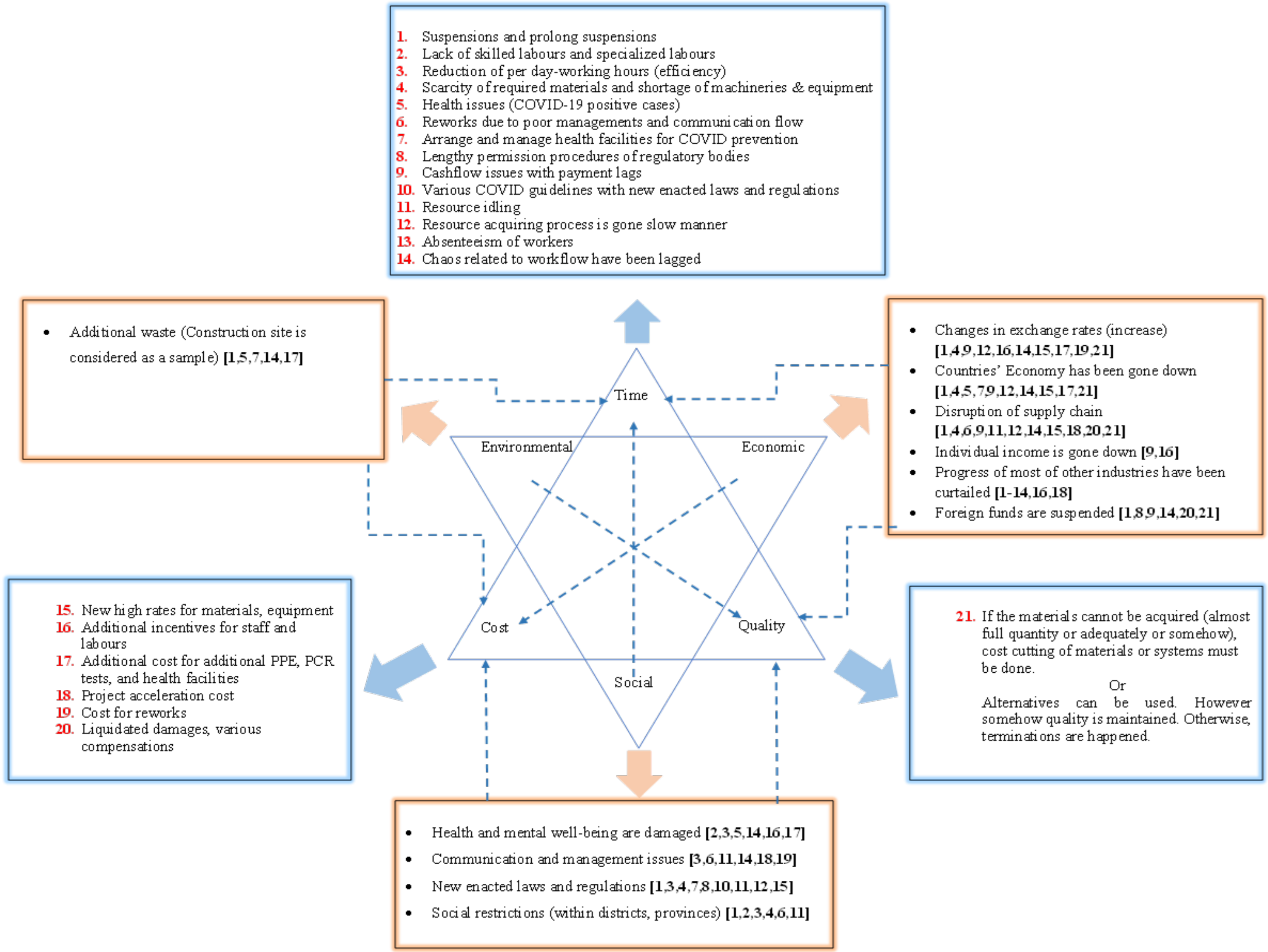

Figure 3: The updated Iron-star

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BEYOND THE REUSE: POTENTIALS AND BARRIERS FOR EXCHANGING TREATED WASTEWATER AMONG THE INDUSTRIES IN SRI LANKA

Harshini Mallawaarachchi[1], Y.G. Sandanayake[2], Gayani Karunasena[3] and Chunlu Liu[4]

ABSTRACT

A major drawback in the present industrial system is that the industries are directly discharging industrial effluent to nearest waterbodies in a linear way. Even though, a few of industries have considered reusing treated and untreated wastewater in their industrial premises, it can be further extended towards 'exchange' among the multiple industries under the concept of Industrial Symbiosis (IS). Initiating IS-based treated wastewater exchange networks is a novel approach to Sri Lankan industries and there is a lack of a study on potentials and barriers of implementing the concept. Hence, this research aimed to investigate the potentials and barriers for exchanging treated wastewater among industries. In order to achieve the aim, 16 semi-structed interviews were conducted with industry experts in the field of Industrial Water Management (IWM) to collect the data. Code-based content analysis technique was used to analyse the data by applying QSR NVivo.12 software. Findings revealed geographical proximity of industries, willingness of industries to engage in water exchange and industry level water management initiatives as major potentials for initiating water exchange networks. Lack of expected water quality for industrial needs, outdated technologies used in water management and lack of expertise and awareness were identified as major barriers. Accordingly, strategies, such as introducing national policy enhancements, ensuring cultural adaptation, enhancing technology & infrastructure, and empowering research & development, were proposed to overcome the identified barriers to ensure a successful implementation of treated wastewater exchange networks targeting the socio-economic development of the country.

Keywords: *Barriers; Industrial Symbiosis; Potentials; Sri Lanka; Treated Wastewater Exchange.*

1. INTRODUCTION

The main challenges with respect to water resources in Sri Lanka are the spatial variability of water availability and the increasing pollution of freshwater bodies due to domestic and industrial waste. The water uses in Sri Lanka mainly include household water supply,

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sewerage and sanitation, irrigation and industrial processes. There is an ever-increasing demand for freshwater in industrial processes, while direct discharge of industrial wastewater into surface and ground water bodies has created severe environmental and health issues in Sri Lanka. As stated by Imbulana, et al. (2021), the respective industrial water withdrawals indicated as 49 litres per day, point to a high density of industry use in the wet zone of Sri Lanka. Further to the authors, major causes of water pollution in Sri Lanka include sewage, industrial waste, agricultural pollutants and physical pollutants. However, the existing policies and guidelines are not supporting the reuse of industry effluent, where direct discharge is permitted within the given water quality limits (Board of Investment [BOI], 2011). Many industries are directly discharging untreated industrial effluent to the nearest waterbodies specially, which were located on riverbanks and upstream of water bodies (Wijesekara, et al., 2020). Therefore, it is important to develop a method to exchange the treated wastewater among the industrial entities in order to reduce the freshwater consumption and wastewater discharge. The concept of Industrial Symbiosis (IS) is an idyllic model to initiate the IS based treated wastewater sharing networks as an innovative water management initiative as it engages the traditionally separated and geographically proximate industrial entities to achieve collaborative benefits through the physical exchange of resources including water (Mallawaarachchi, et al., 2020).

Export Processing Zones (EPZs) in Sri Lanka are offered a great potential for such closed-loop industrial systems. Both new developments as well as the existing or obsolete industrial sites can be transformed into eco-industrial nature. The co-located industries in the EPZs could be realized as industrial clusters by moving them towards a new stage of environmental upgrading, becoming an eco-industrial park. The existing environmental degradation of EPZs due to the elevated freshwater utilisation can be overwhelmed through treated wastewater exchange.

Accordingly, this research aimed at analysing the potentials and barriers for initiating treated wastewater exchange networks in Sri Lanka, which can be served as a basis to call for actions from both industry professionals and policy makers towards empowering Sri Lankan industries towards eco-industrial collaboration. This paper is mainly focused on answering three sub research questions as follows:

1. What are the potentials for initiating treated wastewater exchange networks in Sri Lanka?
2. What are the barriers for initiating treated wastewater exchange networks in Sri Lanka?
3. What are the strategies for overcoming the identified barriers?

2. LITERATURE REVIEW ON TREATED WASTEWATER EXCHANGE NETWORKS ACROSS THE GLOBE

Wastewater reuse in industrial plant is a strategy, which has been considered by many studies in recent decades for Industrial Water Management (IWM) (Taskhiri, et al., 2011). The adoption of water minimisation strategy through wastewater reuse can effectively reduce overall freshwater demand in water using processes and subsequently reduce the amount of effluent generated (Zheng, et al., 2019). On the other hand, wastewater reuse can be extended to multiple industries in which the wastewater from one industrial plant can be reused directly by other plants as long as the quality requirements are satisfied

(Aviso, et al., 2010). Further, geographical proximity of the industries is a major concern in initiating IS-based water exchange networks (Weerasinghe and Sandanayake, 2017).

A number of IS initiatives have been launched across the globe (Tao et al., 2019), expecting to achieve benefits through the exchange of resources including water. Indeed, the IS networks in European countries have been impacted considerably on their environmental and economic development through water savings, reduction of raw material extraction and carbon emissions reductions. Specially, the industries with close proximity and those who have willingness to engage are mainly considered to initiate symbiotic relationships (Domenech, et al., 2019). Kalundborg Eco-industrial park, Denmark, Choctow Eco-industrial Park, USA, Qijiang Industrial Park, China, Songmudao Chemical Industrial Park, China are the examples for IS projects, which have been initiated to exchange the treated wastewater (Zhang, et al., 2017).

Similarly, the industries in industrial zones in Sri Lanka can obtain collective advantages, such as reduction of raw water extraction, ground and surface water pollution, utility and treatment cost reductions, and social enhancements, through this ecological engagement while contributing to the socio-economic and eco-industrial development of the country. Therefore, it is important to initiate treated wastewater exchange networks among the industrial entities in Sri Lanka in order to reduce the industrial demand for freshwater, which ultimately minimise the direct discharge of wastewater to the environment. Identifying barriers and potentials for initiating such treated wastewater exchange networks as well as the strategies to overcome the identified barriers is a fundamental step to be considered as it enables effective industrial engagement and commitment.

The methodology adapted to achieve the aim of this study is described below.

3. RESEARCH METHODOLOGY

Since this research aimed at investigating the potentials and barriers for initiating treated wastewater exchange network in Sri Lanka, qualitative approach was selected. Interviews with industry experts was applied as the suitable research strategy.

Semi-structed interviews was used as the data collection method as it is one of most important sources to collect qualitative data. As Yin (2009) stated, interviews can be either open ended, focused or structured interviews in which semi-structured interviews are highly used to maximise the flexibility of the interview by shaping it as per the need of the individuals. A semi-structured guideline was developed based on the research questions to be answered, which consists of four major sections as: (i) Overview of IWM in Sri Lankan context, (ii) Potentials for initiating treated wastewater exchange networks, (iii) Barriers for initiating treated wastewater exchange networks and (iv) Strategies to overcome the identified barriers.

Accordingly, 16 semi-structured interviews were conducted with industrial experts having more than five years of experience in the field of IWM in Sri Lanka. The respondents were selected through convenient sampling technique. The profile of interviewees is given in Table 1.

Table 1: Profile of interviewees

	Designation	Field of specialisation	Experience
E1	Project Director	Wastewater and water treatment	20 years
E2	Researcher	Civil engineering and water management	15 years
E3	Deputy General Manager - Sewerage	Sanitary engineering	13 years
E4	Project Consultant	Waste management	10 years
E5	Manager - Compliance and Sustainability	Facilities management and sustainability	9 years
E6	Facility Manager	Facilities management	6 years
E7	Executive - Compliance	Facilities management and sustainability	5 years
E8	Assistant Manager - Compliance	Sustainability	5 years
E9	Executive Director	Civil engineering and wastewater	30 years
E10	Senior Expert - wastewater	Environmental science	10 years
E11	Expert - Wastewater	Wastewater treatment	8 years
E12	Mechanical Engineer	Wastewater treatment	10 years
E13	Senior Expert - Resource Efficient and Cleaner Production	Water resources management	10 years
E14	Assistant Manager - Environmental Sustainability	Environmental sustainability and facilities management	8 years
E15	Director	Civil engineering and sustainability	20 years
E16	Mechanical Engineer	Wastewater treatment	8 years

The respondent's demographic information with the purpose of providing an overview of the expertise and experience of the respondents in the IWM field is described below as it generates confidence and credibility in the research findings.

The years of experience of the selected respondents in the field of IWM and relevant fields was first considered. Out of 16 respondents, 69% of respondents are having more than 10 years of experience while only 31% are having experience between 5 to 10 years.

Further, 28% were familiarised with water and wastewater treatment. Sustainability and Civil Engineering were the second highest area of expertise (17%), while water management and facilities management obtained 11% as the third highest area of expertise. The expertise areas of waste management, environmental science and sanitary engineering obtained 6% in each.

The collected data were analysed by using code-based content analysis technique. Content analysis is a technique, which is used for gathering data, involves codifying qualitative information into pre-defined categories (codes) in order to derive patterns in the presentation and reporting of information (Elo et al., 2014). Hence, code-based content analysis was used to reduce data and identify concepts from the data collecting evidences. The two-level coding, such as "internal factors" and "external factors" was used in analysis for identifying the common themes separately under potentials and barriers. Strategies to overcome the identified barriers were also explored. Based on the views of the selected industrial experts, strategies were also proposed to overcome the identified barriers. QSR NVivo.12 (Qualitative Solutions and Research Private Limited) software was used in data analysis as it manages all data very easily. Further, it saves time and energy used for data classification (Dollaz et al., 2017). Further to the authors, the process of data analysis via Nvivo employs six (06) key steps namely, (i) importing data, (ii) exploring data, (iii) coding (making nodes of key words), (iv) running search query for key words, (v) visualising and (vi) recording.

In this research, 16 interview transcripts were imported into the software and explored to identify the keywords. Accordingly, under three main nodes (barriers for exchanging water among the industries, potentials for exchanging water among the industries and strategies to overcome the identified barriers), sub nodes were recognised and coding structure was developed. As the next step, 'search query' was run by restricting the search to minimum three key words. The coding structure was then visualised as a list and recoded to use in data analysis.

The key findings derived through data analysis are presented below.

4. DATA ANALYSIS AND FINDINGS

4.1 OVERVIEW OF IWM IN SRI LANKA

It is noticeable that many industry level strategies are more towards improving the water efficiency, while reusing domestic wastewater (without pre-treatment) within the individual industry premises, such as industry/institutional level guidelines for water management, industry level agreements for water management, reuse of wastewater without pre-treatment, applying water efficiency measures, setting organizational level sustainability targets, investments targeting environmental return and conducting training and awareness programs. The control made over the industries by national policies and regulatory framework is one of the main strategies in IWM.

However, as derived through analysis, industries have become one of major consumers of freshwater as well as the polluter of water bodies. The pollution of surface and ground waterbodies due to industrial activities has created a severe health and sanitation issues in Sri Lanka. As stated by many experts, unavailability of an explicit national water policy can be identified as a main issue of IWM in Sri Lanka.

Further, it has led industries towards the heavy extraction and misuse of raw water for the industrial purposes. Lack of wastewater treatment technologies, their operational inefficiencies as well as the difficulty and ignorance of maintaining the quality of treated wastewater were identified as other issues that hindered the IWM in Sri Lanka.

Therefore, it is important to empower industries towards reusing the treated wastewater among the industrial entities in order to reduce the freshwater consumption and wastewater discharge by the industries in Sri Lanka. Since IS is a new concept to Sri Lanka, the potentials and barriers for initiating treated wastewater exchange networks in Sri Lanka as well as the strategies to overcome the identified barriers were recognised as described in subsequent Sections 4.2, 4.3 and 4.4.

4.2 POTENTIALS FOR INITIATING TREATED WASTEWATER EXCHANGE NETWORKS IN SRI LANKA

As derived through analysis, seven potentials for initiating treated wastewater exchange networks in Sri Lanka were recognised as shown in Figure 1.

Name	Files	Refer...
> Barriers for exchanging water among the industries	0	0
∨ Potentials for exchanging water among the industries	0	0
Existing infrastructure and facilities	3	3
Existing national policies for water management	4	4
Industries govering under one ownership	3	3
Industries located within the same geographical proximity	6	6
Industry level water management initiatives	6	6
Technologies available to use for water treatment	4	5
Willingness of industries to engage in water exchange initiatives	7	7

Figure 1: Potentials for initiating treated wastewater exchange networks in Sri Lanka

Willingness of industries to engage in water exchanging initiatives is identified as a significant potential for exchanging water among the industries in Sri Lanka by adopting the concept of IS. The motivation of industries to invest in water management initiatives by considering the environmental return is a significant way forward, which can be further promoted through government incentives and assistance. It is indicated by Deputy General Manager - Sewerage (E3) as:

> *"if industries are willing to use the treated wastewater for their industrial needs, we can supply it with a reduced price than the pipe born water."*

The existing national environmental policies and regulations available for environmental management including water are motivating the industries towards reuse of water as a good sign for reducing the industrial demand for freshwater. It is stated by Project Director (E1) as:

> *"In near future we may refine the existing policy to protect the catchment areas and ground water. Then industries cannot discharge water to the environment, and they must find their own way to reuse. Empowering the policies for motivating the industries is the requirement."*

As mentioned by Researcher (E2), existing infrastructure and facilities including common treatment and pipe networks as well as the technologies available to use for pre-treatment and central treatment of industrial effluent within the industrial parks is a good potential to initiate the water exchanges between industries, where it can be further improved through government and institutional financial support. It is further proved by Expert - Wastewater (E11) as:

> *"We have treatment facilities, pipe networks, etc. within the zone. So, we can use the existing facilities to initiate this kind of a system to reduce the direct discharge of wastewater."*

Further, industrial zone is an ideal environment to initiate the water exchanges, where it is convenient to identify the possible synergies between industries, which have been located within the same geographical proximity. It is highlighted by Deputy General Manager - Sewerage (E3) as:

> *"Since we have all required facilities and infrastructure within a one geographical location, industrial zones are ideal to initiate water and other resource exchange networks. Specially, factories are located close to each other, which may reduce the cost for transporting water and for laying pipe networks."*

Indeed, selecting industries, which are governing under one ownership is another potential to initiate water exchanging networks between industries. Assistant Manager - Environmental Sustainability (E14) stated that:

> *"I think we can even start this concept within our factories under one ownership. It will be a best way to begin this new strategy as it is manageable with the same ownership of industries."*

In summary, industries located within the same geographical proximity, willingness of industries to engage in water exchange, industry level water management initiatives and industries governing under one ownership, existing national policies for water management, technology available to use for water treatment and existing infrastructure and facilities were encountered as key potentials for initiating treated wastewater exchange networks in Sri Lanka.

As initiating IS-based treated wastewater exchange networks is a new approach and hence, Sri Lankan industries are facing various challenges and barriers in initiating treated wastewater exchange networks as described below.

4.3 BARRIERS FOR INITIATING TREATED WASTEWATER EXCHANGE NETWORKS IN SRI LANKA

As derived through analysis, 12 barriers for initiating treated wastewater exchange networks in Sri Lanka were recognised in the present context, which are shown in Figure 2.

Name	Files	Refer...
Barriers for exchanging water among the industries	0	0
Cultural impact of the industrial organisations towards water reuse	2	2
Difficulty in synchronising synergies from different types of industries	4	4
Expected water quality for industrial needs	9	11
Isolated industries situated in different geographical boundaries	1	1
Lack of expertise and awareness	5	7
lack of goverment incentives and financial assistance for industries	3	3
Lack of legal provisions for reuse of water	3	3
Less investment on water management by the industries	4	5
Less reusable quantity of water available for the exchange	2	2
Non-operational infrastructure	3	4
Outdated technologies use in water treatement	9	10
Unavailability of proper discharging strategies for reject water	3	3
Potentials for exchanging water among the industries	0	0

Figure 2: Barriers for initiating treated wastewater exchange networks in Sri Lanka

As shown in Figure 2, expected water quality is highlighted by experts as a major aspect that need to be considered in implementing water exchange between industries. It is stated by Executive Director (E9) as:

"Industries expect water with potable water quality standards for their industrial processes. It is because colour and odour are very sensitive as it can affect quality of products. So, water quality is a critical factor for exchanging water among the industries to use for their production purposes."

Further, the non-operational existing infrastructure is another barrier as stated by Mechanical Engineer (E12) as:

"Even though we can initiate this with the existing infrastructure, it can be an issue in long term as the Sri Lankan industrial parks are still suffering from the outdated technology and non-operational infrastructure including pipe network."

Moreover, industries are suffering from outdated technologies use in water treatment and lack of expertise and awareness to initiate new water management initiatives, especially the concept of IS. Assistant Manager - Compliance (E8) stated:

"First, industries should aware about these modern concepts. Otherwise, they are always using the older strategies and technologies even in the future. Therefore, outdated technology is a major barrier. It is required to have new technology in treating wastewater that will help to reduce the cost of treatment. Also, do not have expertise knowledge regarding this novel concept, so lack of expertise is another matter. It is important to obtain the expertise in this field even by observing the similar projects in other countries."

It is further proved by Senior Expert - Wastewater (E10) as:

"A main barrier is that the industries are not aware about the concept as well as they could not continue their synergies as they have no experts to do any prior evaluations and analysis."

Consequently, poor attitude and less interest of industries to engage in water management initiatives and cultural impact of the organization towards the reuse of wastewater are identified as other barriers. As stated by experts in the field, many industries are expecting economic return rather than considering the environmental return thus, investing less for water management projects. It is mentioned by Project Consultant (E4) as:

"Only very few industries have this reusing culture. Others just think about the economic gain only. The industries do not prefer to invest on those initiatives, if you cannot show them the financial return to them. So, it is very difficult task to initiate these kinds of programs in Sri Lanka. As I think those initiatives should come from the policy level. Then the industries must follow those provisions unless otherwise it is illegal. Industries are afraid to pay fines and for the cancellation of their industrial activities, so they will effectively engage."

Other than that, both Senior Expert - Wastewater (E10) and Assistant Manager - Environmental Sustainability (E14) proved that the lack of government incentives and financial assistance for industries have hindered the industries' willingness for engaging in water management initiatives. It is stated by Senior Expert - Wastewater (E10) as:

"Earlier we had a workshop for industrial professionals to introduce this concept. They showed a willingness to engage in this concept. However, the programme was not continued since no funding was taken place. Even government can give a financial assistance for those who willing to engage in water management initiatives, that will be really good. It is lack in the present context."

Furthermore, unavailability of proper discharging strategies for reject water, which were generated from the industrial water treatment projects and less reusable quantity of water available for the exchange are other barriers that could affect the water exchange network as stated by Deputy General Manager - Sewerage (E3) as:

> *"The issue will be on managing the reject water. When do the Reverse Osmosis (RO) treatment, 40-50% is rejected water. You cannot just discharge it to the environment as it contains more pollutants."*

The difficulties in initiating water network between the isolated industries situated in different locations and the difficulties face in synchronising water synergies from different types of industrial entities can also be the barriers for exchanging water between industries. It is mentioned by Assistant Manager - Environmental Sustainability (E14) as:

> *"There is a huge possibility to implement this strategy in industrial parks because the factories are closely located. If the factories are in isolation, the reuse is possible only within the same premises."*

In summary, lack of expected water quality for industrial needs, outdated technologies used in water management, lack of expertise and awareness, non-operational infrastructure, isolated industries situated in different geographical boundaries, cultural impact of the organizations towards water reuse, difficulty in synchronizing synergies from different types of industries and less investment on water management by industries were identified as key barriers that need to be considered in initiating treated wastewater exchange networks between industries in Sri Lanka.

Accordingly, the identified potentials and barriers were synthesised under two main codes namely, "internal" and "external" as shown in Figure 3.

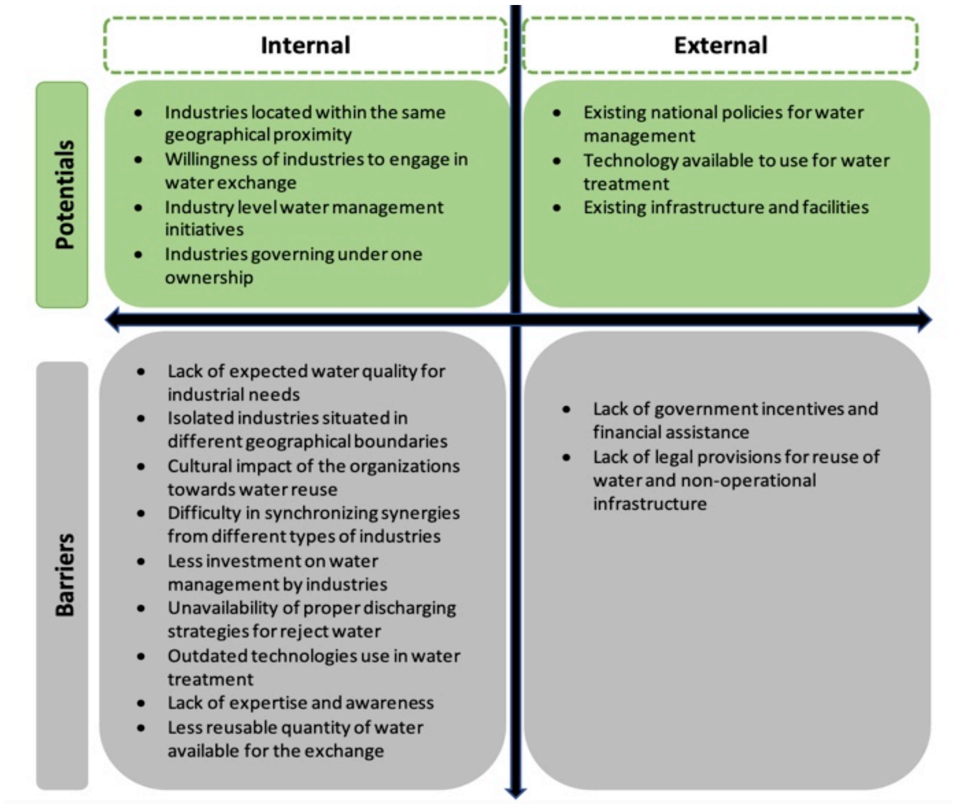

Figure 3: Potentials and barriers for initiating treated wastewater exchange networks in Sri Lanka

As shown in Figure 3, the internal potentials and barriers include the aspects that could be influenced internally or within the IS network while external potentials and barriers consider the aspects that could be influenced externally.

Accordingly, various strategies were also recognised through data analysis in order to overcome the identified barriers as described below.

4.4 STRATEGIES TO OVERCOME THE IDENTIFIED BARRIERS

The identified potentials can be further enriched while taking actions for overcoming the identified barriers for initiating treated wastewater exchange networks in Sri Lanka. Hence, following national and institutional level strategies were proposed as derived through data analysis. The proposed strategies can be taken into account in order to assist Sri Lankan industries, who are eager to engage.

As derived through analysis, 04 key strategies were recognised, which are shown in Figure 4.

Name	Files	References
Barriers for exchanging water among the industries	0	0
Potentials for exchanging water among the industries	0	0
Strategies to overcome the identified barriers	0	0
Cultural adaptation of wastewater reuse among the industries	1	4
Enhancing research and development	1	4
Introducing national policy enhancements for water intensive industries	1	8
Enhancing technology and infrastructure	1	13

Figure 4: Strategies to overcome the identified strategies

According to the analysis, enhancing technology and infrastructure was recognised as a key strategy that can be implemented to overcome the technology and infrastructure related barriers.

Executive Director (E9) stated that as:

> *"The existing infrastructure needs to be retrofitted if we are initiating water exchange networks within the zone. Further, we should have enhanced treatment technologies if we allow exchanging water from one industry to another as many of the industrial in the zone are water intensive industries. Many of them are reputed industries. Thus, they have their own manufacturing standards to be maintained."*

Hence, retrofitting of existing infrastructure & facilities, introducing modern technology for water treatment and obtaining expertise through similar projects are vital to consider. The existing industrial policies distress of having provisions for ecological relocation of industries, which has been resulted in improper location of industries in environmental sensitive areas.

As stated by Deputy General Manager – Sewerage (E3):

> "*We observed the current situation in many of industrial zones. Most of them are located without considering the geographical necessities. Industrial in*

> *environmental sensitive areas have been created a severe threat to the surface and ground water bodies. So, I think revising the existing policy is important by introducing provisions for properly locating the industries."*

Hence, the existing policies need to be enhanced in order to relocate similar industries within same geographical proximity, such as similar industry-oriented industrial zones, which also ensures effective reclamation and reuse of industry effluent. As stated by many experts (E7, E8, E15) it is important to enable a cultural change among the industry professionals through awareness programs exclaiming the need and importance of wastewater reuse and reshare. The industry is required to be adapted to follow new policies and guidelines introduced. Further, national and institutional level incentivisation is also vital to empower industries towards the reuse and reshare of treated wastewater for environmental, social and economic return.

Furthermore, enhancing research and development is another important strategy as proposed by many industry experts (E1, E4). Hence, strengthening the research and development on water synergy identification, synchronisation of various different industries in wastewater treatment, reuse and resharing of water and introducing national & institutional level funding scheme & resources utilisation plans can be considered.

5. CONCLUSIONS

In the current practice, many industries are operating as linear industrial systems, which includes extraction of freshwater, use and direct discharge to the environment with or without pre-treatment. No sharing of treated wastewater among the industries is taken place. Therefore, there is a necessity for reducing the freshwater utilisation as well as the wastewater discharge by the industries. Initiating IS-based treated wastewater exchange network is an innovative solution that empowers the industries for obtaining collective advantages through eco-industrial collaboration. This research facilitates a way for its successful initiation by overcoming the identified barriers and further strengthening the potentials. As key research findings, industries located within the same geographical proximity and willingness of industries to engage in water exchange were significant potentials for initiating treated wastewater exchange networks in Sri Lanka. However, lack of expected water quality for industrial needs and outdated technologies used in wastewater treatment could be influenced as major barriers. Accordingly, four key strategies were proposed to overcome the identified barriers, such as national policy enhancements, enhancing technology and infrastructure to name a few by considering the significance of initiating water exchange networks in Sri Lanka.

Beyond the reuse of treated wastewater within the same industrial boundary, treated wastewater exchange could create a huge impact on raw water extraction and water pollution by the industries as it reduces direct discharge of wastewater through maximum recovery. Further, the reduction of industrial demand for freshwater could facilitate an effective water allocation system within the country. Hence, the eco industrial collaboration of industries under the concept of IS towards the exchange of treated wastewater is an idyllic invention for socio-economic development of any country.

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BIM-LEAN RELATIONSHIP ASSESSMENT FRAMEWORK: A CONCEPTUAL ESTABLISHMENT

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ABSTRACT

The construction industry is seeking ways to reduce waste (material and production-related process waste) to improve productivity and efficiency. Building Information Modelling (BIM) and Lean are two vital innovations for the Architecture, Engineering, Construction and Operation (AECO) industry used in the industry to improve aspects of productivity and efficiency. BIM has been used to generate and compare designs to ensure optimum use of resources, reduce design time, improve collaboration between stakeholders, and reduce errors in design and construction. On the other hand, the main agenda of Lean is to reduce (both material and production process) waste, increase value, and thrive for continuous improvement. In the construction industry, BIM and Lean have been mostly used in isolation. However, studies suggest that BIM and Lean have mutual relationships and are complementary to achieve each other's objectives. To do so, it is very crucial to understand the mechanism behind the relationship and the interaction between BIM and Lean. Informed analysis and understanding of the mutual relationship would help construction management decision-makers to achieve the utmost benefits from the implementation of these two drivers. However, previous studies have explored BIM and Lean relationships, but limited studies were done to support construction management decision-makers in identifying relevant BIM functions to enable Lean or to identify relevant Lean principles to support BIM. Therefore, this paper aims to represent a conceptual BIM-Lean relationship assessment framework by using Design Science Research methodology to identify and measure the relationship between BIM and Lean to support construction management decision-makers.

Keywords: *BIM; Framework; Lean; Relationship.*

1. INTRODUCTION

Modern-day construction projects are getting more complex, fragmented, and challenging day by day. These complexities and challenges have mostly been related to productivity issues (Matta, et al., 2018). Studies on productivity have shown that at the global level, 30% to 50% of the time in construction was wasted on non-value-adding activities such as waiting, Requests for Information (RFI's), design change, and clashes (Horman and Kenley, 2005; Elfving, 2007). A study by McKinsey (2017) found that between 1995-2015, the compound rate of growth of value-added per worker in the construction sector was just 1.0%, while the manufacturing industry's growth reached a rate of 3.6% per year

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within the same time. Therefore, to improve productivity in construction, coordination and collaboration play a vital role. Effective coordination and collaboration can help to reduce design time and design errors which could lead to on-time project completion (Zhang, et al., 2018). Similarly, cost overrun, and quality problems have also been linked to the lack of coordination and poor information flow subsequently leading to reworks and waste (Doloi, et al., 2012; Shanmugapriya and Subramanian, 2013; Mahalingam, et al., 2015).

The construction industry has been identified as the major contributor to overall global waste (Wang, 2009). As an example, 25 to 30 % of the waste generated in the EU comes from the construction industry (European Commission, 2016). Apart from the commonly associated material waste, non-value-adding process waste is another type of waste recognized in construction. Multiple discrete construction organizations are typically associated with different tasks and due to the lack of well-defined management approaches, this often generates waste from waiting time for crews, reworking, unused inventories, and unnecessary movements (Mollasalehi, et al., 2016). Fundamentally, Lean is a management concept to eliminate waste from processes and improve the value through principles, techniques, and tools.

On the other spectrum, Building Information Modelling (BIM) is a technological innovation that helps to improve collaboration, coordination, and information flow in construction projects from inception to demolition. BIM 3D intelligent model can embed, update (design, cost, time, sustainability) and simultaneously share data with multiple stakeholders. BIM has multiple Uses (to perform different tasks) supported by different software to visualize, analyze and simulate virtual 3D models before the real construction begins, which could also improve productivity.

Concerning the low productivity, inefficiency, and wasteful approach, the AECO professionals are searching for new technological and management solutions (Mellado and Lou, 2020). Lean and BIM are two key innovations to improve the productivity and efficiency of the construction industry. However, to achieve the maximum benefits from BIM and Lean, it is important to ensure effective and informed use.

BIM and Lean could be complementary to each other. As an example, BIM can act as an effective tool to achieve Lean goals (the purpose of applying Lean) such as waste elimination and improving value. Similarly, Lean principles, techniques, or tools can ensure the effective implementation of BIM. BIM implementation often involves non-value adding activities and Lean can help to eliminate the non-value adding activities to ensure optimum outcomes from BIM implementation. In the literature, there are more than 30 BIM Uses and Lean principles that are evolving with time. Gaining a better understanding of the advantages a certain BIM Use has over a certain Lean principle or vice-versa would help practitioners to use and invest money in the BIM Use or Lean more wisely.

Past research works have identified the way BIM complements Lean and Lean complements BIM, where relationships were shown in developed frameworks. However, there is still no robust framework or guideline for the construction management decision-makers to determine what/ which BIM Uses can support Lean implementation to eliminate waste or what/ which Lean (principles, techniques, or tools) can support BIM implementation to improve collaboration and coordination. Against this backdrop, this study has proposed a conceptual framework, as a basis to identify how BIM Use can help to achieve Lean or how Lean could help in the implementation of BIM in the construction project. The established conceptual framework could be used as a guide for the practitioners to wisely use BIM and Lean to achieve their goals globally.

2. RESEARCH METHODOLOGY

Design Science Research (DSR) is a constructive research approach that has been used to solve real-life problems, where it has been widely used in the health care, information management, engineering, and construction management research domain (Hevner, et al., 2004; Van Aken, 2004). The DSR approach helps in connecting academic knowledge to solve AECO industry problems by creating tools, frameworks, models, methods, or guidelines (AlSehaimi, et al., 2013).

Pefferes, et al. (2006) have proposed a process model for the conduct of DSR, which consists of six steps in a nominal sequence to create the solution or artifact. The steps are as follows: i) Problem identification and motivation (to identify the main problem and explore the motivation to solve the problem) ii) Objectives of a solution (to represent the desired characteristics of the solution), iii) Design and development (artifact development stage which includes all the activities such as research, define functionality, architecture required to create the artifact), iv) Demonstration (to determine the efficacy of the artifact by testing or implementing it in the real-world scenario), v) Evaluation (to measure and compare artifacts desired and actual results after implementing it in the real scenario. Based on the result, the researcher can iterate back to the design and development stage to make the artifact more robust), vi) and Communication (to communicate the utility and novelty of the artifact to wider audiences via research articles).

This study is also aiming to develop a conceptual framework to use in real life, therefore researcher has chosen the DSR approach limited to a certain extent. Besides, the DSR methodology will provide the opportunity to refine the framework (after the initial establishment) and validate the framework. DSR structured analysis, refinement, and validation process are aligned with the objectives to develop the framework.

Nonetheless, the scope of this study has been limited to demonstrating the three initial stages of the DSR to develop the conceptual framework. The entire paper forms the DSR for this study, where the introduction section has elaborated on the problem and motivation, the literature review section discusses the objectives of the solution and finally, the conceptual framework section discusses the design and development of the artifact.

3. LITERATURE REVIEW

3.1 BUILDING INFORMATION MODELLING (BIM)

BIM has evolved from conventional two-dimensional (2D) drafting to an intelligent three-dimensional (3D) model that encompasses the physical and technical characteristics of a structure (Uddin and Khanzode, 2013). BIM can be defined as a software-based virtual representation of an actual facility rather than a set of paper-based two-dimensional (2D) drawings (Krygiel and Nies, 2008). National Building Information Modelling Standard (NBIMS) described BIM, as a product, process, and system to virtually represent the physical and functional characteristics of a facility and also act as a shared knowledge resource for information about a facility to make informed decisions in different stages of a project (Sacks, et al., 2018; Lu, et al., 2020).

In summary, the core functionalities of BIM are to (1) support collaboration in work processes between multiple team members; (2) create highly photorealistic virtual reality; (3) generate intelligent, data-based three-dimensional (3D) models; (4) share and merge intelligent model data with designers, construction management professionals and facility managers; (5) develop time (4D) and cost (5D) simulations; (6) support different sustainability features (such as energy) analysis; (7) support model-based communication through online and cloud systems; (8) enable data sharing with computer-controlled fabrication systems; (9) maintain information and design model integrity; (10) automate documentation; (11) use model data for different analyses (such as automated quantity take-off, and code checking) (Sacks, et al., 2010).

3.2 LEAN

The word Lean is based on the Japanese word Muda, which means waste: something that uses resources but creates no value. Taiichi Ohno (1912-1990) a Japanese engineer (Toyota Motor Company) first coined the word Muda concerning production that promotes productivity and destroys inefficiencies. To eliminate Muda, Ohno introduced the Toyota Production System (TPS) which inspired Lean thinking to create or specify the value and value-creating actions to achieve customer satisfaction (Rahman, et al., 2013; Singh and Kumar, 2019). Following TPS, Womack and Jones (1996) defined value as the first principle of Lean thinking and specified that all the activities in a process should focus to eliminate non-value adding steps and make value-added activities flow smoothly to achieve customers' requirements. Lean Construction (LC) follows the concepts and principles of Lean Production, which covers different aspects (such as design, supply chain, and processes) of a construction project throughout its life cycle (Ballard, 2008). LC can deal with the inherent construction industry problems like low productivity, poor quality, inefficient supply chain, poor safety, and time and space conflict (Tezel, et al., 2018). Therefore, LC has been recognized as an enabler in the construction production system to minimize waste and increase value (Koskela, et al., 2002; Tezel, et al*.,* 2018).

3.3 BIM-LEAN BI-DIRECTIONAL RELATIONSHIP

BIM functionalities and Lean principles can produce significant benefits for AEC organizations even when implemented in isolation (Sacks, et al*.,* 2010a). Past research has provided robust evidence about the positive impacts that the relationship between BIM and Lean can have on AECO organizations and projects (Sacks, et al., 2010). Theoretically speaking, the BIM-Lean relationship can be bi-directional, which means BIM can support Lean principles, and in turn, Lean can support the implementation of BIM (Bhatla and Leite, 2012).

When BIM influences Lean (BIM→Lean direction), BIM can help Lean achieve elimination of waste (concerning overproduction, reworking, and waiting time), reduce variability, and cycle time, and visualize production methods and processes (Sacks, et al., 2010). For instance, the BIM function of "automated quantity take off" can help to generate accurate, reliable cost estimation information without errors, reworking, and waiting, which are major concerns in Lean. Cost estimation for any project traditionally starts with the quantification of resources. Conventional manual quantification from 2D or CAD documents is a process that is time-intensive, laborious, and prone to human errors that tend to propagate inaccuracies (Hartmann, et al., 2008). As a result, it prevents the flow of correct, complete, timely information and creates variability in the production process (Eastman, et al., 2011).

Similarly, Lean has positive impacts on BIM (Lean→BIM direction), where Lean can help to promote effective BIM implementation by using different Lean principles, tools, and methods (Hamdi and Leite, 2012). BIM's success requires significant skill and knowledge to manage stakeholders, set up the workflow, and analyze supportive project documents such as plans and specifications (Hamdi and Leite, 2012). Lean can help to ease the BIM implementation process by eliminating non-value-adding activities and improving coordination and consistency. For instance, to implement BIM, good preparation, planning, and documentation are prerequisites for a client's representative and consulting architectural or engineering personnel who want to make the implementation happen.

"Standardization" is a Lean principle that helps to determine the best methods to use in a process and to reduce variation as much as possible (Feng and Ballard, 2008). Standardization has a close link to the successful implementation of BIM in any project or organization. To implement BIM, a client's representative has to clearly define the client's requirements in terms of project goals and project deliverables. Similarly, consultant architects or engineers have to evaluate BIM competency requirements and develop a process map of collaboration between different stakeholders regarding information management and maintaining common data environments. Therefore, a standardized system is necessary to carry out all the requirements for the successful implementation of BIM. The New Zealand BIM Handbook, UK BIM Level 2 guideline, and Natspec BIM (Australia) are examples of such standardized ways to implement BIM in any project (BIM Acceleration Committee, 2019).

3.4 OVERVIEW OF BIM AND LEAN RESEARCH

From the literature, researchers have investigated diverse aspects of BIM use and Lean in different areas of construction projects. Through Literature analysis, the researcher has found more than 80 scientific papers (journal papers and conference papers) discussing BIM and Lean in the last 5 years (2016-2021). In general, these papers can be categorized into the following themes i) BIM-Lean integrated application framework/ model development ii) BIM-Lean individual and mutual application advantages to improve the AECO industry, and iii) BIM-Lean interaction identification and interaction framework/model development. However, as this paper's focus is to explore the BIM-Lean relationship, the following section briefly discusses on BIM-Lean interaction identification and interaction framework/model development research.

In the Lean (particularly in LC) community, BIM has been seen as a tool to support the processes towards attaining Lean goals (Dave, et al., 2013). Therefore, to reap the full benefits of BIM-Lean integration and implementation, it is vital to know their mutual interaction. Sacks, et al., (2010) have laid the foundations for investigating and advancing research around the relationship or relationship assessment between BIM and Lean. The most significant work on the BIM–Lean linkage by Sacks, et al., (2010) was in forming a matrix of BIM and Lean. After that, other researchers have also found BIM and Lean integration research to be an evolving and crucial area of investigation (Dave, et al., 2013) in different areas of the built environment. Oskouie, et al., (2012) remarked on the importance of BIM and Lean in the operation and maintenance (O&M) stages of a facility and validated BIM's contribution in the Operation and Maintenance stages to support Lean goals such as reducing waste. Besides that, Oskouie, et al., (2012) have used Sacks, et al. (2010) matrix to identify new relationships between BIM and Lean at the O & M stage. They have further added new Lean principles and BIM functions in the matrix related to O&M activities and further identified additional 17 relationships.

Ningappa (2011) also studied the relationship between BIM and Lean by further illustrating how BIM helped Lean as a tool to achieve Lean goals. Alarcon, et al. (2013) also conducted a study to understand BIM implementation from the Lean perspective. By analyzing different BIM-Lean papers, they have identified 107 new interactions apart from the 56 interactions from Sacks, et al. (2010). Elmaraghy, et al. (2018) researched to explore BIM and Lean integration in demolition projects. In this regard, Elmaraghy, et al. (2018) have used Sacks, et al. (2010) BIM, Lean interaction matrix as reference. Based on that, the researchers have identified the relevant BIM and Lean principles for the demolition project. Gomez-Sánchez, et al. (2019) conducted a case study project in Colombia to understand Lean and BIM implementation impact. The authors have analyzed the BIM functions and Lean Principles mentioned in Sacks, et al. (2010) interaction matrix. After analyzing the BIM output from the case study, the project team found 10 new synergies between Lean-BIM and concluded that there are a few that could be tested with a little more maturity of the project team and additional minimum investment.

McHugh, et al. (2019) investigated an integrated Lean and BIM implementation approach by analyzing a highly modular and offsite production process on a data center project. This research focused on exploring how Lean and BIM can help the project team to visualize and control the production, whilst supporting the continuous improvement process. Koseoglu, et al. (2018) conducted a case study to explore the relationship between BIM and Lean in Istanbul grand airport construction project. The researchers in the study understood how the implementation of BIM in such a mega project (76 million m2 of airport area with six runways) helped to achieve Lean efficiency. In this project, BIM has been used both in the design and construction stages. In design, BIM has helped to achieve Lean targets such as zero defects, eliminating waste, reduce rework by identifying design errors. In the project, more than 600,000 clashes have been solved which saves money, time, and rework. Apart from that, BIM has created a platform of collaboration and data sharing among different stakeholders, which reduces the variability (Lean principle). On the other hand, during construction, BIM 4D planning, 5D cost estimation, and as-built modeling helped to attain the Lean principles of reducing the cycle time of installation, reducing rework on site, and also reducing the non-value adding activities.

4. CONCEPTUAL FRAMEWORK

To develop the conceptual framework, a literature review was conducted on various scientific methods of framework development, such as Morphology Analysis (MA), Cross-Impact Matrix (CM), Multi-Criteria Decision Analysis (MCDA) methods (such as Analytical Hierarchy Process, ELECTRE, Multi-Attribute Utility Theory), Design Structure Matrix (DSM), System Dynamics and Quality Function Deployment (QFD). All of the methods were reviewed and analyzed. In the analysis, the relevance of the method to the research problem, and the pros and cons of the method, were determined and tested hypothetically. The hypothetical test used the above-mentioned methods to find a relationship between BIM and Lean. The aim of selecting the method was to meet the goal or requirements of the framework, which are:

1. able to determine the relationship between two variables,
2. pairwise in-depth and root level analysis,
3. able to measure the interconnection or relationship level.

After careful analysis of different methods and considering the above-mentioned criteria, the researcher has found that Quality Function Deployment (QFD) is the most suitable tool to develop the conceptual framework. The following section has described how QFD helps to fulfill the criteria mentioned above.

4.1 QUALITY FUNCTION DEPLOYMENT (QFD)

QFD, as defined by Akao (1990), is a systematic way to represent the relationship between consumer demand and technical characteristics to improve quality and achieve greater customer satisfaction. Nowadays, QFD is extensively practiced in many industries (including aerospace, defense, and construction) and due to its enormous application and potential, QFD has been extensively researched and the literature has been enriched via comprehensive reviews of this topic (Sharma, et al., 2008).

Considering QFD's ability to support decision-making by translating customer requirements into design characteristics and measuring the relationship, this research has followed QFD to develop the initial framework. The next section discusses the QFD analysis process and how the researcher has embedded the QFD analysis steps into the conceptual framework.

4.2 QFD ANALYSIS PROCESS

QFD is also known as the House of Quality due to the pictorial structure of the analysis process. Figure 1 shows a typical "House of Quality (HOQ)" and represents the different elements of the HOQ. In QFD the analysis process is divided into 11 steps, which are discussed in the following sections.

<u>Voice of customers (1)</u>

The first step in the QFD process is to define the customer requirements. The customer requirement is prioritized customer demand, need, or needs which is usually expressed in general terms. These customer requirements can be gathered by survey, questionnaire, or focus groups.

<u>Customer requirement weighting (2)</u>

The next step is to prioritize the customer requirements (voice of customers) by assigning a weight. A given weight reflects the significance or importance of each requirement. Usually, the weight is expressed in percentages and can be determined via a survey or online questionnaire.

<u>Design requirements (3)</u>

In the third step, the design requirements must be translated into quantifiable technical measures, which represent ways to achieve the customer requirements. Design requirements are the technical requirements or design characteristics of a product or service, which have a significant impact on achieving customer requirements. These requirements represent the product characteristics in technical terms and are usually determined by the product development company. These characteristics are chosen in a way that best achieves the customer requirements.

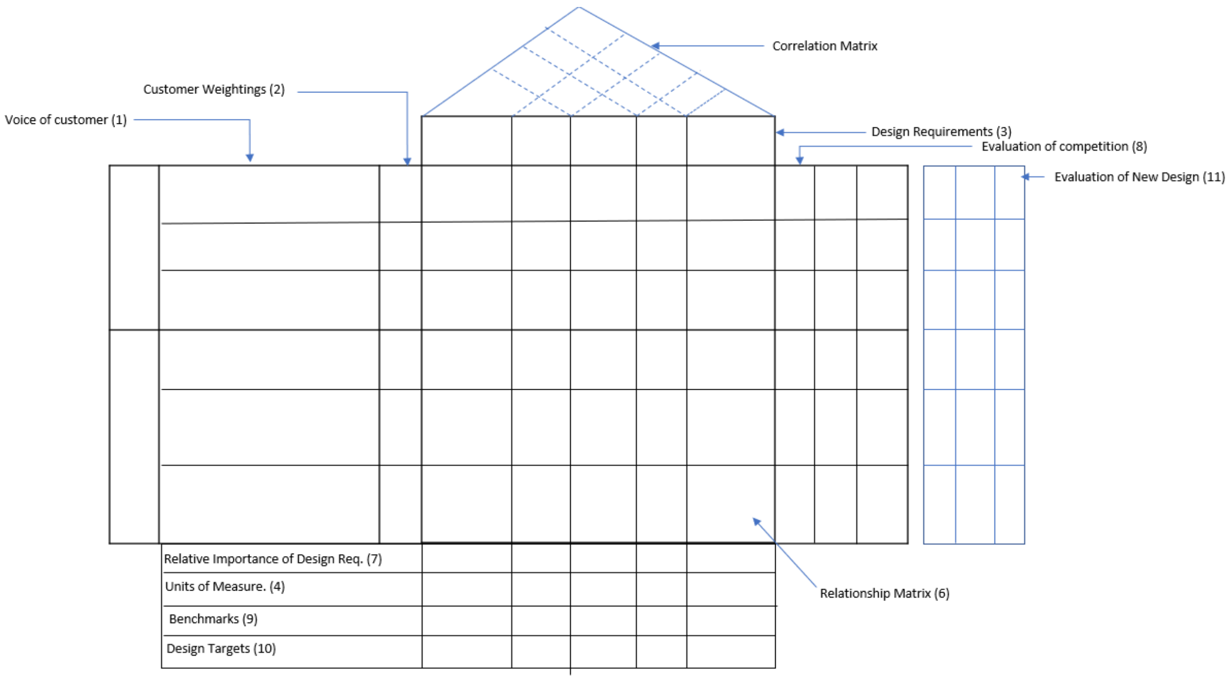

Figure 1: Formation (steps) of house of quality

Source: Adapted from Eldin and Hikle (2003, p. 318)

Units of measurement (4)

To ensure clear communication, units of measurement (such as meter for length) need to be established very clearly to avoid misunderstandings.

Correlation matrix (5)

The correlation matrix represents the relationships between design requirements. It helps to determine whether a design requirement negatively or positively affects other design requirements. The product development team evaluates the correlation among the technical requirements or design characteristics. It helps the product development team to understand how they are affecting each other's performance and how they affect the achievement of the customer's requirements.

Relationship matrix (6)

The relationship matrix indicates how design requirements affect customer requirements. By assigning weight (on a 1-9 scale, where 9 represents extremely strong and 1 represents extremely weak) in the matrix, the strength of the relationship can be determined. The relationship matrix is the core of QFD analysis. The relationship matrix determines the importance of the technical characteristics in meeting the customer's requirements. Based on the impact of technical requirements or design characteristics on achieving the customer's requirements, a product development team assigns a score for each customer requirement and design characteristic.

The relative importance of HOWs (7)

In QFD design characteristics also need to be prioritized according to their importance. To do so, each of the design characteristics weights (given in step 6) needs to be multiplied by the prioritization rating (determined in step 2). After that, according to the total score, each of the design requirements gets prioritized. This prioritization helps the product development team to allocate resources for specific design characteristics.

Evaluate current competition (8)

In this part of QFD, the product being designed is judged (through a rating scale) against other products from a customer viewpoint. This evaluation aims to determine the relative position of the designed product against other products, in terms of fulfilling customer requirements.

Benchmarks (9)

Benchmarking is an important part of QFD. Benchmarking helps to judge the product against a standard and guide the design to achieve customer satisfaction.

Design targets (10)

After analyzing the comparison with other products (in Step 8) and benchmarking, the next step is to set new targets to improve the product.

Evaluation of new design (11)

After setting the new targets, the next step is to re-evaluate the customer's requirements against the proposed design.

4.3 INITIAL FRAMEWORK DEVELOPMENT

The BIM-Lean Relationship Assessment Framework (BLRAF) is developed by embedding the analysis features of QFD. This framework maps the Lean principle needs into definable and measurable BIM function parameters, to understand their impact on Lean. To that end, this framework has followed several key steps of QFD, such as customer requirements and rating of importance, design requirements, relationship matrix, and relative importance of design requirements. However, the other parts of QFD such as the correlation matrix, evaluation of competition, benchmarks, and design targets were discarded because were found to be irrelevant to the requirements of the framework. The proposed framework (see Figure 2) is divided into four phases, as follows:

Phase I: Identifying All Relevant Governing Factors to Achieve the Purpose of Lean Principle and Prioritize

In the first phase, QFD assesses customer requirements. In this framework, the customer is Lean, and the requirement is that the governing factors help to achieve Lean's purposes or objectives. The governing factors can be identified via discussions in focus groups, expert opinion, interviews, literature reviews, or any other method. The governing factors represent the prerequisites or requirements to achieve the goals. As an example, "Reduce the non-value adding activities" is a fundamental Lean principle. This principle can be the customer in this framework and the requirement could be the different non-value-adding activities such as overproduction, motion, and waiting. These requirements or factors then need to be prioritized according to their importance. Each of the customer requirements is then scored on a scale and finally prioritized based on their cumulative value.

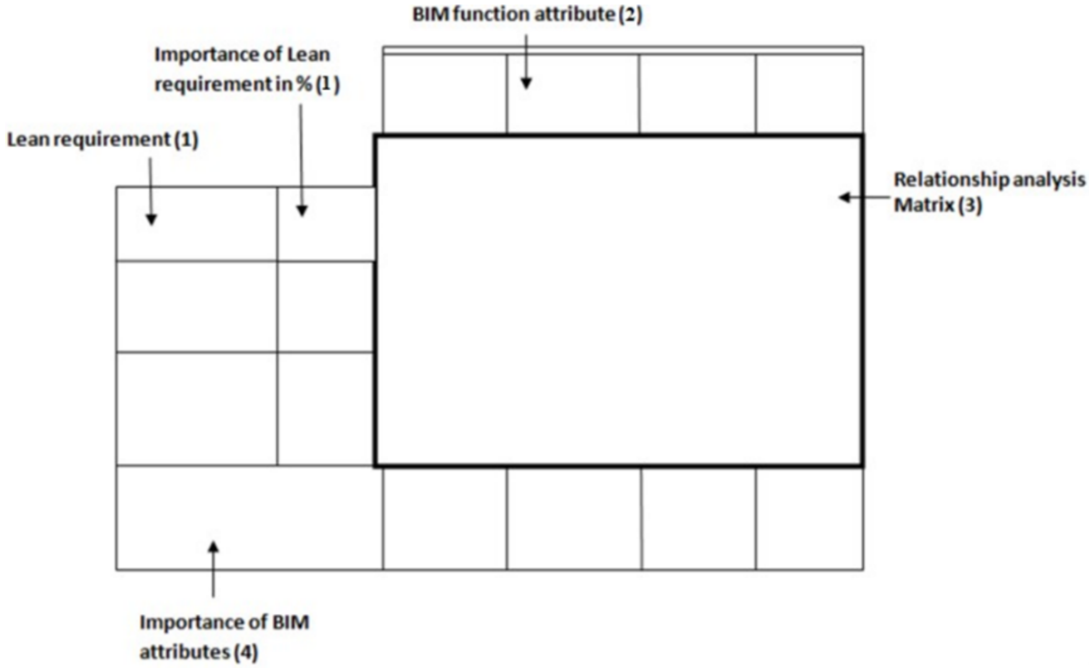

Figure 2: BIM-Lean relationship assessment framework structure

<u>Phase II: Identifying All Relevant BIM Function Governing Factors</u>

In this framework, the BIM function represents the design requirement of QFD to support Lean principles. In this step, BIM functions will be divided into the key governing factors. The governing factor means the core features or usage of a particular BIM function. Consultation with relevant BIM experts focus group study or literature review may help to determine the governing factors of BIM functions.

<u>Phase III: Relationship Matrix</u>

The House of Quality (HOQ) is the key tool used to represent the process of QFD analysis (Bolar, et al., 2014). The middle section of the HOQ represents the relationship matrix, which systematically evaluates the relationships between the customer's requirements and the associated design requirements. The assigned score or points indicate the strength of the relationships between each of the customer requirements and their associated design requirement.

In this framework, the relationship matrix will determine and measure the relationship between Lean principles and BIM functions. The influence level of each pair of Lean and BIM factors is judged by experts, who will focus on assessing whether the BIM factor supports achieving the Lean factor. According to the impact on Lean factors, each of the BIM factors will be assigned a weight (as in QFD analysis). The given weight will represent the level of influence.

<u>Phase IV: Absolute Weight and Ranking of BIM Factors</u>

The bottom section of the HOQ determines the relative importance of the design requirements. To prioritize the ranking, each relationship value is multiplied by the prioritized customer requirement. The sum of the values for each design requirement column then provides the relative ranking or importance of that design requirement. The relative percentage of these individual factors helps to determine, for a certain BIM function, which factor has the greater impact. Similarly, all the BIM factors are ranked to understand their relative impact on Lean factors.

Using this framework, BIM and Lean relationships can be assessed to a finer level of detail because the framework breaks down Lean and BIM into relevant factors. This will enable a greater understanding of how the characteristics of a particular BIM function help to achieve Lean principles. The weights in the relationship matrix and ranking can also help to generate an understanding of how much BIM influences a Lean principle.

5. CONCLUSION

BIM and Lean are two critical factors to improve the performance of the construction industry. However, to get the utmost benefit from BIM and Lean a careful analysis is important to understand how they are fulfilling each other purposes to improve efficiency. This research has presented a framework to assess the relationship between BIM and Lean. This framework will guide the construction management team to identify the right BIM function to achieve Lean and therefore improve efficiency. As a part of ongoing research, this framework would be tested and revised to make it more robust in future studies.

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CHALLENGES ON BONDS AND GUARANTEES UNDER THE PAYMENT SECURITY REGIME IN THE CONSTRUCTION INDUSTRY OF SRI LANKA

P.W.V. Manohara[1] and M.D.T.E. Abeynayake[2]

ABSTRACT

The construction industry is a significant contributor to the national economy. Since construction has been facing risk management issue, bonds and guarantees have become a feasible solution, as a management too and mechanism. Professionals will have to undertake consequential responsibilities in managing bonds and guarantees. However, no significant efforts have been taken to identify how bonds and guarantees affect the construction industry of Sri Lanka. This research aims to explore the challenges and problems in bonds and guarantees, which are used in Sri Lankan construction projects, and to make recommendations to projects in the Sri Lankan context. Initially, a literature review has been carried out on different bonds and guarantees. Consequently, a mixed research approach has been used, which included expert interviews and a questionnaire survey. The collected data from expert interviews were analysed using content analysis that supported the design of the questionnaire. To achieve the study's aim, the bonds and guarantees were ranked against merits, demerits, issues, and suggestions in questionnaires using a Likert scale, considering the significance of those competencies in bonds and construction guarantees. The collected data were also analysed using the Relative Importance Index The research findings are revealed that there are several suggestions to overcome the barriers in bonds, guarantees and payment securities in Sri Lanka. Additionally, contractors' requirement to set up a special guarantee fund to protect business practices and it was identified as new suggestions that would aid the challenges and problems in line with bonds and guarantees in Sri Lankan construction projects.

***Key Words**: Bonds and Guarantees; Contracts; Construction Industry; Payment Securities.*

1. INTRODUCTION

The construction industry is a contributor to the national economy that engages in land preparation and construction, road reconstruction, and reconstruction of buildings, structures, and infrastructure facilities (Ogunsemi, Awodele, and Oke, 2015). In many developed countries, the construction industry is one of the largest, most complex, and comprehensive sectors. Moreover, Gawugah and Daniel, (2015) have mentioned the construction industry is one of the significant contributors to the economy, and payment

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turns into the central focus for both the contractor and the client. The construction sector plays a crucial role in the Sri Lankan economy (Jayalath and Gunawardhana, 2017). Bonds and guarantees are the key factors to reduce construction project failures in the construction industry (Ohol, et al., 2019). Further according to Ogunsemi, Awodele, and Oke, (2015) identified the challenges of advance payment to contractors. Failure to make advance payments, difficulty getting a prepaid guarantee, customer's burden, and customers' extra work (Rameezdeen, Palliyaguru, and Amaratunga, 2006). The practice of retention is becoming increasingly difficult for contractors as the profitability margins are narrowing. It causes many series of related problems in the construction industry, which can eventually lead to cash flow problems and, therefore, to the contractor (Ganiyu, et al., 2015). However, irrespective of the importance of this area, research was carried out to determine whether contractors in Sri Lanka face difficulties in bonds and guarantees in the construction industry.

One of the salient features of construction projects is that it is fraught with risks (Oke, 2016). Since the construction industry is underdeveloped, breach of contract is high (Meng, 2002). Cheng, et al. (2010) expressed that it's not always easy to obtain paychecks. The construction industry can show how much effort is needed to do this and how it affects escalation due to payment issues. In such cases, employers need to reduce risk by using guarantees and guarantees (Knezevic and Lukic, 2016). Thus, Wu, Kumaraswamy, and Soo, (2011) recognised that besides several research types have discussed regulative measures addressing payment problems in the construction industry.

On the other hand, there are several types of research carried out in this area. However, limited research has been done to select problems about bonds and guarantees in the Sri Lankan construction industry. Therefore, this study requires to highlights how bonds and guarantees issues affect the construction industry. Furthermore, considering the literature as mentioned earlier and the industry need, there is a knowledge gap to be filled on the challenges of bonds and guarantees in Sri Lankan contexts. Therefore, this research was carried out to resolve bonds and guarantees and their problems to the construction projects in Sri Lanka.

The aim of this research is to investigate challenges and problems in bonds and guarantees used in Sri Lankan construction projects for proper application of payment securities to projects in the Sri Lankan construction industry.

2. LITERATURE FINDINGS

2.1 BONDS AND GUARANTEES IN THE CONSTRUCTION INDUSTRY

Construction projects in the construction industry use different bonds and guarantees (Banki, et al., 2009). Construction guarantees are also known as risk management tools for improving construction performance (Nursalam, 2016). Furthermore, Meng's (2002) findings confirmed that the employee might demand that the contractor provide guarantees or payments that include bid bonds, performance bonds, advance payment guarantees, and retention bonds pressuring the contractor to pay for components and materials for subcontractors and others, which obligates the contractor to pay subcontractors and others for materials and labour. According to Lukic (2014), the bank guarantee constitutes a commonly employed and internationally agreed instrument for obtaining and executing international trade contract statements of parties, so all stakeholders' rights are efficiently secured. Furthermore, in specific businesses with more substantial obligations and protection, banking assurances are typically needed that the responsibilities exchanged with both the contract are fulfilled in the manner specified. Ndekugri and Rycroft, (2009) explored and summarised construction projects that a bank or any financial institution accomplishes a bond or guarantee to pay to the worker in certain situations up to the bond amount.

2.2 BENEFITS OF USING BONDS AND GUARANTEES

The construction industry is frequently riskier when compared to other businesses (Surahyo, 2018). Payment issues are common in the construction industry around the world (Wu, et al., 2011). Moreover, Hussin (2009) expressed that construction arrangements are always very complicated and unpredictable, so that something may go wrong at any moment. Construction contracts are often too complicated with uncertainties, and anything could go wrong at any time (Surahyo, 2018). Construction contracts are also quite complicated with complexities, and something can go wrong at any moment; moreover, every building contract is particular; each provides a multitude of specific issues and difficulties (Surahyo, 2018). Furthermore, Meng, (2002) mentioned that mostly in the construction industry, it is assumed that there has been a strong trend towards increasing the default danger in past years and creating a construction contract guarantee program vulnerable.

2.3 TYPES OF BONDS AND GUARANTEES

- **Bid Bonds**

Bid bonds promise that, when a contracting contractor accepts an offer and then fails to join the bid in line, the debt shall compensate the purchaser a differential in size, equal to the default limit of the bond, between the lost bid and the next lowest bid (Boswall, 2007).

- **Performance Bonds**

A bond to performance may be considered more critical than other bonds (Meng, 2002). Another important guarantee that a contractor, supplier, or exporter of goods must often be furnished at the beginning of a construction or engineering project, or an international sale of goods contract is the performance guarantee, performance bond, or completion bond (Lukic, 2014).

- **Advance Payment Guarantees/Bonds**

Based on the contractual conditions, a client may pay the contract amount as advance payment before the start of work, also known as the (Wandahl, et al., 2011). If a contractor is entitled to pay the amount stated in advance following the contract, the contracting partner may require a guarantee that the advanced money is reimbursed if the contractor fails to do this (Lukic, 2014).

- **Retention Bonds**

In reality, owners often take over finished contracts before paying contractors, often preventing untrustworthy owners' compensation duty (Meng, 2002). Hughes, Hillebrandt, and Murdoch (2000) concluded that the retention of money is a prevalent means of protecting an employer from bankruptcy and ensuring that contractors complete their work.

- **Factors Affecting Administration of Bonds**

Contractors believed construction bonds administration to be four significant factors (Oke, 2019). These factors demand security before the bond is borrowed, the bond's validity time frame, the contractor's financial standing, and the selection of the customer's guarantor in decreasing order, with the least effect on corruption (Oke, 2016). Hosle (2010) summarised the customer has released the management of bond issues from the beginning of bond management. Identified factors could be summarized as below:

- Requesting collateral and security before underwriting bond, the Validity period of bonds
- Provision of follow up bond agencies
- The technical ability of the contractor
- Integrity
- Experience and performance track record of the firm
- Financial standing of the contractor
- Integrity and personal character of the firm's owner
- Clients' choice of guarantor for the contractor
- The interest rate charged by the guarantor

2.4 ADVANTAGES OF USING CONSTRUCTION BONDS

Construction bonds guarantee time, expense, and efficiency for the project completion and boost the optimum level of service of the contractors (Emmanuel, 2019). Furthermore, Faced, (2009) illustrated the crucial point is that the usage of the construction bond cannot be reduced, and therefore that the fundamental goal is to boost development projects' duration, costs, and productivity. Identified advantages could be summarized as below:

- It serves as a back-up for the client in case of a contractor's default.
- It helps to guarantee that projects are completed to time, cost, and quality
- It helps to guide against fraud on the part of the contractor
- It avoids conflicts among construction stakeholders
- It guarantees an optimum level of contractors' performance
- It helps to ascertain the financial status and buoyancy of contractors/bidders
- It ensures that projects are completed to an acceptable standard
- It helps to guide against abandonment of buildings
- It helps to limit the use of litigation or ADR methods (alternative dispute resolution) in construction contracts.

2.5 CHALLENGES AND PROBLEMS ASSOCIATED WITH CONSTRUCTION BONDS IN SRI LANKAN CONSTRUCTION INDUSTRY

The following challenges, risks, and problems can be identified for further assessing the use and administration of construction bonds in construction industries (Oke, 2019).

- They are increasing value for bonds and guarantees due to political influence.
- The ambiguity of term of reference for bonds.
- The problem of poor administration and leadership.
- Lack of definite standard for administering construction bonds.

- Unprofessionalism by banks in the administration of construction bonds.
- Most construction bonds are one-directional in that it is only binding on the contract.
- Multiple bonds can lead to reduced profit as the contractor bears most of the bond's cost, such as the interest rate charged by financial institutions.

There is no proper monitoring of the bond process, thereby rendering it ineffective. The major problem that can be identified for the parties is that these bonds and guarantees don't have the proper and both parties must also be strict adherence to the involved in terms of the bonds. Besides, there is a need for stakeholders to be faithful to the bonds' condition, and they should have a decent idea of the requirements and the construction contract. A high level of political influence in selecting contractors due to government building projects depends heavily on bond issues and guarantees.

3. RESEARCH METHODOLOGY

For this research, a mixed approach was adopted due to the requirement of assessing subjective data as expert's opinions. Moreover, data as expert interviews and questionnaire survey were adopted to collect data for this research (refer Figure 1). The expert interview is essential to continue this research, researcher selected 4 interviewees with more than 10 years of experience in the construction industry.

Figure 1: Research process

Details of interviewees used for expert interviews is given in Table 1.

Table 1: Details of interviewees for expert interviews

Interviewee	Designation	Years of Experience	Types of Organisations
A	Managing Director	22	Contractor, Consultant, Project manager
B	Consultant Quantity Surveyor	23	Contractor, Consultant
C	Senior Quantity Surveyor	15	Contractor, Consultant
D	Chief Quantity Surveyor	10	Contractor, Consultant

Interview data collected were analysed using code-based content analysis with the help of NVivo software. A comprehensive questionnaire was then mailed to 51 practicing construction professionals, within and outside the country, out of which 30 responded. Respondents had to give a level from the Likert scale for each competency element. The Relative Importance Index (RII) is used as a questionnaire response analysis technique that has been used by many researchers to determine the relative importance of attributes to rank attribute.

4. RESEARCH FINDINGS

4.1 ANALYSIS AND FINDINGS OF EXPERT INTERVIEWS

Semi-structured interviews were conducted as the initial stage of data collection among quantity surveying experts who have been in the construction industry for more than ten years. Following the method described the expert interviews were conducted based on the interview guidelines. Besides, all the interviews were between thirty minutes and forty minutes long. Using the NVivo 10 software package, the interviews were analysed via a code-based content analysis method. For the preparation of the questionnaire, the results of the interviews were used. These are summarised in Tables 2 and 3.

Table 2: The benefits of bonds and guarantees in the Sri Lankan construction industry

After the literature review	After expert interviews
Protects client from the risk of a contractor failing to fulfill its contractual obligations.	Guarantees act as a financial security against money that has been paid.
Avoid the risk in the construction industry	Lack of proper monitoring by guarantors, Lack of definite standard for administering construction bonds & Low level of awareness of construction bonds.
Guarantees act as a financial security against money that has been paid (advance payment or retention money guarantee).	They are increasing of value for bonds and guarantees due to political influence. The ambiguity of term of reference for bonds & the problem of poor administration and leadership.
Financial security against the future performance of the contract (advance payment)	Unprofessionalism by banks in administration of construction bonds & most construction bonds are one-directional in that it is only binding on the contract
Financial security against the validity of the bid (bid security)	Lack of Government rules and regulations to promote the usage of bonds and guarantees

Table 3: Suggestions to overcome the barriers to bonds and guarantees and correctly implement payment security regime in the Sri Lankan construction industry

After the literature review	After the expert interviews
Multiple bonds can lead to reduced profit as the contractor bears most of the bond's cost, such as interest rate charged by financial institutions.	Additional effort and time for obtaining bonds and guarantees from banks. We have to manually obtain it as per the forms in the contract document.
There is no proper monitoring of the bond process, thereby rendering it ineffective.	Need for sensitisation and awareness on the usage of construction bonds.
Lack of proper monitoring by guarantors and low level of awareness of construction bonds & definite standard for administering construction bonds.	There must be strict adherence to the terms of the bonds by the parties.

After the literature review	After the expert interviews
They are increasing of value for bonds and guarantees due to political influence. If it is a tiny contractor, then maybe not having a long-term relationship with the bank.	Need for proper education for stakeholders. Modification to existing legal status. Involvement of insurance companies in policy formation.
Small contractors may find it difficult to deposit for the surety to obtain the guarantee to keep that money freeze for a more extended period of time.	There should be a common standard for construction bond administration. Guarantors should be ready to play their duties to construction bonds as at when due.
Concerning the client, he is having the risk involved in the vat, but he is not getting that vat as far as the contract is concerned.	Reduced level of political influence in the selection of contractors. Guarantors need to make their charges on construction bonds affordable by the contractors.
The requirement for contractors needs to set up a guarantee fund to protect business practices.	Sensitisation and understanding of the use of construction bonds are necessary. State policies to slash guarantee charges.
The financial institutions, the guarantors, should be cautioned of unnecessary intrusion, leading to an extension of project time.	Introduce the construction industry guarantee fund for Contractors.
Guarantors need to make their charges on construction bonds affordable by the contractors.	Encourage the bonds from the Contractor's guarantee fund

4.1 ANALYSIS AND FINDINGS OF QUESTIONNAIRE SURVEY

The final stage of data collection was the questionnaire survey. To carry out a questionnaire survey, the findings of the literature review and expert interviews were used. The findings are summarised in Figures 2, 3, 4 and 5.

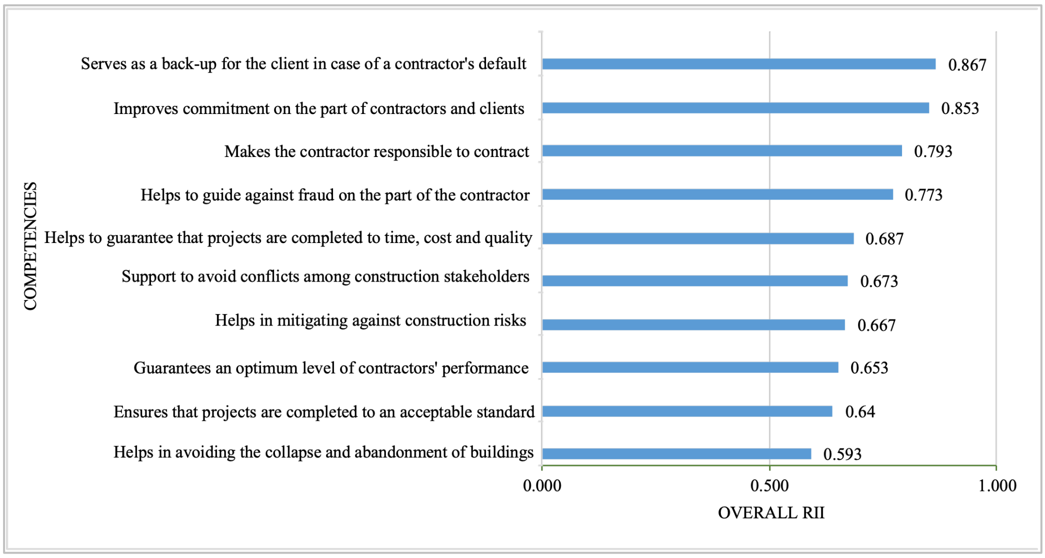

Figure 2: Merits of using bonds and guarantees in the construction industry Sri Lanka

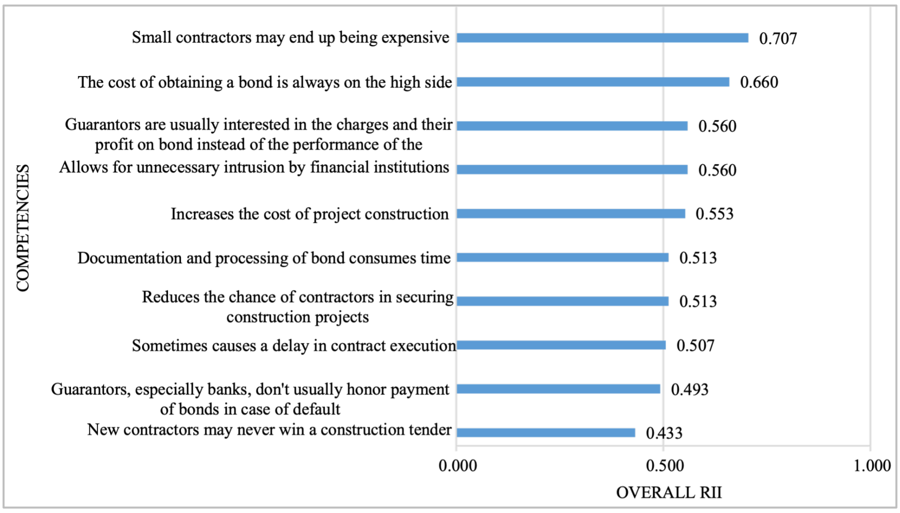

Figure 3: Demerits of using bonds and guarantees in the construction industry Sri Lanka

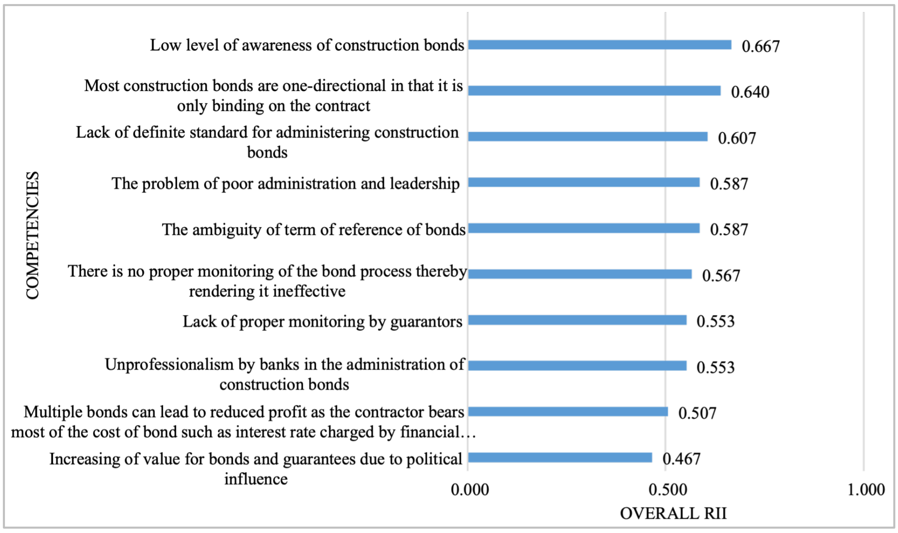

Figure 4: Issues of using bonds and guarantees in the construction industry Sri Lanka

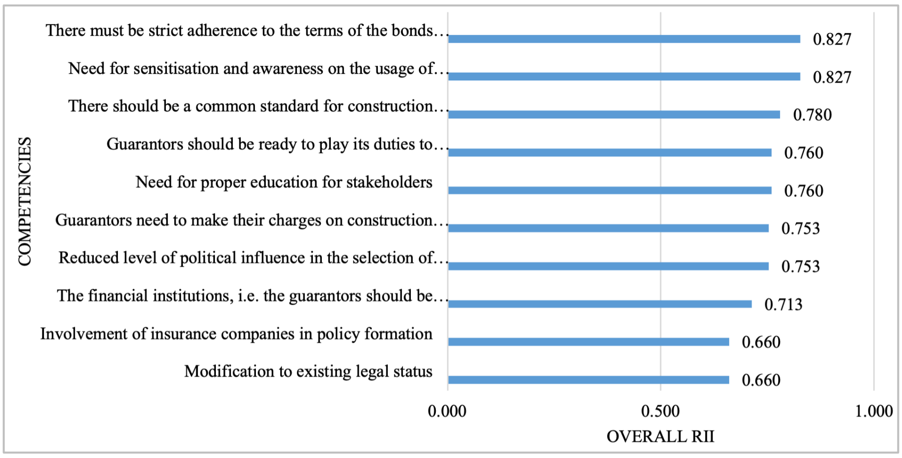

Figure 5: Suggestions for effective administration of bonds and guarantees in the construction industry

5. CONCLUSION AND RECOMMENDATIONS

Findings have pointed out that identifying the challenges and issues on bonds and guarantees in Sri Lankan construction projects would be essential shortly, and bonds and guarantees will play a significant role in the construction industry. Consequently, the research proposes recommendations for the challenges on bonds and guarantees under the payment security regime in the construction industry of Sri Lanka. The analysis reveals suggestions to overcome the challenges on bonds and guarantees under the payment security regime, which have to be used in the Construction Industry in Sri Lanka.

Hence priority should be given suggestions to overcome the barriers to achieve issues of bonds and guarantees. Priority should be given considering that suggestions ranking list. New suggestions identified from the research, the requirement for contractors need to set up a guarantee fund to protect business practices and introduce the construction industry guarantee fund should be established in the Sri Lankan construction industry within the near future. In addition to that, Guarantors need to make their charges on construction bonds affordable by the contractors. That could help construction parties to perform well in the Sri Lankan construction industry. Financial organizations and banks must be updated and educated on bonds and guarantees in the construction industry, and quickly obtainable procedures must be established. Most importantly, the identified challenges and problems on bonds and guarantees in the study and any more challenges and problems that would be identified in the future have to be well established in the Sri Lankan construction projects. Research shall be undertaken in the education system to determine the use of construction bonds necessary for new issues and their suggestions.

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CIRCULAR ECONOMY (CE) BASED MATERIAL SELECTION: DEVELOPMENT OF A CE-BASED '10R' EVALUATION FRAMEWORK FOR BUILDING CONSTRUCTION PROJECTS IN SRI LANKA

Koshalee Wanaguru[1], Harshini Mallawaarachchi[2] and Dimuthu Vijerathne[3]

ABSTRACT

The building construction industry is globally identified as one of the major consumers of materials. Thus, the material wastage in building construction projects is very excessive. In the Sri Lankan construction industry, it was identified that the main reason for generating material wastage is the absence of proper material selection criteria. The concept of Circular Economy (CE) has been obtained the world attention in reducing material wastage in the construction industry as it targets zero waste and pollution throughout the lifecycle of materials. Applying CE principles in the material selection not only reduces the wastage of materials but also reduces the use of virgin materials. Hence, this research aimed for developing a CE-based 10R evaluation framework for materials selection in order to reduce the wastage of materials in building construction projects in Sri Lanka. A comprehensive literature review was first conducted to review the concept of CE, CE principles and its importance for reducing material wastage in the construction industry. Deductive approach was chosen as the suitable research approach in this study. Survey method was applied as the suitable research strategy under quantitative phenomenon. A questionnaire survey was conducted with a conveniently selected sample of 58 industry professionals to collect the data. The collected data were analysed by using Weighted Mean Average (WMA) technique. As key findings derived through analysis, the level of importance of each CE principle for selection of materials was determined. Accordingly, the CE-based 10R evaluation framework for material selection was developed as the main implication of this research. Various strategies, such as reusing demolition materials, adopting prefabricated building components, developing plans to on-site recycle and using alternative materials were also proposed to implement the all identified CE principles assuring a successful application of the developed framework.

Keywords: *Building Construction; Circular Economy Principles; Evaluation Framework; Material Selection; Sri Lanka.*

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1. INTRODUCTION

Construction waste has been identified as a major dilemma in the construction industry as one of the largest worldwide waste streams (Spišáková, et al., 2021). It has emerged as a tremendous environmental issue in both economically developed and developing countries (Mohammed, et al., 2022). As stated by Ekanayake and Ofori (2004), construction waste includes any material that is used on the construction site itself for filling, recycling, reusing, incinerating, or composting land rather than the project's intended specific purpose except earth material.

Improper material selection is one of the main factors contributing to construction material wastage (Ayegba, 2013). Further to the author, the selection of suitable material is critical in completing projects on time, on budget, and at the intended quality and to minimise construction wastage. Also, an efficient and effective waste minimisation strategy for a construction project is a vital component of sustainable building design. Therefore, it is essential to select the appropriate and sustainable construction materials by adopting innovative approaches (Song and Zhang, 2018). Many approaches and concepts have been introduced by experts for minimising waste generation during construction. Among all these concepts "Circular Economy" (CE) has been received an increasing attention as it promotes the most efficient reuse and recycling of resources, goods, and components to minimise waste formation. CE can be applied as a sustainable approach for material selection as it generates various benefits, such as minimising cost overruns, improving the overall life cycle cost-benefit of the project and improving the sustainability of the project. Thus, considering the concept of CE in selection of construction materials is vital to consider.

Accordingly, this research aimed to develop a CE-based 10R evaluation framework for material selection in order to reduce the wastage of materials in building construction projects in Sri Lanka. This paper is mainly focused on answering two (02) research questions as follows;

1. What is the level of importance of CE principles on material selection of building construction projects in Sri Lanka?
2. What are the strategies to implement the identified CE principles for reducing the material wastage of building construction projects in Sri Lanka?

2. LITERATURE REVIEW

2.1 SOURCES OF CONSTRUCTION MATERIAL WASTAGE

For a better material waste management strategy, it is important to identify the reasons behind the generation of waste. According to previous research, construction material waste can appear from the establishment of the project to the end of its life cycle (Nagapan, et al., 2012). Table 1 summarises the sources of construction material wastage identified by reviewing 05 key research papers.

As shown in Table 1, human errors (lack of supervision, poor workmanship, etc.) and wrong selection of materials can be identified as the major sources of material wastage in the construction industry. Hence, the material selection was considered in this research for adopting the CE principles for reducing the wastage of materials in building construction projects in Sri Lanka.

Table 1: Sources of construction material wastage

Sources of material wastage	Source of Reference					%
	R1	R2	R3	R4	R5	
Human errors (lack of supervision and poor workmanship etc.)	X	X	X	X	X	100%
Poor delivery of materials	X	X	X	-	X	80%
Poor storage methods	X	X	-	-	X	60%
Carrying out material manually or by wheelbarrows	-	X	-	-		20%
Not following a proper material reconciliation system / unavailability of the right quantities ordered and on-site	X	X	-	-		40%
Design modifications during the construction stage	X	-	X	X		60%
Site errors	X	-	-	-		20%
Wrong or improper selection of materials	X	X	X	X	X	100%
Lack of attention in dimensional coordination	-	-	-	X		20%
Cutting materials in different sizes and uneconomical shapes	X	-	-	-	X	40%
The residue (Paint, mortar, plastic)	-	-	-	-	X	20%
Dropped, spoiled, or discarded materials during the transportation (Ceramic tiles, roofing tiles, Bricks, Blocks)	X	-	-	-	X	40%

Reference: [R1] Sweis, et al., 2021; [R2] Manewa, et al., 2007; [R3] Liyanage, et al., 2019; [R4] Kulatunga, et al., 2005; [R5] Rameezdeen, et al., 2004

2.2 IMPORTANCE OF CIRCULAR ECONOMY FOR CONSTRUCTION MATERIAL SELECTION

As stated by Gardetti (2019), implementing the CE concept is a need rather than an alternative nowadays. According to Adi and Wibowo (2020), implementing a CE strategy will reduce waste by 30% of the total trash produced by 2025. Further to the authors, CE is a better choice for reducing the quantity of waste produced in the building industry (Adi and Wibowo, 2020). Some of the key benefits for materials exposed by CE are higher material recycling, increased product re-use, and repair, increased material production, more robust long-lasting goods, maximise material recovery, avoiding unnecessary waste, promotes using sustainable materials, avoiding landfills, reducing the end life of materials, minimizes depletion of scarce materials, reduces environmental damage by minimising waste, reduces valuable material losses, increases raw material efficiency, reduces the extraction of virgin raw materials, limit material costs and project cost overruns (McCarthy, et al., 2018; Ekins, et al., 2019; Liyanage, et al., 2019).

CE principles are mainly based on the 3R methodology (Reduce, Reuse, Recycle) which is derived from waste management principles (Han, et al., 2017). Furthermore, this has been developed as a 6R methodology for products over multiple life cycles, such as construction materials. 6R methodology includes Reduce, Remanufacture, Reuse, Recover, Recycle and Redesign (Jawahir and Bradley, 2016). A recent research study carried out by Munaro et al. (2020), introduced that CE principles are mainly based on the concept of Design, Reduce, Reuse, Recycle, Reclassification, and Renew according to findings of past research studies on CE principles.

However, Potting, et al., (2017) proposed a conceptual CE framework that consists of 10 principles. Although there are 10 principles, the framework is titled as "9R framework." It is the only framework that has been established with a large number of "R" principles in the existing literature, namely Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover.

By reviewing key literature on various CE methodologies and frameworks developed by the research scholars, 10 CE principles namely Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover were identified, which were considered in developing the CE based 10R evaluation framework in this research (refer to Section 4).

2.3 MATERIAL WASTAGE IN THE SRI LANKAN CONSTRUCTION INDUSTRY

Jayawardane (1992) stated that material wastage in the Sri Lankan construction industry has exceeded its limit. According to the research study carried out by Rameezdeen, et al. (2004), material wastage in the Sri Lankan construction industry is around 25% of sand, 20%of lime, 14% of cement, 14% of bricks, 10% of ceramic tiles, 10% of timber (formwork), 7% of rubble, 7% of reinforcement (steel), 6% of cement block, 5% of paint, and 3% of asbestos sheets. They found out that in Sri Lanka approximately 38% of construction firms do not have any policies on waste and there are very few recycling contractors. According to Liyanage, et al. (2019), with the standards, such as International Standard Organisation - ISO 9001, and ISO 14001 material wastage is being controlled in Sri Lankan construction sites. Further, Liyanage, et al. (2019) stated that generated waste in Sri Lankan construction projects is either distributed to recyclers or most of the time waste is dumped into landfills. Many past researchers have come up with strategies that influence the Sri Lankan construction industry towards the concept of CE in the selection of materials, such as promoting sustainable, eco-labelled, green materials, procuring materials from green-certified suppliers, pre-planning the places to use materials, double-checking quantities before ordering materials and using renewable materials rather than using non-renewable materials, to name a few (Athapaththu and Karunasena, 2016; Liyanage, et al., 2019; Wijewansha, et al., 2021). However, there is no proper method introduced for selecting suitable construction materials based on the concept of CE for building construction projects in Sri Lanka. Accordingly, the importance of 10R principles for material selection of building construction projects was evaluated to develop a CE-based 10R evaluation framework.

3. RESEARCH METHODOLOGY

In this study, no new theories were built up using the data that were collected and identified CE principles through the comprehensive literature review were tested. Therefore, deductive approach was chosen as the suitable research approach in this study. To rank the level of importance of each CE principle for the selection of building materials, statistical numeric data were gathered. Furthermore, the data were gathered through predetermined questions and the findings were shown in numbers and graphs. Therefore, the quantitative approach was followed to scale the research to provide larger sets of data for reliability and validity.

A questionnaire survey was carried out to evaluate the level of importance of CE principles for developing a CE-based evaluation framework for material selection of building construction projects in Sri Lanka. Based on the 10R principles introduced by Potting, et al. (2017), the questionnaire was prepared. The questionnaire contained 4 sections. The first section was a brief introduction to this research study and the confidentiality of the data provided by the participants. Second section collected the respondent's demographical data such as their profession and their years of experience in the construction industry. Respondent's contextual data were gathered from the third and fourth questions. The third section gathered respondents' awareness of CE and measured the level of importance of each 9R CE principle for material selection in building construction projects in Sri Lanka to reduce material wastage. This question was prepared using the Likert scale where the respondents were asked to rate the importance of CE principles for minimising material wastage in building construction projects in Sri Lanka within the scale ranging from 1 to 5. (1=Very Low, 2=Low, 3=Moderate, 4=High, 5=Very High). The fourth section gathered the strategies proposed by survey respondents to implement CE principles in the material selection of building construction projects in Sri Lanka.

The construction professionals who are having knowledge and experience 05 years of experience in the fields of material selection, CE and waste management were identified as the targeted population for distributing the questionnaire. Creswell (2014) stated that an appropriate research sample is important to reflect the entire population. The non-probability, convenient sampling technique was adopted in this research. Rather than picking randomly from the entire population throughout the given period, this by considering the recruitment of a set of individuals who were easily available, 58 construction professionals were selected by using non-probability convenience sampling technique. An online survey was conducted by using Google forms. The questionnaire was distributed to 58 industry professionals and 37 responses were received in return. Table 2 shows the response rate which reflects the percentage of the number of responses received against the number of questionnaires distributed.

Table 2: Response rate of the questionnaire survey

Category	Distributed Questionnaires	Number of respondents returned	Response rate
Project manager	3	2	67%
Engineer	21	16	76%
Quantity surveyor	19	13	68%
Architect	9	3	33%
Contractor	4	1	25%
Material supplier	1	1	100%
Total	**58**	**37**	**64%**

As stated by Richardson (2005 as cited Nulty, 2008) response rate of 50% is regarded as an acceptable response rate in social research surveys. As stated in table 2, the response rate of the questionnaire survey was 64%.

The data collected from the respondents through the questionnaire survey were evaluated using the Weighted Mean Average to rank the importance of CE principles for minimizing material wastage in building construction projects in Sri Lanka. Weighted Mean Average (WMA) was calculated as per the formula shown in Eq. 01:

$$W = \frac{\sum_{i=1}^{n} wiXi}{\sum_{i=1}^{n} wi} \qquad \textit{(Eq. 01)}$$

Where, Σ = summation, w = the weights (Number of respondents), x = the value (1 to 5).

Data analysis and key research findings are presented below.

4. DATA ANALYSIS AND FINDINGS

This section presents the key findings on the importance of CE principles in material selection, which were derived through data analysis. The proposed CE-based 10R evaluation framework is also presented. Finally, various strategies were proposed to implement CE principles in the material selection of building construction projects in Sri Lanka.

4.1 ASSESSMENT OF THE LEVEL OF IMPORTANCE OF CE PRINCIPLES

Table 3 shows the results of the data analysis, which represents the CE 10R principles, ranked as per the level of importance of each CE principle in terms of material selection in building construction projects in Sri Lanka.

Table 3: Importance of CE principles for material selection

CE principle	WMA	Rank
Reuse	3.78	1
Reduce	3.76	2
Recycle	3.65	3
Recover	3.57	4
Refuse	3.38	5
Repair	3.35	6
Refurbish	3.30	7
Rethink	3.24	8
Remanufacture	3.22	9
Repurpose	3.14	10

Accordingly, the most important CE principle in terms of minimising material wastage in building construction projects in Sri Lanka can be identified as "Reuse" (WMA=3.78). The 2nd and 3rd most important CE principle is "Reduce" (WMA=3.76) and "Recycle" (WMA=3.65) respectively. The main 3R CE principles have been identified as the most important principles in the results. Furthermore, according to the results derived through analysis, Reuse (WMA=3.78), Reduce (WMA=3.76), Recycle (WMA=3.65) and Recover (WMA=3.57) principles have obtained WMA around 4. Other CE principles such as Refuse (WMA=3.38), Repair (WMA=3.35), Refurbish (WMA=3.30), Rethink (WMA=3.24) & Remanufacture (WMA=3.22) have obtained mean weighing around 3. Repurpose (WMA=3.14) can be identified as the least important CE principle according to the results.

The importance of CE principles through the questionnaire survey was compared with the data found in the literature review to improve the reliability and validity of the findings as shown in Figure 1. According to Figure 1, it is obvious that the priority order for material selection in building construction projects in Sri Lanka has deviated from the priority order introduced by Potting, et al. (2017), in the product chain.

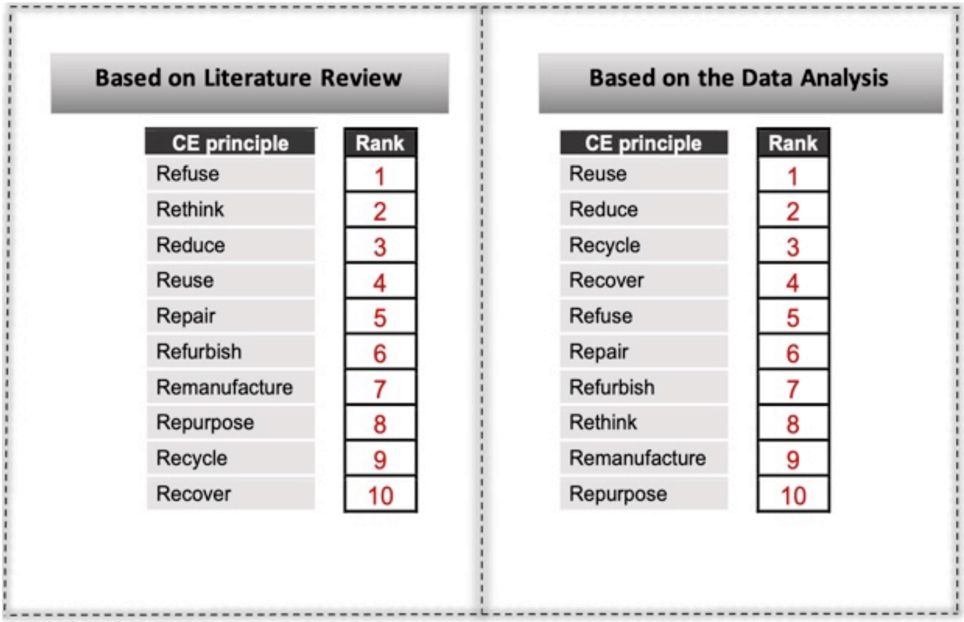

Figure 1: Comparison of CE principles - Literature review vs. data analysis

In the literature review "Refuse" has been identified as the most important CE principle in the product chains followed by "Rethink", "Reduce" and "Reuse". However, the data analysis derived "Reuse" as the most important CE principle for material selection of building construction projects in Sri Lanka. It is further proved by many survey respondents that materials with high reusability provide the maximum benefits of the existing materials rather than going for new material. Further, in the literature review "Recover" was identified as the least important CE principle. However, according to the data analysis "Repurpose" has become the least important CE principle due to a lack of technological advancement relating to the repurpose strategy in the Sri Lankan context.

4.2 THE PROPOSED CE-BASED 10R EVALUATION FRAMEWORK FOR MATERIAL SELECTION OF BUILDING CONSTRUCTION PROJECTS IN SRI LANKA

As derived through analysis, the importance of each CE principle was considered to develop a CE-based 10R evaluation framework for material selection of building construction projects in Sri Lanka. Table 4 provides the importance of each CE principle as a percentage by converting the WMA into percentages.

Table 4: Calculation of the level of importance of CE principles (%)

CE Principle	WMA	Percentage (%)
Reuse	3.78	11.00
Reduce	3.76	10.93
Recycle	3.65	10.61

CE Principle	WMA	Percentage (%)
Recover	3.57	10.38
Refuse	3.38	9.83
Repair	3.35	9.75
Refurbish	3.30	9.59
Rethink	3.24	9.43
Remanufacture	3.22	9.36
Repurpose	3.14	9.12
Total		**100**

Accordingly, various strategies were proposed to implement the CE principles for material selection of building construction projects in Sri Lanka as presented below.

4.3 PROPOSED STRATEGIES TO IMPLEMENT CE PRINCIPLES FOR REDUCING THE MATERIAL WASTAGE

The survey respondents were asked to propose strategies to implement CE principles in the material selection of building construction projects in Sri Lanka, which can be used to assure the practical implementation of the CE principles. The proposed strategies are summarised in Table 5.

Table 5: Proposed strategies to implement CE principles

Rank	CE principle	Proposed strategies
1	Reuse	Getting the maximum outcome from existing materials Reusing demolition & surplus materials
		Reusing materials as secondary masonry
		Choosing materials with high reusability and durability
		Considering reusable steel shuttering materials
2	Reduce	On-site sorting and proper storing of materials
		Adopting prefabricated building components
		Accurately calculating and ordering right quantity
		Using material control & material management
		Proper dimensional coordination
		Using alternative construction methods
3	Recycle	Developing plans to on-site recycle
		Recycling materials for possible reuse (timber etc)
		Using standards such as ISO 9001, and ISO 14001
		Choosing materials with high recyclable content
		Separating waste for an efficient and effective results
4	Recover	Using wood for fossil fuel
		Retrieving energy from non-recyclable materials by incineration
5	Refuse	Avoiding selection of less quality materials
		Refusing hazardous materials such as asbestos
		Using alternative materials
		Avoiding use of virgin material as much as possible

Rank	CE principle	Proposed strategies
		Using multiple functional materials
6	Repair	Maintaining detailed specifications of materials
		Initiating a proper maintenance management plan
		Increasing existing material's lifetime
7	Refurbish	Using old building materials as recycled materials
		Renovating and redecorating the existing materials
		Using refurbished materials such as aluminium
		Renovating old building materials to use for new functions
8	Rethink	Using sustainable, eco labelled, green materials
		Considering standardisation & modularisation
		Checking fit for purpose of materials for intended materials
		Substituting recycled materials for raw materials
		Sharing by-products with other industries
		Using renewable materials rather than using non-renewable
9	Remanufacture	Metal & steel recycling in the iron factory
		Producing more robust long-lived products through design
		Manufacturing with recovered material
10	Repurpose	Using construction material waste to produce another product
		Constructing green buildings
		Using demolished material waste for decorating garden
		Selecting materials with multiple purposes
		Using by-products results in the construction process where it's possible

As the key implication of this research, the CE-based 10R evaluation framework for material selection of building construction projects in Sri Lanka was developed as shown in Figure 2.

The level of importance of each CE principle in the material selection is shown in the proposed framework. As shown in Figure 2, the proposed evaluation facilitates a clear indication about the level of adoption of CE principles for material selection in building construction projects in Sri Lanka. Further, this developed indicator and proposed strategies will be beneficial to the industry stakeholders for sustaining their material selection process in building construction projects. By adopting this proposed 10R evaluation indicator and the proposed strategies, the reduction of construction material waste can be optimised. Accordingly, industry stakeholders can identify what are the most important CE principles in the material selection and compare them and call for actions respective parties, such as Design Engineers, Quantity Surveyors, etc. who are involved in material selection process in order to achieve zero material wastage. The proposed framework and strategies can be used as a basis to evaluate the present status of the material selection of building construction projects in order to adopt CE principles for reducing wastage of materials through circularity.

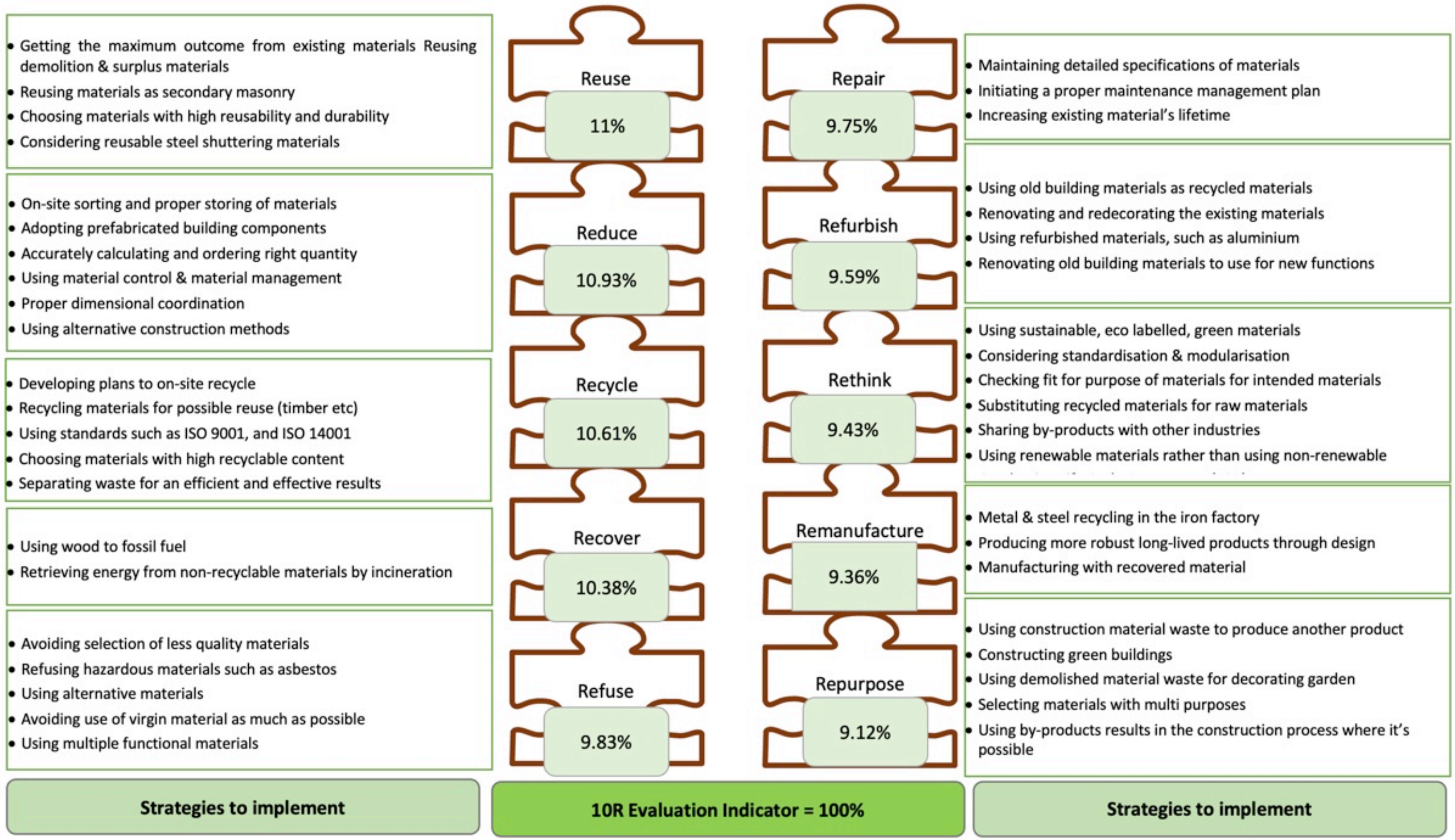

Figure 2: CE-based 10R evaluation framework proposed

5. CONCLUSIONS

In the Sri Lankan construction industry, one of the main reasons behind generating more and more construction material wastage is the absence of proper material selection criteria. To develop a proper material selection criterion, it is necessary to identify the rising concepts and techniques available globally. The zero-waste concept, in other words, the concept of CE has been received increasing attention due to its surprising performances within many industries. The CE principles which can also be identified as the core of the concept of CE, have been applied by past researchers to develop various CE frameworks. According to existing literature, there are only a very few research studies that have been conducted on the application of CE principles in the selection of construction materials, especially in the context of Sri Lanka. Therefore, this paper proposed a CE-based 10R evaluation framework for building construction projects in Sri Lanka. According to the research findings, 'Reuse', 'Reduce' and 'Recycling' are the three most important CE principles while 'Repurpose' is the least important CE principle to be considered in material selection in the Sri Lankan construction industry. Finally, the framework is proposed embedding the 10R evaluation indicator as well as the probable strategies to implement each CE Principle.

This research thus provides new insights and tackles the unexplored areas in material selection in terms of the concept of CE. Also, this research will help construction industry practitioners to realise the significance of reducing construction material wastage by adopting CE principles for material selection of building construction projects. However, this research limited to the adoption of CE principles for material selection of building construction projects in the context of Sri Lanka thus, the developed framework can be generalised to building construction projects with similar industrial settings. Also, the developed framework along with the proposed strategies can be used to make decisions towards zero waste and minimum environmental impacts of material selection in construction projects by focusing on CE. Further, research outcomes can be used by academics and industry professionals as a way forward for future researches in order to further investigate the application of CE principles for material selection by expanding the research to different contexts.

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CONSTRUCTION INDUSTRY ON THE BRINK: THE COVID-19 IMPACT

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ABSTRACT

The COVID-19 pandemic has affected all industries globally, including the construction industry. As a result, the construction industry is experiencing several challenges in terms of delivering projects on time and on budget. However, a few studies have shown that the COVID-19 pandemic has a positive impact on the construction industry. Hence, analysing the issues caused by COVID-19 is vital to lessen the effects of the pandemic. Therefore, this study aims to investigate the impact of COVID-19 on the construction industry. Accordingly, a detailed literature review was carried out to gain a theoretical understanding of the topic. A quantitative research approach was used to collect data. The questionnaire survey was conducted using snowball sampling with a total of one 108 respondents. Statistical Package for Social Science" (SPSS) was used to analyse the collected data. The findings revealed 86 negative impacts for the construction industry owing to the pandemic, which was classified as resources-related issues, project management issues, quality issues, financial issues, contractual issues, safety issues, technology-related issues, and other issues for the construction industry. An increase in the price of materials and equipment, project cost, exchange rate, and inflation rate were noted as significant negative impacts to the construction industry. The research further identified twelve (12) favourable impacts for the construction industry as a result of the pandemic. Encouraging risk assessment and collaboration and encouraging Personal Protective Equipment (PPE) were highlighted as the significant positive impacts. Therefore, strategies need to be identified to neutralise the negative impacts using the positive impacts caused by the pandemic. This study contributes to the body of knowledge to advance the construction industry towards the next level during the post-COVID-19 scenario, which will be the focus of the next phase of this research.

Keywords: *Construction Industry; COVID-19; Negative Impact; Positive Impact; Sri Lanka.*

1. INTRODUCTION

McKibbin and Fernando (2021) emphasised that COVID-19 was initially discovered in Wuhan, China, in December 2019 and rapidly spread throughout the world, creating a worldwide pandemic. Thereafter, the WHO Director-General proclaimed the current epidemic a public health emergency of global concern on January 30, 2020, and the COVID-19 pandemic was designated a pandemic on March 12, 2020 (WHO, 2020).

Moreover, Gamil and Alhagar (2020) underlined many nations have imposed an overall state lockdown after the WHO declared the COVID-19 outbreak as a pandemic following

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a dramatic increase in COVID-19 cases. Alsharef et al. (2021) and Hatoum et al. (2021) indicated that the COVID-19 epidemic has sparked a global health catastrophe that has caused significant disruptions and sufferings in countries and all industries including restaurants, retail, and airlines. The further author highlighted that the construction industry has been affected in many ways. The impact of the COVID-19 pandemic in the construction industry has been listed such as delay (time and cost overrun), payment delay, material shortage, and delivery delay, labour shortage, price variation at the market, lack of site management and supervision, insufficient communication between parties, supply chain disruption, less productivity and workflow, impact on revenue and cash flow (Alenezi, 2020a, 2020b, 2020c; Ghandour, 2020; Ogunnusi, et al., 2020). Nevertheless, the COVID-19 pandemic has had a beneficial impact on the construction industry (Ogunnusi, et al., 2020; Alsharef, et al., 2021; Oey and Lim, 2021).

King and Lamontagne (2021) affirmed construction industries are regarded as major economic foundations of the society in which they operate across the world. Salleh et al. (2020) broadened enhancements in the construction industry are critical for a country's economic success. Likewise, both developed and developing countries have recognized and comprehended the importance of the construction industry in a country's socio-economic and long-term growth (Khan, et al., 2020). Similarly, the Sri Lankan construction industry faces several challenges due to COVID-19 (Pathirana, 2020; Vithana, et al., 2020). However, there is a lack of research to examine the COVID-19 impact on the Sri Lankan construction industry. Accordingly, it is vital to define the COVID-19 impacts that have a significant influence on the Sri Lankan construction sector to recognize a solution to the pandemic. There is a need to fulfill this research gap through a proper empirical study to "investigates the impact of COVID-19 to the construction industry". Therefore, this research aims to "investigate the impact of COVID-19 to the construction industry". This paper written about COVID-19 impact to the construction industry, methodology, findings and discussion of findings.

2. LITERATURE REVIEW

2.1 COVID-19 IMPACT ON THE CONSTRUCTION INDUSTRY

The COVID-19 pandemic has impacted nearly every area of human society, both collectively and individually, from professional and personal aspects (Saurin, 2021). Gamil and Alhagar (2020) testified that many countries are experiencing an economic downturn and recession, and all commercial operations have been halted unless they fall into key categories such as essential medical sectors and supplies, as well as a few critical projects that are required to maintain the people's safety and health system. Furthermore, the COVID-19 pandemic had also sparked a healthcare, environmental, social, and economic disaster affecting all demographics and sectors of the economy (Bsisu, 2020; Gautam, 2020; McKibbin and Fernando, 2021). The research examined the economic impact of the pandemic breakout on the economies of 30 nations, concluded that gross domestic product (GDP) is expected to be affected by 3-6%, with some countries losing more than 10% and 15% (Fernandes, 2020). Globally, the COVID-19 epidemic attacked and impacted all construction industries in unprecedented ways (Gamil and Alhagar, 2020; Alsharef, et al., 2021; Bou Hatoum, et al., 2021; Oey and Lim, 2021; Raoufi and Fayek, 2021; Zamani, et al., 2021). Gamil and Alhagar (2020) argued that the situation was made even worse by a scarcity of construction materials, which had a negative influence on the construction sector. Further, Gamil and Alhagar (2020) asserted many employees in the construction industry have lost their employment, and most small businesses are unable to pay remunerations during lockdowns.

Hence, Ogunnusi et al. (2020) explored well-planned construction projects that have been equally impacted by this epidemic, which was never addressed while tendering for any construction project. All employees in the construction industry have lost their employment, and most small businesses are unable to pay remunerations during lockdowns. Unlike, the Construction sector differs from other sectors in that it generally necessitates the participation of all project participants on-site (Gamil and Alhagar, 2020). Gamil and Alhagar (2020) emphasised during the virus's spread, several nations began taking steps to restrict people's travel, which has affected construction since it necessitates on-site work, and every project parties must be accessible to work, inspect, and supervise all work operations. The COVID-19 impact on the Global and Sri Lankan construction industry is summarised in Table 1.

Table 1: COVID-19 impact on the global and Sri Lankan construction industry

No	Impacts	Reference
	Resources Related Issues	
	Material	
1	Scarcity in material	[4],[5],[7],[8],[9],[10],[11],[13],[14]
2	Supply chain disruptions	[2],[4],[7],[8],[9],[10],[11],[12],[13],[14]
3	Difficulties in finding suitable alternative materials	[10],[11]
4	Delay in delivery	[6],[9],[10],[11]
5	Difficulties in storing material	[12]
	Workforce	
6	Shortage in workforce	[2],[4],[5],[6],[7],[8],[9],[10],[11],[12]
7	Increased in workload	[2]
8	Unstable mental and physical health of workers	[10],[11],[12]
9	Difficulties in transportation	[6]
	Equipment	
10	Delay in delivery	[5]
11	Shortage in construction equipment	[5]
	Project Management Issues	
12	Restriction on operations	[1],[7],[9],[10],[12],[13]
13	Inappropriate site conditions	[5],[9],[10]
14	Difficulties in adapting to the new normal	[12]
15	Lack of experts	[12]
16	Poor decision making	[12]
17	Lack of previous experience on a pandemic	[12]
18	Poor control and monitoring	[2],[11]

No	Impacts	Reference
19	Continuous changes in project scheduling and planning	[5],[7],[10],[11]
20	Lack of communication between parties	[5]
21	Lack of supervision and site management	[2],[5]
22	Disruption to the progress of work and workflow	[2],[4]
23	Lack of safety conditions	[5]
24	Lack of Coordination	[10],[12],[13]
25	Ineffective work on site	[11]
26	Delay on project completion	[1],[2],[4],[5],[7],[8],[9],[10],[11],[12]
27	Slowing and suspension of an ongoing project	[7],[10],[12]
28	Delay to start new projects	[10]
29	Project abandonment/stopped/termination	[4],[6],[12],[13]
30	Reduction of per day working hours	[6]
31	Delay from construction-related activities	[6]
	Quality Issues	
32	Reduction in quality due to continuous changes	[11]
33	Reduction in quality due to material changes	[11]
34	Reduction in quality due to limited time and delay	[11]
35	Reduction in quality due to lack of coordination	[11]
36	Decrease in productivity	[2],[4],[5],[9],[10],[11],[12]
	Financial Issues	
37	Increased in project cost	[4],[7],[8],[9],[10],[11],[13]
38	Increase in exchange rate, and inflation rate	[5],[7],[10],[11],[12],[14]
39	Increase price of materials and equipment	[5],[6],[7]
40	Unstable cash flow and revenue	[2],[4],[10],[11]
41	Lack of funding	[4],[6],[7],[12]
42	Bankruptcy	[13]
43	Reduction in other costs	[9]
44	Employees get payment without work	[13]
	Contractual Issues	
45	Delay in payments	[3],[5],[8],[10]
46	Delay due to approval and revising	[1],[2],[4],[5],[7],[8],[9],[10],[11],[12]
47	Delay from permitting and inspection	[1],[2],[4],[5],[7],[8],[9],[10],[11],[12]
48	Delay in providing instructions	[1],[2],[4],[5],[7],[8],[9],[10],[11],[12]
49	Delay due to main contractor	[1],[2],[4],[5],[7],[8],[9],[10],[11],[12]
50	Delay due to subcontractors	[1],[2],[4],[5],[7],[8],[9],[10],[11],[12]
51	Changed or unclear standard operating procedures	[9],[11]

No	Impacts	Reference
52	Increase in claims, disputes, and litigation	[7], [10],[12]
	Safety-Related Issues	
53	Shortage in personal protective equipment	[10]
54	Quarantining and temporary shutdown	[10]
	Technological Related Issues	
55	Lack of practices in virtual working	[7],[10],[11]
56	Insufficient support to adapt to new technologies	[7],[10],[11]
57	Issues with work from home	[10],[11]
58	Ineffective transition to remote work	[10],[12]
	Other Issues	
59	Challenges to sustainability of future project	[11],[12],[13]
60	Uncertainty of the project	[7],[13]
61	Shrink in market size	[11],[12],[13]
62	Reduction in number of projects	[4],[8], [11],[12],[13]
63	Spend more time to review the project	[11],[12],[13]
64	Anxiety for termination	[11],[12],[13]
65	Lack of improvements to the project	[11],[12],[13]
66	Termination of staff employment	[13],[14]
67	Impact on social sustainability	[7],[14]

[1] (Alenezi, 2020c), [2] (Ghandour, 2020), [3] (Alenezi, 2020b), [4] (Ogunnusi, et al., 2020), [5] (Alenezi, 2020a), [6] (Osuizugbo, 2020), [7] (Gamil and Alhagar, 2020), [8] (Zamani, et al., 2021), [9] (King, et al., 2021), [10] (Alsharef, et al., 2021), [11] (Oey and Lim, 2021), [12] (Kawmudi, et al., 2020), [13] (Vithana, et al., 2020), [14] (Pathirana, 2020)

Table 2 shows that the majority of the problems in the construction sector as a result of the COVID-19 pandemic are linked to financial issues, resource shortages, project delays, decreased productivity, and reduced project numbers. On the other hand, few researches highlighted the positive impact of the COVID-19 pandemic on the construction industry as well (Ogunnusi, et al., 2020; Alsharef, et al., 2021; Oey and Lim, 2021). The positive impact of the COVID-19 pandemic on the construction industry is shown in Table 2.

Table 2: The positive impact of the COVID-19 pandemic on the construction industry

No	Positive Impact	Reference
1	Reduction in other costs	[3]
2	No impact on quality	[3]
3	Increase in demands for local manufacturers and suppliers	[2]
4	Less interest rate for the loan and other favourable loan programme provided by the government	[2]
5	Increase in investment on expand and renovation, buying a new house	[2]
6	Increase in demand on fast rack medical, transportation, residential and Other Projects	[2]
7	Job opportunity for skilled workers	[2]

No	Positive Impact	Reference
8	Improvement on existing systems and internal reviews	[2]
9	Improvement on alternatives for offsite works and virtual	[1]
10	Improvement on workplace design and material planning	[1]
11	Encouraging risk assessment and collaboration	[1]
12	Encouraging on Personal Protective Equipment (PPE)	[1]
[1] (Ogunnusi et al., 2020), [2] (Alsharef et al., 2021), [3] (Oey and Lim, 2021)		

Oey and Lim (2021) specify that reduction in cost including salary decreased as the positive impact from the employer perspective. On the other hand, when considering the contractor perspective reduction in other costs has a negative impact (King, et al., 2021). It means project suspension and reduction as well as lack and no production directly influence the contractors as the contractor did not entitle to claim without working. Similarly, in the Sri Lankan context, Vithana, et al. (2020) mentioned that Employees' getting payment without work has a negative impact due to COVID-19 in the construction industry from an Employer perspective. However, this different perspective occurs, varies between countries' legal amendments, and newly amended rules and regulations as well. Based on the study, provided a table to categorize positive and negative COVID-19 impacts in the construction industry. According to the literature study identified 12 positive impacts and 67 negative impacts with COVID-19 in the construction industry. Accordingly, there is a need to validate, if these impacts are relevant to the Sri Lankan context.

3. METHODOLOGY

A systematic literature survey was conducted to analyse the impact of the COVID-19 pandemic on the construction industry in Sri Lanka. The research has been used a quantitative research approach to accomplish the research aim. Since each respondent is asked to reply to the same set of questions, questionnaires are one of the most extensively used data collection techniques in the survey approach, they provide an efficient means of gathering responses from a large sample before conducting quantitative analysis (Saunders, et al., 2009). Furthermore, Kumar (2011) agreed that they are most effective when asked standard questions. Therefore, the questionnaire survey was conducted to validate the literature findings, which was COVID-19's impact on the construction industry, in the Sri Lankan context. Subsequently, a questionnaire survey was undertaken to identify the additional COVID-19 impact on the Sri Lankan construction industry as well. The questionnaire was created based on the findings of the literature. Moreover, the questionnaire was also divided into three segments. In addition, some critical questions were put together in section one to determine the respondent's profile. The second section was dedicated to determining the impact of COVID-19 on the Sri Lankan construction industry. In this part, the sixty-seven factors found in the literature analysis are organized into eight categories. The final segment identified 12 positive effects of the COVID-19 pandemic on the construction industry. In Parts 2 and 3, respondents were asked to rate the criticality, efficacy, and efficiency of the specified impact of the COVID-19 epidemic on the construction using a five-point "Likert scale” where 1 meant "strongly disagree" and 5 meant "strongly agree”. Thereafter, the questionnaires were administrated electronically via electronic mail using the Internet (Internet-mediated questionnaires). However, a pilot study should be conducted to pre-test the questionnaire to refine it, that respondents will have no trouble completing the questions and recording the data (Kothari, 2004).

A pilot survey of chosen industry employees was conducted for assessment. Thereafter, the questionnaire may be revised in light of the pilot study's findings. Snowball sampling is also known as reputational sampling or network chain referral was chosen as it is based on the concept of a rolling snowball, where one or few individuals are first sampled and then the sample rolls out depending on connections to the initial respondents (Khalid, et al., 2012). Therefore, the respondents for the questionnaire survey were chosen using the snowball sample method. As a result, questionnaires were provided to those who worked in the Sri Lankan construction industry and had prior experience. Accordingly, online questionnaire forms were distributed to 211 respondents and 108 responses were returned out of 211. As a result, the questionnaire survey had a response rate of 51.18%. Figure 1 presents the details of the respondents.

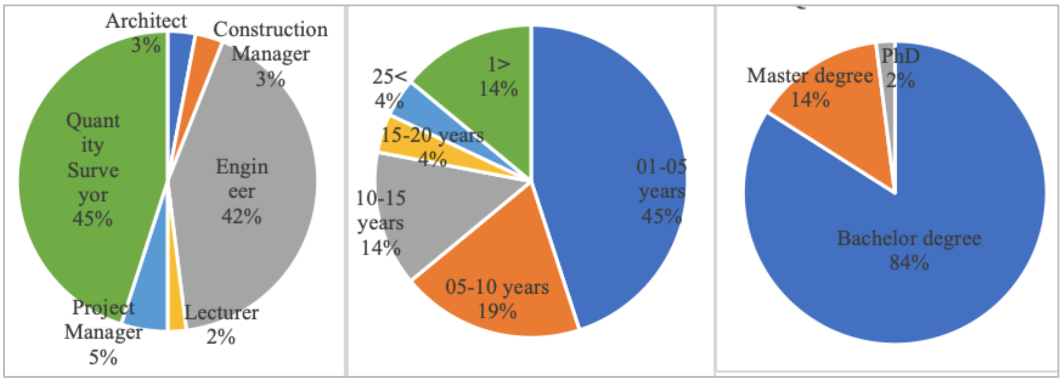

Figure 1: Details of the respondents

According to Figure 1, a large number of respondents fell into two categories: Quantity Surveyors with 45% of respondents and Engineers with 42%. As a result, the results of the questionnaire survey mostly reflect the perspectives of Quantity Surveyors and Engineers. Consequently, the opinions of the remaining types of respondents were also used for analysis, such as Project Managers (5%), Construction Managers (3%), Architects (3%), and Lecturers (2%). Subsequently, Figure 1 depicts respondents' general experiences across five different category ranges. Even though, a high proportion of respondents have experienced between 1 and 5 years with 45% of respondents. Despite this, 41% of responders had more than 5 years of experience. Despite this, 41% of responders had more than 5 years of experience. According to this, the results of the questionnaire survey reflect the opinions of well-experienced respondents, and their perspectives and insights on the proposed questionnaire will be more experienced than those of respondents with less than a year of experience. In addition, when it comes to academic qualifications, Figure 1 shows that 84% of respondents have a bachelor's degree, 14% have a master's degree, and 2% have a Ph.D. As a result, a large proportion of responders fell into one of two categories: Engineers and Quantity Surveyors with more than one year of experience. To enhance the statistical analysis of the Likert scale, the method of RII has been used. Further, the RII approach is commonly used to analyse survey data arising from the use of Likert scales in construction management research questionnaires (Holt, 2013). Throughout this study, RII was employed as a questionnaire survey analysis technique to rank the COVID-19 impacts according to their relative importance. Meanwhile, the findings of the questionnaire and RII were analysed using the SPSS software.

4. RESEARCH FINDINGS

The purpose of the questionnaire was to apply the findings from the literature to the Sri Lankan context, as well as highlight the significant factor and any other additional factors. the results of the questionnaire were analysed using the SPSS software.

4.1 COVID-19 IMPACT ON THE SRI LANKAN CONSTRUCTION INDUSTRY

The impact of COVID-19 on the Sri Lankan construction industry was identified using a Likert scale questionnaire survey (1 meant "strongly disagree" and 5 meant "strongly agree"), and significant COVID-19 impacts identified through the RII analysis are listed in Table 3. They are all divided into eight categories.

Table 3: COVID-19 impact on the Sri Lankan construction industry

No	Impacts	1	2	3	4	5	RII	Rank
	Resources Related Issues	**Scale Percentage**						
	Material							
1	Scarcity in material	0.9	2.8	4.6	48.1	43.5	0.86	**7**
2	Supply chain disruptions	2.8	0.9	4.6	46.3	45.4	0.86	**8**
3	Difficulties in finding suitable alternative materials	0.0	3.7	16.7	57.4	22.2	0.80	25
4	Delay in delivery	1.9	0.9	6.5	44.4	46.3	0.86	**6**
5	Difficulties in storing material	6.5	27.8	31.5	25.9	8.3	0.60	67
	Workforce							
6	Shortage in workforce	2.8	2.8	11.1	41.7	41.7	0.83	14
7	Increased in workload	2.8	4.6	18.5	48.1	25.9	0.78	32
8	Unstable mental and physical health of workers	2.8	3.7	13.0	43.5	37.0	0.82	18
9	Difficulties in transportation	0.9	4.6	10.2	40.7	43.5	0.84	12
	Equipment							
10	Delay in delivery	0.0	4.6	13.9	52.8	28.7	0.81	21
11	Shortage in construction equipment	2.8	6.5	29.6	42.6	18.5	0.74	46
	Project Management Issues							
12	Restriction on operations	1.9	4.6	13.0	50.0	30.6	0.81	24
13	Inappropriate site conditions	1.9	12.0	25.9	49.1	11.1	0.71	56
14	Difficulties in adapting to the new normal	1.9	3.7	11.1	53.7	29.6	0.81	22
15	Lack of experts	1.9	16.7	40.7	28.7	12.0	0.66	62
16	Poor decision making	5.6	20.4	33.3	32.4	8.3	0.64	66
17	Lack of previous experience on a pandemic	1.9	7.4	12.0	39.8	38.9	0.81	20
18	Poor control and monitoring	3.7	11.1	31.5	40.7	13.0	0.70	58
19	Continuous changes in project scheduling and planning	0.0	5.6	8.3	47.2	38.9	0.84	13
20	Lack of communication between parties	2.8	7.4	29.6	43.5	16.7	0.73	51
21	Lack of supervision and site management	2.8	15.7	23.1	39.8	18.5	0.71	57
22	Disruption to the progress of work and workflow	0.9	2.8	13.0	50.0	33.3	0.82	17
23	Lack of safety conditions	5.6	10.2	17.6	44.4	22.2	0.74	47
24	Lack of Coordination	2.8	12.0	27.8	40.7	16.7	0.71	55
25	Ineffective work on site	0.9	12.0	26.9	40.7	19.4	0.73	49
26	Delay on project completion	1.9	0.9	4.6	40.7	51.9	0.88	**4**
27	Slowing and suspension of an ongoing project	1.9	2.8	6.5	56.5	32.4	0.83	15
28	Delay to start new projects	0.0	3.7	9.3	41.7	45.4	0.86	**10**
29	Project abandonment/stopped/termination	6.5	3.7	25.0	35.2	29.6	0.76	42
30	Reduction of per day working hours	2.8	14.8	22.2	38.0	22.2	0.72	52
31	Delay from construction-related activities	3.7	5.6	17.6	46.3	26.9	0.77	34

No	Impacts	1	2	3	4	5	RII	Rank
	Quality Issues							
32	Reduction in quality due to continuous changes	4.6	22.2	29.6	28.7	14.8	0.65	65
33	Reduction in quality due to material changes	3.7	20.4	25.0	38.9	12.0	0.67	61
34	Reduction in quality due to limited time and delay	2.8	20.4	20.4	41.7	14.8	0.69	59
35	Reduction in quality due to lack of coordination	2.8	19.4	35.2	31.5	11.1	0.66	64
36	Decrease in productivity	0.9	10.2	15.7	39.8	33.3	0.79	29
	Financial Issues							
37	Increased in project cost	0.0	1.9	2.8	42.6	52.8	0.89	**3**
38	Increase in exchange rate, and inflation rate	0.9	0.0	1.9	34.3	63.0	0.92	**2**
39	Increase price of materials and equipment	0.0	2.8	0.0	27.8	69.4	0.93	**1**
40	Unstable cash flow and revenue	0.0	2.8	8.3	45.4	43.5	0.86	**9**
41	Lack of funding	1.9	4.6	14.8	45.4	33.3	0.81	23
42	Bankruptcy	0.9	7.4	34.3	36.1	21.3	0.74	45
43	Reduction in other costs	3.7	20.4	29.6	34.3	12.0	0.66	63
44	Employees get payment without work	10.2	11.1	28.7	32.4	17.6	0.67	60
	Contractual Issues							
45	Delay in payments	2.8	2.8	3.7	50.9	39.8	0.84	11
46	Delay due to approval and revising	0.0	4.6	7.4	58.3	29.6	0.83	16
47	Delay from permitting and inspection	0.0	5.6	16.7	51.9	25.9	0.80	26
48	Delay in providing instructions	1.9	7.4	30.6	42.6	17.6	0.73	48
49	Delay due to main contractor	4.6	3.7	25.9	46.3	19.4	0.74	43
50	Delay due to subcontractors	0.0	2.8	18.5	56.5	22.2	0.80	27
51	Changed or unclear standard operating procedures	0.9	5.6	24.1	52.8	16.7	0.76	41
52	Increase in claims, disputes, and litigation	0.9	2.8	12.0	56.5	27.8	0.81	19
	Safety-Related Issues							
53	Shortage in personal protective equipment	2.8	11.1	25.9	42.6	17.6	0.72	53
54	Quarantining and temporary shutdown	0.9	0.9	4.6	44.4	49.1	0.88	**5**
	Technological Related Issues							
55	Lack of practices in virtual working	1.9	7.4	14.8	58.3	17.6	0.76	38
56	Insufficient support to adapt to new technologies	1.9	5.6	24.1	46.3	22.2	0.76	39
57	Issues with work from home	1.9	7.4	13.0	46.3	31.5	0.80	28
58	Ineffective transition to remote work	0.9	6.5	16.7	50.9	25.0	0.79	30
	Other Issues							
59	Challenges to sustainability of future project	1.9	2.8	20.4	56.5	18.5	0.77	35
60	Uncertainty of the project	1.9	4.6	18.5	52.8	22.2	0.78	33
61	Shrink in market size	0.9	10.2	15.7	49.1	24.1	0.77	36
62	Reduction in number of projects	1.9	5.6	22.2	46.3	24.1	0.77	37
63	Spend more time to review the project	1.9	5.6	22.2	51.9	18.5	0.76	40
64	Anxiety for termination	0.9	12.0	30.6	38.0	18.5	0.72	54
65	Lack of improvements to the project	1.9	12.0	20.4	50.9	14.8	0.73	50
66	Termination of staff employment	5.6	5.6	21.3	46.3	21.3	0.74	44
67	Impact on social sustainability	0.9	3.7	18.5	55.6	21.3	0.79	31

The result shows that overall RII values are more than 0.60, which indicates that most of the respondents considered all these sixty-seven (67) COVID-19 impacts apply to the Sri Lankan construction industry as well. Furthermore, as per RII value which is more than 0.86, shows that the majority of the problems in the Sri Lankan construction sector as a result of the COVID-19 pandemic are linked to financial issues (increase price of materials and equipment, increase in the exchange rate, and inflation rate, increased in project cost, and unstable cash flow and revenue), safety-related issues (quarantining and temporary shutdown), project management issues (delay on project completion, and delay to start new projects), and resources related issues (delay in delivery, scarcity in material, and supply chain disruptions). Furthermore, Figure 2 graphically demonstrates the level of significance of COVID-19 impact in the Sri Lankan context through findings of the questionnaire survey.

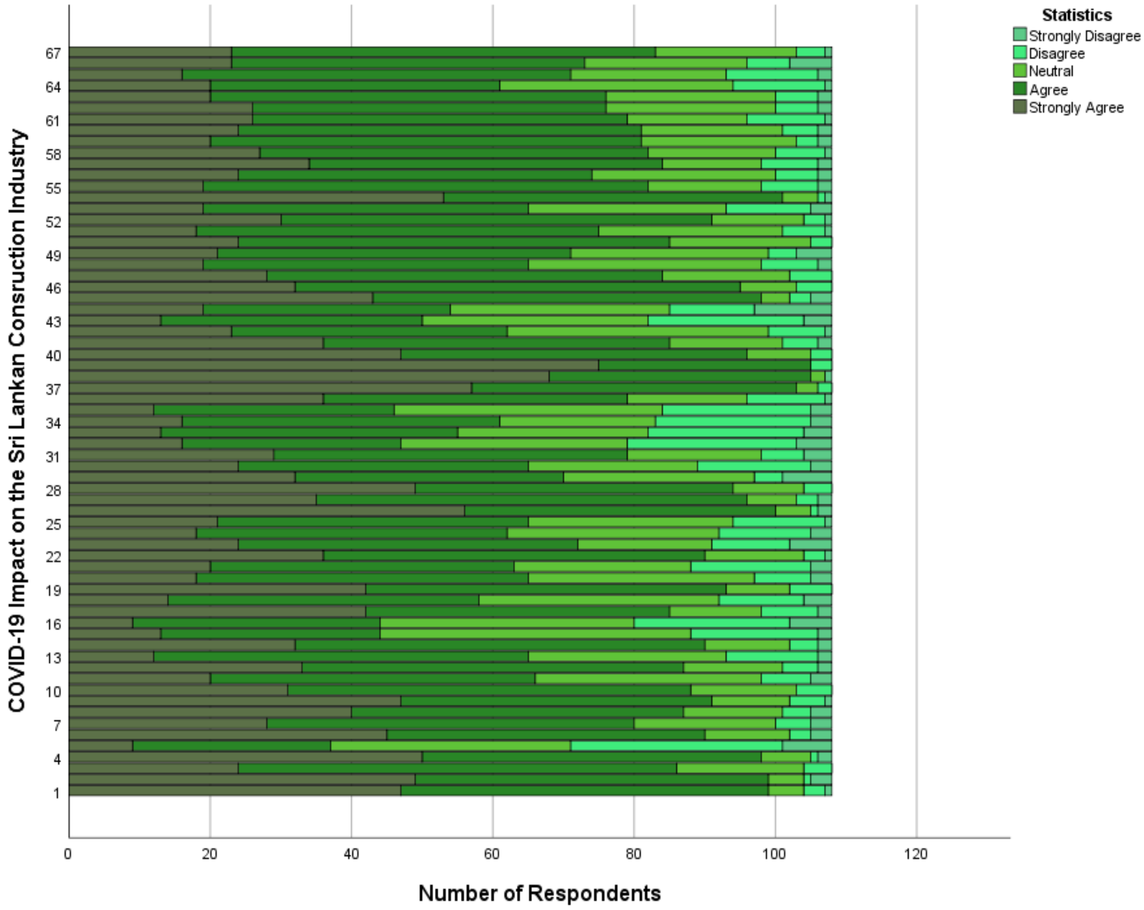

Figure 2: Impact of COVID-19 on Sri Lankan construction industry

Figure 2 shows that all respondents agreed that COVID-19 influences the Sri Lankan construction industry. Consequently, this figure merely shows the extent to which respondents agree or disagree with the COVID-19 impact and how it has affected the Sri Lankan construction sector. Finally, Figure 3 summarises the significant COVID-19 impacts on the Sri Lankan construction industry, industry through a polar chart, arranged from most influencing to least influencing factors.

Figure 3 demonstrates that the construction industry in Sri Lanka was strongly influenced by impacts 39, 38, 37, 26, and 54, while it was least impacted by impacts 5, 16, 32, 43, and 35. Further, few respondents have noted and elaborated on the COVID-19 impacts that have been reported in the literature under contractual-related issues, particularly delayed payments in government projects. Furthermore, the respondents have emphasised lack of communication and coordination (most notable, no direct communication with managements) (Alsharef, et al., 2021), difficulty to adapt to the workers to work with the new government health and safety guidelines (Kawmudi, et al., 2020), difficulties in staff and labour movement off-site (Osuizugbo, 2020), difficulty to work with new government rules and regulations (King, et al., 2021a), lack of plans for pre-and post-disaster events (Oey and Lim, 2021), and less controlling and monitoring of main contractors (as they are a foreign contractor) (Ghandour, 2020)are all project management related issues. Furthermore, as noted in the literature, equipment operator shortages (Alenezi, 2020a) were mentioned by a few respondents under equipment-related concerns. Similarly, under workforce-related issues, only a limited number of labourers are allowed within sites, inadequate accommodation, work progress is affected abruptly when workers are quarantined, at the initial stage of COVID-19, labours turned to agriculture and left construction work in March 2020, and workers accommodation must be maintained for safety according to COVID 19 regulations (Gamil and Alhagar, 2020; Ogunnusi, et al., 2020) specified by few respondents as mentioned in literature.

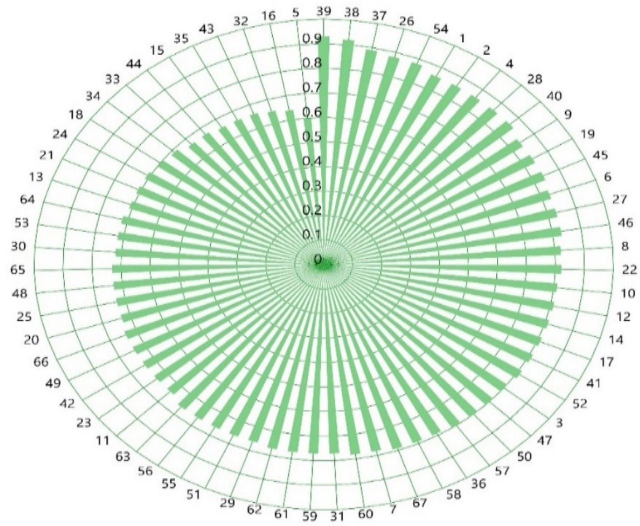

Figure 3: COVID-19 impacts on the Sri Lankan construction industry

Furthermore, under material-related issues, an increase in material prices (Zamani, et al., 2021), as well as the instability of the foreign currency component (Gamil and Alhagar, 2020) in Sri Lanka, had an impact on imported materials such as DI and PE, as well as restrictions on the import and shipment of material from foreign countries, as mentioned in the literature. In addition, due to a lack of funds (Ogunnusi, et al., 2020), government projects have decreased, international and domestic investment in the construction industry has been reduced (Zamani, et al., 2021), and the tourism business (Oey and Lim, 2021) has had a significant impact on the construction industry, as stated by the respondents in the literature. Table 4 lists some further COVID-19 impacts highlighted in the respondent's additional remarks that they have encountered.

Table 4: COVID-19 impacts added by the respondents

No	Impacts
	Resources related issues
	Material
1	Reduction in quality of materials
2	Some materials will ruin after a long period of storage
	Workforce
3	Difficulties in finding relevant Skill labours on a limited salary scale
4	Increased in salary
5	Unable to get Specialist workforce from foreign countries
6	Difficult in coordination with workers

	Equipment
7	Equipment price fluctuation
8	Unable to repair the equipment due to shortage in spare parts
9	Increased in hire vehicle rate due to fuel price increase
10	Equipment corroded due to lockdown
11	Scarcity of equipment
	Quality Issues
12	Reduction in a quality due use of labour of inappropriate skills
13	Often rectifications, and reworks
	Financial Issues
15	Liquidity issues of money
16	Delay in approval of compensation
	Contractual Issues
17	Poor contractual interpretation on pandemic situation
	Safety-Related Issues
18	The difficulty of managing labours as per health standards
19	Avoidance of health and safety standards due to increasing Working space/ accommodating space

Table 4 demonstrates that the study revealed nineteen (19) new COVID-19 impacts in the Sri Lankan construction industry that were not found in the literature review. According to the findings, the COVID-19 pandemic has caused eighty-six (86) negative elements in the construction industry, which are classified under resources-related issues, project management issues, quality issues, financial issues, contractual issues, safety issues, technology-related issues, and other issues.

4.2 POSITIVE IMPACT OF THE COVID-19 PANDEMIC ON THE SRI LANKAN CONSTRUCTION INDUSTRY

In contrast, a few studies in the literature review showed the positive impact of the COVID-19 pandemic on the construction industry (Ogunnusi et al., 2020; Alsharef et al., 2021; Oey and Lim, 2021). 53% of respondents believe the COVID-19 pandemic has had a positive impact on the Sri Lankan building industry. Table 5 shows the significance of the COVID-19 pandemic's positive influence on the Sri Lankan construction industry.

Table 5: The positive impact of the COVID-19 pandemic on the Sri Lankan construction industry

No	Positive Impacts	1	2	3	4	5	RII	Rank
		Scale percentage						
1	Reduction in other costs	15.7	39.8	19.4	20.4	4.6	0.52	12
2	No impact on quality	9.3	38.9	26.9	15.7	9.3	0.55	11
3	Increase in demands for local manufacturers and suppliers	3.7	11.1	25.0	44.4	15.7	0.71	4
4	Less interest rate for the loan and other favourable loan programme provided by the government	3.7	15.7	34.3	37.0	9.3	0.66	7
5	Increase in investment on expand and renovation, buying a new house	5.6	24.1	30.6	31.5	8.3	0.63	9
6	Increase in demand on fast rack medical, transportation, residential and Other Projects	3.7	14.8	25.9	47.2	8.3	0.68	6
7	Job opportunity for skilled workers	9.3	23.4	22.4	34.6	10.3	0.62	10
8	Improvement on existing systems and internal reviews	2.8	20.8	36.8	26.4	13.2	0.64	8

No	Positive Impacts	1	2	3	4	5	RII	Rank
		Scale percentage						
9	Improvement on alternatives for offsite works and virtual	2.8	12.0	27.8	38.9	18.5	0.72	3
10	Improvement on workplace design and material planning	2.8	16.7	22.2	42.6	15.7	0.70	5
11	Encouraging risk assessment and collaboration	1.9	11.1	22.2	48.1	16.7	0.73	2
12	Encouraging on Personal Protective Equipment (PPE)	1.9	6.5	15.7	52.8	23.1	0.78	1

RII values for the 10 COVID-19 positive impacts are greater than 0.60, indicating that the majority of respondents believe these 10 COVID-19 positive impacts apply to the Sri Lankan construction industry. Nevertheless, for the first two positive impacts, which are reduction in other costs, and no impact on quality, RII is less than 0.6. Except for those two positive outcomes, all others were found to be positive COVID-19 impacts on the Sri Lankan construction industry. According to the RII value of 0.78, the positive effects of the COVID-19 pandemic on the Sri Lankan construction industry are linked to encouraging PPE. Finally, Figure 4 depicts the considerable COVID-19 positive impacts in the Sri Lankan construction industry.

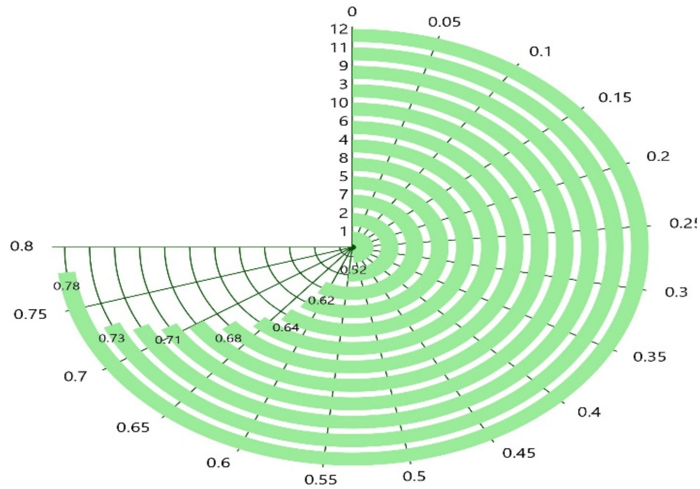

Figure 4: COVID-19 positive impacts in the Sri Lankan construction industry

According to the findings of the literature, Alsharef, et al. (2021), Oey and Lim (2021), and Ogunnusi, et al. (2020) discovered 12 positive impacts on the construction industry. Only a few respondents have mentioned things that have already been mentioned in the literature, such as increased demand for local manufacturers (Alsharef, et al., 2021), and increased usage of or adaption to BIM/Digital Construction (Ogunnusi, et al., 2020; Alsharef, et al., 2021). Consequently, additional COVID-19 positive impacts are emphasised in the respondent's additional notes: the labour force's availability whereas many workers in the tourism industry have lost their jobs and have turned to the construction industry to make ends meet, and work can be monitored more carefully than previously. Finally, the research found 12 positive impacts.

5. DISCUSSION OF FINDINGS

The construction industry was affected by the COVID-19 pandemic (Alsharef, et al., 2021; Raoufi and Fayek, 2021). Furthermore, most of the research has been highlighted while evaluating the influence of the COVID-19 pandemic on the construction sector, such as resource shortages, financial concerns, project delays, lower productivity, and reduced project numbers (Ghandour, 2020; Ogunnusi, et al., 2020; Oey and Lim, 2021; Zamani, et al., 2021). Based on the literature review 67 COVID-19 impacts have been identified under eight categories including resources-related issues, project management issues, quality issues, financial issues, contractual issues, safety issues, technology-related issues, and other issues, and all of them have been validated using a Likert scale questionnaire survey. In addition, the respondents indicated nineteen additional COVID-19 impacts. Eighty-seven COVID-19 impacts on the Sri Lankan construction sector have been discovered under eight categories. In contrast, a few research in the literature review revealed that the COVID-19 pandemic had a twelve 12 favourable influence on the construction industry (Ogunnusi, et al., 2020; Alsharef, et al., 2021; Oey and Lim, 2021). Based on that, ten 10 positive COVID-19 impacts on the Sri Lankan construction industry have been validated and identified as positive COVID-19 impacts. Further, two more COVID-19 positive impacts were also highlighted by the responders. Twelve COVID-19 positive impacts on the Sri Lankan construction industry have been identified.

6. CONCLUSIONS

The research's objective was met by conducting a systematic literature study and conducting a questionnaire survey of construction industry professionals. By referring to journals and conference proceedings, the impact of COVID-19 on the construction sector was covered in the literature review. As a result, 67 COVID-19 impacts were found, which were divided into eight categories: resources-related issues, project management issues, quality issues, financial issues, contractual issues, safety issues, technology-related issues, and other issues. Furthermore, using a questionnaire survey, these findings from the literature were confirmed in the Sri Lankan context by construction industry professionals. Further, a total of 19 new COVID-19 impacts were gathered from construction industry professionals. On the other hand, ten positive COVID-19 impacts found in the literature were confirmed in the Sri Lankan context. In addition, data analysis revealed two more positive impacts. COVID-19's impacts on the Sri Lankan construction industry have been recognized as a result. This study highlights that COVID-19 is catastrophe as well as a blessing in disguise to the Sri Lankan construction industry. For example, this pandemic has developed a platform for the construction industry to enter the digital environment. As a result of this pandemic, the construction industry has been promoted to the next level. However, while the COVID-19 pandemic has had various detrimental effects on the construction industry, it has allowed the sector to improve and advance to the next level by providing a solution to the situation. The outcomes of this research will be valuable to Sri Lankan construction organizations in developing a strategy based on these impacts. Further, the findings will assist construction organizations in better understanding the impacts that the construction sector experiences to develop solutions and, as a result, to enhance the evolutionary process to mitigate the impacts in Sri Lanka. Finally, the findings results will open the way for the next stage of the study that focus on investigating a solution to the COVID-19 impact using innovative technology such as Building Information Modelling and lean construction, which will be the focus of the next phase of the research.

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CONTAINER-BASED RELOCATABLE MODULAR BUILDINGS FOR CONSTRUCTION SITE OFFICES IN SRI LANKA: CONTRACTORS' PERSPECTIVE

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ABSTRACT

The temporary site offices are directly provided by the contractor, and hence, any associated risk is non-transferable. Thus, the contractors should be aware of sustainable, and cost-effective technologies to be implemented to survive in the competitive construction industry. Relocatable Modular Building (RMB) technology is employed globally as a multi-beneficial building technology for temporary shelter purposes such as site offices. Hence, the research aimed to explore the applicability of RMB technology for temporary offices on construction sites in Sri Lanka. The literature synthesis reviewed the modular building concept and RMB technology globally. Following the qualitative approach, the research adopted a survey strategy. Data was collected through seven semi-structured interviews with industry professionals who were purposively selected under several criteria. Further, data collection was limited to container-based RMBs due to the limited availability of RMB varieties in Sri Lanka. Template analysis was the data analysis technique followed. The findings disclosed that RMBs have already been established in the Sri Lankan construction industry. 'Relocatability', reusability, high security, larger usable space within limited land space, ability to rent out, and air-conditioned working environment were found as key benefits of RMBs whereas the unbreathable smell of glue in newly fabricated RMB, handling difficulties, the possibility of overturning, initial cost and external body corrosion were identified as key challenges. Significantly, the contractors are recommended to use RMBs for temporary site offices following proposed strategies such as periodic maintenance procedures, systematic site administration, and safety improvements to overcome identified challenges.

Keywords: *Benefits and Challenges; Container-based Site Offices; Contractors; Relocatable Modular Building (RMB); Strategies.*

1. INTRODUCTION

The construction industry comprises an extremely competitive market mostly controlled by prices (Chan, 2012). Hence, the contractors have to constantly pursue the efforts to decrease the cost of projects while concurrently achieving the quality of the final product to adhere to the competitiveness of the industry (Chan, 2012). Although trade work

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accounts for the majority of project costs, project overheads are crucial since they relate to items directly delivered by the contractor, and hence, any related risk is non-transferable (Chan, 2012). In addition, the cost of providing a construction site office is a site overhead that is unavoidable by any contractor (El-Sawalhi and El-Riyati, 2015).

On the other hand, modular construction technology is an innovative method for buildings that can provide significant value to any building project (Ambler, 2013). The benefits of modular construction include faster project duration, improved standardisation, less waste, less pollution in construction sites, less job site disruption, and greater ease of fabrication (Yang, et al., 2005; Ferdous, et al., 2019; Innella et al., 2019; Pasquale, et al., 2020). As cited by Smith (2014), there are two diverse segments in the modular construction industry such as permanent modular, and relocatable modular or temporary modular. A Relocatable Modular Building (RMB) is a structure that provides temporary shelter needs (Smith, 2014). Further, RMBs can be dismantled and reused multiple times (Lawson, et al., 2012). Hence, RMB technology can be identified as a viable option for site offices because, they have temporary nature, and can be reused for several construction projects. However, there is a paucity of research evidence on the use of RMB technology for temporary site office construction in the Sri Lankan context. Therefore, the study aims to explore the applicability of container-based RMB technology for temporary offices on construction sites in Sri Lanka to overcome the existing knowledge gap.

Accordingly, the paper presents the literature review on modular buildings in construction, followed by the use of RMB. Then, the research method adopted, and research findings are presented. Finally, conclusions drawn from the study are discussed.

2. LITERATURE REVIEW

2.1 MODULAR BUILDINGS

Modular building is an increasingly important Modern Method of Construction (MMC) in the prefabrication industry. Recent developments in the field of prefabrication have led to a renewed interest in modular buildings. There have been several longitudinal studies involving modular buildings that have reviewed modular buildings from numerous angles. Kamali and Hewage (2016, p. 1172) introduced modular building as "a set of modules that are built in an off-site fabrication centre, delivered to the construction site, assembled, and placed on the permanent foundation". Schoenborn, et al. (2012) mentioned that the Modular Building Institute (MBI) had classified modular buildings as 60% to 80% completed off-site before being moved to a destination. Further, Smith (2014) stated that modular is the most completed 3D volumetric unit, which is manufactured within a factory condition, even up to 95% in some scenarios. Similarly, Lawson, et al. (2012) claimed that modular building construction is an illustration of high-level prefabrication technology. Referring to available literature, modular building can be introduced as an assembled collection of 3D modules which are fully fabricated in an enclosed factory environment and transported to the site.

Kamali and Hewage (2016) argued that modular building delivers a wide range of environmental, economic, and social benefits, it may help to achieve sustainability goals. Further, the same authors have summarised the key benefits of modular construction according to six parameters such as time, cost, on-site safety, product quality, workmanship and productivity, and environmental performance. Table 1 illustrates the key benefits of modular building construction as summarised by Kamali and Hewage (2016) and further acknowledged by many researchers.

Table 1: Benefits of modular construction

Benefits	Source of References											
	[1]	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**	**[7]**	**[8]**	**[9]**	**[10]**	**[11]**	**[12]**
Time saving	x	x	x	x	x	x	x	x	x	x	x	x
Cost reduction		x	x		x	x	x	x				
On-site safety			x		x		x	x				
High product quality		x	x		x	x		x		x		x
High productivity		x	x		x	x		x				x
Less environmental impact			x		x	x		x		x		x

Source of Reference: [1] (Bertram, et al., 2019); [2] (Blismas, et al., 2006); [3] (Chen, et al., 2010); [4] (Kawecki, 2010); [5] (Kyjaková, et al, 2014); [6] (Lawson and Ogden, 2008); [7] (Lu and Liska, 2008); [8] (Mapston and Westbrook, 2010); [9] (Modular Building Institute (MBI), 2012); [10] (Pasquale, et al., 2020); [11] (Schoenborn, et al., 2012); [12] (Trubiano, 2013)

Similar to benefits, there are several challenges of modular construction identified by the previous researchers. According to Molavi and Barral (2016), the list of challenges of modular construction includes a lack of quality control over structural integrity, aesthetic appearance, and the need for greater design work to maintain structural and architectural integrity. Further, Samani, et al. (2016) stated that avoiding overheating in buildings is a big challenge in modular buildings. Further, the challenges of modular construction as identified by Kamali and Hewage (2016, p. 1175) are listed in Table 2.

Table 2: Challenges of modular construction

Challenges	Description
Project planning	Need for more pre-project planning Extra engineering effort Hard to make changes later
Transportation Restraints	Modules' dimensional constraints Hard to transport modules far away Time delays due to late transit permits for oversized components Customs delays in borders when transporting internationally
Negative perception	Negative perception of new construction methods
Site constraints	Availability of cheap labour in the area Availability of experts such as engineers and designers in the area
Coordination and communication	Need for increased and more detailed coordination in all stages of a project More communication among all stakeholders
Initial cost	Need for a large initial investment to run modular services

Source: (Kamali and Hewage, 2016)

Moreover, Kamali and Hewage (2016) and Schoenborn, et al. (2012) explained that the construction of modular structures can be more costly than traditional structures in several circumstances. As an example, when the number of storeys in a modular building project climbs, the time saving decreases significantly since the project becomes more difficult, necessitating additional engineering and communication as well as more workforce on the site (Kamali and Hewage, 2016). Similarly, Schoenborn, et al. (2012) stated that cost savings from time savings (i.e., time means the money in the construction) in modular construction might be countered by transportation or extra professional needs.

2.2 PERMANENT MODULAR CONSTRUCTION VS RELOCATABLE MODULAR BUILDING

Relocatable modular and permanent modular are the two different industry segments in the modular building industry (Smith, 2014). Permanent modules are off-site manufactured modular units used to construct a permanent modular building with a lifespan ranging from 30 to 60 years. In general, their performance is comparable to that of conventional buildings (Mapston and Westbrook, 2010). Correspondingly, permanent modular buildings provide a service similar to on-site construction where permanent modules are affixed to a permanent base of the structure (Schoenborn, et al., 2012). Further, permanent modules are used for the buildings utilised for any purpose including multi-storey residential buildings, government buildings, hospitals, schools, and hotels (Smith, 2014). This construction technology is known as Permanent Modular Construction (PMC).

Relocatable modules as its name implied are used to build relocatable buildings that can be moved according to user preference. While whole building prefabricated off-site is only transported once from the construction yard to the project site and is permanently connected to the foundations, relocatable buildings are meant to be moved a few times during its life lifetime (Shahzad, 2016). Generally, relocatable modular structures that are used to provide temporary space facilities can be leased by short-term leasing arrangements or purchased (Smith, 2014). Similarly, movable buildings, such as portable toilets and site offices, are lightweight and small-scale constructions that are designed to be relocated as and when required (Shahzad, 2016). This construction technology is also referred to as Relocatable Modular Building (RMB) technology.

2.3 RELOCATABLE MODULAR BUILDINGS

Withstanding the current literature, an RMB can be defined as a repetitively usable temporary structure of a volumetric unit or combination of several units that is movable from one location to another according to user requirements. RMBs are built to be readily disassembled, transported, and relocated. They are primarily intended for temporary or semi-permanent structures and have a relatively limited lifespan of 15 to 30 years owing to material selection more than workmanship (Mapston and Westbrook, 2010). Generally, if an RMB is well maintained and operated, it has usable life equivalent to any other form of building. These units should be often upgraded with HVAC repair and roof replacement, which can prolong their usable life by many years (MBI, 2019).

Recent RMB markets include real estate development, industrial production, commercial firms, education, financial organizations, government entities, and resource industries. Customers in these industries move to utilise RMBs mainly because of the speed, flexibility, practicality, and cost of the construction (MBI, 2019).

2.4 RELOCATABLE MODULAR BUILDINGS IN THE CONSTRUCTION INDUSTRY

RMBs are mainly used in construction sites since speed, temporary space, and ‘relocatability’ are important in the construction market. Construction-site trailers are used as standard site offices in the industry cause they are readily available at construction sites and plants for instant delivery (MBI, 2019).

Commonly, RMB can be used seven times on average within its whole life span. However, it will vary depending on the size, type, and the market served of that RMB unit. Basu (2012) described this fact through the typical usage pattern of a construction site office. Construction site offices are generally manufactured for the fulfilment of limited space requirements. Therefore, they are made up of one or two relocatable modular units that are comparatively smaller than RMBs used in other markets. Further, according to the industrial nature site offices have to be continuously relocated. Because of these reasons, RMBs that are used as construction site offices can be moved an average of 12 to 15 times within its whole usable life cycle.

According to MBI (2019), though wood is the standard material, steel units are widely used in the North American context to achieve incombustible requirements. Further, RMBs are available as one or two-storey relocatable units for construction site environments with soundproofing and they can be typically moveable by a forklift. Additionally, these units contained electrical and telecommunication wiring, service lines for heating, air conditioning, and even plumbing.

Further, RMBs may be modified for a variety of access control situations, including toll booths, ticket sales offices, security posts, and weigh stations, all of which are typical uses (Basu, 2012; MBI, 2011). In the construction industry, RMBs are used as security huts to facilitate access control to the construction site.

Additionally, RMBs can offer economical and convenient equipment protection facilities and storage facilities for stored items such as raw materials, work-in-progress goods, and final products at on-site protection from adverse weather conditions and burglary. Regularly, RMBs offer durability and strength to the unit which can increase the protection for equipment and stored items. RMBs are used for construction equipment shelters, chemical storage structures, temporary generator housing, pump room housings, and other applications which provide a guard to equipment. Further, RMBs which are heavy-duty storage units, have ground-level entry and are excellent for construction site storage and equipment storage (MBI, 2019).

3. METHODOLOGY

This paper addresses the research inquiry “How container-based RMB construction technology is implemented as the temporary site office construction technology in construction sites?”. To assess the modular construction concept as the study's basis, an exhaustive literature research was undertaken by referring to journals, books, conference proceedings, and other reliable sources. Though the global literature highlighted the benefits and challenges of modular construction, RMB technology had not been treated in detail. Thus, the researchers attempted to ascertain the benefits and challenges of the RMB construction and propose strategies to overcome challenges in the contractors’ perspective to implement container-based RMB technology successfully for temporary site office construction in Sri Lanka. However, due to the lack of existing knowledge with relevance, the researchers needed to identify the contextual background to get a better understanding through expert knowledge and experiences. As Naoum (2007) stated, this kind of research which concerns the subjective evaluation of attitudes, views, and experiences adopts a qualitative research approach. Hence, the current study adopts a qualitative research approach to investigate the utilisation, applications, benefits, and challenges of RMB technology as a temporary site office and strategies to overcome the key challenges for the contractors in the Sri Lankan construction industry through the experts' experiences.

Since the study focuses on a specific construction method, centralising to the purposive sampling method, only eligible experts who have experience on using container-based site offices for construction projects were selected to gather reliable data. The following two criteria were considered when purposively selecting experts for the data collection.

- Industry professionals who currently work at a container-based site office, and
- Industry professionals who have previous experience working at container-based site offices from construction to dismantling stage.

Guest, et al. (2006) mentioned that sample size of six is sufficient to develop meaningful themes, if a higher level of homogeneity is maintained within the sample. Accordingly, the initial sample was limited to ten interviewees. However, the sample size was reduced to seven since the data was saturated (Mason, 2010). Therefore, seven professionals were interviewed following a semi-structured interview guideline which was based on literature findings. Table 3 summarises the profiles of the interviewees.

Table 3: Profiles of interviewees

Interview Participants	Profession	Designation	Industry Experience
IP1	Civil Engineering	Project Manager	27 years
IP2	Civil Engineering	Manager (Civil Works)	13 years
IP3	Civil Engineering	Site Manager	10 years
IP4	Civil Engineering	Site Manager	9 years
IP5	Engineering	MEP Engineer	6 years
IP6	Quantity Surveying	Project Quantity Surveyor	9 years
IP7	Quantity Surveying	Project Quantity Surveyor	8 years

Further, 70% of participants in the sample have more than eight years of experience in the construction industry. Hence, the collected data from the interview participants was more reliable. Furthermore, the template analysis technique was implemented to analyse the primary data collected. Referred to Saunders, et al. (2019), template analysis provides a methodical, adaptable, and approachable method for analysing qualitative data. It adopts a greater degree of structure through the formation of initial coding templates mainly based on literature findings. However, both literature findings and the transcripts of initial interviews in the study were used to form the initial templates, in the qualitative data analysis process.

4. RESEARCH FINDINGS

To determine the current level of knowledge over the RMB technology in Sri Lanka, the knowledge on the concept of RMB was investigated through the construction industry professionals. Research findings on the RMB concept in terms of utilisation and applications in the construction industry, benefits, and challenges of RMB technology, and strategies to overcome identified key challenges are discussed in this section.

4.1 UTILISATION AND APPLICATIONS OF RMB TECHNOLOGY

The professionals' opinion on the level of utilisation of RMB technology was that the RMB concept is widely used in the construction industry in many applications. Further, the interviewees revealed that the RMBs used in the construction industry are mainly container-based units.

Moreover, applications of RMB in the Sri Lankan construction industry were identified. Table 4 presents the applications of RMB in the construction industry highlighted by the interview participants.

Table 4: Applications of RMB in the Sri Lankan construction industry

Applications	Interview Participants						
	IP1	IP2	IP3	IP4	IP5	IP6	IP7
Site offices	√	√	√	√	√	√	√
Labour accommodation	√			√	√	√	
Houses						√	
Storerooms	√	√		√	√	√	√
Meeting rooms	√						
Security huts							√
Toilets	√		√				√

As per interview participants, the concept of RMB has already been established in the Sri Lankan construction industry. Further, applications of RMB spreads in a wide range of construction site administrative purposes such as site offices, labour accommodation, houses, storerooms, meeting rooms, security huts, and toilets.

4.2 BENEFITS AND CHALLENGES OF RMB TECHNOLOGY FOR SITE OFFICE CONSTRUCTION

The interviewees were questioned regarding the benefits and challenges of using RMB technology for site office construction. The listed benefits and challenges of modular construction in the literature synthesis were used as a guide. Although RMB is a type of modular construction, there are major dissimilarities between PMC and RMB construction. Thus, the interviewees were questioned on their agreement on the benefits and challenges of modular construction relating to the benefits and challenges of RMB technology for site office construction.

Table 5 provides the agreement of interview participants on the facts identified through the literature survey (L) and additional benefits recognised through interviews (I).

Table 5: Benefits of RMB technology for site office construction

Benefits	L/I	Interview Participants						
		IP1	IP2	IP3	IP4	IP5	IP6	IP7
Time-saving	L/I	√	√	√	√	√	√	√
Cost reduction	L/I	√	√	x	x	x	x	x
On-site safety	L/I	x	x	√	x	√	√	√
High product quality	L/I	√	√	√	√	√	√	√
High productivity	L/I	√	√	√	√	√	√	√
Less environmental impact	L/I	√	√	√	√	√	√	√
Relocatability	I	√	√	√	√			√
Reusability	I		√		√			
High security	I	√		√		√		√
Larger usable space within limited land space	I	√						
Ability to rent out	I	√					√	
Air-conditioned working environment	I	√		√				

As per interview participants, time-saving is the main benefit regarding RMB technology due to less mobilisation period. However, IP1 mentioned that time-saving is a benefit only when the contractor buys a fully finished RMB from a manufacturer rather than the contractor manufactures its own office using a container box. Though it is mentioned cost reduction as a benefit of modular construction in the literature, IP5 stated that the mandatory requirement of an air conditioning system results in high energy cost, maintenance cost, and repair cost. Therefore, cost reduction can be identified as a benefit when the contractor owns an RMB because the contractor can get the benefit of Whole Life Cycle Cost (WLCC) reduction due to reusability. The majority of the interviewees agreed that using RMB increases onsite safety because of less construction at the site. However, IP2 and IP4 highlighted several risks such as overturning, and electric shocks in the utilization stage of RMB. Even though all interview participants believed that high product quality is a benefit of RMB site offices, IP5, and IP6 mentioned that RMBs can be bought according to the contractor's requirements since there are both high quality and low-quality RMBs on the market. All interviewees agreed that the contractors can achieve high productivity using RMB site offices in comparison to traditional methods because of less construction time at the site and IP2 further elaborated that productivity is high since the contractors can have a site office as the final product within less construction period and less labour involvement. It is the common view of interviewees that RMB construction has less environmental impact because of reusability and no construction waste generation in the contractor's hand.

Moreover, 'relocatability' was highlighted as a benefit by most respondents because the RMB site office can be relocatable according to the construction stages of the project. As per IP2, reusability is a sustainable feature of RMB and beneficial for the contractors, especially in terms of cost. IP4 confirmed that an RMB can be used for four to six projects throughout its lifetime. Further, the container box site offices are lockable, and hard to break the walls and enter to the office, and thus it provides high security to the kinds of stuff such as important documents, computers, photocopy machines, and scanners inside the site office. As commented by IP1, RMB serves larger usable space within limited land space, as modules can be stacked one on top of another. Both IP1 and IP6 remarked that the ability to rent out is a benefit of owning an RMB because the contractors can rent out the RMB when they are not in use. According to IP1 and IP3, since an air conditioning system is a mandatory requirement when container-based RMB is used as a site office, office staff can have an air-conditioned working environment. As a result, contractors can have a dust-free room and it reduces the damage to the computers, scanners, and photocopy machines. Therefore, the repair cost of the electronic equipment used can be considerably reduced.

Returning to the challenges of RMB technology, Table 6 indicates the agreement of the interview participants on the facts identified through the literature survey (L) and additional challenges recognised through interviews (I).

Table 6: Challenges of RMB technology for site office construction

Challenges	**L/I**	**Interview Participants**						
		IP1	IP2	IP3	IP4	IP5	IP6	IP7
Project planning	L/I	x	x	x	x	x	x	x
Transportation restraints	L/I	√	√	√	√	√	√	√
Negative perception	L/I	√	x	√	x	x	√	√
Site constraints	L/I	x	√	x	x	x	x	x
Coordination and communication	L/I	x	x	x	x	x	x	x
Initial cost	L/I	x	√	√	x	x	x	x
Newly fabricated RMB	I		√					
Handling difficulties	I	√	√	√	√			
Possibility of overturning	I	√				√		
External body corrosion	I						√	

As summarised in Table 6, though project planning, coordination, and communication are challenges in PMC, according to interviewees, they are not challenges in RMB construction because only simple work must be done at the site and a maximum of two days will be spent. Further, all interviewees hold the view that transportation is challenging, because of high transportation costs and difficulties in transporting involved. The majority of the interview participants stated that people involved in the construction industry have negative perceptions of modular construction due to less aesthetic appearance, less comfort for occupants, and less space. By contrast, IP4 and IP5 commented that industry people are familiar with this concept and therefore, now the contractors have a positive perception regarding RMB technology since it is easy and time-saving. However, IP2 argued that negative perception results due to poor site administration. The common view amongst interviewees except IP2 was that site constraints are not a challenge. The majority of the interviewees highlighted that if the land surface is not flat, the contractors must level the surface to locate the building unit. Thus, RMBs can be used as site offices even in a sloping area. By contrast, IP2 argued that an RMB can be overturned when it heavily rains and if the area is full of ground settlement because even no proper foundation is used to place the RMB. Accordingly, site constraints can be identified as a challenge for the contractors. Turning to the initial cost, the general opinion of the interview participants was that though the initial cost is comparatively higher than traditional methods of construction, it is worth investing in

RMB because of its long-life span. However, IP2 and IP3 argued that RMBs are not suitable for large-scale construction projects, because when the site staff increases, the initial cost to bear is considerably high. Hence, the researchers deduced, that the initial cost of RMB is only a challenge when the office space becomes larger.

IP2 pointed out that, using fresh built RMB is a challenge for the contractors because the smell of glue used to fabricate the RMB is not bearable. Further, most of the interviewees expressed handling difficulties as a challenge for the contractors in the construction process of RMB especially when limited space is available at the site. As IP1 and IP5 mentioned, the overturning possibility of RMB is a challenge for the contractors because RMB has a high possibility to overturn due to heavy rains, hurricanes, ground settlement, and lack of connection with the ground. Further, the research focused on container-based RMB site offices in which the external body is made of steel. Therefore, the external body corrosion of RMB is a challenge for the contractors in the maintenance stage.

4.3 STRATEGIES FOR CONTRACTORS TO IMPLEMENT RMB TECHNOLOGY SUCCESSFULLY FOR TEMPORARY OFFICE CONSTRUCTION

Table 7 illustrates the strategies that were proposed by the interview participants to overcome key challenges identified and so to successfully implement the RMB technology for temporary site office construction in Sri Lanka.

Table 7: Strategies for contractors to overcome challenges

Challenges	Strategies to overcome challenges
• Unbreathable smell of glue in newly fabricated RMB	• Place the order earlier
• Possibility to overturn during bad weather	• Avoid two-storeyed RMB in a windy area
• External body corrosion	• Avoid RMB standing on the bare ground • Follow periodical maintenance procedure
• Negative perception	• Adhere to systematic site administration • Use thermal insulation layer (Mac foil) inside the RMB wall
• Initial cost	• Reduce LCC
• Electric shocks	• Use an earthing system to increase the safety

According to the previous discussion, newly fabricated RMB was identified as a challenge for contractors because the smell of glue used to fabricate the RMB is unbearable. To avoid this, the contractors have to order the RMB earlier, if they need a new RMB. IP2 detailed that if the contractors can purchase RMB at least one month before the requirement, this challenge can be overcome. Since prevention is better than cure, avoiding two-storeyed RMB and going for a large flat office complex in the windy area is a solution to eliminate the risk of overturning modular units due to strong winds. Further interviewees suggested solutions for external body corrosion such as the contractors should avoid RMB standing on the bare ground, use an appropriate foundation structure, and periodical maintenance procedures such as clearing the rust with sandpaper and painting with appropriate paint. The previous discussion revealed that negative perception is a challenge of RMB technology where site administration is poor. Hence, IP2 recommended that the contractors should follow a systematic site administration procedure to provide appropriate facilities to avoid negative feedback from the staff. Further, the contractor can use a thermal insulation layer such as a Mac foil layer inside the cladding and it is useful to retain the cool air inside the building. As the solution to high initial cost, the interview participants suggested reducing LCC through different strategies such as the use of durable materials for flooring and cladding boards, and precautions for steel corrosion to reduce repairing and maintenance costs. And also, there is a risk in the utilisation stage of RMB because electric shock can happen. The use of an earthing system is a solution provided by the interviewees to prevent the risk of electric shock and increase the safety of the site staff. Along with the discussion, the contractors can use these strategies to avoid key challenges, which were identified as barriers to the implementation of RMB technology successfully for temporary site office construction in Sri Lanka.

5. DISCUSSION

The lack of literature on RMB technology in the local context forced the researcher to fill that gap by identifying the utilisation, applications, benefits, and challenges of RMB technology. According to Uthpala and Ramachandra (2015), the practice of modular building technology is lesser than in other countries. However, it was found that the RMB technology has already been established in the Sri Lankan construction industry and spreads in a wide range of construction site administrative purposes such as site offices, labour accommodation, houses, storerooms, meeting rooms, security huts, and toilets. Along with this, it was realised that the RMBs used in the construction industry are mainly container-based units. This finding further supports the finding of Uthpala and Ramachandra (2015) that the volumetric prefabrication practiced in Sri Lanka is mainly container-based modular units.

The research found that the benefits of modular construction discussed in the literature review relate to RMB technology. However, the findings showed that time-saving is a benefit only when the contractor buys a fully finished RMB from a manufacturer. Expanding the list of benefits, the research disclosed that benefits such as ‘relocatability’, reusability, high security, large usable space within limited land space, ability to rent, and the air-conditioned working environment can be served by RMB technology. Further, results revealed that RMB technology is a sustainable site office construction method since reusability results in considerable waste reduction.

Though Kamali and Hewage (2016) had identified project planning, coordination, and communication as challenges for modular construction, research indicated that they are not challenges in RMB construction. However, other challenges of modular construction recognised by Kamali and Hewage (2016) are relatable to RMB technology as well. In addition, the current study showed that newly fabricated RMB, handling difficulties, possibility of overturning, and external body corrosion are challenges in the RMB approach. Moreover, the study recommends the contractors to pursue strategies identified in Table 7 to successfully implement the RMB site offices.

6. CONCLUSIONS

In the Sri Lankan context, there is a lack of research evidence on utilisation of RMB technology. However, the global literature provided evidence on RMB applications for temporary site office construction, thusly the study aimed to explore the applicability of RMB technology for temporary offices on construction sites in Sri Lanka to bridge the existing knowledge gap. The study revealed that RMB technology has already been established in the Sri Lankan construction industry but is limited to container-based RMBs and spreads in a wide range of construction site administrative purposes. Further, the research findings contributed to link the knowledge gap by acknowledging the specific benefits and challenges of RMB technology. Further, the research proposed strategies to the contractors for the avoidance of key challenges and the implementation of RMB technology successfully for temporary site office construction in Sri Lanka. However, the strategies recommended in the study are limited within the scope of contractors, strategies for all the challenges identified were not addressed. Hence, further studies are needed to identify strategies to overcome challenges, within the scope of modular building manufacturers.

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CONTRACTUAL IMPLICATIONS RELATED TO THE CONSTRUCTION INDUSTRY IN PANDEMIC SITUATIONS: A REVIEW OF CASE LAWS

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ABSTRACT

COVID-19 catastrophe has created various complications related to the construction industry. Conflicts arise between parties to the contract and among the majority of stakeholders. A successful contractual implication can manage the contractual challenges arising within construction job sites. The most common contractual provisions for the situation are Force Majeure and Changes in Legislation clauses in standard conditions of contracts. Sufficiency of the available remedies under the provisions applicable to COVID-19 or any other pandemics is a current talking point in the construction industry. Following questions are addressed to manage these unprecedented situation-related contractual conflicts: 'what are the contractual challenges faced by the construction industry?', 'what are the most applicable contractual provisions to a pandemic situation?', 'what are the pandemic-related guidelines applicable to the construction industry?', and 'what are the available legal cases to use in a pandemic situation?' The questions were discussed by carefully analysing existing literature referring to Case Laws. Future researchers are encouraged to suggest appropriate strategies for contractual challenges to facilitate the construction stakeholders to prepare them for future pandemics.

Keywords: *Case Law; Contractual Challenges; Contractual Provisions; Construction Industry; Pandemic.*

1. INTRODUCTION

The world has been affected by crises such as Spanish Flu in 1918, Asian Flu in 1957, and Hong Kong Flu in 1968 during the last century, and Severe Acute Respiratory Syndrome - SARS in 2002, Swine flu in 2009, and Ebola in 2014 during near past (Vithana et al., 2020). COVID-19 is the prevailing crisis, announced as a pandemic by the World Health Organisation (WHO) and expeditious diffusion worldwide (Husien, et al., 2021). Kiraz and Ustun (2020) stated that the world had faced a critical situation where none could foresee its impact. The prevailing COVID-19 pandemic has been a massive threat to the contractual performance in many industries, including the construction sector (Niraula, et al., 2008). Apart from the high risk of infection through droplet contamination and exposure to the virus, workers and professionals in the construction industry are currently facing a job risk with the novel Coronavirus pandemic

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(Zheng, et al., 2021). COVID-19 outbreak reminds the researchers about the need for creative responses to contractual challenges arising with pandemics (Pedamon and Assileva, 2021). The construction organisations have been daunted with COVID-19 due to the uncertainties and less awareness on contractual challenges resolution (Andres, et al., 2020). Furthermore, Bailey et al. (2020) expressed that events such as the COVID-19 pandemic generally engage contractual provisions concerning the consequences of unforeseen events. Evidently, the construction industry was always embroiled with protracted and costly dispute resolution procedures (Construction Leadership Counsil [CLC], 2020). In addition, Sierra (2021) stated that the terms time and money are related to disputes in construction projects, and the most common conflicts are finance-related and time-related failures.

Moreover, the author disclosed that the prevailing pandemic situation had aggravated both these problems. The pandemic originated by COVID-19 adverts the necessity of pre-preparation to overcome unforeseen risks and have contingency plans for managing projects in the construction sector (Ogunnusi, et al., 2020). Therefore, it is prudent to address the pandemic's impact at the beginning and end of the crisis to prepare for any future potential and learn lessons for future preparations of the construction industry (Iqbal, et al., 2021).

This paper aims to review available most common contractual provisions related to cases within the construction industry, globally and locally, to determine whether these available cases can implement when parties to the contract claim their entitlements for pandemic-related challenges. The paper is structured as follows. First, a brief introduction to the study, followed by the research method adopted, a compressed literature synthesis, an insight of the research methodology adopted for the study, and a discussion of findings. Finally, the conclusion is formed based on the key research findings of the study.

2. RESEARCH METHOD

A researcher can review existing researches using several methods (Grant and Booth 2009). To achieve the aim of this research study, a comprehensive review of case laws was conducted. Available cases in counties like United State (US), France, England and Wales, Ghana, Singapore and China were incorporated to come up with a good review.

3. COVID-19 AND THE CONSTRUCTION INDUSTRY

Aviantara (2020) brought up the 'pandemic' as a critical risk factor that ought to discuss within the construction industry. The construction industry is always linked with the other industries directly or indirectly (Tripathi and Jha, 2018). As summarised by Iqbal, et al. (2021), the construction industry in most countries investigates the applicable approaches to overcome the negative impacts which may arise due to pandemics, such as the novel Coronavirus; this is a fundamental need to obstruct an economic downturn (Zamani, et al., 2021). Therefore, construction stakeholders should be able to answer the following questions: *what are the absolute recommended practices to make secure the construction industry against a pandemic situation?* and *what are the unprecedented impacts and consequences of the COVID-19 on the construction industry?* (Porter, 2020). Husien, et al. (2021) explained that some of the impacts by cause of COVID-19 were more wrathful and pathetic for all construction practitioners in the construction industry. Porter (2020) reported that multiple questions remain within the construction industry and the pandemic situations, which have not been answered yet.

3.1 CONTRACTUAL CHALLENGES IN CONSTRUCTION JOB SITES

The most prominent impacts of COVID-19 are the suspension of projects, labour impact and job loss, time overrun, cost overrun, and financial implications (Gamil and Alhagar, 2020). Husien, et al. (2021) reported that the pandemic raised many challenges at the level of the workforce including low or halting productivity, production time and costs, as well as disputes in contractual formulas for construction projects.

3.1.1 General Challenges with a Pandemic in Construction Job Sites

Through the existing literature, Pamidimukkala and Kermanshachi (2021) have identified general challenges faced by the construction industry and classified them into five categories: organisational, economic, psychological, individual, and moderating factors.

Table 1 shows the challenges under each category.

Table 1: General challenges related to COVID-19 in construction job sites

Category	Challenges
Organizational Factors	• Lack of safe working environment • Challenges due to work from-home practices • Managing a heavier workload • Management team's lack of leadership knowledge and skills
Economic Factors	• Reduced accessibility to updated tools and equipment needed to accomplish the tasks • Uncertainty regarding future of workplace • Supply chain disruptions • Cash flow delays
Psychological Factors	• Social isolation due to teleworking • Stress and burnout
Individual Factors	• Responsibility for personal and family needs when working • Learn communication tools and overcome technical difficulties • Feelings of not contributing enough to work • Adjusting to new work schedules
Moderating Factors	• Effect of COVID-19 on vulnerable groups • Gender-based impacts • Impacts on migrant workforce

Delays in permits or license, Escalations in prices, High demand of suppliers and manufacturers, Increase of claims and disputes, Lack of funding, Less productivity in site works, Payment delays, Project abandonment, and Suspensions or terminations of projects are the other issues summarised by Alsharef, et al. (2021), American Society of Civil Engineers [ASCE] (2020), and Osuizugb (2020), in addition to the general challenges identified by Pamidimukkala and Kermanshachi (2021). On the other hand, Zamani, et al. (2021) mentioned project duration, construction material, and human resources are the three main factors related to project operations. According to the authors, project operations were delayed because COVID-19 smashed these three factors. Although parties to the contracts needed to restart project activities, the inherent labour-intensive nature of the construction project caused additional challenges due to the onsite necessity of construction task delivery and the constraints on the feasibility of social distancing on an active job site (Zheng, et al., 2021). The most common reasons for delays in projects are that the daily working period has been shortened and the absence of employees to the assigned work on time (Alenezi, 2020). Construction parties should always be aware of uncertainties, incompleteness, and unforeseeable circumstances affecting construction costs (Elhag, et al., 2005).

3.1.2 Contractual Challenges with a Pandemic in Construction Job Sites

The contractual challenges, stakeholders' obligations, and contractual provisions may differ from the general situation in pandemics like COVID-19 (Andres, et al., 2020). Kabiru and Yahaya (2020) addressed the impact of COVID-19. They discovered that professionals face legal challenges in the construction industry - e.g., contractual issues raised to assist contractors in claiming loss and expenses and extension of time (King, et al., 2021). Proper contract administration is one of the main challenges the construction stakeholders face with this crisis (Niraula, et al., 2008). Legal provisions in several contractual documents related to construction contracts may vary among countries and from project to project (Ogunnusi et al., 2020).

The government, as the client, should revise the contract to aid the contractor to claim losses for projects delayed due to lockdown, and the government should grant an Extension of Time (EOT) to cover the period of projects stopping (King, et al., 2021). Figure 1 presents the contractual challenges related to a pandemic situation in the construction industry identified by Jayathilaka and Waidyasekara (2022) through a systematic literature review.

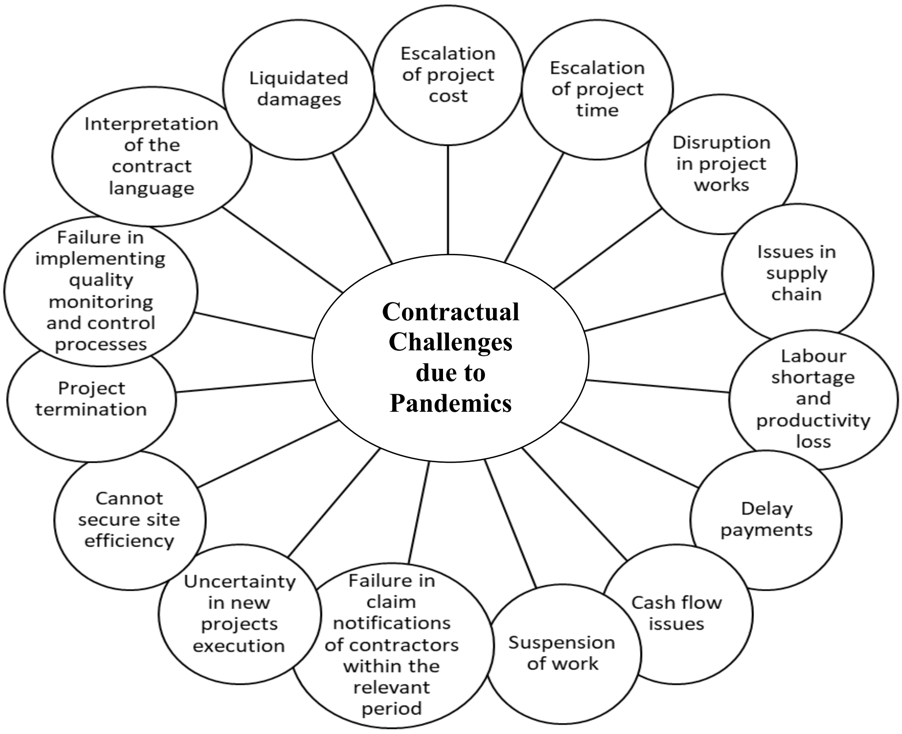

Figure 1: Contractual challenges due to a pandemic situation in construction industry

3.2 CONTRACTUAL PROVISIONS RELATED TO A PANDEMIC SITUATION IN CONSTRUCTION INDUSTRY

There was much confusion and uncertainty about dealing with a pandemic on construction job sites due to the absence of definite construction-related guidelines and best practices (Budds, 2020). Although the government and health organisations have issued guidelines to prevent the spread of the virus on job sites, there have not been many specific guidelines for construction industry workers (Afkhamiaghda and Elwakil, 2020).

Different countries and organisations have developed guidelines and suggestions for infection prevention (Zheng, et al., 2021), as below:

- COVID-19 - Temporary Measures Act (Singapore)
- Health and Safety Guidelines for Sri Lankan Construction Sites to be adopted during COVID-19 outbreak (Construction Industry Development Authority - CIDA, Sri Lanka)
- Quarantine and Prevention of Disease Act - 1897 (Health and Safety Guidelines for Sri Lankan Construction Sites to be adopted during COVID-19 outbreak, Sri Lanka)
- Quarantine and Prevention of Diseases Ordinance - 2020 (Sri Lanka)
- FIDIC COVID-19 Guidance Memorandum (To users of FIDIC standard forms of works contract)
- Phase I COVID-19 construction guidelines for the safety of returning construction workers (Washington)
- Gazette Extraordinary No. 2167/18 (COVID-19 announced as a quarantinable disease for the existing Quarantine Regulations passed under the Ordinance in 1925 and 1960 - Sri Lanka)
- Gazette Extraordinary No. 2168/6 (Defining the proper authority and a diseased locality - Sri Lanka)
- Gazette Extraordinary No. 2197/25 (Restriction of movement and guidelines to be followed in public places - Sri Lanka)

Ogunnusi, et al. (2020) mentioned that the construction industry had been substantially affected by COVID-19, and construction stakeholders have given full attention to the standard forms of contracts to seek appropriate entitlements. Despite the contractual challenges experienced by the construction industry due to the prevailing crisis, numerous parties still incite construction stakeholders to rely upon the available uncertain circumstances related to legal provisions in contractual documents (Alsharef, et al., 2021).

In line with Bailey, et al. (2020), these provisions commonly fall into two broad categories, ‘force majeure’, and ‘changes in law’, which is relevant and may yield a different legal effect. Chivilo, et al. (2020) declared that, since the conditions covered through a force majeure or excusable delay provision may vary, it should not be presumed that any contractual language addressing excusable delays applies automatically to the COVID-19 outbreak. Moreover, the authors reported that a careful review of the language of any force majeure provision should be undertaken to determine whether impacts resulting from the COVID-19 outbreak are covered as an excusable delay.

By contrast with force majeure, change in law provisions in construction and engineering contracts may confer a right to both an extension of time for the contractor and compensation for the unavoidable costs incurred due to the change in the law (FIDIC, 2017).

Figure 2 compares "force majeure" and "changes in law" clauses in standard forms of contracts.

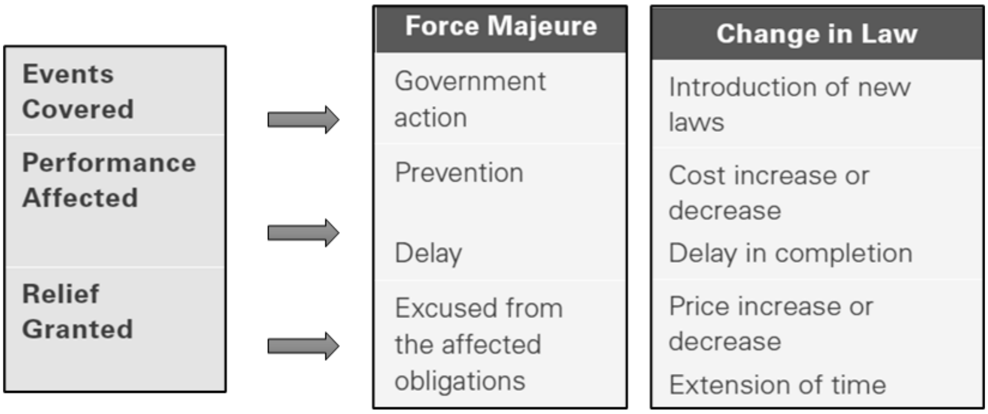

Figure 2: Force majeure clause vs changes in law clause in standard forms of contracts

Source: Ford and Bloch (2020)

Under many forms of contract, including the FIDIC forms, a force majeure event would typically entitle a contractor to an EOT for critical delay caused by the event, but not to compensation for costs incurred during the period of delay, except in agreed-upon circumstances (FIDIC, 1999).

Changes in the law/legislation clause would be more useful than the force majeure clause in the current COVID-19 situation, where the contract can still be performed, but there is delay and increased cost due to compliance with government regulations (Ford and Bloch, 2020). Parties to the contract should analyse the additional time and costs and contractual provisions under force majeure and legislation changes to be aware of risk allocation between parties (Baker, 2021).

Dealing with the force majeure clause is crucial when there is a pandemic situation, and carefully drafted contractual provisions would ensure that parties are not liable when the situation is out of the parties' control (Benarroche, 2020). Furthermore, Bailey, et al. (2020) expressed, contractually, events such as the COVID 19 pandemic generally do engage contractual provisions concerning the consequences of unforeseen events. Moreover, when there are more case laws available to apply for unforeseen situations, it may help construction parties to unravel the contractual challenges quickly. Still, the issue is the unavailability of applicable case laws related to unforeseeable circumstances (Cartwright, et al., 2020).

Parties to the contract in construction projects should be aware of the construction industry-related case laws, which can apply to pandemic situations for the future use of potential contractual issues (McLennan, 2021). Therefore, this paper reviews available most common contractual provisions addressed in few cases related to the construction industry which can be applied to unravel contractual challenges in a pandemic situation.

Table 2 presents contractual provisions related to cases applicable to a pandemic situation by reviewing recent past literature.

Table 2: Contractual cases related to a pandemic situation

Country	Case
United States (US)	• JN Contemporary Art LLC vs Phillips Auctioneers • Rudolph vs United Airlines Holdings • R & B Falcon Corp. vs American Exploration • LLC vs Conoco Phillips • Am. Nat. Red Cross vs Vinton Roofing Co • SNB Farms, Inc. vs Swift & Co.
France	• Lebeaupin vs Richard Crispin & Co,12 McCardie J • General Construction Co. Ltd vs Ibrahim Cassam & Co. Ltd
England and Wales	• Fibula Air Travel Srl vs Just-US Air Srl • Entertain Video Limited and Others vs Sony DADC Europe Limited and Others • McCardie J in Lebeaupin vs Crispin • Clifford Gardner vs Clydesdale Bank Limited • Thames Valley Power Ltd vs Total Gas & Power Ltd
Ghana	• Tennants (Lancashire) Ltd vs CS Wilson & Co Ltd • Seadrill Ghana Operations Ltd vs Tullow Ghana Ltd
Singapore	• Holcim Singapore Pte. Ltd vs Precise Development Pte Ltd
China	• Li Ching Wing vs Xuan Yu Xiong

United States (US)

New York courts use strict interpretation for legal issues. Cartwright et al. (2020) stated US courts rely on the express language, and only events specifically listed in the delay clause will excuse performance as well as determine that any construction delay caused by the COVID-19 pandemic is way beyond the "reasonable control of the parties," and covered with force majeure clauses. Moreover, California requires the party invoking the clause to prove reasonable efforts to avoid the consequences of the force majeure event.

A decision given for ***JN Contemporary Art LLC vs Phillips Auctioneers, LLC, No. 1:20-cv-04370-DLC*** in the Southern District of New York has presented the COVID-19 pandemic as a 'natural disaster' that is beyond the parties' 'reasonable control', and thus triggered the force majeure clause (McLennan, 2021). McLennan (2021) stated the case, ***Rudolph vs United Airlines Holdings, Inc., 2021 WL 534669,*** related to US District Court, provided that there must be some point where a force majeure event ends and a schedule change or irregular operation begins. The author further mentioned that the mere existence of a force majeure event was not sufficient, and demonstrating causation was essential. The defendant could not rely on the force majeure clause. Moore and Cornelius (2021) stated that Texas Supreme Court held that a force majeure event is not an excuse for non-performance when a prior material breach has occurred. Moreover, the author discussed that, in the construction industry context, a contractor seeking to claim a pandemic as an "Act of God" force majeure excuse for its failure to meet a specific turnover date would have to demonstrate that no concurrent delays existed. The following cases suggest pandemics may fall into a "catch-all" provision:

R & B Falcon Corp. vs American Exploration and LLC vs ConocoPhillips, in the context of pandemic-related government regulations, the more stringent state or local government stay-at-home orders that did not exempt construction activities could arguably be the type of regulation constituting an excusable event under an applicable force majeure provision (Moore and Cornelius, 2021). The case of ***Am. Nat. Red Cross vs Vinton Roofing Co., 629 F. Supp. 2d 5, 9 (DDC 2009)*** highlighted that an act of God, such as pandemic situations, cannot be avoided by parties before it happens or cannot be prevented (McLennan, 2021). Huie (2020) stated that ***SNB Farms, Inc. vs Swift & Co.*** case provides an important point when parties follow the process of seeking entitlements during a pandemic. The parties can have their remedies when a notice is given to the other party by mentioning the force majeure event.

Germany

The required standards are associated with the High Supreme Court Verdicts in Germany. Haas and Markovic (2021) mentioned that if the circumstances are related to 'force majeure' or 'act of God', when the claimant grants legal/contractual merit, entitled to get time extensions and can grant the additional cost suffered totally or some.

France

According to Haas and Markovic (2021), ***Lebeaupin vs Richard Crispin & Co,12 McCardie J*** case referred that an epidemic could amount to an event of force majeure. The authors mentioned that in general, if the situation is relatively uncontroversial, whether an event of force majeure has actually arisen on a particular set of facts is a question of fact in every case. The case of ***General Construction Co. Ltd vs Ibrahim Cassam & Co. Ltd*** provides the following two characteristics to consider an event as a force majeure event under the Court of Civil Appeals:

- The event must have been unforeseeable/unpredictable at the time of the conclusion of the contract
- The event must be irresistible/Insurmountable (DLA-Piper, 2022)

DLA-Piper (2022) stated it is worth noting that epidemics outbreaks have not always been considered as force majeure events. In 2014, the epidemic of H1N1 Flu was officially announced and foreseen even before the implementation of health regulations but did not constitute an event of force majeure. In addition, the author mentioned that such reasoning could be applied perfectly to the current COVID-19 pandemic and outbreak that contains both a natural component, which is the virus itself, as well as governmental element (curfew) measures which make the execution of contracts even more difficult.

England and Wales

English courts have taken a cautious approach to the effect of the COVID-19 pandemic under force majeure provisions: for example, in the High Court decision in ***Fibula Air Travel Srl vs Just-US Air Srl (2020) EWHC 3048 (Comm),*** a party could not rely on the pandemic to invoke a force majeure clause to escape its obligations before government restrictions and 'failure or delay in the performance of any obligations under the agreement' would continue for a period (McLennan, 2021). In the absence of express language covering 'pandemics' or 'infectious disease', courts will be unlikely to accept arguments that the existence of COVID-19 is sufficient to invoke a force majeure clause (McLennan, 2021). Cheung (2020) stated even the government has failed to comply with public procurement law under the COVID-19 pandemic pressure, the High Court in

London has ruled that landlords are entitled to recover rent and service charges owed to them by tenants whose businesses were mandated to close by coronavirus restrictions.

Based on the case, ***Entertain Video Limited and Others vs Sony DADC Europe Limited and Others***, the Technology and Construction Court has recently considered the meaning of a force majeure clause which could have implications for how these clauses are interpreted within construction contracts. Fenwick (2021) stated the clause, "Neither party shall be liable for its failure or delay, if such failure or delay is caused by circumstances beyond the reasonable control of the party affected including but not limited to riot, civil commotion, malicious damage, etc. as well as pandemics". As per the mentioned clause, the current COVID-19 pandemic comes under the force majeure clause.

The case ***McCardie J in Lebeaupin vs Crispin (1920) 2 KB 714*** was applied for many situations in England. It established that the events independently happening come under the force majeure category (Albertini, 2020). Further, ***Clifford Gardner vs Clydesdale Bank Limited (2013)*** provides that a flu pandemic belongs to the force majeure category. According to the case ***Thames Valley Power Ltd vs Total Gas & Power Ltd (2006),*** no reported cases are testing the scope of the term "force majeure" in the context of some types of standard forms of contracts (Albertini, 2020).

<u>Saudi Arabia</u>

The Saudi Arabian Supreme Court issued decision No. M/45/M of 08/05/1442AH (the KSA Decision) 2020, and the decision sets out how contracts governed by Saudi law will be impacted by COVID-19. The Saudi Arabian Supreme Court has confirmed that COVID-19 is considered an 'emergency event' and will be deemed a force majeure if certain conditions are met (McLennan, 2021).

<u>Ghana</u>

Some standard forms of contracts do not have the word 'prevent', and on behalf of that, there may be another term (Lucy and Chambers, 2019). The case of ***Tennants (Lancashire) Ltd vs CS Wilson & Co Ltd [1917] AC 495*** provides the following requirement for parties to the contract, which should be present when seeking entitlements. "Parties shall put their full effort to minimise the impact, void, or overcome the circumstances of force majeure." When dealing with a pandemic, ***Seadrill Ghana Operations Ltd vs Tullow Ghana Ltd [2018] EWHC 1640*** case is also important because it highlights the key importance in the context of a pandemic. In this case, the Court emphasised that "the force majeure event must be causative to the contractual breach and that reasonable steps to avoid the effects of force majeure event must be taken" (Lucy and Chambers, 2019).

<u>Singapore</u>

Holcim Singapore Pte. Ltd vs Precise Development Pte Ltd (2011) provides that "the force majeure event must be causative to the contractual breach and that reasonable steps to avoid the effects of force majeure event must be taken" (Lucy and Chambers, 2019).

<u>China</u>

Li Ching Wing vs Xuan Yu Xiong (2004) 1 HKLRD 754 case is related to SARS pandemic, and the Court held that even though that is an unforeseeable circumstance, contractual parties should fulfil their duties and obligations accordingly to have the applicable entitlement (Hansen, 2020).

4. CONCLUSIONS

Since this is the first time most construction stakeholders face a pandemic situation like COVID-19, many disputes have occurred, are still occurring, and may occur in future regarding contractual provisions available in the construction industry. According to the findings, the most common contractual provisions which are applicable to contractual conflicts in pandemic situations available in the construction industry are 'Force Majeure' and 'Changes in Legislation' clauses. Accordingly, the Laws in terms of the Contracts have been changed in preventive measures of the COVID-19 pandemic. Parties to the contract should pay attention to whether they will depend on the available clauses and terminologies related to the pandemic or adjust available provisions concerning the crisis COVID-19. Since COVID-19 is a novel pandemic crisis, only a few cases are available within the construction industry. Most of the cases have mentioned 'pandemic' as an 'unforeseen situation beyond the reasonable control of the parties'. If more case laws are available to apply for unforeseen situations, it may help construction parties to unravel the contractual challenges easily; however, the issue is the unavailability of applicable case laws related to an unforeseeable circumstance. Due to the unavailability of particular contractual provision to 'pandemic' with in the standard forms of contracts, identified cases will be provided ground for applicable contractual implications to the contractual challenges faced by the construction industry in a pandemic situation. Further, parties to the contract must determine whether they should include new contractual provisions within the standard forms of contracts or use the existing provisions with minor changes. Finally, construction stakeholders should pay attention to available legal cases to implement when claiming their entitlements to be a success in coming contractual challenges related to pandemic situations.

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COST OVERRUN FACTORS IN PRE-CONTRACT AND POST-CONTRACT STAGES: A CRITICAL ANALYSIS

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ABSTRACT

"Cost overrun" is considered as an unavoidable phenomenon in the construction industry. Despite the professional effort and adaptation of advanced technologies, still the construction industry experiences cost overruns. Especially, among many stakeholders, contracting organizations are one of the key stakeholders that would be highly affected by the construction cost overrun. Poor coordination between the pre & post-contract stages in the contracting organizations has been a critical issue over many decades which leads to cost overruns. Professionals involved in the pre-contract stage have not possessed the knowledge regarding the significance of the cost overrun factors that may appear in the post-contract stage and vice versa. Therefore, this research aims to comparatively analyze the significance of cost overrun factors in the pre & post-contract stages in Sri Lankan construction projects from the perspective of industry professionals. A total of 5 semi-structured interviews were conducted among professionals who have experience in cost estimation and post-contract cost management in contracting organization to categorize the selected cost overrun factors into pre-contract and/or post-contract stages. Then, a questionnaire survey was conducted to evaluate the significance of those categorized cost overrun factors. A total of 80 responses were collected from the questionnaire survey and the data were analyzed using statistical analysis. Then the quantitative data was analyzed using the Mann-Whitney U-Test. The results of the Mann-Whitney U test concluded that there is a statistically significant difference between the perspective of professionals involved in the pre & post-contract stage.

Keywords: *Construction cost; Cost Overrun; Post-Contract Stage; Pre-Contract Stage.*

1. INTRODUCTION

Among many other industries and sectors in the world, the construction industry contributes and stimulates economic growth as the construction industry is highly dynamic and it is considered to possess the enormous potential of contributing to the economy due to the creation of linkage between many other sectors and industries (Durdyev and Ismail, 2012). The construction industry provides a wide range of necessary infrastructure inclusive of hospital buildings, roads, school buildings and many other projects (Rahman, et al., 2013). According to Raftery, et al (1998), there are major 3 aspects on which the Asian construction industry focuses. They are more involvement in foreign participants, potential private sector involvement in infrastructure development and improving vertical integration in projects. The incredible transformation of Singapore

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to a highly developed nation is one of the best examples of the impact of the construction industry as Singapore emphasized infrastructure development as a crucial sector (Ofori, 1998).

Numerous reasons have been identified over the last years which affect the success of the project. Such reasons include effective monitoring and feedback by the project manager, timely decisions, regular budget updates, construction control meetings, delegating authority to project manager by top management and monitoring and feedback by the client (Iyer and Jha, 2005). Among numerous factors, researchers have emphasized that exceeding budgets and cost overrun attribute to the success of the project. Therefore, this shall be carefully managed to achieve the intended targets of a project (Ahady, Gupta and Malik, 2017). According to the authors, the employees who work in different phases of a certain project (i.e., pre-contract and post-contract) have proper knowledge in their particular stage however not the other stage of the project which might lead to certain issues as the communication in between these two stages are considerably less. The establishment of cost estimation of a particular project is quite difficult and associated with a higher level of risk in project management as it must be done prior to the work being commenced (Oberlender, 2014).

Many studies such as Akanni, et al. (2014) have been carried out regarding the factors affecting the cost overrun in both pre-contract and post-contract stages and several studies have analyzed their significance based on the respective research methodologies. However, the recent study of Mahmud, et al. (2021), emphasized that still the cost overrun issue has not been properly addressed and requires an in-depth investigation. According to certain studies, pre-contract and post-contract management are not well-combined and managed in the construction industry (Akanni, et al., 2014). As Igwe, et al. (2020) stated that proper management is required in both the pre-contract and post-contract stages in order to have better cost performance from the contractors' perspective. The authors further argued that conducting several kick-off meetings would not develop a proper linkage between the pre-contract stage and the post-contract stages. It is not clear whether the estimation team is focusing on the most significant cost overrun factors that affect in both stages.

The problem has been drastically affected for a long period as some cost overrun facts have less concern during the estimation period however has a significant impact during the physical construction stage as well as the pre-contract stage, ultimately affecting the overrun cost of the project. The opposite also might occur in the industry. It is therefore important to fill the knowledge gap by examining the relationship of cost inhibit factors and providing a guideline and better platform to estimators to focus on more significant cost items when carrying out the price estimation. Moreover, it requires statistical analysis to compare the opinion on the cost overrun factors in pre-contract and post-contract stages of the professionals who are engaged in those two stages to critically review whether they have a similar perspective in terms of the significance of cost overrun factors. Therefore, this research aims to conduct a comparative analysis on the cost overrun factors in the pre- and post-contract stages of the construction projects.

2. LITERATURE REVIEW

2.1 COST OVERRUN IN CONSTRUCTION PROJECTS

The variance between the actually incurred cost and the baseline cost would be referred as the cost overrun in a construction project (Amoa-Abban and Allotey, 2014). Thus, cost overrun is the exceeding of finally incurred cost at the completion stage of the project compared to initial cost estimation (Ullah, et al., 2017). This figure of final cost indicates the total expenditure encountered at the completion stage of the project whereas initial cost figure indicates the planned and determined cost during the initiation of the project (Lee, 2008). Table 1 depicts the cost overrun factors along with the frequency count of previous studies.

Table 1: Cost overrun factors

Factor	Source	Frequency
Factors related to project financier/owner		
Owner's financial crisis	[1], [4], [5], [8], [9], [10], [11], [12], [14], [17]	10
Delayed payments	[1], [2], [3], [4], [5], [7], [10], [12], [13], [15], [17], [21]	12
Discrepancy in details and incomplete briefing regarding the project	[3], [4], [6], [7], [8], [9], [10], [11], [12], [13], [14]	11
Rapid and unrealistic alterations in client's requirements	[4], [11], [18], [19], [20], [23]	6
Delay in decision making and management	[1], [2], [3], [5], [6], [9], [10], [14]	8
Allowing unrealistically shorter time periods for design, approvals and tendering process to get delivered the project as earliest as possible.	[6], [11], [15], [17]	4
Factors related to designers and consultants.		
Lack of experience of design team related to the project	[7], [10], [12], [13], [19], [20]	6
Misinterpretation of client's design requirements and other information	[3], [8], [13], [16], [19], [22], [26]	7
Discrepancies in tender document	[9], [11], [14], [15], [16], [17], [19], [22], [23], [24]	10
Delay in issuing instructions and information to the contractor	[10], [11], [12], [18], [20]	5
Inappropriate procurement approach	[10], [12], [13], [17]	4
Deficiencies in communication and negotiation with stakeholders	[11], [15], [16], [19], [21]	5
Inaccurate cost estimations	[10], [11], [12], [15], [16], [17], [19], [20], [21], [23]	10
Lowest bid might not be the most technically feasible bid	[12]	1

Factor	Source	Frequency
Factors related to contractor		
Inaccurate cost estimation	[13], [15], [16], [18], [19], [20], [24], [25], [26]	8
Poor cost planning at the initial stage of the project	[12], [14], [17], [21]	4
Ineffective post contract cost controlling and management	[7], [13], [18], [21], [24],	5
Errors in prepared documents and schedules	[4], [6], [8], [9], [11], [16], [23]	7
Incompetence in technical aspects and lack of experience	[9], [10], [12], [14], [15], [26]	6
Cost of reworks	[15], [16], [17], [19], [20], [21], [22], [26], [27], [28]	10
Contractor's bidding strategies such as front-end loading	[1], [5], [8], [10], [13], [28]	6
Delay payments to suppliers and subcontractors	[2], [6], [7], [17]	4
Assignment of incompetent and inexperienced subcontractors	[4], [5], [9], [10], [28]	5
Delay in supply of material, plant & equipment	[1], [3], [8], [11], [15], [18], [23]	7
Previous experience on the projects of the contractor	[13], [14], [15], [19], [26], [27]	6
Cost of testing and commissioning and approval for samples	[17], [25], [28]	3
Factors related to external environment		
Market condition and the level of competition	[2], [4], [5], [7], [10], [13], [24]	7
Taxes and duties on imported materials and import restrictions on material	[16], [18], [19], [20], [22], [27]	6
Culture of conflicts and lack of trust	[2], [3], [6], [7], [12], [14], [17], [18], [21], [23]	10
Increase in cost of workmanship	[3], [4], [5], [8], [9], [10], [13], [15], [19], [22], [24]	11
Adverse weather impacts an unrealistic site condition	[3], [9], [17], [28]	4
Weather conditions	[1], [2], [4], [6], [7], [11], [14], [18], [19], [21], [26]	11
Unrealistic site conditions	[2], [4], [6], [8], [9], [12], [13], [17], [19], [23], [25]	11
Labour nationality and social impacts	[2], [3], [5], [8], [10], [12], [16], [19], [21], [27]	10
Material, plant & equipment shortage	[5], [9], [11], [28]	4

Factor	Source	Frequency
Price fluctuation in material, plant & equipment	[1], [3], [15], [24], [26], [27]	6
Economic stability and market conditions in the country	[2], [5], [7], [10], [15],[25]	6
Impact on foreign construction companies to the local industry	[17], [18], [19], [22]	4
Fluctuation in foreign currency exchange rates	[3], [5], [7], [9], [16], [27], [28]	7
Site safety and likelihood of accidents faced by the workers	[3], [11], [14], [17], [19], [20], [21]	7
Absence of construction cost data	[11], [12], [14]	3
Site constraints based on the location and several other factor (access, storage, services)	[1], [4], [6], [10], [14], [25], [26]	7
Epidemic and pandemic	[29], [31], [32]	3

[1] (Sohu, et al., 2020); [2] (Haslinda A. N., Xian, Norfarahayu, Hanafi, & Fikri, 2018); [3] (Alinaitwe, et al., 2013); [4] (Jayalath, 2019); [5] (Frimpong, Oluwoye, & Crawford, 2003); [6] (Olubunmi & Olukanyin, 2015); [7] (Vu, et al., 2016); [8] (Rajakumar, 2016); [9] (Cantarelli, et al., 2012); [10] (Park & Papadopoulou, 2012) [11] (Ameh, et al., 2010) [12] (Tan & Suranga, 2008) [13] (Mahamid & Dmaidi, 2013) [14] (Rosenfeld, 2014) [15] (Forcada, et al., 2017) [16] (Aljohani, et al., 2017); [17] (Ahady, Gupta, & Malik, 2017); [18] (Rodrigo & Malkanthi, 2018); [19] (Fagbenle, et al., 2018); [20] (Azhar, et al., 2008); [21] (Adedokun, et al., 2019); [22] (Baloi & Bekker, 2011); [23] (Akanni, et al., 2014); [24] (Aziz R. F., 2013); [25] (Famiyeh, et al., 2017); [26] (Hatamleh, et al., 2017); [27] (Mahamid & Dmaidi, 2013); [28] (Amoa-Abban & Allotey, 2014); [29] (Hesna, et al., 2021); [30] (Larsen, et al., 2016); [31] (Abdullah, et al., 2020); [32] (Isa, et al., 2021)

Table 1 presents the cost overrun factors that are common to most of the aspects in the construction industry from the findings of the literature with the frequencies out of 32 references. According to the findings, the cost overrun factors can be categorized mainly into 4 categories such as related to project financer/owner, related to designers and consultants, related to contractor and related to external environment.

In most of the research papers, owner-related cost overrun factors have been elaborated as crucial in most of the segments in the construction industry such as civil & infrastructure development, building construction, Mechanical, Electrical & Plumbing (MEP), and rehabilitation as well as renovation works. According to Alinaitwe, et al. (2013), cost overrun factors would relate to the financier of the project have made a critical impact on the overall cost overrun of the project as the project is supposed to finance and lead by the owner. If any error occurs in virtue of the client's fault such as delay in decision making, faulty documents and inaccurate briefing the significance would be quite considerable (Olubunmi and Olukanyin, 2015).

The designers and consultants would manage the project on behalf of the owner of the project throughout the project period from initiation to completion (Rajakumar, 2016). Therefore, in any segment of the construction industry the management, consultation to the employer and coordination of the project would be done by the consultants. As explained by Park and Papadopoulou (2012), designer and consultant related cost overrun factors may affect in the whole life cycle of the project as design and consultation are of utmost important attributes that requires competence and careful attention.

Amoa-Abban and Allotey (2014) found that the cost overrun is crucially affected by the factors relating to the contractor. From the submission of the bid to the handing over of the project to the employer, there are numerous aspects in which the cost overrun may occur in relation to the contractor (Baloi and Bekker, 2011). Among many cost overrun factors, inexperience, incompetence and delays cause a major role in cost overruns in construction projects.

Apart from the major three parties (i.e., Owner, Consultant, and Contractor) involved in a construction project, there are certain other factors attribute that may lead to cost overruns (Amoa-Abban and Allotey, 2014). Those factors can be categorized as external factors which inclusive of different stakeholders to the construction projects such as sub-contractors, labors, public, government, and suppliers. Moreover, there are certain other aspects relating to the external environment such as the economic condition of the country, weather conditions, man-made and natural disasters, and epidemics and pandemics which may have a massive impact on cost overrun in construction projects.

3. METHODOLOGY

A comprehensive literature synthesis has been carried out to gather information regarding the key components of the research such as cost overrun factors, cost overrun, and issues related to the construction industry around the world. This research then adopts a mixed research approach in order to investigate the cost overrun factors in the pre-contract and post-contract stages of construction projects in Sri Lanka. The mixed research approach diminishes the limitations associated with monomethod and enhances the rationality and reliability of collected data by assisting complementarity, and the advancement, initiation and expansion of study findings. Furthermore, this type of methodological triangulation allows to distinguish the variances or similarities among the results that can remain unexplored when one research approach is applied.

3.1 SEMI-STRUCTURED INTERVIEWS

The face-to-face interviews were conducted 5 QSs occupied in the construction industry who have the experience in both pre-contract stage and post-contract stage, working in contracting organizations (refer Table 2).

Table 2: Details of the interviewees

Interviewee	Organization Type	Designation	Experience (Years)
IP-1	Consultant/Contractor	Director	27 Years
IP-2	Contractor	General Manager- Contracts	16 Years
IP-3	Contractor	Assistant General Manager - Estimation and Contracts	15 Years
IP-4	Contractor	Quantity Surveyor and Estimator	12 Years
IP-5	Contractor	Contracts Manager and Quantity Surveyor	17 Years

The interviewees were chosen through convenient sampling. The industry professionals, who were having experience in post-contract cost management and technical aspects of cost estimation were selected as per the role they performed. Accordingly, industry practitioners, who were involved in cost management and cost estimation were selected. Categorize the pre-contract related and post-contract related cost overrun factors according to the Sri Lankan context based on how often those factors can occur in either stage, were the main roles considered, for selecting the respondents.

3.2 QUESTIONNAIRE SURVEY

The questionnaire survey was carried out targeting professionals in the construction industry who had knowledge of the construction cost and involved in either pre-contract stage or post-contract stage. Hence, non-random convenient sampling was selected as the sampling technique. Data were collected from 40 pre-contract involved professionals and 40 from post-contract involved professionals out of distributed 93 questionnaires obtaining a response rate of 86%.

A questionnaire survey was conducted among professionals who have experienced in contracting organizations in order to evaluate the significance based on their perspective. The collected data were then analyzed using Mann-Whitney U test. The rankings of the individual values in two groups are determined and then those ranks add up and derive the rank sum which usually denotes by T. Then the U-values are calculate using formulas (Eq. 01).

$$U_1 = n_1 * n_2 + \frac{n_1(n_1+1)}{2} - T_1 \qquad U_2 = n_1 * n_2 + \frac{n_2(n_2+1)}{2} - T_2 \qquad \textit{(Eq. 01)}$$

n_1 – Number of cases in group 1

n_2 – Number of cases in group 2

T_1 – Rank sum in group 1

T_2 – Rank sum in group 2

Once the U numbers are calculated, then minimum U number is taken for further calculations. $U = min\ (U_1, U_2)$. The minimum U number is taken from the minimum value of U_1 and U_2. Then the expected value of u (μU) and standard error of U (σU) is taken by applying the following formulas (Eq. 02).

$$\mu U = \frac{n_1 * n_2}{2} \qquad \sigma U = \sqrt{\frac{n_1 * n_2 * (n_1+n_2+1)}{12}} \qquad \textit{(Eq. 02)}$$

Once these calculations are done then the Z value is derived by using the following formula (Eq. 03).

$$Z = \frac{U - \mu U}{\sigma U} \qquad \textit{(Eq. 03)}$$

Once the Z value is calculated then the related P-value of that Z-value can be derived by using Z-value tables. Then it can be determined whether to reject or retain the null hypothesis.

Null hypothesis - There is no difference in difference between two groups in the population.

Alternative hypothesis - There is a difference between two groups in the population.

4. RESEARCH FINDINGS AND ANALYSIS

4.1 FINDINGS OF THE SEMI-STRUCTURED INTERVIEWS

Findings of the semi-structured interviews are presented below.

4.1.1 Cost Overrun Factors Directly Related to Pre and Post-Contract Stages

According to the interviews carried out, the above cost overrun factors are sorted as the most probable of occurring in pre-contract stage and/or post-contract stage. Thus, it has higher likelihood of appearing in the respective stage/s and impact to the cost overrun in the Sri Lankan construction industry. The thematic analysis of the qualitative data reveals that the majority of the interviewees believe these factors have a relevance to the respective stage/s and even stated certain factors as "*highly related*" and "*definitely related*", which convince that these factors have the top priority when consider the relevance for pre-contract stage and post contract stage.

4.1.2 Cost Overrun Factors Partially Related to Pre and Post-Contract Stages

The above cost overrun factor have less relevance according to the majority of the respondents. These factors cannot be completely eliminated by stating these factors are irrelevance in either stage for cost overrun. They have a certain likelihood of occurring and impact to the cost. The majority of the interviewees stated these factors as "*partially related*" and "*may be related*" which emphasize the weak relevance to their respective stage.

4.1.3 Cost Overrun Factors Not Related to Pre or Post-Contract Stages

The aforementioned factors are more likely to occur in the opposite stage in which they have been mentioned. Thus, the effect of cost overrun will not be there as these factors are more likely to not appear in the particular stage and interviewees reason out why they do not cause any cost overrun in that particular stage. IP-1 argued regarding the delayed payments factor as "*usually, the interim payment application happens in the post-contract stage so only in that stage delay can be occur if any. So, no relevance to the pre-contract stage as no payment is done in that stage since that stage is prior to award the contract*". Moreover, IP-1 expressed that the reason for non-relevance of the lowest bid might not be the most technically feasible bid as "*this can happen in tender evaluation phase which is happened in pre-contract stage*".

4.1.4 Cost Overrun Factors Not Related to Both Pre and Post-Contract Stages

As per the perspective of the interviewees, the factors shown in Figure 1 have been eliminated for further analysing as they are not related to cost overruns in construction projects. These factors also confirmed by at least 3 members out of 5. Different reasons have been identified for denying those factors and some factor has their unique feature in order to get eliminated from this initial analysis.

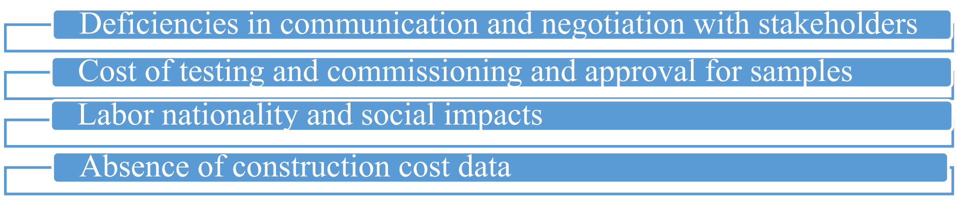

Figure 1: Cost overrun factors not related to both pre and post-contract stage

Excluding the factors mentioned in Figure 1, all the other factors have been categorized into pre-contract and/or post-contract stages and further proceed to questionnaire survey to evaluate the significance. Hence, in the pre-contract stage, there were 35 factors and in the post-contract stage, 39 factors have been categorized as related factors.

4.2 FINDINGS OF THE QUESTIONNAIRE SURVEY

A questionnaire survey was carried out among the professionals involved in cost estimation and controlling in Sri Lankan construction projects. The professionals were asked to indicate the significance of the cost overrun factors using 10-point Likert scale. The collected quantitative data were analysed using SPSS software. Figure 2 depicts the data distribution histogram and Figure 3 shows the results of Mann-Whitney U-test.

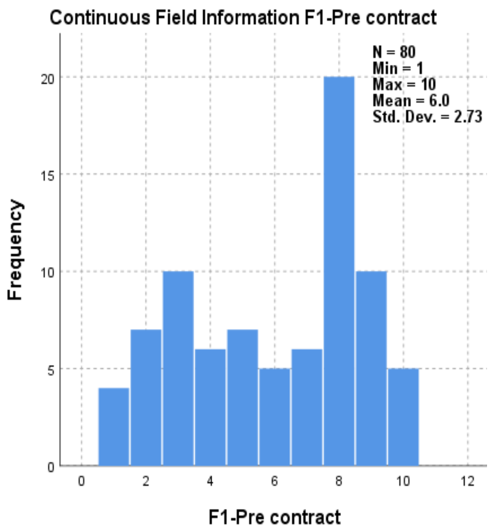

Figure 2: Data distribution histogram

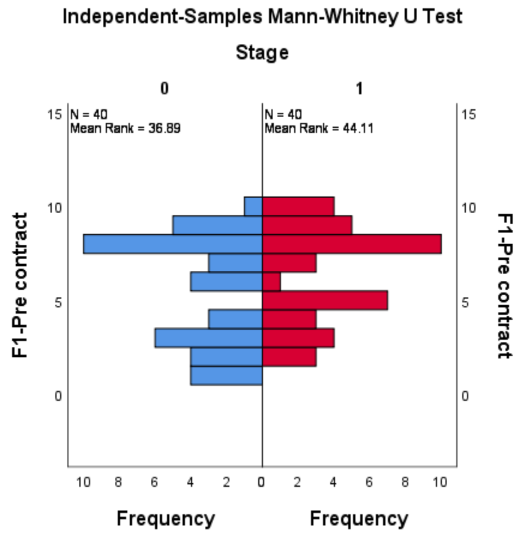

Figure 3: Mean rank distribution graph

The above histogram of frequency demonstrates the numerical data set (significance of the particular cost overrun factor in Likert scale) is not normally distributed. Therefore, the parametric t-test cannot be applied due to non-normality of data, and Mann-Whitney U-test needs to be adopted as these numerical data are non-parametric.

As demonstrated in Figure 3, there is a sizeable difference in mean rank for two stages (36.89 in the pre-contract stage and 44.11 in the post-contract stage). However, by referring to the above graph alone cannot come to a conclusion that there is a statistically significant difference is there. To determine it, the results of the Mann-Whitney U test need to be referred and analyzed. If the test result shows that the p-value of the corresponding Z-value is less than 0.05 (alpha value), then only it can be stated as those two groups have a statistically significant difference. When the p-value is less than 0.05, it means that the standard error of rejecting the null hypothesis is less than 0.05(5%). Thus, the result supports that there is more than 95% confidence of rejecting the null hypothesis which is, there is no difference between pre-contract and post-contract stages in terms of the significance of the factor.

4.2.1 Hypothesis test

Once the Z-value is calculated corresponding p-value (0.160) has been denoted as Asymptotic significance in 2-tailed test. Since the sample size is greater than 20, the p-value (Asymptotic significance) can be taken or otherwise the significance value is derived from U value. This will be further confirmed by the hypothesis test summary which was generated from the SPSS software as shown in Table 2.

Table 2: Hypothesis test summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of F1-Pre contract is the same across categories of Stage.	Independent-Samples Mann-Whitney U Test	0.160	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is 0.050

SPSS reports that the 2-tailed p-value is 0.160 which is quite higher that the 0.05 (the standard alpha level) and it is therefore, concluded that the null hypothesis cannot be rejected as the null hypothesis can be rejected only of the p-value is less that the alpha value (0.05). Therefore, the null hypothesis shall be retained based on the available data.

4.2.2 Hypothesis Test Results

Thus, there is no statistically significant difference in mean rank between the pre-contract stage and post-contract stage in terms of the significance of factor F1(owner's financial crisis) in pre-contract stage. The above results demonstrate the results of F1 in pre-contract stage. To obtain the conclusion of whether there is a difference in perspective of the cost overrun factors between professionals in pre & post stages, it was required to carry out 74 number of Mann-Whitney U tests (35 in pre-contract and 39 in post-contract) for each cost overrun factors and results are then summarized. Out of 74 tests, 45 tests resulted in rejecting the null hypothesis as in all those tests, the p-value is less than 0.05. Thus, all cost overrun factors that come under those 45 tests, have a different perspective in professionals between pre-contract stage and post-contract stage. It is 60.81% out of total tests. Therefore, it can be stated that 60.81% cost overrun factors have been rated as significantly different by the professionals involved in the two phases of the projects.

4.3 DISCUSSION

One of the major issues of the construction industry is that no proper management and knowledge is sharing between pre-contract stage and post-contract stages in contracting organizations. This was the reason for carrying out this research specifically and to statistically evaluate the view of the industry professional's perspective on the significance of cost overrun factors, based on the stage in which they are involved. The output of the tests can be interpreted as it supports the statement which means professionals involved in the pre-contract stage view the cost overrun factors in a way different to professionals involved in post-contract stage. Usually, estimators are carrying out price estimation based on their perspective and the way they incorporate certain risk measures and activities to mitigate cost overrun would be completely based upon their assumptions and perspective. When it comes to the physical construction of the project, post-contract involved professionals provide the priority to the cost-related activities based on their opinion and they have limited knowledge on the perspective of the estimation team. This can lead to allocate time, money and other resources by the post-contract team, which might have been forecasted as unnecessary by the pre-contract team.

For instance, when there are two cost overrun factors (F1 & F2) occurring in the construction phase and the post-contract team view F2 as the most significant cost overrun factor and allocate resources to mitigate the cost overrun. However, the pre-contract team has a different perspective and they have prepared the estimation by viewing F1 as the most significant cost overrun factor and therefore, there is an unnecessary cost overrun can be occurred due to this poor understanding of these two phases. Therefore, this situation needs to be avoided by proper coordination and conducting frequent meetings and knowledge-sharing sessions in the construction projects.

5. CONCLUSION AND RECOMMENDATIONS

The current research well-identified that the poor pre-contract and post-contract management and coordination have a massive impact on this cost overrun. The professionals working in one phase have less knowledge and concern on what other professionals concerned about the significance of cost overrun factors. The responses on each factor have been tested by using the Mann-Whitney U test to examine whether there is any statistically significant difference in significance of the cost overrun factor in the particular stage in terms of the perspective of pre-contract stage involving professionals and post-contract stage involve professionals. Therefore, this statistical analysis further confirmed the discussion on the problem statement which is the poor coordination between pre-contract and post-contract is also happening in the Sri Lankan construction industry. Immediate attention requires for this issue and proper coordination between pre-contract stage and post-contract stage shall be established rather than limited to several kick-off meetings in order to minimize the cost overruns of construction projects.

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CULTURAL BASIC ASSUMPTIONS OF CONSULTANTS AND CONTRACTORS DURING NEGOTIATIONS: THE CASE OF SOUTH AUSTRALIAN CONSTRUCTION INDUSTRY

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ABSTRACT

Negotiations are required in every stage of a construction project. The process of negotiation involves being able to understand the position and emotions of the other side of the negotiation. A reliable means for understanding cultural basic assumptions on negotiation tactics assist in better predicting how individuals may act in a negotiation. This research aims to analyse the effect of basic assumptions of consultants and contractors on negotiations in the South Australian construction industry. This was approached through a case study research strategy, utilising semi-structured interviews with two contractors and two consultants each from three large South Australian Road projects followed by a Content Analysis. Findings reveal that both the contractors and consultants believe the nature of human relationships as collaborative and therefore view negotiations as a mean of strengthening the partnership. They negotiate openly to reach win-win outcomes. They view the nature of human nature to be good, therefore more trust and more openness to creative new ideas in negotiation planning. Respondents mostly believe the nature of the human activity to be harmonizing and are more likely to use trade-offs in reaching mutually beneficial negotiation outcomes. The knowledge created in this research will be useful for anyone preparing to negotiate within the South Australian construction industry or similar cultural setups to understand and predict how contractors and consultants would react to different situations and issues within negotiation processes and to achieve effective outcomes. Further research can study the basic assumptions of sub-contractors about negotiations.

Keywords: *Basic Assumptions; Construction Industry; Culture; Negotiations; South Australia.*

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1. INTRODUCTION AND THEORETICAL BACKGROUND

Construction projects have become highly complex due to the involvement of numerous parties with often conflicting goals. For example, the owner prefers projects that are inexpensive and completed quickly, whereas the contractor prefers large, income-generating projects with limited time constraints (Yousefi, et al., 2010). Trying to maximise their own benefits by project parties, incorporating special conditions in the contract, changing construction plans, and presenting contradictory and erroneous information in the mass of documents contribute to the emergence and manifestation of construction disputes (Cheung, et al., 2006). Once the disputes are crystallised, it is vital to resolve them. Negotiation is a fast, least cost and least hostile mode of resolutions, which have been proved efficient and effective in complex situations involving the beliefs and thinking of people (Yousefi, et al., 2010). Adair (2004) explain that different strategies of negotiation yield different outcomes, particularly communication strategies, being direct and indirect approaches, and power strategies, being hierarchical and egalitarian. Brett (2017) discusses the importance of gaining and giving trust between negotiation parties as well as the use of trade-offs and multi-issue offers. In a negotiation, it can be advantageous to understand the opposing party's position and how they are likely to negotiate (Lewicki, et al., 2015). To understand how a subject will negotiate, it is important to have an understanding on how they make decisions and what values, beliefs and morals underpin these decisions. Brett (2017) finds that global negotiation benefits from understanding how the negotiating parties' culture affects their choice of negotiation strategies and priorities. Gajendran, et al., (2012) describe that an understanding of cultural differences can aid to eliminate misunderstandings across cultures. This concept introduces that having background knowledge of another culture would aid in efficient communication and relationship building. Further, by having this understanding of the culture could potentially dodge a negative outcome such as no deal being achieved or offending the other party.

Schein (1984) recognise that to completely understand a group's values and overt behaviour, it is essential to investigate the unconscious underlying assumptions, which determine how people think, feel and behave. Research has been conducted into cultural beliefs, and it has been theorised that all cultures universally can be analysed from their basic assumptions about a small number of questions (Hills, 2002). Schein (1984) presents these as five major basic assumptions by all humans: the nature of human relationships, the nature of human nature, the nature of reality and truth, the nature of the human activity, and the organisation's relationship to its environment. Adair (2004) and Brett (2017) provide a depth of knowledge about the impact on culture on negotiation strategies but is limited and does not delve into basic assumption theory. Figure 1 presents a conceptual framework on how cultural basic assumptions are associated with elements of negotiation. It summarises and captures the above discussion on cultural assumptions of contractors and consultants during negotiations. The box on left hand side indicates the four basic assumptions proposed by Schein (1984), and the box on right hand side indicates the different components of negotiations that could be shaped through the underlying basic assumptions.

Whilst the literature has discussed different components of negotiation strategies and the fact that different cultures favour different strategies. However, it does not comprehensively analyse the effect of cultural basic assumptions on negotiation components. The way cultural basic assumptions drive the behaviour and thinking of people into negotiations is an area without adequate existing knowledge. Therefore, the proposed research is aimed to analyse cultural basic assumptions of consultants and contractors and their effect on components of negotiation, adding significant value to negotiation efforts in construction project teams. This aim carries the following objectives:

1. Extract the basic assumption of South Australian construction consultants and contractors in negotiation situations
2. Investigating the impact of basic assumptions held by consultants and contractors on the common negotiation tactics and positions in the South Australian construction industry.

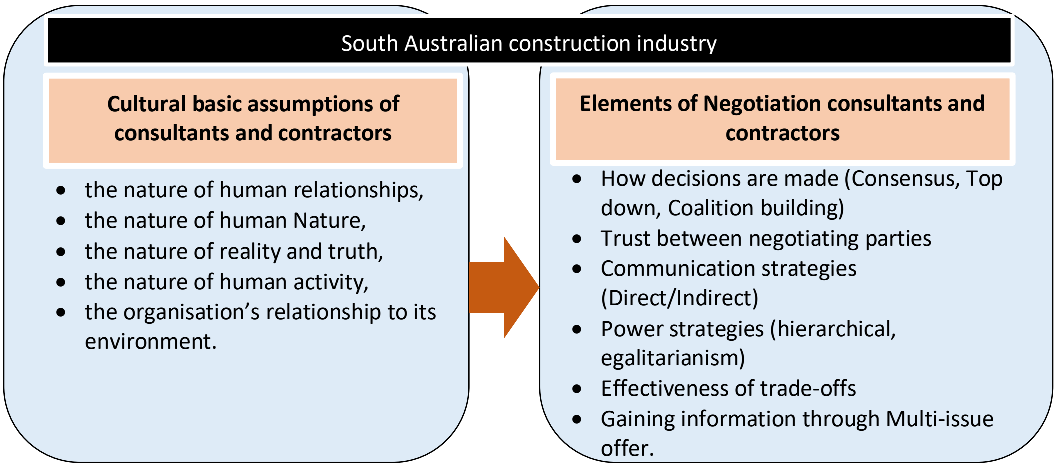

Figure 1: Conceptual framework on how cultural basic assumptions of contractors and consultants affect the elements of negotiation

2. RESEARCH METHODOLOGY

This research attempts to analyse how cultural basic assumptions of contractors and consultants in the South Australian construction industry affect the elements of negotiation. As suggested by Saunders, et al., (2009), it is clear that the exploratory nature of this research topic, the limitation of time and the access to members of construction projects determined the appropriate methodology to be a qualitative approach, utilising an embedded case study research strategy. Case study research has been particularly useful as it has enabled us to get a rich understanding of the context of the research, and three case studies allowed us to generalise from the research (Saunders, et al., 2009). As such, qualitative data was collected from three separate case studies. With the theoretical replication expected from the data collection, three case studies allow for the required depth of observation and provide an adequate number of cases (Barratt, et al., 2011).

Three public sector road projects were selected as the cases. The cases were identified based on a number of criteria designed to ensure quality data can be collected to obtain a rich understanding of the cultural basic assumptions of contractors and consultants. As the criteria for the selection of the case studies, projects had to have been within the South Australian construction industry; utilised both contractors and consultants (traditional procurement); been valued at over $100M; commenced works within the last 5 years (to ensure data was current). Three road projects were selected for the purposes of this research as road projects are the largest value construction projects in South Australia and therefore have the highest number of negotiations around claims. Within each case study, data was collected from two consultants and two contractors. The details of the respondents are summarised in Table 1.

Table 1: Respondent's details

	Respondent Code	Project	Contractor or Consultant	Role	Industry Experience
CASE A	RA	CA	Contractor	Engineering Coordinator	8 years
	RE	CA	Contractor	Contract Manager	21 years
	RC	CA	Consultant	Infrastructure advisory	32 years
	RG	CA	Consultant	Estimating Manager	25+ years
CASE B	RD	CB	Contractor	Engineering Lead	12 years
	RB	CB	Contractor	Commercial Manager	25+ years
	RF	CB	Consultant	Engineer	24 years
	RJ	CB	Consultant	Advisory	5 years
CASE C	RH	CC	Contractor	Design Manager	12 years
	RI	CC	Contractor	Quality Manager	14 years
	RL	CC	Consultant	Consultant Advisory	2 years
	RK	CC	Consultant	Consultant Advisory	3 years

The primary data collection technique for this research was semi-structured interviews, using an interview guideline that focused on indirect questioning to extract underlying cultural basic assumptions. During data analysis, trends, recurring themes and principles were analysed using code-based content analysis. Content analysis is a method that enables replicable and valid inferences from qualitative data to provide knowledge, new insights and a practical guide for action (Woo and Heo, 2013). This study utilised manual coding, where the vast quantity of data was codified for ease of categorisation for the development of theory. Using a coding structure developed to clearly set out the themes within the collected data, a code was allocated to each project name, cultural basic assumption, negotiation behaviour and respondent, to create recognisable notations. From here data from many hours of transcribed interviews was easily collated and drawn from were relevant. Using these codes, three layers of coding were conducted; open coding, axial coding and selective coding. A cross case analysis was performed to derive findings. This analysis also aimed to uncover a set of recommended tools and strategies that can be developed to assist in negotiating with people of these sub-groups and other people holding these cultural basic assumptions.

3. CASE STUDY FINDINGS

Table 2 provides a brief background on the projects selected.

Findings from these three cases are explained in the subsequent sub sections to derive underlying basic assumptions of the contractors and consultants in the South Australian construction industry and to learn their association with the components of negotiation.

Table 2: Background details of the cases

Project	Background details
1 Darlington Upgrade Project	This is a large urban road project that is to deliver 3.3 km of motorway for South Australia. A Design and Construction contract was selected to build this infrastructure. The Australian and State governments have jointly committed $754.5 million for the completion of this project. The project started in early 2016 and is scheduled for completion in mid-2020.
2 Oaklands Crossing	This Project is a road and rail project to remove a level crossing by lowering the rail line under the road. This project also included a new train station and a pedestrian bridge. Not only was this funded by the Australian and State Governments, but also the local council had a financial input. The amount committed was $174 million for this project to be achieved. The project started in June 2018 and was completed for operation in July 2019, but residual works are still being conducted.
3 Regency to Pym Street upgrade	This is a large road project which consists of a 1.8 km section of motorway through metropolitan Adelaide. The type of contract executed to produce this work was an alliance contract. The Government has committed $354.3 million for the project to be constructed. The project commenced on 10 July 2019 and is forecasted for completion on 31 January 2022.

3.1 THE NATURE OF HUMAN RELATIONSHIPS

The first basic cultural assumption that will be analysed from the interviewee's responses is the nature of human relationships. In Case A, although one respondent indicated that they believed the nature of human relationships to be competitive, the rest of the respondents provided more signals about cooperative relationships. Speaking of their experience on project A, Respondent B indicated that "*most project team members would tend to start with trying to find a cooperative solution*" (CA, RB). This was reiterated by respondent F, who said, "*the vast majority look to cooperatively look at the holistic bigger picture. There is a small minority that looks to defend their party, but they're definitely in the minority*." (CA, RF). This showed an inclination of respondents to want to cooperate with contracting parties and work together. Case B respondents followed a similar vein to Case A and were unanimous in their response that they saw human relationships as cooperative. Respondent L discussed how performance issues are managed in the industry, offering: "*In terms of how we'd manage performance issues within our team as consultants, I think, um, it is a very cooperative process*" (CB, RL). When speaking about the process of doing work Respondent I said, "*We also focus on the experience. Making that enjoyable for all because that's the best chance of success and working collaboratively should help with the overall outcome*." (CB, RI). From these responses, it was found that contractors and consultants on case B also found the nature of human relationships to be cooperative. Keeping the trend with the respondents from Case A and Case B, respondent G from case C said, "*Generally at the start of the project they're fairly cooperative*." (CC, RG) when describing project members' attitudes toward conflict resolution. Also, on the topic, respondent E offered, "*I think generally, people try to do it cooperatively and [through] mutually accepted agreements. [that is what is] best for all parties but if it's not agreed then they'll go in another direction*" (CC, RE). These tend to show that Case C respondents also view the nature of human relationships as working together. They see relationships as collaborative more than competitive, and this showed in their negotiation tactics that they identified with. Respondent F showed a willingness to work with contractors through debts rather than chase every cent contractually owed. "*We don't want to send them bust even though contractually we might be able to*." (CA, RF). When speaking 'showing your hand' in a negotiation to try and reach a mutually beneficial outcome, respondent G said, "*If you're completely closed off, it is highly unlikely to have a productive discussion*." (CC, RG). From analysing the three cases, it can be seen that all three cases agreed that the nature of human relationships was cooperative. So, people in the SA Construction industry view the nature of human relationships as cooperative, and this leads them to work collaboratively and look for 'win-win' situations in negotiations that are mutually beneficial.

3.2 THE NATURE OF HUMAN NATURE

The nature of human nature - whether humans are primarily good, neutral or evil also have an impact on negotiation tactics. A negotiating party that believes people are evil could be less likely to trust someone whom they are meeting for the first time. An absence of trust could require the terms of a contract to be much more stringent to mitigate the risk of agreements turning sour and resulting in litigation. Respondents from Case A had mixed views on the nature of human nature. One subject interviewed believed that if a party they were contracted with could breach the contract for gain and get away with it, that they always would (CA, RF). This respondent also found in their experience that men in the industry were often aggressive in their negotiations (CA, RF). Another respondent said that they thought people were generally good, however, later told a story of refusing to work again with a "*concrete companies [that] tried to screw me over about 12 years*" (CA, RB). This feeling that the nature of human nature is evil is not carried across the entire South Australian construction industry, however. Interviewees who worked on Case B returned different responses to Case A, finding mostly that people were good. Showing a keenness to trust and cooperate, respondent I (CB, RI) said that they enjoy working collaboratively with the client. This cooperation can extend to the openness of discussion in negotiations to reach win-win outcomes. Contractors and consultants who worked on Case C followed a similar course to those on Case B. Respondent E said, *"No-one's going into a contract to hoodwink someone*". This shows that they generally believe people are good and have honest intentions. This was not a completely unanimous position as Respondent D told that they would withhold key design information during the tender negotiations as they fear companies will take their design and contract with a cheaper builder (CC, RD) because they only want what is the best outcome for themselves. In comparing the three case studies' responses to the nature of human nature, Case A stands alone in their responses of 'evil'. This is interesting when examining against habits toward negotiation. Case A was also distinguishable from Cases B and C when looking at whether they would change negotiation plans upon recommendation of a new and promising employee or rather stay with tried and tested methods. A link can be drawn between believing humanity is good and trusting stakeholders who present new ideas. Conversely, those in Cases B and C who found human nature to be good take a more flexible view.

3.3 THE NATURE OF REALITY AND TRUTH

The 'nature of reality and truth' looks at how cultures decide what is true; whether that be reliance on wisdom, social consensus or a pragmatic test. In analysing this, the SA construction industry was looked at in terms of how final agreements are made in negotiations over project matters. Across the three cases, there was a range of responses, with some trends emerging. By looking at this through a negotiation lens, we can draw links between this Basic Cultural Assumption and find possible reasons for negotiation habits. Subjects from Case A identified most closely with pragmatic testing as the way that reality and truth is defined. Respondent D said at Q3, "*Generally it's fact and technical. In construction, it generally has a black and white answer*" (CA, RD). This shows a reliance on technical and contractual facts, consistent with pragmatic testing, and this shows an inclination toward keeping decision making processes consistent. Differing from Case A, Case B were more closely aligned with 'social consensus' as the nature of reality and truth. This is normally based on careful consideration of opinions and agreement of both parties. Respondent L encouraged input to reach a consensus among parties, quoting, "*we're open for anyone to bring an idea to the table*" (CB, RL). This lends the belief that interviewees on Case B would be more inclined to take on different perspectives rather than just the letter of the law written in the contract. The respondents from Case C had very similar responses to their colleagues in Case A. The 'pragmatic test' approach was favoured for reasons akin to those illustrated above. The majority finding from a viewpoint encompassing all three cases is that the nature of reality and truth is pragmatic testing. This primarily deals with technical and contractual facts. *"You're more likely to go with something that's dependable and proven*" (CC, RA). Interestingly these two cases also indicated that they would prefer to utilise negotiation personnel that have consistent views and understanding when selecting their negotiation team. Contrastingly, Case B opted for social consensus and, rather than consistent views and understanding, would prefer negotiation personnel to have diversity and differing perspectives. This is a logical trend as 'social consensuses' involves input from several parties and could encourage this kind of decision making, whereas pragmatic test is 'black and white' and therefore more consistent.

3.4 THE NATURE OF HUMAN ACTIVITY

To identify contractor and consultant beliefs toward the nature of human activity, attention was given to respondents' impressions of the attitudes of people they have negotiated with- whether harmonizing, passive or dominating. Being another basic cultural assumption relating to human-to-human interactions, this could also be relevant for drawing conclusions regarding negotiations. The predominant trend to emerge from Case A was in favour of the nature of human activity being 'harmonizing'. This would indicate that subjects from Case A are willing to look for negotiated solutions rather than trying to force their own way or accepting unfavourably one-sided positions. Respondent D described their experience negotiating in the industry as "*They'll hear what you have to say and provide feedback*" (CA, RD). Those interviewed from Case B returned a mix of responses, including both dominant and fatalistic. Respondent I said that in past dealings, they would "maybe try to dominate sub-contractors". Another subject said that they had found parties to often be passive (CB, RK). This report that parties are often passive could be a result of the respondent being overly dominant, like Respondent I, or this could simply show a range of human activities varying from person to person. Much like Case A, Case C respondents found the nature of human activity to be harmonizing. Reiterating the position of Case A, Respondent C said: "*during the tender phase [people are] definitely trying to harmonise with the other party*" (CA, RC). This response emerged as the most popular among the three cases. Cases A and C both found the nature of human activity to be 'harmonizing', with Case B identifying dominant and passive behaviours are sometimes present. In a negotiation, a trade-off is a tactic that refers to giving up an item of low interest to gain an item that is worth more to you. This can be useful when parties have different levels of interest in different negotiation tactics (or contract terms). During the interviews, Cases A and C both indicated that they found trade-offs to be useful in negotiations. Contrastingly, Case B, who had a mix of responses including dominant and fatalistic, unanimously said that they did not use trade-offs in negotiation. This could be because they are dominant or passive in these conversations and not keen to give-and-take to explore mutually beneficial outcomes.

3.5 THE ORGANISATION'S RELATIONSHIP TO ITS ENVIRONMENT

The aim of the basic assumption, the organisation's relationship to its environment, is to try and relate the construction project or company to its situation (Samaraweera, et al., 2018). For this research, a multiple-choice question was asked to the respondents, with four possible answers being: dominant, submissive, harmonising and searching out a niche. The question was asked from the point of view of why the company tendered for the project work. The results of the interviews in Case A were split between contractors answering dominant and consultants searching out a niche. Contractor respondent E said, "*that would be their bread and butter*" (CA, RE), suggesting that this type of work is in their core duties and dominant in. Although consultant respondent G said, "*we tendered for that role on the project because it is in our niche primarily*" (CA, RG), which proposes that their role in the project fits into a specialised line of work. Results for Case B were exactly the same as Case A, with a split between contractors answering dominant and consultants searching out a niche. Respondent D, who is a contractor, said that their company asks the question when looking for work "are we dominant enough and is this our kind of project?" (CB, RD). This leads to the idea that the company has a set criterion of work that they are industry leaders in. In terms of the consultants on Case B, participant J said, "*in the context of us, it's probably because it's in our niche*" (CA, RJ). Regarding case 3, the results were very similar to Case A and Case B, but with one of the consultants answering, they are dominant in the industry. Respondent K, who was a consultant, said, "*I think we are dominant in this space*" (CC, RK) as opposed to the other consultant, respondent L, who said, "*we are now up to our fifth potentially our sixth Alliance in South Australia… It's really our niche*" (CC, RL). Both of the contractors answered the question as being dominant. It became clear that for these types of projects, the contractors and consultants were usually either dominant in the industry or searching out a niche. Furthermore, the findings also showed that the contractors working on these projects were dominant, with all of the contractor respondents choosing dominant as the answer to this question. All but one consultant selected searching for a niche. The link to negotiation for basic assumption, the organisation's relationship to its environment, found that consultants that are searching out a niche are highly likely to use multi-issue offers and are willing to openly discuss them. The reason for this is that the consultant wants to gain information for themselves on the niche work. "*If you're completely closed off, it is highly unlikely to have a productive discussion*" (CA, RG). In the case of contractors, there are situations of personnel not wanting to disclose information. The reason for this is to not release any information that may jeopardise their dominancy on the market. Contractor respondent E said, "*I don't disclose people's information*" (CA, RE). In summary, a consultant who is searching out a niche is highly likely to be open to multi-issue offers and to discuss them openly to endeavour to develop their niche work, and a contractor that is dominant may hold back information as to not jeopardise their dominancy on the market.

4. DISCUSSION

The contractors and consultants in the South Australian construction industry realise the nature of human relationships as collaborative and therefore view negotiations as a partnership and negotiate openly to reach win-win outcomes. This finding was consistent with a study conducted by Russo (1992), who analyses how cultures can effectively engage in trade. Although Russo looks at the Lummi people, a Native American tribe that traded in retail liquor and deep-sea fishing, their need to relate successfully to their consumer base was found to be similar in this study. Russo notes that the Lummi people were able to trade successfully with distributors and suppliers of raw materials by making themselves aware of the similarities and differences of those with whom they were negotiating. Further, negotiators in the South Australian construction industry believe being cooperative lead them to work together and look for 'win-win' situations in negotiations that are mutually beneficial with any party, which is consistent with Russo's study. South Australian construction industry negotiators view the nature of human nature to be good and, therefore, more trusting and more open to creative new ideas in negotiation planning. As noted by Brett (2017), trust can be a very sought-after value to a lot of parties and cultures when attempting to negotiate. As trust and creative ideas are important values in the SA construction industry, Brett's research would agree with these findings. Another study by Meyerson, et al., (1996) raises the term swift trust, which is when you trust another party until one party betrays the trust. This research agrees with the view of the South Australian construction industry but is limited to the initial trusting view because this research did not touch on the betrayal of the trust. South Australian construction industry consultants usually search out a niche and are open to multi-issue offers to develop their niche work. Lytle, et al., (1999) describe approaching a negotiation in a certain way can have a range of different results, being positive, negative or somewhere in between. They nominate three main negotiation approaches: power, rights and interests. The findings of this research project confirm consultants would be consistent with the interest-based approach as described by Lytle, et al., (2009). They note that by focusing on both parties' interests, you get an opportunity to understand the other party. Consultants of the South Australian construction industry consider each party's underlying needs, concerns and desires to further develop their niche work with the project client.

5. CONCLUSIONS

This research analyses cultural basic assumptions of consultants and contractors and their effect on the components of negotiation among them. Both contractors and consultants in the South Australian construction industry believe that the nature of human relations is more cooperative. Both parties show an inclination to wanting to be more cooperative with the contracting parties and work together. Therefore, they look for 'win-win' situations in negotiations that are mutually beneficial. Further, they view the nature of human nature to be good are therefore more trusting and more open to creative new ideas in negotiation planning. Both contractors and consultants find pragmatic testing to be the nature of reality and truth. This correlates with their tendencies to utilise negotiation team members with consistent views, compared with their colleagues, who opted for social consensus and preferred diverse negotiation team members. Further, both contractors and consultants mostly believe the nature of human activity to be harmonizing, and they are more likely to use trade-offs in reaching mutually beneficial negotiation outcomes.

Consultants are mostly searching out a niche and are open to multi-issue offers to develop their niche work, while contractor respondents are dominant and may hold back information as to not jeopardise their dominancy on the market.

This research builds on existing knowledge of the cultural basic assumptions to interpret its version of the South Australian construction industry and develops it in relation to how it affects different components of negotiation. A deeper understanding of cultural basic assumptions and impact on negotiation along with the carefully inferred recommendations could assist in negotiating in the South Australian construction industry to realise joint gains, reach agreement quicker, create a civil negotiation process and ultimately, provide a better negotiation outcome with contractors and consultants. This research has developed a set of recommendations that deliberately support such assumptions and leverage these to create benefit in negotiation. Such recommendations include: place value on trust; utilise a direct, collaborative, interest-based approach to maximise joint gains and utilise trade-offs during negotiation. For example, as the finding that contractors and consultants hold the basic assumption that the nature of human relationships is cooperative, there is an indication that they are willing to collaborate and work together. Therefore, the recommendation that an interest-based approach, focussing on sharing interests to maximise joint gains without detriment to either party, could be implemented to achieve the best possible outcome. Further research arising out of this research include repeating the same research to understand the basic assumptions of sub-contractors about negotiations, as trades people as sub-contractors play a major role in the Australian construction industry.

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DEFICIENCIES IN BESPOKE LABOUR SUBCONTRACT AGREEMENTS: THE CASE OF LARGE-SCALE CONTRACTORS IN THE SRI LANKAN CONSTRUCTION INDUSTRY

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ABSTRACT

Labour subcontracting has become popular and has been extensively utilized in the building construction industry due to the potential for a reduction in initial cost for site mobilization. However, there are high risks involved in labour subcontracting due to inadequate and ambiguous subcontract agreements, which lead to disputes between parties. Thus, this paper aims to identify the deficiencies in large-scale contractors' bespoke labour subcontract agreements in the Sri Lankan construction industry. Eight semi-structured interviews were carried out with main contractors (CS1 and CS2 as per the CIDA registrations) to identify the current practice of labour subcontracting and the terms/clauses included in their company-based labour subcontract agreement. The collected data was then subjected to a content analysis, and accordingly, deficiencies in the agreements were identified that fall into areas such as defects in the works, materials, tools and equipment, contract termination, discipline at the site, services provided by the main contractor, penalties, dispute management, health and safety, retention clause, quality of the works, rate of progress, laws and regulations, variations, insurance, and skill of the labour subcontractors.

Keywords: *Construction Industry; Labour Subcontract Agreement; Labour Subcontractor; Main Contractor; Sri Lanka.*

1. INTRODUCTION

Subcontracting practice is fostered by the provisions made available for domestic and nominated subcontractors from a contractual point of view. On the other hand, Mbachu (2008) expressed that there are three main categories of subcontractors in the construction industry: trade contractors, specialist subcontractors, and labour-only subcontractors. Labour-only subcontracting has become popular and has been extensively utilized in the construction industry over the past decades. A labour subcontractor is a type of employment system whereby a contractor would hire, on a labour-only basis, a subcontractor, which is often an individual worker or a collection of individuals, and pay

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a lump sum, or measure and pay for an agreed amount of work. Further, Kadan (2016) has indicated that labour subcontractors are widely engaged in building development projects because civil engineering projects are not too labour-intensive and involve only a few trades.

However, as Chiang (2009) mentioned, many disputes are generated as a result of breaches in the rights and responsibilities of the general contractor and the subcontractor. Moreover, Chiang states that the main contractor and subcontractor should maintain a long-term business relationship that is built upon trust and loyalty for a problem free subcontract. Furthermore, as Yoke-Lian, et al. (2012) state, problems related to subcontractors are considered to be one of the main risks of a construction project, owing to the fact that labour subcontract issues like payment problems, safety issues, quality issues, disciplinary issues, etc., always affect the productivity of a construction project. Therefore, it is safe to assume that problem free subcontracting would allow successful project completion.

As Fagbenle, et al. (2018) point out, when subcontractors enter into a contract with main contractors, most of them are not registered as subcontractors under the main-contractors, and some subcontract agreements are inadequate and ambiguous, which can be claimed as the main reasons for the disputes. Therefore, research is needed to figure out solutions to minimize the issues caused by the absence of a standard format for labour subcontract agreements in the construction industry.

Standard labour subcontract agreements are not a practice in the Sri Lankan construction industry, but some standard labour-only subcontract forms and agreements are traceable in the international context. For instance, both the Building Industries Federation of South Africa (BIFSA) and the Construction Industry Development Board of South Africa (CIDB) adopt standard labour-only subcontract agreements (CIDB, 2005). In this setting, there is an exigent need to develop a standard labour subcontract agreement for the Sri Lankan construction industry. Thus, forming part of a wide research, this paper investigates deficiencies in the currently available bespoke labour subcontract agreements among large scale contractors in the Sri Lankan construction industry. In order to achieve this aim, the paper addresses the following three research objectives:

1. Identify the prevalent labour recruitment practices and problems that arise as a result of labour subcontracting practices.
2. Review the locally available labour subcontract agreements and standard international labour subcontract agreements to identify the major provisions available in them.
3. Identify the deficiencies in the currently available bespoke labour subcontract agreements among large scale contractors in the Sri Lankan construction industry that may have given rise to the problems generally rising between main contractors and labour subcontractors.

This paper begins with a comprehensive literature review on the labour subcontract process; issues generally arising in labour subcontracting; standard forms of labour subcontract agreements available; and the advantages of having such standard labour subcontract agreements. Subsequently, it introduces the research methodology adopted for the study to achieve the aim and objectives, along with reasoning for each method adopted.

The analysis of the primary and secondary data collections that involved in the identification of the deficiencies in the bespoke labour subcontract agreements used by large-scale building contractors is presented next, followed by the conclusions, recommendations, and suggestions for further research.

2. LITERATURE REVIEW

2.1 LABOUR-ONLY SUBCONTRACTORS

Labour-only subcontractors normally just supply their labourers and work under the direction of main contractors. Labour-only subcontracting is particularly common in the building construction industry. Most of the main contractors are subletting a great bulk of their construction work to labour-only subcontractors, to significantly reduce the supervision, office staff, and accommodation costs (Mbachu, 2008), which has become a trend in the construction industry recently. Being concurred with the Mbachu's view, Ohnuma, et al. (2000) held that main contractors use labour-only subcontracting as a mechanism to reduce the risk associated with the main contractor, especially because it:

- **Improves flexibility:** Labour subcontracting improves the functional flexibility of workers, the volume of workers, and the financial position of the main contractor through smaller fixed costs.
- **Increases productivity:** Generally, the labour subcontractors are specialized in certain areas of services, so they can achieve higher productivity compared to the productivity of the main contractor's own labour force.
- **Improves the product's quality:** As labour subcontractors are "specialists" in their own field, such as formwork, reinforcing, tiling, painting, and plastering, main contractors can expect high quality work by utilizing skilled and qualified labour subcontractors.
- **Reduce delays:** If the productivity of services executed by the labour subcontractor is better, it naturally results in a reduction in delays if the task has been planned and programmed well.
- **Less expensive:** A labour subcontractors are less expensive than finding and using the main contractor's own employees. Through labour subcontracting, the main contractor can find workers with the required skills and can reduce the maintenance of a heavy and uneconomical full-time labour force.

These benefits become realized, if both parties (labour subcontractor and main contractor) do their duties and responsibilities properly as agreed and only well-written subcontract agreements are drafted between the main contractor and labour subcontractor.

2.2 LABOUR SUBCONTRACT AGREEMENTS

A labour subcontractor agreement is a contract between the main contractor or project manager and labour-subcontractors. It solidifies any agreement between the two parties in order to ensure the delivery of work. Subcontractors are expected to read the agreement carefully and verify specifics to protect themselves from unfair risks being transferred to them. Although various conditions for the formation of subcontracting agreements have been put in writing, they are not very explicit about the benefits to the subcontractor and are not written in a manner favourable to the subcontractors (Webster, et al., 1997). Most labour subcontractors do not enter into formal, written, and signed documents, which are to be binding and enforceable. Instead, most labour subcontracts end up with an oral agreement without any offer or acceptance in writing. Furthermore, most verbal labour subcontract agreements are solely based on price or trust. Conversely, the subcontract agreement needs to be in writing in a language that the subcontractor can understand and acknowledge because the majority of the labour subcontractors are not in a position to understand and acknowledge written agreements of complex nature.

According to Hoffmeister, et al. (2011), the following factors lead to the essentiality of a well-documented labour subcontract agreement for construction projects, and those factors themselves led the authors of this study to select large-scale contractors as the subject of the study rather than medium-scale or small-scale contractors.

- construction being large-scale
- flow of a large amount of money between a large number of parties
- lengthy production periods of construction projects
- heterogeneous nature of work involved in construction projects
- high complexity and high risks associated with construction projects

When the main contractor is adopting labour subcontractors' services, it needs to define the rights, obligations, and duties clearly to avoid conflicts between each party and to get expected performance from the labour subcontractor through a labour subcontract agreement. In Sri Lanka, it has become common practice for large-scale to use non-standardized formats to establish labour subcontract agreements. These company-based bespoke agreements do not cover the various rights and responsibilities that the contract parties originally promised during verbal agreements. As a result, payment issues, quality issues, timely completion issues, security issues, termination, disciplinary problems, and insurance issues are some of the issues that frequently arise between the main contractors and the labour subcontractors. Therefore, it is reasonable to assume that these problems tend to occur due to the usage of non-standardized formats for forming labour subcontract agreements.

Standard labour subcontract agreements can be used to manage and mitigate the risks involved in labour subcontracting. It is a common basis for contract agreements that define the rights and obligations of contracting parties. Although standard labour subcontract agreements are not a practice in Sri Lanka, different company-based bespoke forms of subcontract agreements that are not recognized as standards by the construction industry are available. Conversely, some standard labour-only subcontract forms and agreements used in international contexts were able to be identified through the literature review. For instance, both the Building Industries Federation of South Africa (BIFSA) and the Construction Industry Development Board of South Africa (CIDB) adopt standard labour-only subcontract agreements (CIDB, 2005).

Although there are two forms of labour subcontract agreements that have been identified, there was no enough literature related to the BIFSA form of labour-only subcontract. Therefore, it is only the CIDB standard labour subcontract document that is discussed within this manuscript. Similar to other standard forms of contract, the CIDB standard subcontract also initially provides the definitions and interpretations. Afterward, the contract clauses are provided under the following headings.

- Performance of the subcontract work, capabilities of labours, laws and regulations, surety, insurance, execution of the subcontract work, instructions, materials, services provided by contractor, tools, defects, payment (progress payments and retention monies), variations, resolution of disputes, cancellation of subcontract.

3. RESEARCH METHODOLOGY

As mentioned by Uyangoda (2010), a literature review is an important assessment conducted by researchers to search for existing knowledge in the relevant problem domain. It enables the authors to gain a sound understanding of the labour subcontract process in general and the existing standard forms of subcontract agreements produced by foreign authorities and their characteristics.

Desk review was basically involved in this study to collect data from existing company-based labour subcontract agreements of ten large-scale contractors, which is often considered a low-cost technique as compared to field research. A desk review was conducted for the purpose of identifying the terms/clauses as well as the gaps in the bespoke labour subcontract agreement formats and also to help build a good understanding of those agreements in order to fulfil objective No. 02 of the research. The labour subcontractor agreements collected from the ten CS1 and CS2 contractors that are currently in use in the industry were analysed by reviewing the clauses in them through a desk review.

Furthermore, the study is focused on the prevailing practices and issues of labour subcontracting in the local construction industry. Accordingly, the technique of semi-structured interviews was found to be the most appropriate data collection technique to fulfil the first objective of the research as it enables collating rich and in-depth data about current labour subcontract practices, their issues and impacts; adapting questions as relevant to the context; clarifying doubts during interviews; and ensuring the response is properly understood by giving certain indications through semi structured questionnaires.

Hence, data was collected through ten semi-structured interviews conducted across ten main contracting organisations in Sri Lanka (CS1 and CS2) with one respondent from each organization. In Sri Lanka, there are only ten organizations registered as CS1 and CS2 building contractors with the CIDA (Construction Industry Development Authority), and all of these have been taken into account for the research. According to the literature findings, it is the main contractors who are familiar with labour subcontracting procedures and consider them important for their business rather than the consultants; another reason why large-scale contracting organisations (CS1 and CS2) were selected for this study. The ten interview respondents are well-experienced professionals with substantial exposure to the labour subcontracting procedures of their organisations. The profiles of the interview respondents are presented in Table 1.

According to Fellows and Liu (2008), content analysis is helpful in determining the meaning of qualitative data, which involves the data being categorised into themes and allocating codes to them during the analysis. Hence, the manual content analysis method was adopted to analyse the data obtained from the semi-structured interviews in order to achieve the best outcome.

Table 1: The profile of semi-structured interview respondents

Company	Respondent	Description
A	MC-01	Quantity Surveyor 02 years of experience
B	MC-02	Civil Engineer 10 years of experience
C	MC-03	Engineering Assistant 04 years of experience
D	MC-04	Chief Quantity Surveyor 04 years of experience
E	MC-05	Quantity Surveyor 02 years of experience
F	MC-06	Quantity Surveyor 6.5 years of experience
G	MC-07	Project Manager 10 years of experience
H	MC-08	Quantity Surveyor 09 years of experience
I	MC-09	Quantity Surveyor 06 years of experience
J	MC-10	Quantity Surveyor 5.5 years of experience

4. DATA ANALYSIS AND RESEARCH FINDINGS

4.1 THE USE OF LABOUR SUBCONTRACTORS BY LARGE-SCALE CONTRACTORS IN SRI LANKA

In the initial step of studying current practices of labour subcontracting by large-scale main contractors, the interviewees were questioned about the usage of labour subcontractors for their construction projects and the type of work that they are employed for. By analysing the responses, it was discovered that labour subcontractors are hired for various types of work categories, as shown in Figure 1.

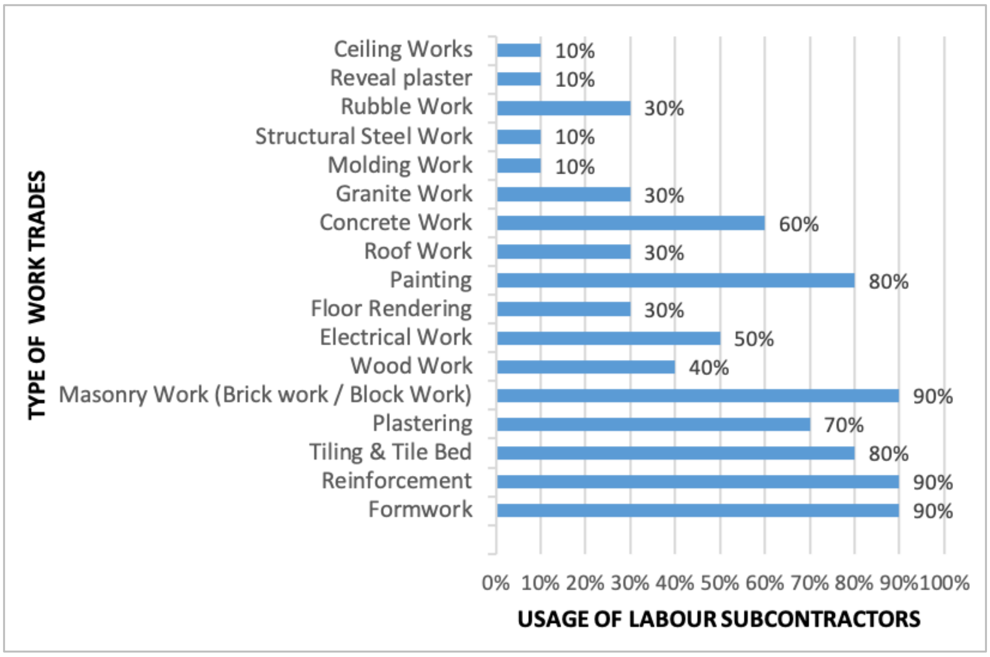

Figure 1: The use of labour subcontractors by large-scale contractors in Sri Lanka

As per Figure 1, labour subcontractors are used by 90% of CS1 and CS2 companies for formwork, reinforcing, and masonry work in their projects. Plastering, tiling, painting, concrete works and electrical works fall into the middle category, which employs labour subcontractors. When compared to the aforementioned, other work categories (woodwork, floor rendering, roof work, granite work, moulding work, structural steel work, rubble work, reveal plaster and ceiling work) involve less use of labour subcontractors among the CSI and CS2 contractors. The interviewees confirmed that the above-mentioned work trades are fully covered by the labour subcontractors on their construction sites. It backs up Azmy's (2012) and Kadan's (2016) assertion that main contractors heavily rely on labour subcontractors to complete their construction projects since it provides them with advanced benefits.

4.2 COMMON ISSUES ARISING BETWEEN MAIN CONTRACTOR AND LABOUR SUBCONTRACTORS AND THE IMPACTS OF THE ISSUES

The industry practitioners from the ten large-scale contracting organisations who are well-versed in labour subcontracting procedures were interviewed about the issues generally they have encountered while using labour subcontractors in their projects based on their experience with respect to the previous and ongoing construction projects. The interview results from 10 respondents were analysed manually for the purpose of identifying the common issues generally arising between the main contractor and the labour subcontractor when adopting labour subcontracting procedures. Codes were identified from the interview transcripts mainly under the themes of quality-related, payment-related, disciplinary-related, safety-related issues etc. Accordingly, the codes that were derived from the interviews include:

- Quality issues in the work
- Issues related to labourers' discipline
- Leaving the authorized scope of work without completion and prior notification
- Payment issues
- Migration of subcontractor's labourers
- Safety issues (Not following the safety guidelines and procedures)
- Drugs addictions
- Staling company's materials
- Unskilled labour representation within the labour subcontract group
- Workers' lack of continuous attendance at work (labourer absenteeism)
- Requesting money in advance before their bill is being processed
- Language problems
- Labour idling
- High material wastage

According to the results of the analysis of interviews, the majority of the respondents (09 companies out of 10) highlighted the practice of non-adherence of labour subcontractors to the safety guidelines and procedures imposed by the project. Therefore, they are prone to many accidents at the site. Most respondents emphasized that payments issues and labour subcontractors' leaving the authorized scope of work without completion and prior notification are major issues when dealing with labour subcontractors. Quality issues in the work and issues regarding labour discipline also fall into the above category.

- Furthermore, the interviewees were able to point out the resultant impacts of the issues associated with labour subcontracting. A summary of the impacts derived from the interviews is below:
- The need for rework on certain items

- Delays in project completion
- Project cost overruns
- Damage to the reputation of the company and the project staff
- Disputes with adjacent neighbours
- Damages to company properties
- Disputes arising between contract parties
- Increased demand for more workers than is actually required
- Increased need for more supervisors for monitoring labour subcontract works

According to the majority of respondents, the most significant negative effects on project time and cost include safety concerns, leaving the allowed scope of work without prior notification by labour subcontractors, payment challenges, and labourer absenteeism on a regular basis.

Being concurred with the above viewpoints, additionally MC-04 and MC-05 stated that "*the migration of the labour subcontractors and labour subcontractor's trends of fulfilling the required number of labourers within the site by recruiting unskilled labours, create progress issues and quality issues.*" Hence, it results in a low-quality product at the end of the project. It also badly affects the company name while resulting in delays because such unskilled workforces do require considerable time to get used to the system. Also, some completed work tends to require re-working due to the shortcomings of unskilled workers. On the other hand, such an unskilled labour force requires the main contractor to increase the number of supervisors to monitor the labour subcontractors' work and handle them as per the site rules and regulations. It also generates additional costs on the project and results in project cost overruns at the end.

According to the MC-03, "*most of the time, the labour subcontractors stop working halfway due to arguments or disputes between the contract parties that arise due to issues like payment problems, disciplinary problems, safety issues, etc.*"

As expressed by the majority of the respondents, the absence of a proper disciplinary code to follow for the labour subcontractors disturbs the peacefulness of the site and the project's progress. Hence, labourers' behaviour is not at a satisfactory level. In some circumstances, the main contractor had to report to the police or seek litigation measures through the courts to find solutions to the problems caused by the unethical behaviour of the subcontractors' labourers and settle the disputes between the contract parties and the third parties. Furthermore, the contractor's staff members have had to waste their valuable time solving those problems, creating additional cost on the project and a bad image of the organization within society.

4.3 THE USE OF BESPOKE LABOUR SUBCONTRACT AGREEMENTS AND THEIR DEFICIENCIES

The interviewees were questioned about the usage of labour subcontract agreements in their projects. It was discovered that all the main contractors in the CS1 and CS2 categories already use company-based bespoke labour subcontractor agreements for recruiting labour subcontractors, which is consistent with Mbachu's (2008) assertion that all subcontractors should enter into a contractual relationship with the main contractor. Having found that such bespoke agreements are in use by all the CS1 and CS2 organizations, copies of those agreements were obtained from each interviewee to analyse them to acquire a better understanding of the characteristics and identify the deficiencies in these agreements, which was considered to be the desk review of this study.

The desk review found that those labour subcontract agreements are available in Sinhala, English, and both languages, and Figure 2 describes the distribution of the use of language among the labour subcontract agreements by the different large-scale construction organisations in Sri Lanka.

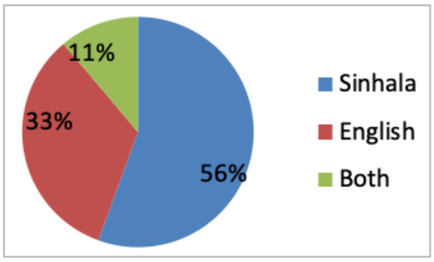

Figure 2: Languages used in labour subcontract agreements by Sri Lankan large-scale construction companies

Accordingly, it has been revealed that 56% of bespoke agreements of large contracting organizations within the Sri Lankan construction industry are based on the Sinhala language, while 33% of organizations use the English language. In addition, 11% use both languages for their labour subcontract agreements. Accordingly, it can be concluded that Sinhala is the preferred language by the main contractors in preparing subcontract agreements and there is no rule governing the use of language. Therefore, the contractors are using either Sinhala or English formats, although it leads to some understanding difficulties for the most labour subcontractors when the language is limited to English.

Aside from that, Table 2 depicts the coverage of areas within the company-based bespoke labour subcontractor agreements in Sri Lanka as revealed from the desk review.

Table 2: Key terms/clauses in company-based bespoke labour subcontractor agreements

Key terms/clauses	Company									
	A	B	C	D	E	F	G	H	I	J
Work scope	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Agreed rates and prices	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Defects of the works				✓	✓	✓		✓		
Material, tools & equipment		✓	✓	✓		✓		✓	✓	✓
Payment terms	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Contract termination	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Discipline at the site			✓		✓		✓	✓		
Services provided by the main contractor		✓	✓	✓		✓	✓	✓		
Penalties					✓		✓		✓	✓
Dispute managing			✓	✓		✓			✓	
Health and safety	✓	✓	✓	✓		✓	✓			✓
Retention clause	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Quality of the works	✓	✓					✓	✓	✓	

Key terms/clauses	Company									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
Rate of progress	✓			✓	✓			✓		
Laws and regulations	✓	✓	✓	✓		✓			✓	✓
Variations					✓	✓				✓
Insurance	✓									
Skill of the labour subcontractors	✓			✓			✓			✓

The desk review identified the key terms/clauses currently incorporated into the company-based bespoke labour subcontract agreements used by CS1 and CS2 organizations within the Sri Lankan construction industry. It was evident that different agreements cover different clauses where the majority of agreements include reasonable coverage of provisions within their labour subcontract agreements, while the others are limited to "a single page of agreement" with no attention to essential details and clauses.

As per Table 2, all the companies include a clause defining the assigned work scope, the agreed rates for the job, and the payment terms. The majority of organizations include terms/clauses in their agreements that benefit both parties, such as contract termination, health and safety, rules and regulations, retention, quality of work, services supplied by the main contractor, and the usage of materials, tools, and equipment. However, just a few have paid attention and added clauses regarding work faults, site discipline, penalties, and dispute resolution, as well as variations, rate of progress, and labour subcontractors' skills. In addition, only Company "A" had a clause on insurance, whereas the other companies failed to include it in their contracts.

In addition, the following gaps depicted in Figure 3 were identified from each company-based labour subcontract agreement through the desk review. These gaps were derived by comparing and contrasting the whole set of clauses in Table 2 with the actual coverage of clauses in each bespoke agreement.

By addressing the above-mentioned deficiencies in the existing company-based labour subcontract agreements, such as defects in the work, discipline at the site, health and safety, insurance, skill of the labour subcontractors, laws and regulations, penalties, and retention clauses, it is reasonable to presume that the issues generally arising between main contractors and labour subcontractors, such as quality issues, issues related to labourers' discipline, payment issues, leaving the authorized scope of work without completion, migration of subcontractor's labourers, unskilled labour representation within the labour subcontract group and penalties, are resolvable.

Hence, there is an exigent need to establish a comprehensive standard labour subcontract agreement that covers all the required clauses and provisions to mitigate the occurrence of common issues between main contractors and labour subcontractors.

5. CONCLUSIONS

This study provided an overview of the labour subcontracting practices and deficiencies in the bespoke labour subcontracting agreements within the CS1 and CS2 main contractors in the Sri Lankan construction industry. As far as labour subcontracting is concerned, it was identified that adopting non-standardized formats for forming labour subcontract agreements has been the common practice among large-scale contractors in Sri Lanka.

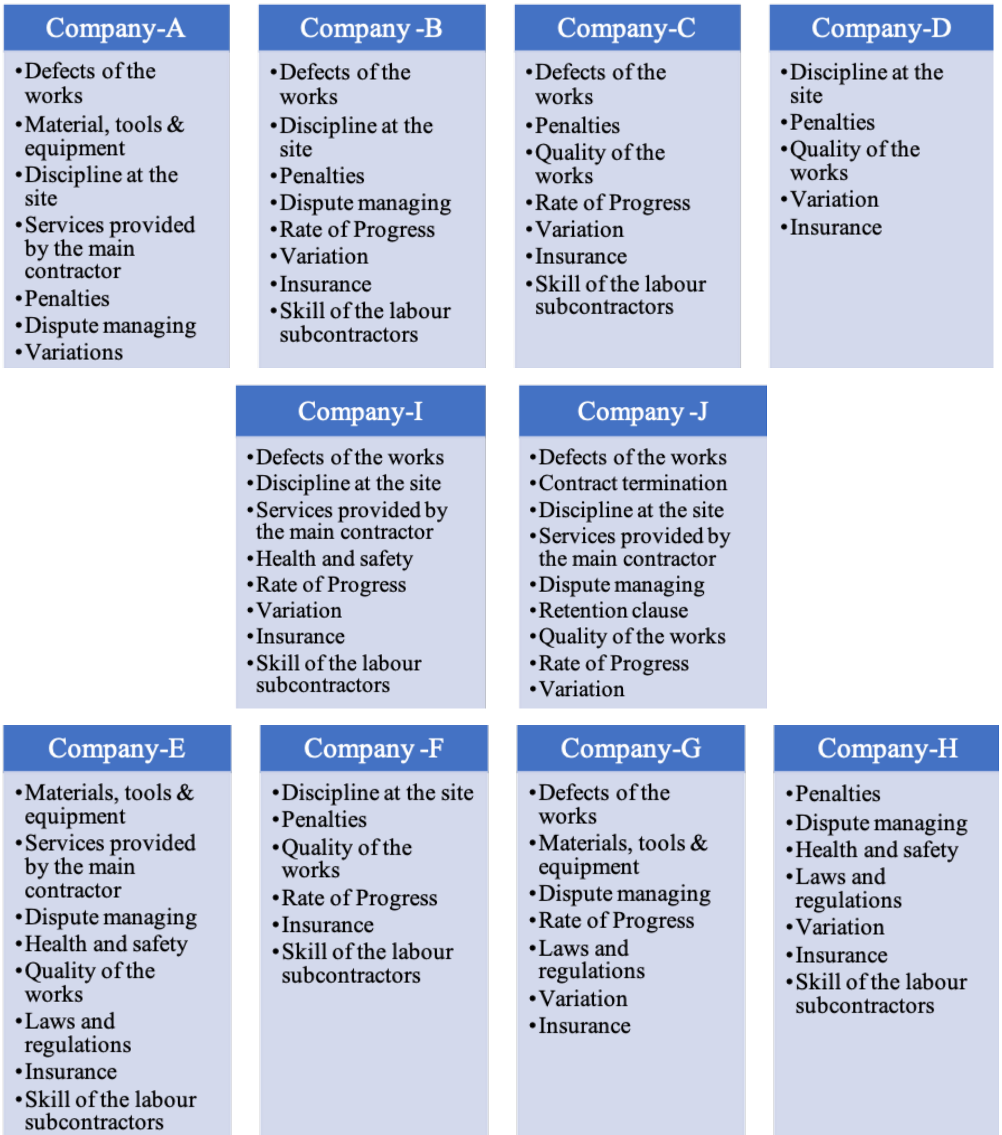

Figure 3: Deficiencies in currently used company-based labour subcontractor agreements

As a supplementary method of data collection, ten semi-structured interviews were conducted among ten CS1 and CS2 contracting organizations in Sri Lanka, which helped to identify the labour subcontracting practices in Sri Lanka along with common issues between the main contractor and the labour subcontractor. The various types of work that labour subcontractors are involved in under large-scale contractors' building projects include formwork, reinforcement, tiling, plastering, masonry work, wood works, electrical work, floor rendering, painting, roof work, concrete work, granite work, moulding work, structural steel work, rubble work, reveal plaster, and ceiling work. Furthermore, quality issues in the work, issues related to labour discipline, leaving the authorized scope of work without completion and prior notice, payment issues, migration of subcontractors' labourers, safety issues, delay in completing the authorized jobs, drug additions, stalling company materials, and unskilled labour representation within the labour subcontract group were revealed as the common issues between the main contractor and labour subcontractors.

Then a desk review was conducted for the purpose of identifying the terms/clauses as well as the deficiencies in the company-based bespoke labour subcontract agreements collected from CS1 and CS2 contractors. The assigned work scope, the agreed rates for the job, and the payment terms are the only clauses that all the companies have properly mentioned in their company-based agreements, while the others vary between the companies. Defects in the work, materials, tools and equipment, contract termination, discipline at the site, services provided by the main contractor, penalties, dispute management, health and safety, retention clause, quality of the work, rate of progress, laws and regulations, variations, insurance, and skills of the labour subcontractors were identified as the deficiencies in the company-based bespoke labour subcontract agreements.

Therefore, it is reasonable to state that there is a critical need for a comprehensive standard form of labour subcontract agreement to be developed for the Sri Lankan construction industry in order to minimize the conflict between parties and provide some important benefits to both labour subcontractor and the main contractor. The next phase of this research has continued to develop a comprehensive outline for a standard labour subcontract agreement for the Sri Lankan construction industry, which will be published in the near future.

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DEFINING A 'MATURITY MODEL' IN THE CONSTRUCTION CONTEXT: A SYSTEMATIC REVIEW

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ABSTRACT

A maturity model is critical in analysing an entity as it evaluates the current situation and provides insights on enhancing the capabilities to reach higher maturity. Maturity models are being used in many industries and proven to have a positive impact on organisational development. Definition of a context specific maturity model is vital as it brings clarity to the model identification and better understanding relevant for a respective industry. Even though several construction maturity models exist, a clear and a comprehensive definition is not noticeable. A comprehensive definition for maturity models in construction sector would assist industry stakeholders to understand the components and key areas of construction maturity. Consequently, it would provide accurate and impactful results for construction firms to achieve higher maturity levels. Thus, the main aim of this paper is to establish a new definition for construction maturity models. In the process, the methodology included a systematic literature review adopting PRISMA literature review method and a content analysis using thematic analysis. The study analysed fifteen construction maturity models and identified nine overarching themes which were fundamental in developing the definition. The proposed definition would facilitate a better understanding among end users of construction maturity models, and it would assist the readers to distinguish it from other various models. Therefore, the derived definition would promote application of the concept of construction maturity in the industry. Further research could be conducted for diverse types of construction to enhance the effectiveness of the maturity models.

Keywords: *Construction Maturity; Maturity Models; PRISMA; Systematic Review.*

1. INTRODUCTION

Maturity models (MMs) describe gradual improvement paths toward the development of good practices, to the point of achieving a desirable state in any organization (Lacerda and Wangenheim, 2018). Maturity also explains what the higher levels can be achieved and therefore it enables to identify shortcomings and ways to correct or preclude (Schlichter, 1999). MMs are significant as they assist organisations to understand their existing capabilities and provide a systematic pathway to improve organisation's capabilities to reach higher maturity levels (Facchini, et al., 2020). Moreover, a maturity

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model is vital for organisations related to construction as it provides ability to reach the desired strategic position by continuously improving its desired outputs in a predictable, controllable and a reliable manner (Machado, et al., 2021). MMs in Information Technology (IT), Continuous improvement and Software development sectors have presented comprehensive definitions (Software Engineering Institute , 2006; Liu and Zhang, 2019). On the other hand, majority of maturity models relevant for construction sector are an extension of conventional maturity models thus, there is a lack in comprehensive and construction specific definitions. For example, maturity models like Construction supply chain maturity model (CSCMM), Construction industry macro maturity model (CIM3), Standardised Process Improvement for Construction Enterprises (SPICE), Change Management Maturity Model (CM3) are all based on the Capability maturity model (CMM) (Nesensohn, et al., 2015). Since these models are developed based on the CMM, they lack comprehensive and industry specific definitions (Finnemore and Sarshar, 2002; Vaidyanathan and Howell, 2007; Sun, Vidalakis and Oza, 2009; Willis and Rankin, 2012).

In the search of definitions, Capability maturity model integrated (CMMI) which is the upgraded version of CMM, provides a comprehensive definition. CMMI defines itself as a model with proven set of best practices organized by critical business capabilities which improve business performance. It is designed to be understandable, accessible, flexible, and integrate with other methodologies such as agile (Software Engineering Institute, 2006). The definition provides a detailed idea covering all the related aspects. Similarly, MMs in software development sector like Capability Maturity Model (CMM) (Brotby, 2009), MMs in service industry like Logistics 4.0 Maturity in Service Industry (Werner-Lewandowska and Kosacka-Olejnik, 2019) or Maturity model for product development information (Sinnwell, Siedler and Aurich, 2019) have defined and outlined the models which are specifically catered for the respective industries. Even though there are definitions in MMs in industries like manufacturing and IT, such definitions do not fully comply to construction firms since the industries have fundamental differences. Since factors like nature of the final product, time factor, variations and attention on defects are fundamentally different in manufacturing and construction, it is not viable to adapt a manufacturing or IT related maturity model definition in its original form to a construction maturity (Fernández-solís, 2008). However, construction industry has been using several project management maturity models in their practices but there is a dearth of literature specifically in construction maturity model definitions. This is evidenced by analysing models like Project Management Process Maturity Model (PM)2, where project management attributes were taken in to consideration however, the model does not define its parameters nor a clear definition was provided specifically relevant for construction (Kwak and Ibbs, 2002). In Sri Lankan context also, there is a deficiency in literature trying to define a construction maturity model. Therefore, considering the construction industry, there is a clear need to establish a comprehensive maturity model definition as it directly assists to comprehend and enhance the maturity in construction sector.

There are models that provide definitions which can be related to construction sector to a certain context. Models which provide a reasonable idea about a definition, i.e. Berkley Project Management Process Maturity Model (Kwak and Ibbs, 2000), Portfolio, Programme and Project Management Maturity Model (Office of Government Commerce (OGC), 2010), Project Management Process Maturity Model (Kwak and Ibbs, 2002) are more concerned on definitions which are suitable for any industry relative to project management but not specifically rendered the construction industry, Therefore, it is difficult to identify a definition for the construction related maturity models. Inversely, some available models provide definitions that are only relevant for a specific, narrowed down area itself, however not in the context of construction. For example, Off-site construction readiness maturity model is only concerned in offsite construction related practices (Bendi, et al., 2021). Therefore, considering the lack of a construction maturity model definition, the study attempts to contribute to the body of knowledge on construction maturity models by reviewing the literature carried out by various scholars and by generating a definition for construction related maturity models.

The aim of this paper is to propose a definition for the construction maturity models. The paper starts with an introduction and followed by a comprehensive systematic literature review using the PRISMA systematic review method on existing maturity models and their definitions. Next, the research method, comprising of data collection techniques, is explained. Then the data collected from literature would be presented and analysed through a thematic analysis in order to identify the themes in developing the definition for construction maturity model. Finally, the findings would be discussed and the final definition for construction maturity model is presented. The research is significant as it contributes to the body of knowledge of construction maturity models and therefore will promote the application of construction maturity in the construction industry.

2. LITERATURE SYNTHESIS

Maturity Models originated within the practices of Total Quality Management systems where the continuous improvement is considered a main aspect through analysing the current status and the capabilities of the organisation compared to the future goals (Brookes and Clark, 2009). CMM is considered one of the prominent maturity models which was initially developed with the goal of improving software process and later, due to the success of the model, US defence department and other entities adapted it (Nesensohn, et al., 2015). With the success of the maturity models mainly in software development, other industries like manufacturing management and IT, adopted maturity models to enhance their business capabilities (Santos-Neto and Costa, 2019). Currently, the maturity models have been extended to different domains such as education, health, energy, finance, construction, industrial sector, government and general use (Tocto-cano, et al., 2020).

In defining maturity models, it is imperative to comprehend the idea behind the word "maturity". As per the Oxford English Dictionary (2021) maturity means the state of being fully grown or developed and this can be designated to a person, organisation, plant or for a principle even. The maturity itself defines the idea that how advanced or ripened any entity is. A maturity model can be defined as a tool with structured set of elements that describes and progressive path towards improvement from immature processes to mature and effective processes (Facchini, et al., 2020). A maturity model mainly facilitates a pathway or rather a framework which benchmarks and improve the performance on a continuous scale (Demir and Kocabaş, 2010). Maturity models help organisations to critically analyse their activities and identify the inefficiencies that halts organisation from achieving their objectives. The basis of the maturity model is the fact the people, organisation, functional areas, process etc. could evolve and develop through a process of growth to an advanced or enhanced maturity level (Vásquez, et al., 2021).

In compare and contrast of maturity models relating to construction industry, it is visible that a considerable number of models have similarities. A noticeable similarity is belongingness to the CMM family. Models like CSCMM, Organisational Project Management Maturity Model (OPM3), Berkley Project Management Process Maturity Model, CIM3, SPICE, CM3, Portfolio, Programme and Project Management Maturity Model (P3M3) all are developed considering CMM as a fundament (Eadie, Perera and Heaney, 2011). On the contrary, a model like Off-site construction readiness maturity model has followed a different approach where it is developed using empirical studies to suite specifically offsite construction (Bendi, et al., 2021). Another fact that is seemed to be common is having distinct maturity levels and the idea is visible in analysing their respective definitions as well. On the same note important aspect is that, most of these models provide a gradual and progressive pathway towards higher maturity assisting organisations to grow (Khoshgoftar and Osman, 2009). Maturity models are beneficial in many ways for organisational enhancement as emphasised by several scholars. Maturity Model can be equipped as a tool assisting organisations to analyse their core areas with their existing capabilities (Silva, et al., 2021). Creating awareness of current situation and discovering potentials and requirements for improvement (Wendler, 2012), providing directions and actions of improvement and evaluating complexities and areas of improvement to a new cultural change (Pennypacker, 2005), analysing strengths and weaknesses to plan out the transformations (Perkins, et al., 2010), serving as reference point or benchmark to implement a change or improvement approach in a systematic and well-directed way (Cooke-Davies, 2007), providing the platform to a common communicating tool (Klimko, 2001), embedding change through cultural excellence and sustained embedment of business processes (Eadie, Perera and Heaney, 2011) are few highlights of the benefits of maturity models.

There are numerous MMs related to construction sector that are being used in the industry for a reasonable time. The term maturity is being used in several sectors and provide different definitions. In the field of management, maturity is an idea that explains the progressive improvement in project management systems and processes that can be used to assess an organization's capabilities and to provide an improvement path (Pennypacker, 2001). In the field of IT and software development, the idea of maturity stands off as a process management device which streamline all the procedure (Tocto-cano, et al., 2020) indicating that maturity models and their definitions tend to be industry specific. On the same note since construction industry is unique and different to other industries in technological, economic, cultural aspects, same definitions of other industries would not be compatible to construction. This suggests the idea that even though there are fundamental similarities in maturity models, their definitions vary and provide different meaning considering the context. Therefore, there is a clear need to research on the area of construction maturity models to develop a definition for construction maturity models.

3. METHODOLOGY

A comprehensive literature review helps gaining valuable insights from the prior studies carried out through analysing and understanding of the respective subjects (Saunders, Lewis and Thornhill, 2016). Systematic reviews such as PRISMA are rigorous studies used to collate all available evidence that conforms to a predefined set of eligibility criteria, to address a specific matter of interest (Sohrabi, et al., 2021). A systematic review collects all possible studies related to a given topic and design, and reviews and analyses their results (Ahn and Kang, 2018). Adopting a method like PRISMA is ideal for literature review since it captures all relevant evidence as it provides check lists which covers all the relevant aspects related to the area of research (Page, et al., 2021). Therefore, the study adopted the PRISMA systematic review in search of the relevant literature for the study. One crucial component of a systematic review is the literature search. The literature search, or information retrieval process, not only informs the results of a systematic review; it is the underlying process that establishes the data available for analysis (Rethlefsen, et al., 2021). Figure 1 illustrates the research process followed.

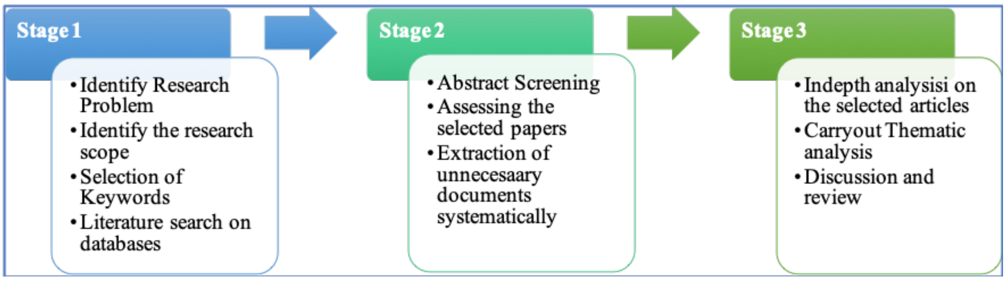

Figure 1: PRISMA Research Process

As shown in Figure 1, the study was carried out in 3 main stages. Firstly, key words were determined for the search which are imperative for the systematic search as shown in Figure 2. To begin with, the authors selected 175 articles from a scientific data search from leading databases. The three main data bases used for the study were ‘Science Direct, Google Scholar and Emarald Insight.

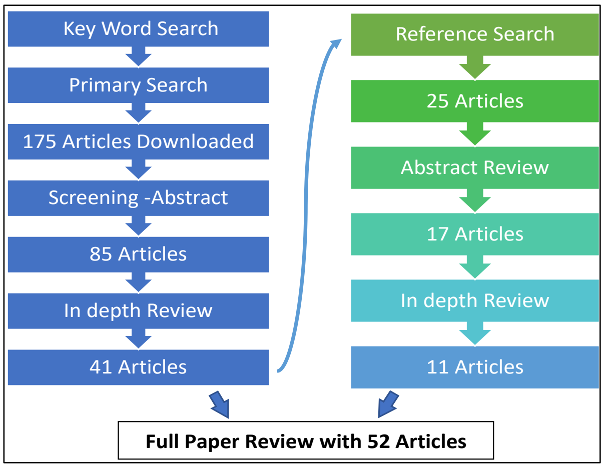

Figure 2: Stages of Prisma Systematic Literature Review

After identifying the key words *(Maturity, Maturity Models, Modern Maturity Models, Construction Maturity, Construction Maturity Models, Project Management Maturity Models, Construction Management Maturity Models, AEC industry maturity model),* 175 articles were discovered through PRISMA systematic analysis. Subsequently, the articles were screened through the abstract as an initial collection. 85 articles were stored and later these articles were critically analysed for further screening. From those, 41 articles were selected as directly relevant for the study and used for the review. Furthermore, 25 articles were further identified through the references from the selected 41 articles. Similarly, they were firstly screened from the abstract and later comprehensively screened and reduced to 11 articles. Ultimately 52 articles were selected for the final review and analysis of the study. The study scrutinised 15 maturity models that were selected according to the two main criteria of 1) relevancy for construction sector and 2) visibility of basic concepts of a definition of a maturity model.

4. FINDINGS

4.1 THE IDENTIFIED MATURITY MODELS

Through the PRISMA systematic literature review conducted, 15 maturity models were identified as appropriate and directly relevant for the discussion and presented them in Table 1. These models were selected after rigorously following the PRISMA review and identifying the models which fulfilled the two criteria mentioned in Methodology section. Further, the definitions of the identified models were determined as direct definitions and derived definitions as shown in Table 1.

Table 1: Maturity models

Key Model	Direct Definition	Derived Definition	Related Industry
1	✓		IT/Adopted for Construction related MMs
2	✓		IT/Construction
3		✓	Construction
4		✓	Construction/Project Management
5	✓		Construction/Project Management
6		✓	Construction/Project Management
7	✓		Construction/Project Management
8		✓	Construction
9		✓	Construction/Project Management
10		✓	Construction/Project Management
11		✓	Construction/Project Management
12	✓		Construction/Project Management
13		✓	Construction/Project Management
14		✓	Lean Construction
15		✓	Construction/Project Management

[1]CMM, [2] CMMI, [3] Standardised Process Improvement for Construction Enterprises (SPICE), [4] Change Management Maturity Model (CM3), [5] Organizational Project Management Maturity Model (OPM3), [6]Maturity Assessment Grid (MAG) from the Strategic Forum for Construction, [7] Projects In Controlled Environments off-site construction readiness maturity model (PRINCE2), [8] Off-site construction readiness maturity model, [9] OMG Business process maturity model (BPMM), [10] Construction supply chain maturity model CSCMM, [11] construction industry macro maturity model (CIM3), [12]Berkley Project Management Process Maturity Model, [13] Portfolio, Programme and Project Management Maturity Model -P3M3, [14]Lean Construction Maturity Model (LCMM), [15] Project Management Process Maturity Model (PM)2

Above listed fifteen MMs were taken for consideration in developing a definition for the construction maturity models and methodical of presentation of data collected from the systematic literature review are summarised in Table 2.

Table 2: Analysis of maturity model definitions

Key Maturity Model	Direct Definition	Derived Definition	Source
Capability Maturity Model (CMM)	A reference [process] model of mature practices in a specified discipline, used to improve and appraise a **group's capability** to perform that discipline		(Brotby, 2009)
Capability Maturity Model Integrated (CMMI)	CMMI model is a proven set of best practices organized by critical business capabilities which improve **business performance**. It is designed to be **understandable, accessible, flexible**, and integrate with other methodologies such as agile.		(Software Engineering Institute, 2006)
Standardised Process Improvement for Construction Enterprises (SPICE)		SPICE provides an **evolutionary framework** for **business process improvement** and also an **assessment tool** for organisational maturity	(Hutchinson and Finnemore, 1999; Finnemore and Sarshar, 2002)
Change Management Maturity Model (CM3)		CM3 defines **five levels of maturity** – ad hoc, informal, systematic, integrated, and continuous improvement. Measurement is carried out on six key **process areas** – management process, risk management, communication, management information, collaboration, and leadership/objectives.	(Sun, Vidalakis and Oza, 2009)
Organizational Project Management Maturity Model (OPM3)	OPM3 is **a standard to understand and measure organisational** project management maturity against a comprehensive and broad-based set of organisational project management **Best Practices**"		(Project Management Institute (PMI), 2003)
Maturity Assessment Grid (MAG) from the Strategic Forum for Construction		MAG measures **cultural maturity** and to guide both individuals and an organisation in how to introduce a **change of culture** and behaviours towards better 'integration' within the **construction industry**	(Strategic Forum for Construction (SFC), 2003).

Projects IN Controlled Environments (PRINCE2)	PRINCE2 is a standard provides a framework which organizations can assess their current adoption of the PRINCE2 project management method and put in place **improvement plans** with measurable outcomes based on **industry best practices.**		(Williams, 2010))
Off-site construction readiness maturity model		A **structured process** to enable organisations to **assess** their Off-Site Construction readiness in the market enabling to **evaluate and benchmark processes** through the strategic and operational phases. The maturity model identifies the areas of concern and the scope for further **development or change to secure the optimal** advantage of Off-Site Construction methods.	(Bendi, et al., 2021)
OMG's business process maturity model (BPMM)		The BPMM is a **process** model by itself, or it can be used as a **framework for improvement** efforts based on other models. It is containing of **five maturity levels and 30 process areas**	(Gardiner, Weber and Curtis, 2008)
Construction supply chain maturity model (CSCMM)		Provides a **framework** to both assess where a company is today along the **maturity curve**, and how they can go to more **advanced maturity levels**. It integrates the efforts of the various efforts of the tool vendors, process experts, and interoperability research and allows for companies to adopt some or all of them as part of their strategy	(Vaidyanathan and Howell, 2007)
Construction industry macro maturity model (CIM3)		A **structured model**, providing leading indicators of project performance, providing a context in which to interpret project performance; enable comparisons between various regions; and provide **guidance with respect to construction industry performance improvement initiatives**	(Willis and Rankin, 2012)
Berkley Project Management Process Maturity Model	A **fully integrated maturity** model to measure, locate and compare an organisations' **current** project **management** level in a **systematic and an incremental approach**.		(Kwak and Ibbs, 2000)
Portfolio, Programme and Project		A **structured model** with **Maturity Levels**, Process Perspectives and **Attributes** providing a snapshot of **where an organisation is now** with	(Office of Government

Management Maturity Model (P3M3)	respect to any of the Process Perspectives in all or any of their portfolio, programme, and project management capabilities. Further providing, **knowledge of where the organization needs or wants to be in the future**, offers the basis for an improvement plan to be devised and for progress towards the target to be tracked.	Commerce (OGC), 2010)
Lean Construction Maturity Model (LCMM)	LCMM provides organisations with crucial information of their **current position in the maturation process** ("in the fog"). Furthermore, the LCMM provides **businesses a tool** to plan and direct organisations with **support and guidance** in their LC **maturation Process and embedded change**	(Nesensohn, et al., 2015)
Project Management Process Maturity Model (PM)2	(PM)2 model provides a means for **identifying and measuring** different PM levels by integrating nine PM knowledge areas with five **project processes** under a quantified scheme. It is well suited to assess an organizational **project management level**	(Kwak and Ibbs, 2002)

Through the systematic literature review, 15 key models were identified for further examination, which fitted the criteria, as they were directly relevant for the scope of the study as well as considering the value given by the previous scholars. The identified models were further analysed using the thematic analysis method and the findings of the analysis are discussed in the following section.

4.2 IDENTIFYING THE KEY THEMES AND WORDINGS

The paper studied fifteen maturity models which are identified through the systematic literature review. Subsequently, the identified models were critically analysed using a thematic analysis method. Thematic analysis is identified as a method of identifying, analysing, and reporting patterns (themes) within data (Braun and Clarke, 2008). Thematic analysis is commonly adopted in situations where wide variety of data is available (Castleberry and Nolen, 2018). Since there were variety of data the study requires analysing data of various themes thus, a thematic analysis was carried out in order to identify the overarching themes and wordings in developing the definition for the construction maturity.

The thematic analysis identified nine key themes and wordings as shown in Figure 3, that are critically important in defining a maturity model which is catered for the construction sector. Figure 3 shows the frequency of the themes evidence in the elected maturity models of the study.

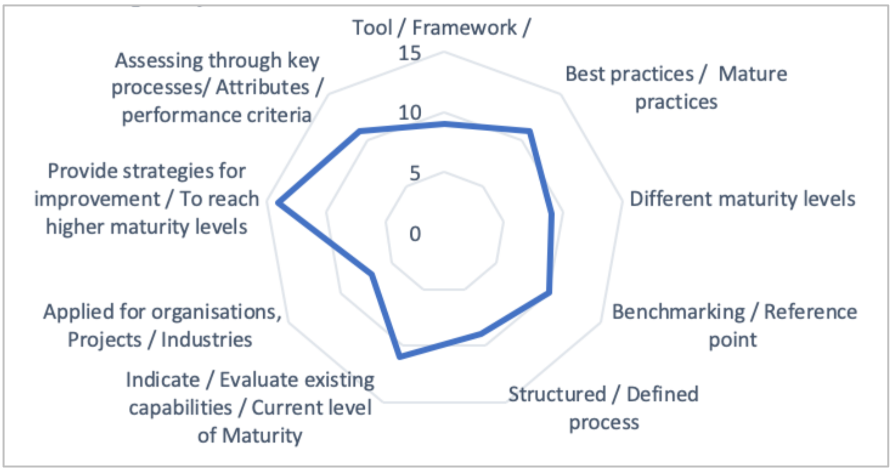

Figure 3: Identified themes from existing maturity models

As Table 2 portrays many themes were identified through analysing the definitions. The identified key themes and words are bolded in Table 2. Since several wordings and themes were identified a frequency analysis was carried out to group and summarise the identified themes and wordings which have similar meaning. This allows to comprehend all the key aspects related to each individual model and aggregate them under overarching themes. Accordingly, nine overarching themes and wordings were identified as imperative to the proposed definition as shown in Figure 3. Analysis of the themes and words clearly depict that all the models have identified these nine key overarching themes as important in defining the models. Therefore, each of these themes were considered in the proposed construction maturity model definition. A critical analysis of how each of these themes were used in developing the new definition is explained step by step next.

In defining construction related maturity models, many models are defined as tools that consist of a framework including construction industry related performance criteria and related attributes. SPICE (Finnemore and Sarshar, 2002; Hutchinson and Finnemore, 1999), PRINCE2 (Williams, 2010), BPMM (Gardiner, et al., 2008), CSCMM (Vaidyanathan and Howell, 2007) evidence throughout the analysis that the idea of a framework is crucial in defining the model.

> *"A construction maturity model is a tool with a defined framework consisting of construction related performance criteria and attributes……."*

A considerable number of models investigated in the study have used the word 'process' or similar interest of a process in defining the models. Models like SPICE, CMM, CMMI, CM3, OCRMM, BPMM, CSCMM, P3M3, (PM)2, have used the theme of a process in defining the respective models. Several authors (Bendi, et al., 2021; Willis and Rankin, 2012; OGC, 2010), in defining the respective models, OCRMM, CIM3, P3M3 have indicated that models have to be structured in order to provide uniformity in the evaluating process.

> *"A construction maturity model is a tool with a defined framework consisting of construction related performance criteria and attributes providing a structured process………."*

Most of the models investigated directly or indirectly embraced the idea of 'evaluating and indicating' suggesting that the models assist to investigate and measure the current level of capabilities. It is evidenced in most of the definitions. For instance, CSCMM (Vaidyanathan and Howell, 2007) defines, '……. a framework to both assesses where a company is today along the….'. This idea is highly relevant for maturity models as prior for higher development it is crucial for entities to understand the current level.

> *"A construction maturity model is a tool with a defined framework consisting of construction related performance criteria and attributes providing a structured process offering indicators of the existing capabilities…………."*

A key theme highlighted in defining the maturity models was the idea of distinct levels of maturity in their respective fields. CM3 - The model defines five levels of maturity – ad hoc, informal, systematic, integrated and continuous improvement (Sun, Vidalakis and Oza, 2009). Further OMG'S business process maturity model in defining itself stresses that BPMM is a process model containing of five maturity levels and 30 process areas (Gardiner, Weber and Curtis, 2008).

On a different note, to where the model should be applied was not clearly indicated. Several models indicated that the model could be utilised to assess organisations or an entire industry (Bendi, et al., 2021; Vaidyanathan and Howell, 2007 ; SFC, 2003). On the contrary, some of the models have declared that the application is suitable only on project-based works (Willis and Rankin, 2012). Therefore, to cover all the aspects of construction it is vital to incorporate both these entities into the definition of the model.

> *"A construction maturity model is a tool with a defined framework consisting of construction related performance criteria and attributes providing a structured process offering indicators of the existing capabilities of an organisation / project through evaluating the current level of maturity………."*

In the definitions of the models, it is evident that the future state of the organisation is also considered with respect to what the particular entity intends to achieve. P3M3 elaborates in its definition that the model would provide, knowledge of where the organization needs or wants to be in the future and offers the basis for an improvement plan to be devised (OGC, 2010). Fostering the idea further, the models provide areas for further development and enhancement by comparing the existing practices of the organisation with benchmarked best practices in the industry (Vaidyanathan and Howell, 2007).

Thus, considering these themes and ideas which were supported by the studied models, the final definition of the model is presented as below.

> *"A construction maturity model is a tool with a defined framework consisting of construction related performance criteria and attributes providing a structured process, offering indicators of the existing capabilities of an organisation / project through evaluating the current level of maturity and providing strategies for further improvement through industry best practices to reach higher maturity levels by comparing the existing level to the desired level."*

The proposed definition covers the essential areas identified though models and provide a more holistic and in-depth definition which can be used in in the construction sector with a more pragmatic approach.

5. DISCUSSION

The definition developed for construction maturity mod1el is fundamentally established through identifying the key themes discovered among the reviewed fifteen maturity models proving that there are substantial similarities among them. However, the final model definition has modest variations from few of the models. For instance, A key model like Maturity Assessment Grid from the Strategic Forum for Construction (SFC, 2003), mainly focuses on the premise of cultural maturity. The definition of the said model clearly outlines that it emphasises how the cultural differences to be managed through various means. Whereas the new model definition explains about a broader theme of evaluating current self and reaching for higher maturity. Moreover, models like Off-site construction readiness maturity model (Bendi, et al., 2021), are defined to address a very specific part of construction. On the contrary the newly founded definition for construction maturity model covers the full spectrum of the construction sector.

Evaluating models and their definitions contemplating to other industries apart from construction industry, there are notable differences. A model which initially measured only the capability of software, CMM, defines maturity as Software process maturity is the extent to which a specific process is explicitly defined, managed, measured, controlled, and effective (Fraser, Moultrie and Gregory, 2022). The fact is that the definitions is mainly focusses on the process itself only. In contrast, the construction maturity model definition considers not only the practices but the entire lifecycle of a construction procedure. It is important to note that even though there are differences in the model definitions, several similarities exist as well. Existence of distinct maturity levels, consideration of evolutionary pathways and guidance for improvement (Issa, et al., 2018; Stachowiak and Oleśków-Szłapka, 2018; Werner-Lewandowska and Kosacka-Olejnik, 2019) are key similarities observed in definitions.

6. CONCLUSIONS

The necessity for a comprehensive definition for maturity models in the construction sector was identified after recognising the absence of such a definition. Thus, the aim of the study was to propose a new definition to construction maturity models. A systematic literature review was carried out in identifying the existing models that assisted establishing the new definition using PRISMA systematic analysis. Fifteen models which have a direct relationship to construction sector were identified during the process. Later a thematic analysis was conducted in order to identify the overarching themes in determining the definition from the said models. Through the analysis, nine key themes were developed and wordings were extracted from existing maturity models and finally, a comprehensive definition was proposed. The key idea behind the developed definition is that the model should provide a systematic, structured set of guidelines to analysis the existing strengths and weaknesses of the point of interest and to provide an evolutionary guide for improving the current maturity level.

The impact of the study is twofold. From a theorical perspective this study contributes to the existing knowledge base of construction maturity models by establishing a more specific definition to construction maturity. Further it provides a platform for future studies on maturity models. From an industry perspective, the proposed model definition enables organisations in construction sector to comprehend what construction maturity means and it enables firms to evaluate themselves in the interest of maturity and improve. Moreover, it enables organisations to conduct industry specific and relevant maturity evaluations in order to get more accurate and impactful results to reach higher maturity levels. The scope of the research was limited to maturity models related only to construction and construction related sectors. Future research can be conducted in customising the definition for diverse types of constructions as well as for novel industries in developing industry specific models.

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DEFINING CRITICAL INFRASTRUCTURE FOR SRI LANKA

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ABSTRACT

In the last few decades, infrastructure has played a major role in supporting modern society. Moreover, there has been an increase in natural and human-induced disasters worldwide. In these situations, securing infrastructure is a major requirement. Confusion and misinformation can result if the boundaries of what constitutes critical infrastructure for a country are not clearly defined. Identification of critical infrastructure is the first step in the process of securing and protecting the available critical assets. This study aims to establish the infrastructure that can be classified as "critical infrastructure" in Sri Lanka. This includes establishing a clear margin for subsectors that fall within and operate within critical infrastructure and, consequently, ascertaining a clear definition for the critical infrastructure of the nation.

This study adopted a mixed-method approach, which included an initial comprehensive literature analysis on infrastructure and the parameters involved in determining the criticality of infrastructure. Secondly, a questionnaire and semi-structured interviews were conducted to determine which infrastructure sectors would be most critical to Sri Lanka. The most significant infrastructures with the parameters of national security, economic sustainability, quality of life, public health, and safety, the criticality of infrastructure were ranked in both pre- and post-disaster scenarios, and an appropriate margin for the Sri Lankan critical infrastructure was demonstrated. The emergency services sector was found to have the most significant infrastructure in both pre- and post-disaster situations. Accordingly, the study reveals emergency services, water, energy, transportation, telecommunication, and finance as the critical infrastructures for Sri Lanka.

Keywords: *Criticality of Infrastructure; Infrastructure; Parameters of Criticality; Pre- and Post-Disaster.*

1. INTRODUCTION

The quality of a nation's infrastructure is one of the foundations of its rate of growth and the living standards of its people. Infrastructure strengthens and drives the economy, creates jobs, and acts as a key enabler for future economic development and rising living standards across the whole country (Peerenboom, et al., 2001). In general, the term "infrastructure" refers to the sufficiency of a country's public works. However, the term "Critical Infrastructure" can be broadly defined as the systems, assets, facilities, and networks that provide essential services and are necessary for the national security,

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economic security, prosperity, and health and safety of their respective nations (New Zealand Treasury, 2014).

They ensure important social functions. Access to and availability of critical infrastructure varies from country to country. In Sri Lanka, none of the ruling governments in history so far has been able to specify which infrastructure could be considered critical, as opposed to countries such as Canada, the USA, the United Kingdom, and Australia, which have clearly specified infrastructure that is “critical” and further their sub-areas too. Failure or destruction of that infrastructure has severe effects on the health, security, or economic and social wellbeing of the population or the functioning of governmental institutions (Critical Infrastructure - CIPedia, 2022.).

Moreover, in the last few decades, there has been an alarming increase in natural and human-induced disasters worldwide. Most of these disasters affect infrastructure and cause chaos. A minor damage can be a cause of a catastrophic danger to a country. With all these glaringly dangerous situations, securing infrastructure has been a critical requirement. Identification of critical infrastructure is the first step in the process of securing and protecting the available critical assets. Thus, having a definite idea of the critical infrastructure can ensure our nation’s security. Therefore, this article aims to establish the infrastructure that can be classified as “critical infrastructure” in Sri Lanka.

It involves establishing a clear margin within which critical infrastructures can operate and, consequently, ascertaining a clear definition for the critical infrastructure of the nation.

2. LITERATURE REVIEW

2.1 OVERVIEW OF CRITICAL INFRASTRUCTURES

Modern society heavily depends upon critical infrastructure networks that cater to essential services (Puuska, et al., 2018). There are numerous definitions of the term "critical infrastructure". All these definitions ultimately describe assets that provide resources or services that have a compelling impact on societal functions (Lewis and Petit, 2019). According to Wiley (2021), "critical infrastructure" is a body of systems, networks, and assets that are essential to the continued operation of a nation, its economy, and public health and safety. Critical infrastructure systems can comprise an array of services such as water, wastewater, telecommunications, power, and transportation (road, rail, airport, port) (Brown, et al., 2017).

Nevertheless, when exploring extant literature and government publications, it is evident that Sri Lanka has been unable to define its critical infrastructure yet. Regulation of critical infrastructure is essential in every country to develop legal governance regimes. According to Harašta (2018), without clearly defined boundaries on what constitutes critical infrastructure at the national level, the focus on protecting the infrastructures would be burdensome and incomplete. Further, defining critical infrastructures is vital to a nation because it alters the responsibility and management of public funds and the method of identifying the infrastructures (Harašta, 2018). In Sri Lanka, the Essential Public Services Act. No 61 of 1979 has stated that in the event of a disaster, any service which would be named as essential at that time would be considered as critical for that particular time period. This may lead to a risk of the criticality of a particular infrastructure being misinterpreted for political advantage, mismanagement of public funds, etc. Thus, the country is vulnerable to exploitation.

Furthermore, defining the boundaries of critical infrastructure is another critical but difficult task, mainly because of the interdependencies of infrastructure. Infrastructure interdependency can be defined as a bidirectional relationship between two assets in which the operations of both assets affect each other (Lewis and Petit, 2019). According to Peerenboom, et al. (2001), interdependencies can be differentiated into four classes based on natural resource transit between the systems and by the level of interactions as physical, geographic, logical, and cyber interdependencies. So, the boundaries are difficult to define in some cases.

2.2 COUNTRIES WITH RECOGNIZED CRITICAL INFRASTRUCTURES

Different countries have recognized critical infrastructure suitable for their needs and contexts. For example, the US government has identified seventeen critical infrastructures, namely: agriculture and food, water, public health, emergency services, government, defence, information and telecommunications, banking and finance, energy, transportation, chemical industry and hazardous materials, postal and shipping, national monuments and icons, and critical manufacturing etc (Harašta, 2018). In Canada, ten critical infrastructures have been identified as critical, namely, energy and utilities, communication and information technology, finance, health care, food, water, transportation, safety, government, and manufacturing (Malalgoda and Amaratunga, 2015). Table 1 illustrates a comparison of the recognized critical infrastructures of four countries.

Table 1: Critical infrastructure sectors and the countries

Infrastructure Sectors	**Countries**			
	A	**B**	**C**	**D**
Water Sector	√	√	√	√
Transportation Sector	√	√	√	√
Energy Sector	√	√	√	√
Telecommunication Sector	√	√	√	√
Finance Sector	√	√	√	√
Armed Forces	√	√	√	
Health Sector	√	√	√	√
Manufacturing Sector	√	√		
Chemical Sector		√	√	
National Monuments		√		

Canada, B-USA, C-United Kingdom, D-Australia

As per Table 1, water, transportation, energy, telecommunication, finance, health, and armed forces sectors were considered critical by almost all four countries. The infrastructure common to these four countries was used as the basis for the questionnaire and the interview. Furthermore, out of the 17 sectors in the USA, only the sectors that are directly relevant to Sri Lanka were taken into consideration in this research. This is because, as a developing nation, some of the sectors are not relevant to Sri Lanka (e.g., nuclear reactors, materials and waste sector).

2.3 PARAMETERS USED IN RECOGNIZING CRITICAL INFRASTRUCTURE

It is essential that clear boundaries are set when defining critical infrastructure for which various parameters are used by other countries. Table 2 illustrates a comparison of those parameters used by other countries. Definitions of critical infrastructure from both developed and developing countries have been considered in the preparation of Table 2.

Table 2: Parameters used to define critical infrastructure

Respective Countries/Organizations	Parameters						
	A	B	C	D	E	F	G
European Union	√	√	√	√			
NATO (North Atlantic Treaty Organization)	√	√	√	√	√	√	
Australia	√	√	√				
Austria	√	√	√	√			
Belgium	√	√	√	√			
Brazil	√	√	√				
Canada	√	√	√	√			
Germany	√	√		√			
United Kingdom	√	√	√	√			
New Zealand		√		√			√
Ethiopia		√		√			
India	√	√		√		√	
Pakistan	√	√		√			

A-Economic Sustainability, B- National Security, C- Quality of life, D- Public Health and safety, E- Environment, F- Effective functioning of the government, G-Fundamental Rights

Table 2 demonstrates that four parameters, namely, economic sustainability, national security, quality of life, and public health and safety, are commonly adopted by almost all the countries/organisations listed in the table. Here, "economic sustainability" stands for the practice of aiding long-term economic growth without any unfavourable impact on the social, cultural, and environmental aspects of the community (Economic Sustainability, 2015) According to the (United Nations, 2022), "national security" is the security and defence of a sovereign state, including its citizens, economy, and institutions. Quality of life, which, according to the World Health Organization., 2022, is a measure of happiness that varies according to the personal preferences of the citizens. And finally, "public health and safety" is about protecting and improving the health of people and their communities (CDC Foundation, 2022). Nevertheless, it is interesting to note that countries such as Germany, New Zealand, Ethiopia, India, and Pakistan have not considered the parameter called "quality of life" in their definitions of infrastructure. It is an indication that those particular countries do not consider the quality and happiness of their citizens as critical; instead, they consider national security and public health and safety more critical.

3. METHODOLOGY

3.1 DATA COLLECTION

Initially, a comprehensive literature synthesis on the importance of infrastructure for Sri Lanka and the parameters involved in determining the criticality of infrastructure was carried out. Secondly, the mixed-method approach was adopted for the collection of empirical data. It consisted of: (1) a questionnaire survey in order to determine the significance of the infrastructures with reference to the selected four parameters, which can be ultimately used to define critical infrastructures; and (2) ten semi-structured interviews among the professionals attached to the chosen five infrastructure sectors with an experience of over twenty years. Interviewees were selected through the purposive sampling technique, ensuring the selected interviewees have an in-depth knowledge of the functions of the relevant infrastructure sector and the legal and policy background of them.

In the questionnaire, the respondents were asked to rate the significance of various infrastructures with reference to four parameters that define the "criticality" (i.e., national security, economic sustainability, quality of life, public health, and safety) on a five-point Likert scale that extends from 1 (being very less significant) to 5 (being highly significant). The four parameters were selected as per Table 2, which are recognized to be commonly adopted by almost all the countries/organizations listed in the table in defining their critical infrastructure. The questionnaire mainly consisted of two parts: the first part refers to the significance of infrastructure during the normal situation (i.e., before a disaster), whereas the second part refers to the significance following a disaster. Each included six major infrastructure sectors and several sub-sectors under each, totalling 23 sub-sectors. The sectors for the questionnaire survey were determined from the literature review as indicated in Table 1, which have already been recognized as critical infrastructures in other countries.

When it came to identifying the infrastructure, it was decided to forgo manufacturing, chemicals, and national monuments because Sri Lanka does not have a thriving chemical or national industry that would cripple the nation. The USA has identified the above sectors as critical because its economy is mostly based on them. As for monuments, the USA has several monuments with great economic and historical value for the nation. (i.e., the Abraham Lincoln Statue, Lady Liberty, etc.). Accordingly, the infrastructure that would be most suitable for our nation was chosen, namely, water, energy, telecommunication, transportation, essential services, and financial infrastructure. The questionnaire was distributed among 109 built environment and other related professionals associated with various infrastructure sectors in Sri Lanka who had adequate knowledge to provide informed opinions about the nation's infrastructure. The total number of responses (70) received out of 109 questionnaires dispatched indicates a response ratio of 64%. Before the original questionnaire was sent, a pilot study was conducted to determine whether the questionnaire was designed appropriately. The reliability of the questionnaire was analysed, and the Cronbach's Alpha was determined to be in the range of (0.953 to 0.798), which exceeds the threshold value of 0.7, indicating that the questionnaire was reliable and consistent.

3.2 DATA ANALYSIS

The questionnaire was analysed using descriptive statistics techniques, which are used to describe the characteristics of a data set. The use of these techniques enabled the identification of the relative importance of the chosen infrastructure. The Relative Importance Indexes (RII) of infrastructure against the stated parameters were calculated using MS Excel as per Eq. 01 (Khaleel and Nassar, 2018).

$$RII = \Sigma(Wn)/A \times n \qquad Eq.\ 01$$

Where, W = Constant expressing weight given to each response, A = Highest weighting, n = Frequency of responses = Total number of responses

In determining the level of "criticality", it was considered that the most significant infrastructures have an RII score of above 0.800, as per Khaleel and Nassar's (2018) following five expressions, which are defended at equal intervals:

0.1≤ little effect (LE) < 0 .2, 0.2 ≤some effect (SE)< 0.4, 0.4 ≤ average effect (AE) <0.6, 0.6 ≤ high effect (HE)< 0.8 ,0.8 ≤very high significances (VHE) ≤ 1.0

The semi-structured interviews were analysed using the manual content analysis method with reference to the themes identified from the questionnaire survey to further solidify its findings and finally to determine which infrastructure sectors and sub-sectors would be the most critical for Sri Lanka.

4. RESEARCH FINDINGS AND DISCUSSION

4.1 PRE-DISASTER SIGNIFICANCE OF INFRASTRUCTURE

As indicated in Table 3, four subsectors out of the twenty-three scored an overall RII of more than 0.800, which suggests that they are of very high significance. Among these, two are related to the emergency sector, which are law enforcement infrastructure (police, military) (0.819) and fire and emergency services infrastructure, including health services (0.808). Moteff, et al., (2003) suggest that emergency infrastructure reduces the threat to life or property and cannot be established at a moment's notice. The other two are related to the telecommunications sector, which are internet (deep sea cable) infrastructure (0.827) and postal and shipping infrastructure (0.814). The majority of the infrastructures in the 21st century is dependent on information systems, so a disruption in information can cause a ripple effect that would in turn lead to serious consequences that affect the performance, security, and reliability of those infrastructures (Alcaraz and Zeadally, 2015). As for all the other subsectors, their significance was found to be high where the overall RII scores remained above 0.6, but none of the subsectors of water, transport, finance, or energy can be classified as of very high significance. As far as the sector RIIs are concerned, the energy sector has remained as the least significant infrastructure among the selected infrastructures, even though it has an RII score above 0.6 and is a vital input in economic growth because there is a close link between the availability of energy and the growth of a nation (Bridge, et al., 2018)

Also, the analysis suggests that the emergency services subsectors have very high significance when it comes to national security (0.903, 0.848, 0.846), quality of life (0.806) and public health and safety (0.800, 0.846, 0.811). The finance sector has very high significance in terms of economic sustainability (0.891, 0.803) and quality of life

(0.843). As for the water sector, it was analysed to be of very high significance in quality of life (0.863, 0.803, 0.8499) and public health and safety (0.849, 0.809, 0.860). The telecommunication sector was analysed to be of very high significance in all four parameters: economic sustainability (0.803, 0.840), national security (0.866, 0.837), quality of life (0.811, 0.837) and public health and safety (0.829). The transportation sector shows a RII score of 0.831 in national security, 0.9, 0.863, 0.894, 0.806 in economic sustainability, and 0.826 in quality of life, suggesting that its significance degree is very high. Finally, the energy sector has a very high significance in quality of life (0.814, 0.811) and the rest of the infrastructure subsectors were classified as "high" except for the water (sewerage system: 0.597), telecommunication (telephone: 0.586) and energy (wind powerplant: 0.586), which are classified as of "average" significance in relation to the national security parameter. Even though sewerage systems play an important role in sanitation and disease prevention, they do not directly lead to national security, and also, when just considering wind power plants and telephone services, they do not directly affect national security.

Table 3: Significance of infrastructure during pre-disaster context

Infrastructures	Sub-Sectors					Main Sectors		
	RII Against Parameters							
	National Security	Economic Sustainability	Quality of Life	Public Health and Safety	Overall RII	Sector RII	Rank	Degree of Significance
Emergency Services Sector								
Law Enforcement (Police, Military) infrastructure	0.903	0.76	0.806	0.80	0.811	**0.801**	1	VHE
Fire and Emergency Services infrastructure including health	0.848	0.76	0.780	0.84	0.808			
Public Safety Answering Points (119)	0.846	0.67	0.774	0.81	0.776			
	0.866	**0.73**	**0.787**	**0.81**				
Finance Sector								
Banking infrastructure	0.780	0.89	0.843	0.66	0.794	**0.780**	2	HE
Insurance infrastructure	0.703	0.80	0.780	0.77	0.766			
	0.741	**0.84**	**0.811**	**0.72**				
Water Sector								
Water Supply infrastructure	0.660	0.79	0.863	0.84	0.792	**0.770**	3	HE
Irrigation Drainage and Flood Control infrastructure	0.683	0.78	0.803	0.80	0.769			
Sewerage Systems infrastructure	0.597	0.69	0.849	0.86	0.749			
	0.647	**0.75**	**0.838**	**0.83**				
Telecommunication Sector								
Internet (Deep Sea Cable) infrastructure	0.866	0.80	0.811	0.82	0.827	**0.758**	4	HE
Postal and Shipping infrastructure	0.837	0.84	0.837	0.74	0.811			
Internet (Satellite) infrastructure	0.774	0.78	0.749	0.64	0.739			
Television/Radio infrastructure	0.694	0.79	0.794	0.66	0.737			

Infrastructures	Sub-Sectors					Main Sectors		
	RII Against Parameters							
	National Security	**Economic Sustainability**	**Quality of Life**	**Public Health and Safety**	**Overall RII**	**Sector RII**	**Rank**	**Degree of Significance**
Telephone infrastructure	0.586	0.78	0.697	0.62	0.674			
	0.751	**0.80**	**0.778**	**0.70**				
Transportation Sector								
Airport infrastructure	0.831	0.90	0.769	0.69	0.798			
Road infrastructure	0.649	0.86	0.826	0.74	0.769			
Harbour infrastructure	0.791	0.89	0.723	0.66	0.768			
Railway infrastructure	0.649	0.80	0.780	0.67	0.727	0.750	5	HE
Underground Pipeline infrastructure	0.660	0.72	0.706	0.66	0.686			
	0.716	**0.83**	**0.761**	**0.68**				
Energy Sector								
Hydro Powerplant infrastructure	0.749	0.68	0.814	0.68	0.734			
Solar Powerplant infrastructure	0.737	0.66	0.811	0.62	0.709			
Thermal Powerplant infrastructure	0.683	0.62	0.746	0.66	0.679	0.699	6	HE
Wind Powerplant infrastructure	0.586	0.78	0.697	0.62	0.674			
	0.689	**0.69**	**0.767**	**0.65**				

4.2 Post-Disaster Significance of Infrastructure

As per Table 4, five subsectors out of twenty-three have scored an overall RII of more than 0.800, which suggests that they are of "very high significance." Among these, three are related to the emergency sector: law enforcement infrastructure (police, military) (0.814), fire, public answering points (0.809) and emergency services infrastructure, including health services (0.804). According to Rothery and Branch (2005), there are infrastructures that rely on the availability of other types of infrastructure, and emergency services is one of those infrastructures that would benefit other infrastructure sectors. Another "very high" significance is related to the telecommunications sector, which is the disaster warning system (0.821). The public's reliance on warning systems for protection in a post-disaster situation would be the result of this score. The other is related to the transportation sector, which is road infrastructure (0.814). This result suggests the dependence of the transportation sector on relief aid, emergency care, protection, and on-time deliveries in a post-disaster situation. As for all the other infrastructure subsectors, their significance is found to be "high," where the RII scores remained above 0.6. None of the subsectors of finance and energy can be classified as of high significance.

According to the analysis, the emergency services subsectors have very high significance in terms of national security (0.840, 0.846, 0.854), quality of life (0.803), and public health and safety (0.814, 0.809, 0.804). As for the water sector, it is found to be of very high significance in quality of life (0.800, 0.811, 0.829) and public health and safety (0.811, 0.806, 0.820). The telecommunication sector is found to be of very high significance in terms of national security (0.843 and 0.814), quality of life (0.820 and 0.806) and public health and safety (0.821). The transportation sector has an RII score of

0.803 in national security, 0.823 and 0.809 in economic sustainability, suggesting that its significance is very high. The rest of the infrastructure is classified as "high." The energy sector is still the least significant with an RII of (0.680, 0.752, 0.699, 0.659) but still with "high" significance.

As for the sector rankings, the one with the most significance is the emergency services sector (0.809), whereas the rest of the infrastructures are identified as having "high" significance (water: 0.782, telecommunication: 0.765, finance: 0.758, transportation: 0.754, energy: 0.698). The energy sector has remained the least significant infrastructure among the selected infrastructures. It might be due to energy not being an immediate aftermath need. Food, water, medicine, and shelter are considered basic needs in the event of a disaster.

Table 4: Significance infrastructure during the post-disaster context

Infrastructures	**Sub Sectors**					**Main Sectors**		
	RII Against Parameters							
	National Security	**Economic Sustainability**	**Quality of Life**	**Public Health and Safety**	**Overall RII**	**Sector RII**	**Rank**	**Degree of effect**
Emergency Services Sector								
Fire and Emergency Services	0.84	0.78	0.80	0.83	0.814	**0.809**	1	VHE
Public Safety Answering Points (119)	0.84	0.73	0.78	0.81	0.809			
Law Enforcement (Police, Military)	0.85	0.76	0.79	0.80	0.804			
	0.847	**0.762**	**0.792**	**0.817**				
Water Sector								
Water Supply infrastructure	0.76	0.79	0.80	0.81	0.792	**0.782**	2	HE
Irrigation Drainage and Flood Control	0.73	0.79	0.81	0.80	0.786			
Sewerage Systems infrastructure	0.697	0.723	0.829	0.820	0.767			
	0.730	**0.771**	**0.813**	**0.812**				
Telecommunication Sector								
Disaster warning system	0.843	0.797	0.820	0.826	0.821	**0.765**	3	HE
Telephone infrastructure	0.789	0.797	0.806	0.746	0.784			
Internet (Satellite)	0.814	0.803	0.771	0.740	0.782			
Television/Radio infrastructure	0.757	0.760	0.754	0.737	0.752			
Internet (Deep Sea Cable) infrastructure	0.780	0.774	0.729	0.686	0.742			
Postal and shipping infrastructure	0.70	0.77	0.71	0.64	0.709			
	0.781	**0.784**	**0.766**	**0.730**				
Finance Sector								
Insurance infrastructure	0.711	0.806	0.774	0.677	0.742	**0.758**	4	HE
Banking infrastructure	0.75	0.76	0.80	0.77	0.774			
	0.734	**0.787**	**0.787**	**0.724**				
Transportation Sector								
Road infrastructure	0.803	0.823	0.826	0.803	0.814	**0.754**	5	HE
Airport infrastructure	0.794	0.809	0.766	0.714	0.771			

Infrastructures	Sub Sectors					Main Sectors		
	RII Against Parameters							
	National Security	Economic Sustainability	Quality of Life	Public Health and Safety	Overall RII	Sector RII	Rank	Degree of effect
Harbour infrastructure	0.786	0.794	0.720	0.694	0.749			
Railway infrastructure	0.720	0.769	0.751	0.711	0.738			
Underground Pipeline infrastructure	0.680	0.723	0.706	0.691	0.700			
	0.757	**0.783**	**0.754**	**0.723**				
Energy Sector								
Hydro Powerplant infrastructure	0.723	0.786	0.740	0.669	0.729			
Solar Powerplant infrastructure	0.669	0.749	0.697	0.677	0.698			
Thermal Powerplant infrastructure	0.689	0.737	0.689	0.640	0.689	**0.698**	6	HE
Wind Powerplant infrastructure	0.640	0.737	0.671	0.649	0.674			
	0.680	**0.752**	**0.699**	**0.659**				

4.3 COMPARISON OF SIGNIFICANCE OF INFRASTRUCTURE BETWEEN PRE- AND POST-DISASTER CONTEXTS

There has been an increase in natural and human-induced disasters worldwide. Sri Lanka's inability to define critical infrastructure has left the nation behind in terms of enhancing its infrastructure stock. The purpose of considering both pre- and post-disaster contexts for this research was to show that in day-to-day life, regulation of critical infrastructure is essential to develop legal governance regimes, and without clearly defined boundaries on what constitutes critical infrastructure at a national level, the focus on protecting the infrastructure would be incomplete. In the case of a disaster, identifying which infrastructures are critical would be necessary to provide vital community and individual functions. Also, to be protected and remain operational during a disaster situation.

As per Table 3, the most significant infrastructure in both pre-and post-disaster is found to be the emergency services sector (0.801 and 0.809, respectively). The results prove that the emergency sector is not something that can be established overnight. Therefore, its significance cannot be overlooked during normal conditions. In the pre-disaster context, the sector RIIs appear in descending order from emergency services sector (0.801), telecommunications (0.758), water (0.770), transportation (0.750) and energy (0.699) when compared to the post-disaster context, where the order follows from the emergency services sector (0.809), water (0.782), telecommunication (0.765), finance (0.758), transportation (0.754) to the energy sector (0.698). The post-disaster scenario has resulted in an increased level of significance in every infrastructure sector except in the energy and finance sectors. The reason for this could be that finance and energy are not immediate post-disaster needs. They would actually come after basic needs like food, shelter, water, and medicine. The significance of the finance sector has gone down by two positions from pre-disaster to post-disaster. The reason for the energy sector's low significance compared to other infrastructure sectors, both in pre- and post-disaster, could be the public's failure to realise the significance of the energy sector until they suffer from a complete failure of it. As far as the current situation (from February 2022 to date) in Sri Lanka is concerned, the nation's restlessness due to the current power crisis alone could be enough to imagine how significant the energy sector is. As this questionnaire survey was conducted in December 2021, none of the respondents were concerned about the level of significance of energy infrastructure and the potential fallout from an energy crisis.

One respondent stated that "*In Sri Lanka under the emergency law, critical infrastructure has been identified",* but upon further research, it was found that the emergency law does not state any infrastructures as critical, but it states the personnel who has the power to name the particular infrastructure as critical in the face of a disaster. Interviewees also confirmed that the non-existence of a definition for critical infrastructure in Sri Lanka, whereas each respective sector has its own internal protective measures taken even though they are not stipulated in the respective Acts. For example, hydro dams can only be accessed through an army base. In this case, as per the interview respondents, the energy sector's significance to national security, economic stability, and public health and safety has been acknowledged and considered. Nevertheless, infrastructure interdependency has made setting up parameters against which to define the criticality of infrastructure difficult due to the interconnectivity of its functions. In other words, for the functionality of one sector, another sector's output would be important. In this context, even though there are Acts such as the National Water Supply & Drainage Board Act, the Ceylon Electricity Board Act, the Road Development Authority Act, the Telecommunication Act, and the Essential Public Services Act, and policies for infrastructure, the governing bodies of the infrastructure sectors in Sri Lanka have a blurred understanding of their remits of work due to the lack of defined critical infrastructure.

5. CONCLUSIONS

Critical infrastructure could be defined as a "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 study proposes suitable "critical infrastructures" for Sri Lanka while identifying the respective parameters against which they are considered to be significant (critical). As per the literature review, four parameters were recognized as applicable to Sri Lanka: national security; economic sustainability; quality of life; and public health and safety. The aim of the study was achieved through a questionnaire and semi-structured interviews. Among the 6 infrastructures, the 4 parameters identified through the literature survey were analysed with the RII values determined for one infrastructure exceeding 0.800, namely the emergency services sector, which was in turn identified as "very high" in significance, and the other five infrastructures as "high" in significance in both pre- and post-disaster contexts. The findings prove the importance of emergency services and other infrastructure in both situations.

Accordingly, the study reveals emergency services, water, energy, finance, transportation, and telecommunication as the critical infrastructure for Sri Lanka. The remits of these sectors are that the essential services sector includes any service provided by the armed forces, health, and fire; as for the water sector, any service concerning sanitation, irrigation, drainage, flood control, and water supply; the energy sector to include the generation of power; and the telecommunication sector to include every means of telecommunication, including telephone, internet, television, radio, and postal services; transportation to include every service under transportation by air, land, and sea; and finance to include its services concerning management of money through investing, borrowing, lending, saving, forecasting, and budgeting.

The primary outcome of this study is the identification of critical infrastructure for Sri Lanka. Thus, the study findings can be used as a reference when conducting further studies on critical infrastructure, for example, defining the boundaries of critical infrastructure, realizing and analysing interdependencies between critical infrastructure, and determining protection measures for critical infrastructure.

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DELAYS AND DISRUPTIONS IN THE CONSTRUCTION INDUSTRY DURING THE GLOBAL PANDEMIC

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ABSTRACT

COVID-19 pandemic has become a global catastrophe today dragging many nations towards severe economic distress. The Sri Lankan economy has no exception. Not surprisingly, the sluggish economic conditions in the country have adversely affected the construction industry in Sri Lanka. The pandemic has resulted in almost every construction project getting delayed or disrupted. This research aims to determine the factors that caused delays and disruptions in large scale construction projects in Sri Lanka due to pandemic. The overall impact of the global pandemic on construction projects in both local and international platforms were identified through a comprehensive literature review. Additionally, the impact on the local domain in terms of delay and disruption was assessed based on exploratory interviews and survey questionnaire disseminated among industry experts. Final conclusions were drawn by conducting 9 case studies and analysing responses to survey questionnaire provided by 30 industry practitioners. This study assisted in finding measures and mechanisms currently in use to mitigate the impact of delay and disruption of the construction phase of construction projects. The findings also paved the way to recognize innovative mitigation strategies to control the adverse impact on on-going construction projects. Analysis of the responses concluded that, delay in project kick-off, delays in material delivery, shortage of material, project suspension, reduction in the workforce productivity, health and safety concerns, regular price escalations as the key elements attributed to impact the project progress. The study has identified the present mitigating controls over delays or disruption are barely sufficient to address the concern and thus emphasised the need to resort to more effective techniques to remedy the issue.

Keywords: *Construction; COVID-19; Delay; Disruption.*

1. INTRODUCTION

The COVID-19 pandemic has been the world's most serious health emergency in the recent past. The influence of COVID-19 on the society is evident due to worldwide lockdowns, labour mobility restrictions, travel bans and airline suspensions (Shafi, et al., 2020). Moreover, the world has had a negative impact on the manufacturing industry, affecting both market distribution and supply chain (Tambrallimath, et al., 2021). The travel restrictions and curfews imposed regularly, caused major delays and disruptions in construction projects. During the crisis, construction, planning and scheduling were considerably impacted. The findings indicated that the project delays were serious, and

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the main reason being 95% of staff was unable to work at any moment due to the government's response to the epidemic (Alenezi, 2020). In fact, many construction firms found it difficult to retain their existing workforce due to cashflow constraints. Partly the job losses were due to work interruptions caused by work-related limitations enforced to stop the spread of the virus, a scarcity of personal protective equipment (PPE) since it was prioritised for healthcare personnel, and general market anxiety (Alsharef, et al., 2021).

More importantly the research gap should be identified in order to contribute towards research objectives. The delays and disruptions in construction projects have not only been avoidable but also created an unfavourable impact on the industry at large. Therefore, it is essential to identify and implement methods to avoid or minimise construction project delays. However, before implementing counter solutions, one should identify which factors affect the delays in the construction stage of a construction project, which is currently lacking in terms of research. Identifying these factors and prioritising them with regard to the impact on the project efficiency is crucial when implementing solutions to the said delays and disruptions.

The aim of this study was to identify factors that cause delays and disruptions of large-scale construction projects in Sri Lanka at its construction stage, due to the COVID-19 pandemic. In order to facilitate systematic achievement of the aim, few research objectives were developed such as to identify the impact of COVID-19 pandemic on the construction industry globally and locally, to investigate the impact of the pandemic to a construction project in terms of delays and disruptions during the construction phase of a project, identify and evaluate the significance of those factors, to explore the existing methods which are used to mitigate those delays and disruptions during the construction phase of a construction project and to recommend strategies which could be used by the industry to minimise delays and disruptions due to pandemic.

2. LITERATURE REVIEW

In a pandemic scenario, concepts of delay and disruption are most relevant to the construction industry. Disruption is a term which is directly combined with the loss of efficiency in construction projects (Haidar, 2011). In addition, the concept of ‘Force Majeure’ has been a point of controversy, as it permits the contracting party to avoid fulfilling its obligations due to events beyond their control (Hansen, 2020). Kikwasi (2013) has specified ten (10) critical causes of delay and disruption in construction projects. They are building permits approval, change orders, changes in drawings, incomplete paperwork, inspections, changes in specifications, decisions made during the development stage, shop drawings and approval. Further, the researcher has ranked the effects of delays and disruptions on the construction stage of a project in relation to their significance. Time overrun was the number 1 ranked effect in terms of significance followed by cost overrun, idling resources, disputes, poor quality of work due to hurry, delaying in getting profit by clients, bankruptcy, create stress on contractors, and total abandonment, were ranked in order of highest to least significance, whereas acceleration losses being the least significant factor as per the research findings.

It is evident that the global economy has been negatively impacted in almost every sector due to the pandemic. Sri Lanka has had no exception to this global phenomenon. The construction industry in Sri Lanka is among the critically affected industries among many.

According to the Department of Census and Statistics Sri Lanka, Gross Domestic Product (GDP) from the construction industry decreased from LKR 154.3 billion in the 1st quarter of 2021 to LKR 137.3 billion in the 2nd quarter of 2021. However, it has increased from LKR 142.8 billion in the 3rd quarter of 2021 to LKR 170.3 billion in the 4th quarter of 2021.

The study was mainly focused on the current situation in the construction industry in Sri Lanka and it was limited to high rise commercial buildings which have a project value of more than LKR 50 million. The intention was to cover a fair representation of the building construction projects which are at construction stage at present. Most of the existing building projects are of commercial type of developments in the western province in Sri Lanka. Research was carried out studying nine (9) construction projects in detail as case studies and only focused on the construction phase of each project.

3. METHODOLOGY

This study was carried out following a mixed method approach involving both qualitative and quantitative approaches in varied degrees. Qualitative research possesses specific benefits compared to quantitative approach. According to Kumar (2011) the primary goal of qualitative research is to understand, explain, discover and clarify circumstances, perceptions and experiences of a group of people. On the other hand, empirical assertions are expressed numerically in quantitative research. These empirical evaluations are described as a method of determining the degree to which a program or policy empirically meets or fails to meet a set of standards or norms (Sukamolson, 2007). Through further evaluation, a mixed method approach was used in this research study.

A researcher uses sampling as a technique to systematically pick a sample of representative items or individuals from a predefined population to serve as subjects for observation or experimentation based on the study objectives (Sharma, 2017). As the sampling method for this research, purposive sampling was used. Purposive sampling is a simple and straightforward, yet effective sampling method. It improves the rigour of the study and the reliability of the data and outcomes by better matching the sample to the research's goals and objectives (Campbell, et al., 2020). Under purposive sampling there are various study designs such as case studies, oral history, focus groups, participants' observation, holistic research and community discussion forums. Out of these study designs, case studies were used for this research. Case studies are very useful when exploring a scenario where knowledge is limited or to have a holistic understanding of the situation (Kumar, 2011). Therefore, nine (9) case studies were carried out with the engagement of a specific focus group which consists of construction industry professionals. Conclusions of the research are based on these nine case studies.

Purposive sampling was used as the sampling method, with the aim of focusing only on professionals from the construction industry in Sri Lanka. In order to generate quantitative results, a questionnaire survey was shared among professionals in the construction industry. The questionnaire survey consisted of 16 questions which included multiple choice questions, Likert scale questions and open-ended questions. The sample size of the survey was 30 respondents. The questionnaire survey was followed by nine (9) case studies using open-ended expert interviews which generated qualitative data. Finally, the qualitative data which was gathered through case studies, were analysed through a thematic data analysis while quantitative data which was gathered through the questionnaire survey was analysed through a descriptive statistical analysis.

Questionnaire survey and case studies were employed as the data collection methods. However, due to the sudden outbreak of the 3rd wave of COVID-19, interviews have to be conducted over the phone or online video calling methods. It solely depended on the interviewee's preference and convenience. According to (Blumberg, et al., 2008), because of the privacy and cost-effectiveness it provides to the interviewee, data gathering via email has become indispensable. Therefore, questionnaires were emailed to respective professionals in advance, which was then followed up with a telephone interview.

The scale of the impact was evaluated with respect to the local construction market. The adverse impact in terms of delays and disruptions of a construction project were also identified and analysed. There were several delay and disruption factors that emerged as a result of the pandemic such as travel restrictions, partial or complete closure of sites, stringent health regulations and spread of virus among construction workers. The data collected through questionnaire surveys and case studies provided a large amount of specific data which revealed the possible factors that have caused delay and disruption on a construction phase of a project. The quantitative analysis of the study paved the way to discover twelve (12) factors that have made a significant impact on projects. Moreover, these 12 factors were ranked based on their severity. The study confirmed that all of these factors have a negative impact of moderate to major scale. Finally, existing methods, which are implemented in construction projects at present, are ascertained through a thematic analysis of nine (9) case studies. A thematic analysis was used to analyze data which was collected through interview and questionnaire survey. In addition, Clarke and Braun (2014) states that many research questions can be addressed with Thematic Analysis, ranging from inquiries about people's practices and beliefs in specific circumstances. The collected data from case studies were divided into six themes. They are the adverse impact from COVID-19, impact on the continuation of site works, impact on the workforce, impact on suppliers and imported goods, health and safety measures and delay and disruption mitigation techniques.

The descriptive statistical analysis and Significance Index (SI) were used to analyze quantitative data. There are two major outputs of statistical analysis, which are the Standard Deviation (SD) and mean.

4. RESULTS

4.1 QUANTITATIVE FINDINGS

The objective of the study is to offer a holistic understanding of the impact due to the COVID-19 pandemic on the construction industry in relation to delay and disruption. The first and foremost concern was to confirm whether all construction projects were severely affected due to the pandemic. It was evident that only 63% of the projects were severely affected while 30% were affected moderately and 7% were less affected. Most of the participants have experienced labour shortage as a common issue. The main reason for this burning issue is prophylactic absenteeism among workers. Moreover, labourers show reluctance to work in distant areas to their hometowns due to sudden lockdowns and travel restrictions. It reflected the government-imposed travel restrictions as yet another cause for the negative impact. It is understandable that all the factors that caused adverse consequences are interconnected. Another factor given by respondents is the rapid price escalations and material scarcity. Due to the unexpected increase in operational costs many material prices have also increased in tandem. Consequently, contractors were unable to source basic materials such as sand, cement and bricks during the early months of the pandemic. In addition, finishing materials are in high demand due to import restrictions. Higher concern in health and safety protocols have also resulted in delaying of projects. As an example, contractors are unable to occupy the total number of workers due to health issues. At the same time complying with safety conditions at site level has slowed down work proceedings significantly. In contrast, as a result of all these factors almost every construction project got delayed or overran the budgeted cost limits. Further, investors are reluctant to invest in the industry, making a big blow to the country's economy.

More than 93% of the respondents agreed that their construction projects are significantly delayed and disrupted due to regular shutdowns of the country. Participants were asked to give a number on a scale of 1-5 (1 being the most) about how much of an adverse impact caused due to the pandemic on their current construction project in terms of delay and disruption. Figure 1 displays the summarized results of it.

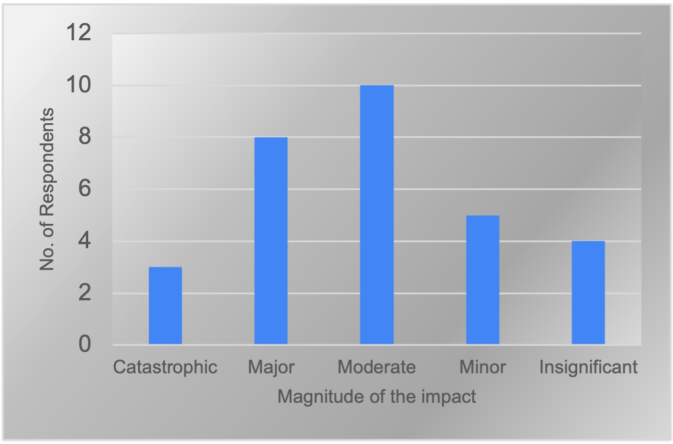

Figure 1: Scale of adverse impact due to COVID-19

Even though the general public interprets the impact of the pandemic on the construction industry as a severe one, the above bar chart mirrors the true magnitude of the impact which is at moderate level. In terms of factors impacting the project progress, after conducting a thorough literature survey, 12 major factors were identified which could have a severe impact on the project in terms of delay and disruption during the pandemic period. All the participants were asked to rank these factors on a Likert scale from 1 to 5 (1 being insignificant and 5 being catastrophic, Refer Table 1), based on the magnitude of the impact. Furthermore, collected data was analysed and ranked by the Weighted mean method using Eq. 01. Findings are presented in Table 2.

$$Weighted\ mean = \frac{\sum_{i=1}^{n} \omega_i \cdot x_i}{\sum_{i=1}^{n} \omega_i} \qquad \text{(Eq. 01)}$$

Where,

ω = Frequency of responses

x = Rating of each factor

Table 1: Likert scale weightings

Scale	Description
1	Insignificant
2	Minor
3	Moderate
4	Major
5	Catastrophic

Table 2: Rankings of delay and disruption factors

Factor	Weighted mean	Rank
Safety concerns regarding virus spread in the construction site	3.900	**1**
Material delivery delays and shortage of material	3.670	**2**
Suspension or slowing of the project	3.670	**2**
Disparities across government parties and governing bodies whether construction operations are essential or non-essential	3.567	**4**
Workforce related challenges	3.533	**5**
Delay in the start date of the project	3.533	**5**
Delays in inspections and securing permits	3.500	**7**
Price escalations, additional costs, loss of revenue, and payment delays	3.500	**7**
Lack of motivation in the workforce	3.500	**7**
Reduction in efficiency and productivity rates	3.467	**10**
Transition to work from home for non-site personnel	3.300	**11**
Increase in Disputes and Claims	3.200	**12**

Table 2 reveals the factors that have the most to least impact on a construction project in terms of delay and disruption during the pandemic. Those factors are ranked and shown in a tabular format based on their weighted mean. Considering the data received from the respondents it is noticeable that all the factors have a weighted mean ranging in between 3 and 4. Therefore, the impact of these 12 factors can be interpreted as either a major or a moderate impact according to the Likert scale weightings. According to the respondents, out of 30 participants 20 of them have taken extra measures to mitigate the impacts of the pandemic on their project. Furthermore, they have implemented following specific strategies to control the negative impact (Refer Table 3).

Table 3: Current strategies implemented at site level to mitigate delay & disruption

Strategy	Activities
Adhere to new health & safety practices	Maintain daily record book which includes body temperatures, any diseases, telephone numbers and body oxygen level of workers when entering into the site, keep 1m distance, wear masks, random body temperature check during the day.
	Provide masks, sanitizers, safety equipment, hand washing areas & steam machines, promote personal disinfectant practices.

Strategy	Activities
	Use signs of safety practices and symptoms inside the site and training for employees on the spread of the disease.
	Using Environmental Protection Agency-approved cleaning chemicals from List N or that have label claims against the corona virus for cleaning frequently touched surfaces like tools, handles, and machines.
	Restrict entry for all visitors during the pandemic.
	Instructions are given that if workers feel sick, that they must stay home.
	Antigen and Polymerase Chain Reaction (PCR) tests are done when workers show symptoms.
	Prohibit site gathering and close contacts.
Implementation of Bio Bubble concept	Isolating the work staff and labours including supplying food and accommodations for them.
	Prohibit workers from going outside the site premises.
	One team is allocated to bring necessary items for workers from outside.
Other strategies in terms of construction work proceedings	Work from home method for non-site based personnel and minimizing site staff and follow roster basis.
	Parallel tasks were omitted in the same area for two gangs of workers to minimize labour congestion.
	Working and negotiating potential changes for time, schedule, project completion and management.
	Understanding supply agreement and purchase orders to determine impacts of delays, delivery obligations, payment and financing issues, and other liability risks.
	Encourage vaccination.
	Prioritize most important materials to purchase.
	Prioritize critical tasks.
	Minimize physical meetings and transfer to an online platform and plan to work shift or roster basis.
	Instruct staff and workers to avoid public transport. Provide transportation facilities.
	Using this extended time period to finalize designs which will ultimately reduce variations and disputes due to design changes in projects which are at design stage.

4.2 QUALITATIVE FINDINGS

4.2.1 Sample information

Respondents were asked to provide a brief outline of their current project. All the nine (9) projects were clustered together based on their characteristics and given in Table 4.

4.2.2 Study Findings

The thematic analysis approach paved the way to summarise and categorise data and present them in a comprehensive manner. The purpose of a thematic analysis is to find relevant or intriguing themes or patterns in data and utilize them to address the research or make a point about a problem. (Maguire and Delahunt, 2017). It is a standard method generally utilized to analyse qualitative data of an unknown phenomenon (Amoah, et al., 2021). Therefore, thematic analysis can be regarded as the most suitable method to analyse qualitative data related to this study. The data collected from interviews were reviewed and divided into five themes. As the 3rd step of the analysis, five themes were defined and collected data were divided among these five themes. These categorised data is used to interpret the final outcome of the research.

Table 4: Details of case studies

Project	Type of project	Estimated duration before COVID-19 (months)	Total value (LKR)	Government /Private	No of days delayed	Delay as a Percentage of the total duration (approx.)
P1	Office building	12	192Mn	Government	40	11%
P2	Office building	22	1.7Bn	Private	100	15%
P3	Apartment	9	283Mn	Government	21	8%
P4	Housing	22	1.2Bn	Private	140	21%
P5	Housing	30	2Bn	Private	21	2%
P6	Apartment	36	6.35Bn	Private	200	19%
P7	Water resource development project	72	3.8Bn	Government	90	4%
P8	Mixed development	12	425Mn	Government	90	25%
P9	Mixed development	44	15Bn	Private	250	19%

Note: "Mn" refers to Millions and "Bn" refers to Billions

Theme 01 - Impact on the continuation of site works

All the projects are currently continuing their site works despite the pandemic situation. However, projects P4, P5 have reported that it took less than one month to fully restore operations after 1st and 2nd waves of COVID-19 in Sri Lanka. It has taken more than one month to completely restore operations in other projects. Conversely, respondents had no idea on the question on how long it would take their site to fully restore operations after the current wave. Every construction activity of projects P1, P3, P4 and P6 are delayed or disrupted as a result of the pandemic. However, in other projects, only specific activities were delayed. For example, structural works of P2 were affected due to the fact of having only one skilled carpenter at a particular time for the whole site. Furthermore, there were no skilled bar benders for certain periods of time. In P5, mobilization, foundation and excavation work has been delayed. The delay of the foundation and excavation stage which is in the critical path has made a major impact on the progress of the project. In addition, there were delays caused due to delays in client supply materials. Another concern for P5 was that the advance payment has also been delayed. The respondent from the P5 stated that if the advance payment was paid on time, they could have purchased materials before any price escalation. Similarly, mobilization of P7 is also affected by the pandemic. According to the case study of P8, all work activities are connected with each other. Therefore, even a slight delay in one activity has caused a more or less of a delay in another activity. For instance, delivery of plywood was delayed in P8 and it has delayed the reinforcement process. In the same way, supply of imported glass façade materials was delayed in P9 which has affected the pace of the project.

Theme 02 - Impact on the workforce

At the time of this study, there are 50 or less workers in P1 and P2 projects, while P2 and P8 projects accommodate 51-100 workers. All the other projects have more than 100 workers currently working in the sites. According to the study, during the 3rd wave, projects P1, P4 and P2 have faced a reduction in workforce of 11-20, 21-50 and more than 50 respectively. Despite the travel restrictions and rising number of positive cases throughout the island, projects P3, P5, P6, P8 and P9 have managed to retain their existing workforce. A quite controversial data was collected from P5 and P7 where they explained a 20% increase in productivity during the 3rd wave. In P5, workers have done more overtime work during this period compared to the time period before the pandemic. Mainly financial difficulties and job insecurity have driven workers' mindset to work more during these trying times. P7, which is a public sector project, has also reported a 20% increase in productivity. As an example, previously it has taken at least a week to get approval for certain items whereas now it takes only a couple of days for approval. Therefore, this is a significant benefit in the planning stage for P7. In general, all other projects have reported a decrease in productivity levels. Inability for people to move freely, health restriction, higher distress on exposure to the virus and lack of motivation are some of the reasons for the lack of productivity. On the other hand, it is impractical to exhaust the available workers beyond their capacity. There were specific measures which also affected productivity such as, in P6, only 4 people were allowed to travel in the lift which has a capacity of 8. In overall following were the percentages of productivity decrease in each project.

30% - P3

40% - P4, P9

50% - P1, P6

60% - P2, P8

Theme 03 - Impact on suppliers and imported goods

All the projects have faced challenges in bringing materials to the site due to travel restrictions. For example, supply of lift has been delayed in P1 delaying the installation process. In P2 few of their materials are imported from India, where there are issues in the movement of goods from factories to ports, increase in transportation costs, closure of infrastructure to transport goods and lack of manpower. Furthermore, due to restrictions imposed on imported materials, there was an artificial scarcity created in the market and there were price increases of materials to cater to the increasing demand. Therefore, respondents stated that there was an immense loss to the contractor since there was a lower material price at the tender stage, but when they require to purchase those items, prices have increased drastically. Further, both clients and contractors were unable to open up Purchase Orders (POs) and Letter of Credits (LCs) due to the closure of relevant departments/banks. The main reason for the import restriction by the government is to preserve foreign reserves. Moreover, the government has been prescribed to take at least a 90-day credit period from the foreign suppliers, which enables US dollars to leave the country after 3 months. Even though some suppliers have agreed to this condition, some of them have not. Therefore, in case of P9 they have acquired the service of an intermediary financial provider from Dubai. Using sales through their facility, P9 was able to open LCs to the suppliers where the credit is given to the Dubai based financial organisation. The financial company has charged a margin from them for providing the service. Although it was an extra cost, there had been no other option for P9 to get the imported goods.

Theme 04 - Health and safety measures

In general, all the projects have implemented various health and safety measures required by the government health guidelines. Body temperature checking at the gate, providing hand sanitization facilities, and making it compulsory to wear masks all the time were common safety measures applied in every project under study. At the initial phase of the pandemic, staff members were cooperative with respect to wearing the masks, but some workers did not adhere since they are uneducated and unaware about the severity of this situation. Most workers were reluctant to wear the mask, reasoning that it is difficult to wear it during construction activities since they have to breathe heavily. In some of the projects, to make people wear the mask, continuous supervision was done by a safety officer. As a controlling measure, project P9 has introduced a fine for the people who do not wear the mask. If they still found it difficult to make them wear the mask, they have released them from the site. In P1, P3, P5 and P6 to make people wear the masks, continuous supervision was done by a safety officer. However, in P7 and P8 supervisors were not in a position to implement strict health regulations since they are government-based institutes. In case of positive cases or if workers show symptoms, they were accommodated in separate labour billets and quarantine inside the site. Furthermore, some contractors have asked workers to get a Rapid Antigen Test (RAT) as it is cheaper than a PCR. In some projects they have done PCR testing within the site incurring an extra cost by the contractor. In terms of making awareness about the pandemic, projects P1, P3, P4, P5, P6, and P7 have displayed signs related to health measures and symptoms. In P2 and P3 training was conducted on special health regulations in a pandemic situation for workers. In projects P4, P5, P6 and P8, they conduct daily meetings to announce and remind about health measures whereas in P1 it is done in 3-4days. In project P7, they have not been reminded about health measures on a daily basis, because they believe that all the people are now well aware about all safety measures and guidelines. Furthermore, many contractors mentioned that they have encouraged vaccination, but they were unable to make it compulsory as the government has not made it compulsory. Contractors have found that previously mentioned health and safety measures were not 100% effective hence, they have come up with more practical and effective methods, which are mentioned in theme 6 below.

Theme 05 - Delay and disruption mitigation techniques

After the pandemic started, many organisations from different industries focused on teleworking policies and developed the concept of work from home. Unfortunately, construction workers or professionals do not have that luxury of work from home since it is a site based physical delivery. However, in some projects Quantity Surveyors were allowed to work from home for a short period of time, but then again when it comes to activities such as taking measurements, they must be physically present in the site. Nevertheless, some portion of communication activities were shifted to online platforms. As an example, monthly progress meetings are held in virtual platforms such as Zoom and increased the use of emails, WhatsApp etc. In terms of project management, professionals have regularly monitored the master programme of the project, pre plan activities and ask for Extension of Time (EOT) justifying the delays. The delay and disruption mitigation techniques followed by each project are summarised in Table 5.

Table 5: Delay and disruption mitigation techniques

Project	Delay and disruption mitigation techniques
P1	Increase the number of times that we communicate with clients and consultants. Discuss about the progress of the site regularly. Limit the travels of labourers. Facilities are provided for workers to cook their own meals inside the site
P2	Implemented a formwork system to minimize the use of skilled carpenters. Managed to train the workforce to be able to carry out multiple tasks therefore, if anyone of their team is down, they can handle other team's work. Break workers into isolated gangs, therefore the exposure is minimized.
P3	Increase number of skilled labours. Limit the travels of labourers.
P4	Increase labour rates. Increase number of skilled labours. More Overtime work – provided workers with an additional meal.
P5	Provide transport facilities and issue curfew passes to workers and staff members. Special focus on reducing labour idling. - As an example, workers tend to take more time to get back to work after their lunch. Therefore, they tried to reduce that kind of idling time Rented out 2 houses outside the site in order to fulfil the additional space requirement. Encourage both labourers and staff to steam and use Ayurveda medicines, provide herbal drinks to staff members instead of tea.
P6	Increase the number of suppliers per material. Divided the work into mini contracts and increased the amount of work per gang. Procure material in advance.
P7	Limit the travels of labourers. Increased the use of emails to get approvals.
P8	Provide transport facilities and issue curfew passes to workers and staff members. Increase labour rates.
P9	Pre ordered meals and delivered to the site at their cost, canteen is also available in the site. Did not hold meetings to make sure that workers do not gather in one place. Set up speakers in their own accommodation and the canteen to share COVID-19 related guidelines and instructions.

In summary all projects reported that these techniques are 90% successful compared to earlier methods.

5. CONCLUSIONS

The COVID-19 pandemic has been the most serious economic catastrophe in the world recently. It has negatively impacted almost every industry pushing national economies to deeper troubles. The construction industry is no exception, in fact it has been identified as one of the highly disrupted industries as it involves many physical activities. Therefore, the study was begun with the aim of exploring the consequences of the COVID-19 pandemic on the industry and to identify factors that cause delays and disruptions in the construction projects due to this. Accordingly, four main objectives were set up upfront to identify the impact on the construction industry, to investigate the impact in terms of delays and disruptions, identify and evaluate factors that have the most to least impact and finally identify existing methods to mitigate delays and disruptions due to these factors.

The scale of the impact was evaluated with respect to the local construction market. The adverse impact in terms of delay and disruptions of a construction project were also identified and analysed. There were several delay and disruption factors that emerged as a result of the pandemic such as travel restrictions, partial or complete closure of sites, stringent health regulations and spread of virus among construction workers. Finally existing methods which are implemented in construction projects at present, are ascertained through a thematic analysis of nine (9) case studies. The collected data from case studies were divided into five themes. They are the adverse impact from COVID-19, impact on the continuation of site works, impact on the workforce, impact on suppliers and imported goods, health and safety measures and delay and disruption mitigation techniques. Methods of controlling delay were common in most of the construction projects and only few of them have looked forward to implementing innovative and suitable techniques to mitigate delays.

Recommendations could be made on the need of a contingency plan in a pandemic situation can be very useful and beneficial to contractors. Moreover, steps such as creating a bio bubble inside the site, regular health and safety monitoring, providing sanitation facilities, division of work into small contracts and allocating separate labour gangs to them, limit movement of workers by providing all the basic amenities, procure material as early as possible and shifting into online platforms for meetings can be further recommended as effective delay and disruption mitigation techniques.

There were few limitations to the study despite making significant contributions for researchers, industry practitioners and decision makers. Although the study reveals important findings related to the impact of the pandemic on the construction industry, this might not be an exhaustive list of factors. There could be certain factors overlooked. On the other hand, there are frequent updates on the health and safety guidelines, which will have an impact on the performance of the industry. Further, the study was limited only for the large-scale construction projects where they were defined as projects which have a value of more than LKR 50 million. Also, the study was limited on projects in Sri Lanka and the impact on the construction phase of the project.

The results of the study could be very useful for industry practitioners. In addition, delay and disruption mitigation methods presented in the study could be directly implemented in construction projects since they were acquired from existing projects which have effectively managed the adverse impact. The study has assisted in filling the knowledge gap of discovering the impact of the pandemic in terms of delay and disruption in construction projects. In fact, the study has opened the door for researchers to explore innovative delay and disruption mitigation techniques, and to uplift the standards of the construction industry in the future.

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DEVELOPING A DECISION-MAKING MODEL FOR SELECTING SMART RETROFITS

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ABSTRACT

The world is now experiencing a large environmental crisis, particularly buildings contributing significantly to the problem. Hence, building energy demand has been continuously growing in parallel with the rise in occupant energy demand. Smart retrofitting has been highlighted as one of the most effective ways to reduce energy consumption. However, the selection of suitable smart retrofits (SRs) has become a challenging task, from a range of SRs. A qualitative research approach was used in this research to identify relating to smart retrofits (SRs) for office buildings and establish governing factors for their selection. Semi-structured expert interviews were conducted to collect data related to SRs techniques, and content analysis was carried out to establish governing factors for selection of each SR. Out of 18 identified SRs from literature, fan cycling, ventilation control, and LED luminaires are the most implemented retrofit technique during the operational stage of the office buildings in Sri Lanka. Further, fan cycling, and ventilation controls were identified as commonly used types. Those findings were used to develop the decision-making model. Although SRs implementation is a comprehensive process, the recognized governing factors can be used to select suitable forms and features of SRs based on proposed decision-making model. This research further establishes metrics to benchmark the performance of SRs. The proposed model and the metrics could be valuable tools for building owners and facility managers to optimize facility operations.

Keywords: *Decision Criteria Model; Performance Evaluation; Smart Retrofits.*

1. INTRODUCTION

The primary source of global climate change in the atmosphere is human influence and environmental perturbation that is mainly caused by pollution associated with energy use (Karkare, et al., 2014). From 1984 to 2004, the rate of primary energy consumption and the amount of c discharged grew by 49% and 43%, respectively (Omar, 2018). According to Ahmad, et al. (2017), the non-residential building stock worldwide consumes about 46% of energy consumption and account for 30% of total CO_2 emission and 36% of the greenhouse gas emission. Hence, European Union (EU) decided to reduce CO_2 emission and greenhouse gas emission by 80% before 2050 (Khan, et al., 2021). The "smart retrofitting" concept has been introduced as the newest sustainable approach to reduce emission outputs while improving energy efficiency (Jaspert, et al., 2021). Approximately, 61% reduction in national CO_2 emission was found possible through

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implementing SR in building stock (Hirvonen, et al., 2021). Davies and Osmani (2011) viewed SR as the foremost approach in attaining sustainability in existing buildings at comparatively low cost compared to building lifetime and high uptake rates.

Smart retrofitting focuses on cost-effectively expanding existing assets' digital capabilities and functions to allow their adoption into smart environments and create value with existing physical support by integrating the sensor, connection, and data layer (Hassan Al-Maeeni, et al., 2020). In other words, SR aims to provide environmentally friendly, energy-efficient, and comfortable transformation of the current state in the building into smart assets (Jagarajan, et al., 2017). Pueo, et al. (2020) viewed SR as a process of upgrading, updating, or refurbishing existing physical assets. In this research, SRs are described as converting an existing building into the most advanced automated process by enhancing energy saving, human comfort, and green attributes with BMS integration used to monitor and control building facilities sustainably. A wide range of retrofitting technologies are available, including ventilation control, electricity demand limiting, optimum start-stop, vacuum glazing windows, smart windows, LED luminaires, sensors, elevator group optimization, and green roof (Gluszak, et al., 2019).

However, the implementations for SRs are at a marginal level due to the difficulty in selecting efficient retrofits options according to the type of buildings (Jagarajan, et al., 2017). Since various smart retrofitting technologies are available, selecting a cost-effective retrofit has become challenging (Ma, et al., 2012; Si, et al., 2016; Fasna and Gunatilake, 2019). Further, lack of knowledge of energy efficiency, lack of financial incentives, lack of communication between stakeholders, specific legal obstacles, and negative attitudes and their effects are forwarded difficulties in selecting the most appropriate SRs (Davies and Osmani, 2011; De Silva, et al., 2019). Also, standards to benchmark the performance of SRs are critical needs for facility managers.

With the aim of finding a solution for the gap as mentioned above, the research is conducted to develop a SR decision criteria model for selecting the best SRs for the office buildings in Sri Lanka. Further, the metrics to set benchmarks were established to assess the performance of the SRs.

2. LITERATURE FINDINGS

2.1 INTRODUCTION TO SR

The smart building concept was initiated in the United States in the early 1980s. The growing need for sustainable designs and environmentally friendly architecture has pushed the industry to create the SR concept.

Ghaffarianhoseini, et al. (2016) stated that the effectiveness of SR depends on their capability of managing critical systems and establishing necessary coordination between essential systems of building to provide desired technical performance, operational cost-saving strategies, and flexibility. Thus, usage of automation and high technology are prime elements of SRs.

2.2 SRS TECHNIQUES

Numerous SRs forms are used to improve building performance in existing buildings (Jiangjiang, et al., 2008). They include HVAC, air quality control, lighting, shading, window opening, elevators, and other electrical devices and applications (Park and Rhee, 2018). The literature reveals that 18 SR techniques apply to an office building in the Sri Lankan context, and they can be categorized into five forms as follows:

HVAC retrofits (T1) - Mathews, et al. (2001) identified HVAC retrofits methods as regulating indoor temperature set-point at an acceptable level, air-bypass and reset control on AHUs, setback control on spaces, controlling start-stop timings, consisting of economizer cycle combined with all the above, and CO_2 control.

Elevator retrofits (T2) - The elevator retrofits could have a significant impact on the use of zones as well as their numbers, and to segregate the different modes of traffic heading to other parts of the building, with overall savings resulting from the group's elevators sharing capacity (Missler, et al., 2016).

Lighting retrofits (T3) - Sensing techniques for smart lighting control and LED retrofits are commonly used (Ab Halim, et al., 2017). Optimizing daylighting with LED luminaires can achieve approximately 40% energy saving in office buildings (Sun, et al., 2018).

Building façade retrofits (T4) - Heat insulation solar glass, wall insulation, and green roof are common SRs for building façade of an office building (Cuce and Riffat, 2017; Simona, et al., 2017; Shafique, et al., 2018).

Window retrofits (T5) - Low emissivity applications, vacuum glazing windows, and smart windows are the most common SRs to reduce the thermal transaction through windows in office buildings (Han, et al., 2010; Ye, et al., 2013; Cuce and Cuce, 2016).

2.3 GOVERNING FACTORS FOR SR SELECTION

Governing factors for SR selection can be grouped into 3, including energy-saving, human comfort, and green attribute as follows:

Energy-saving (F1) - energy-saving techniques such as using renewable energy sources to achieve Nearly Zero energy buildings and reduce CO_2 emissions are considered (Morelli, et al., 2012; Pikas, et al., 2014).

Human comfort (F2) - allowing users to task-based interaction without getting any troubles and understanding smart technologies' capabilities are ensured (Gelazanskas and Gamage, 2014; Galinina, et al., 2018)

Green attributes (F3) - The ability of a building to provide flexibility is determined by physical characteristics such as thermal insulation and building layout, technologies and controlling its demand and generation in response to local climate conditions, user demands, and grid requirements (Reynders, et al., 2017; Parrish, et al., 2019; Al Dakheel, et al., 2020).

2.4 SR PERFORMANCE BENCHMARKS

Performance benchmarking provides organizations a better understanding of competitive organizations' success and the factors that can be optimized to succeed (Weicker, 1990). On the perspective of SR, it is estimated the performance such as energy-saving, human comfort and green attributes of the building is compared to other similar buildings (Ho, et al., 2000; Menezes, et al., 2013). Hence, the benchmarking process leads buildings to keep with regular monitoring and altering to achieve success.

The benchmarking process is a good practice that can help facility managers in intervention decision-making to select suitable techniques (Pestana, et al., 2021). Table 1 depicts the applicable metrics for energy saving, human comfort, sand green attributes of office buildings.

Table 1: Selected metrics for benchmarking of office buildings

Metrics	Unit of measure	Benchmark	Reference
Energy Saving			
Total energy consumption per area (Building energy index)	kWh/m^2	The low value is better (120 kWh/m^2)	Energy Conversation Building Code
Lighting system energy consumption per area	kWh/m^2	The low value is better	(Balbis-Morejón, et al., 2021)
HVAC energy consumption per area	kWh/m^2	The low value is better	(Balbis-Morejón, et al., 2021)
Human comfort and green attributes			
The average value of indoor illumination level	Lux	250 – 500 Lux is desired with 40 Lux for access areas and walkways	OSHA 1915.82
The average value of indoor temperature	°C	A low value more than 24°C and above 10.5°C is better	ASHRAE Standard 55-2017
Average value of indoor CO_2 concentration	ppm	600 - 1000 ppm	EN 13779:2007
The average value of indoor RH	%	40%-60%	EN 13779:2007
No complaints per area per annum	no./m^2	The low value is better	

3. RESEARCH METHODOLOGY

A qualitative approach was selected to achieve research objectives. The qualitative approach is the best technique if the author intends to learn about respondents' thoughts and opinions based on their experiences, expertise, and behaviour (Brayer, 2008). This research design includes a comprehensive literature review, semi-structured interviews, data analysis, and discussion of research findings, respectively. Since, this study focuses on the causes behind the factors used for retrofits selection and how they can be mapped with the existing building conditions. According to Yin (2011), the case study is used in this research. Hence, the researcher needs an in-depth investigation in a particular area and focuses on understanding the full scope of the problem, not on quantifying the problem.

Restrictions in accessibility due to COVID-19 pandemic at the time of data collection and the time constraints, six cases were selected, and the unit of analysis for this study was considered more than six years old office buildings. Since retrofitting are used in older buildings and further the retrofitting technology has been improved during last five years (Streicher, et al., 2020). The building older than six years were selected, with the aim of selecting retrofitted buildings. Hence, this research was used the purposive sampling technique to select buildings with the retrofits. The expert interviews were conducted in the individual cases to collect data on available SRs of HVAC, lighting, building Façade, window, and elevator retrofits to develop the decision criteria model. The profile of the selected office buildings and experts are tabulated in Tables 2 and 3, respectively.

Further, energy bills, datasheets, and retrofit proposals were reviewed to analyze energy consumption. Content analysis using NVivo 12 software was used to analyze interview transcripts. Finally, cross-case analysis was carried out based on the created themes to propose the decision criteria model for selecting the most suitable SRs in conventional office buildings in Sri Lanka.

Table 2: The profile of the selected office buildings

Case	Description	Used SRs type
C1	Bank building, 10 years old	HVAC retrofits, Lighting retrofits
C2	Commercial type office building, renting office blocks to their tenants, 20 years old	HVAC retrofits, Lighting retrofits, Elevator retrofits
C3	Bank building with Green Building Certification, 10 years old	HVAC retrofits, Lighting retrofits, Window retrofits
C4	Commercial type office building with Green Building Certification, 25 years old	HVAC retrofits, Lighting retrofits, Building façade retrofits, Window retrofits, Elevator retrofits
C5	Bank building, 36 years old	HVAC retrofits, Lighting retrofits, Elevator retrofits
C6	Government building consists of ministry complex, 10 years old	HVAC retrofits, Lighting retrofits, Building façade retrofits, Window retrofits, Elevator retrofits

Table 3: Profile of experts

Case	Respondent	Description
C1	C1R1	Head of Facilities Management with 6 years of working experience in banking buildings and responsible for all maintenance activities
	C1R2	Facility Executive with 2 years of working experience in the banking sector and responsible for energy reduction of building operation
C2	C2R1	Facility Manager with 10 years of working experience in commercial and office buildings
	C2R2	Facility Engineer with 8 years of working experience in building automation projects
C3	C3R1	Senior Facility Manager with 8 years of working experience in especially green development projects

Case	Respondent	Description
C4	C4R1	Head of Facilities Management with 12 years of working experience in leading commercial sector buildings
C5	C5R1	Maintenance engineer with 15 years of working experience in banking sector buildings
C6	C6R1	Maintenance engineer with 6 years working experience in mechanical engineering (both factory and commercial sector buildings)

4. RESEARCH FINDINGS AND DATA ANALYSIS

4.1 SRs TECHNIQUES USED IN OFFICE BUILDINGS

The details of SRs used in selected cases are summarized in Figure 1. Out of 18 identified SRs, findings show fan cycling, ventilation control, and LED luminaires are the most implemented retrofit technique during the operational stage of the building. In comparison, fan cycling and ventilation controls are reported as commonly used types. Conversely, night purge, image sensoring, green roofs, and smart windows have not been implemented in any of the cases used for the study.

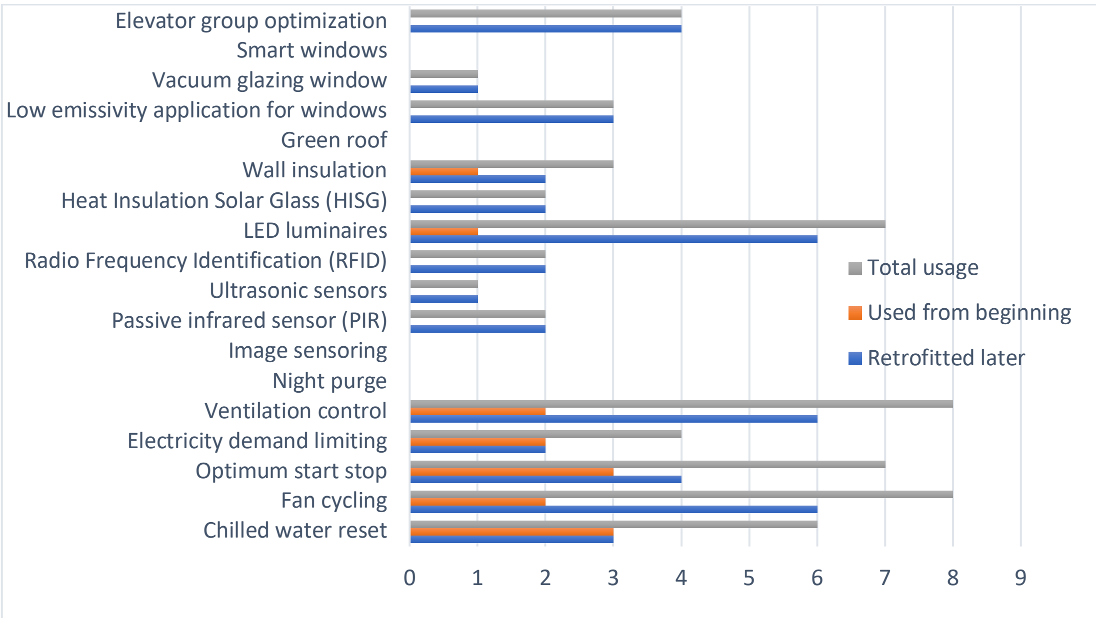


Figure 1: Current usage of SR techniques

**Total Usage = Used from beginning + Retrofitted later*

4.2 ENERGY SAVINGS ACHIEVED FROM DIFFERENT FORMS OF SRs

Results showed that the most implemented SR forms are HVAC retrofit and Lighting retrofit applications. Further, the highest saving has been obtained by adapting HVAC retrofits, compared with other forms (Table 4). That may be since HVAC is the highest energy consumer for office buildings (Fong, et al., 2006).

Table 4: Current forms of SR practices

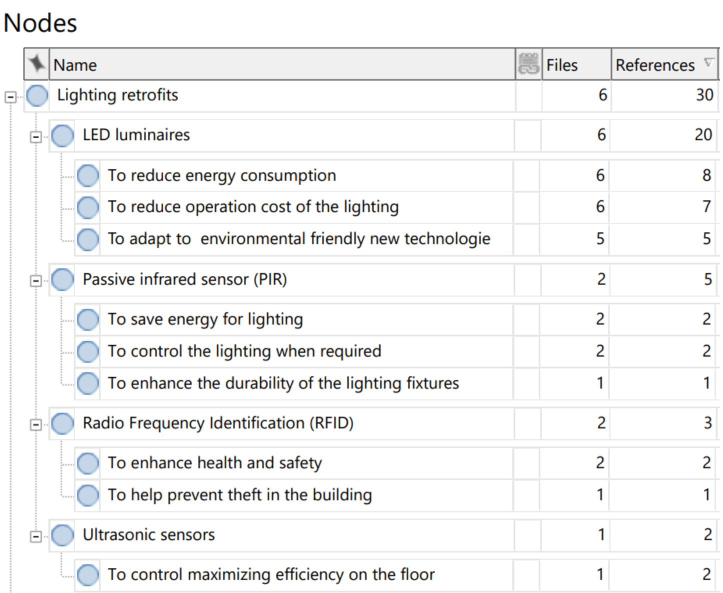
Smart Retrofit Area Based on Model	**Approximate % of Saving**	**Cases**					
		C1	**C2**	**C3**	**C4**	**C5**	**C6**
HVAC retrofits (T1)	55%-70%	✓	✓	✓	✓	✓	✓
Lighting retrofits (T3)	10%-12%	✓	✓	✓	✓	✓	✓
Window retrofits (T5)	6%			✓	✓		✓
Building façade retrofits (T4)	4%-5%				✓		✓
Elevator retrofits (T2)	2%-6%		✓		✓	✓	✓

Table 5: Energy consumption of selected case studies

	C1	**C2**	**C3**	**C4**	**C5**	**C6**
Total energy consumption (Monthly)	316,520.7	2,003,878.8	3,630,600.0	7,608,759.0	7,500,000.0	637,100.0
GFA	4645.2	25292.0	60,000.0	117,057.8	50,000.0	5,000.0
Unit cost	68.1	79.2	60.5	65.0	150.0	127.4

4.3 Factors Considered for SRs Techniques Selection

Knowledge of experts was elicited to establish factors under three areas: energy saving, human comfort, and green attributes. All experts showed that energy consumption per gross floor area (GFA) is the main factor when selecting SRs. Expert C4R1 stated that the thumb rule used in choosing suitable forms of retrofitting is *"…implementing retrofitting technologies into a system that consumes more energy …"*. When analysing on multiple data sources at the same time, NVivo is a realist approach that can help structure the iterative under qualitative approach (Dalkin, et al., 2021). Accordingly, one of the SR forms examined was illustrated in Figure 2.



Nodes

Name	Files	References
Lighting retrofits	6	30
LED luminaires	6	20
To reduce energy consumption	6	8
To reduce operation cost of the lighting	6	7
To adapt to environmental friendly new technologie	5	5
Passive infrared sensor (PIR)	2	5
To save energy for lighting	2	2
To control the lighting when required	2	2
To enhance the durability of the lighting fixtures	1	1
Radio Frequency Identification (RFID)	2	3
To enhance health and safety	2	2
To help prevent theft in the building	1	1
Ultrasonic sensors	1	2
To control maximizing efficiency on the floor	1	2

Figure 2: Factors governed for lighting retrofits

Summary of the code-based content analysis using NVivo 12 software was analysed. Twenty-seven factors are extracted to select five forms of SRs, as shown in Table 6.

Table 6: Governing factors for SR selection

Forms of SR	Factors governed for selection	No of References
HVAC retrofits (T1)	To avoid freezing the chiller	7
	To increase safety to the chiller	6
	To reduce peak energy consumption	6
	To get smooth performance	2
	To tally with building operation time	5
	To compute the usage pattern of the buildings	5
	To reduce the total cost for energy consumption at once	5
	To provide cooling and heat simultaneously	7
	To enhance human comfort	5
	To comply with the IAQ requirements	2
Lighting retrofits (T3)	To save energy	2
	To control the lighting when required	2
	To enhance the durability of fixtures	1
	To maintain maximizing efficiency on the floor	2
	To improve health and safety	2
	To help of preventing theft	1
	To reduce operation cost	7
Window retrofits (T5)	To get shading and sunray controls	2
	To get thermal comfort	3
	To avoid sound transmission	1
Building façade retrofits (T4)	To control UV rays through applying UV wall stickers	1
	To avoid solar heat coming to building inside	2
	To reduce energy for HVAC system operation	1
	To reduce thermal transaction	2
Elevator retrofits (T2)	To reduce the waiting time of the queue	6
	To enhance the performance	6
	To provide human comfort	2

4.4 PROPOSED DECISION MODEL

The SR selection criteria model is proposed by considering the type of SRs, governing factors for SRs selection, and energy savings achieved from different forms of SRs. Figure 2 illustrates the proposed model.

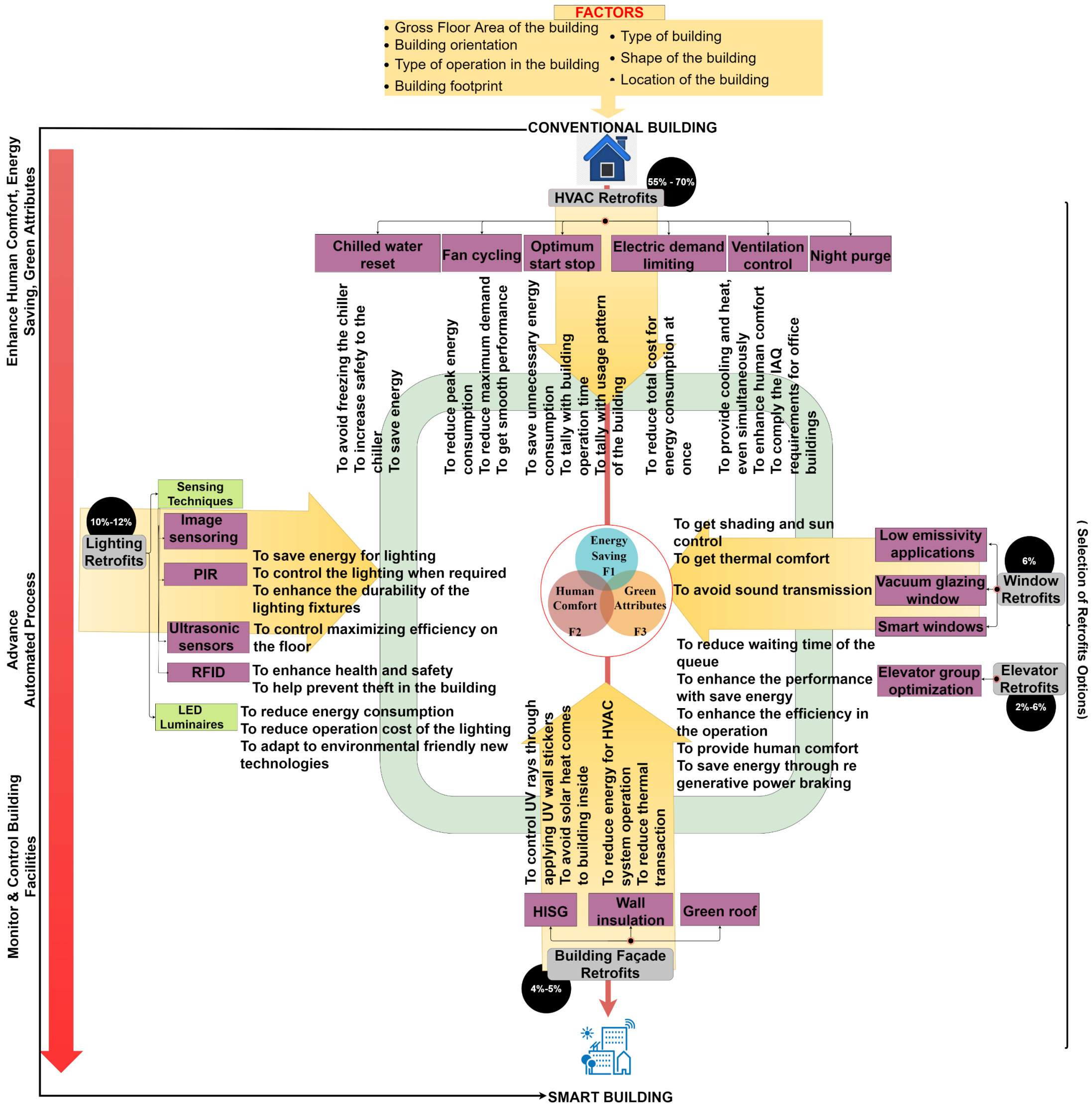


Figure 3: Proposed decision-making model

4.5 PERFORMANCE EVALUATION OF SR

In Sri Lanka, there are no specified standards to set benchmarks for the performance of SRs. Therefore, as per the experts, the metrics for SRs were established considering high energy consumption and human comfort in the built environment (see Table 7). Table 7 shows the values derived from energy consumption levels, human comfort parameters, and green attributes. Arrows indicate that those SRs need more improvements to achieve the best performing level. Results show that C2, C5, and C6 require further improvements in their SRs, compared with their peers when considering total energy consumption. Accordingly, when comparing the performance SRs used in case studies, the average value can be used as the benchmark for further improvements.

Table 7: SR performance matric

	Metrics	C1	C2	C3	C4	C5	C6	Average Value
Energy Saving	Total energy consumption per area (Building energy index) (kWh/m^2)	68.14 ↓	79.23 ↑	60.51 ↓	65 ↓	150 ↑	127.42 ↑	73.69
	Lighting system energy consumption per area (kWh/m^2)	21.19 ↑	12.9 ↑	7.2 ↓	6.5 ↓	22 ↑	12.74 ↓	12.82
	HVAC energy consumption per area (kWh/m^2)	24.23 ↓	33.65 ↓	33.28 ↓	34.45 ↑	79 ↑	76.45 ↑	34.05
Human comfort and green attributes	Average value of indoor illumination level (Lux)	250 ↓	400 ↓	600 ↑	500 ↑	450 ↓	525 ↑	475
	Average value of indoor temperature (°C)	22.77 ↑	23.2 ↑	22 ↓	22.5 ↓	22 ↓	23 ↑	22.64
	Average value of indoor CO_2 concentration (ppm)	988 ↑	1428 ↑	768 ↓	800 ↓	800 ↓	1120 ↑	894
	Average value of indoor RH (%)	51 ↓	55 ↑	50 ↓	55 ↑	55 ↑	50 ↓	53
	No of complaints per year (Relating to building performance) (No./year)	50 ↓	120 ↓	250 ↑	300 ↑	750 ↑	70 ↓	185

5. CONCLUSION

SRs are known for converting conventional buildings to eco-friendly, automated facilities by optimizing resource consumption. Among applicable SRs, fan cycling, ventilation control, and LED luminaires are the most implemented SRs techniques, while fan cycling and ventilation control are the most commonly used SRs techniques during the operational stage of office buildings in Sri Lanka. Further, HVAC retrofits could save more energy than other forms of retrofitting. In this regard, the HVAC system has various parameters to adjust and integrate to reduce energy consumption and wastage. Moreover, lighting retrofits give the most adapted form due to easy implementation with few changes to the existing systems.

However, identifying and deciding to select effective SR techniques should be done by considering various factors. Thus, a decision criteria model was developed to select the most suitable smart retrofits for office buildings in Sri Lanka. The proposed model can be used to choose the best way of taking the decision on SRs techniques selection.

Further, this research was established metrics to set benchmarks for the performance of SRs. The findings show that SRs used in C2, C5, and C6 need further improvements to achieve their best performing level when considering total energy consumption. Having a benchmark for SRs can compare the performance of SRs in similar buildings. Further facility managers can use those findings to adopt alternative technologies to enhance the existing performance of SR to minimize the over-resource consumption and environmental impact of Sri Lankan office buildings.

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DEVELOPMENT OF POST-DISASTER RESETTLEMENT STRATEGIES FOR SRI LANKA

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ABSTRACT

A disaster is known as an unexpected hazardous event that impacts the communities through extensive damage, disruption and potential fatalities, which makes the affected communities seek external assistance to recover from the impact. Post-Disaster Resettlement (PDR) has been identified as a good option to convert the destructive zone into a sustainable society with long term developmental guidance. PDR projects can be defined as a complex process that deals with uncertainty and change the facility partially or entirely by replacement. The success of PDR programmes highly influences the mitigation and preparedness phases of the next disaster. Currently, PDR projects in Sri Lanka are not at the required success level due to different types of social and economic challenges. This study, therefore, aimed to identify and develop suitable post-disaster resettlement strategies for the successful development of PDR projects in Sri Lanka. A qualitative research stance was used for the proposed research as it requires in-depth inquiry into the PDR strategies. The research developed twelve strategies to succeed with PDR projects in Sri Lanka. The required knowledge sharing among parties of the PDR project, and using disaster-affected communities for managing and controlling of the PDR project are the main key strategies. The study highlighted the importance of PDR strategies to Sri Lanka, factors considered when developing PDR strategies, the shortcomings that have been witnessed in past PDR projects, and the possible ways of developing appropriate PDR strategies for Sri Lanka. Further, the study identified the levels that each strategy must implement in the resettlement process.

Keywords: *PDR Strategies; Post-Disaster Reconstruction (PDR); Project Success.*

1. INTRODUCTION

A disaster is known as an unexpected hazardous event that impacts the communities through extensive damage, disruption and potential fatalities, which makes the affected communities seek external assistance to recover from the impact (Benson and Twigg, 2007). Socio-cultural impacts will badly affect the communities after a disaster, with economic disruptions and other various issues (Lindell and Prater, 2003). Even if disaster hurts communities, it creates an opportunity for a new future with accelerating change (Schwab, 2014). Accordingly, Post-Disaster Resettlement (PDR) has been identified as a good option to convert the destructive zone into a sustainable society with long term developmental guidance (Ye and Okada, 2002).

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The initial series of decisions for PDR projects have long term impacts on changing the lives of the affected community (Jha, 2010). Therefore, the success of PDR programmes depends on how far they have addressed the structural and non-structural requirements of the disaster affected community (Sridarran, et al., 2008). PDR projects can be delayed mainly due to the difficulties of finding suitable land areas to build a large number of housing schemes, which are compatible with the disaster affected community culture and the unwillingness of beneficiaries to be relocated and inadequate provision of infrastructure by the government (Jha, 2010). Sridarran, et al. (2008) have revealed that the success of PDR projects is not at a sufficient level in developing countries like Sri Lanka. When considering the Sri Lankan context, it is functioning with a very unique culture and is hugely disturbed by different types of natural disasters such as tsunami, floods and landslides (Amaratunga, et al., 2015).

The success of PDR programmes highly influences the mitigation and preparedness phases of the next disaster (Smith, 2002). However, studies show that post-disaster resettlement objectives are frequently not reached, and opportunities for community development are decreased as a result of ineffective resettlement (Vijekumara, 2015). Therefore, appropriate PDR strategies need to be planned and implemented that address the physical and economical improvements and social and cultural factors of a country and its community. Henceforth, this study aims at identifying and developing suitable PDR strategies for Sri Lanka. In order to achieve the aim, research was conducted to identify the PDR strategies in the world and with reference to Sri Lanka, to evaluate the identified PDR strategies in Sri Lanka in terms of addressing community needs, planning policy and long-term development goals, and to develop suitable PDR strategies for Sri Lanka as objectives. This research was initiated with a comprehensive literature review and continued with methodology, research findings, conclusions and recommendations.

2. LITERATURE REVIEW

2.1 OVERVIEW OF DISASTERS

A disaster is an event that exceeds normal protection with an impact on the community or one of its subdivisions through physical harm and social disruption by damaging the essential functions of the community (Lindell, 2013). Disaster affected communities require external assistance to recover from the impact of the disaster (Benson and Twigg, 2007). Different types of catastrophic disasters, including floods, earthquakes, and cyclones, have damaged the functioning of South Asian countries such as Sri Lanka, Pakistan, Bhutan, India, and Nepal in recent years (Eshghi and Larson, 2008). According to the Disaster Management Centre (DMC, 2017), the impact of the disasters on Sri Lanka is high as it is directly linked to nature. Sri Lanka faced economic issues with vast damage to the development of the country through natural disasters in past years (DMC, 2017). Further, they identified the most common disaster events in Sri Lanka as floods, landslides, extreme wind, droughts, and lightning.

2.2 POST-DISASTER RESETTLEMENT PROJECTS

According to Ismail, et al. (2014), PDR projects can be defined as a complex process that deals with uncertainty either by partially changing the facility or entirely replacing the facility, through identified post-disaster stages such as emergency, restoration, reconstruction, and improvement. The generation of resettlement process could follow the strategies that protect the livelihoods of the disaster affected community and should reduce the vulnerability to economic problems (Bang and Few, 2012). Smith (2002) stated that the continuation of disaster with expanded vulnerability and ability to fail in technological protective futures for the existing sites are the reasons for the resettlement after a disaster.

There are many PDR operations around the world, but their negative results continue to challenge the knowledge of post-disaster social risks and the efforts to re-establish livelihoods (Bang and Few, 2012). However, PDR projects have three major goals: restoring normal activities and living circumstances as soon as possible, protecting the community from future impact of hazards, and formulating and achieving agreed objectives among the parties concerned (Alexander, 2004).

2.3 POST-DISASTER RECONSTRUCTION PROJECTS IN SRI LANKA

Disasters such as floods, cyclones, and landslides and major disasters like tsunami have damaged Sri Lanka majorly affecting its community and its subdivisions (Jayawardane, 2010). Different types of PDR projects were implemented to recover economic damage and impact on the affected community from those disasters in Sri Lanka (Amaratunga, et al., 2015). The implementation of the PDR projects required guidelines, frameworks, and policies provided by the Sri Lankan Government (Ministry of National Policies and Economic Affairs, 2017). Although disasters badly affect the economy, they increase the development of Sri Lanka with new opportunities. For example, the housing reconstruction due to disasters helped to increase Gross National Product from 5.4 to 8.0 after the tsunami in 2004 (Amaratunga, et al., 2015).

The reconstruction of PDR projects is not at an acceptable community level, and improper standards and lack of knowledge sharing among involved parties are leading to a decrement in the success level of projects (Ophiyandri, 2008). However, studies show that post-disaster resettlement objectives are frequently not reached, and opportunities for community development decrementing as a result of ineffective resettlement (Vijekumara, 2015).

2.4 STRATEGIES FOR SUCCESSFUL POST-DISASTER RECONSTRUCTION PROJECTS

PDR projects use various types of technologies that aim to mitigate disasters (Lorch, 2005). Organizations involved in PDR projects such as governments, private sector entities, and NGOs should make proper strategies to mitigate the negative impact on the community, economy and environmental effects of resettlement (Bang and Few, 2012). The strategies must be compatible with the culture of the affected communities and social issues by fulfilling their basic needs (Jayaraj, 2008).

The required knowledge about PDR should be shared among professionals and other stakeholders who are involved with PRD projects (Jigyasu, 2002). These programs should be implemented to develop the services of stakeholders according to the actual situation of the project (Jones, 2006). Further, knowledge-sharing workshops provide a better understanding to professionals of the culture of the affected community, as it should be integrated when making decisions.

The issues that may arise when conducting PDR projects can be minimized by the participation of affected communities throughout the project by analysing real practices with theoretical proposals (Davidson, et al., 2007). Therefore, when managing and controlling PDR projects, it can be successful to use disaster-affected communities as resources to continue the project in a socially and culturally acceptable manner (Jayaraj, 2008). Implementation of such strategies to involve the communities would satisfy both authorities and end-users (Davidson, et al., 2007).

Using innovations and technologies implemented with local knowledge under local conditions and policies is identified as a strategy to succeed in the PDR projects (Twigg, 2006). Furthermore, Jaygasu (2002) states that such strategies should be labour-intensive technology that provides employment opportunities for the community. The vulnerability to future disasters could be increased due to the use of labour who does not belong to the affected community (Twigg, 2006). Further, the author stated that end-users will be in difficult situations in modifying and repairing the houses due to the lack of knowledge after imported labour left the project.

Identification of old building materials, which can still be useful and used for projects would mainly reduce the cost with minimum wastage of materials (Jayaraj, 2008). Local resources that are familiar to the community must be allowed to use in PDR projects, and those resources, skills, and subsidies, which are available locally, should be used with locally existing low-cost materials that are ecologically friendly (Saunders, 2006).

According to Hayles (as cited in Prasad, 2005), utilization of local skills could provide opportunities to the community affected by a disaster. Further, he identified that PDR can be successful through indigenous technology because the adaptation of hazards is well maintained in indigenous technology. Therefore, PDR projects must select modern technology integrated with indigenous technology (Jigyasu, 2002). According to the author, PDR will be more compatible if it is simple, economical, and easily adaptable with low maintenance to the project. Furthermore, Hayles (as cited in Prasad, 2005) stated building technologies used in PDR projects should be compatible with local needs, locally available resources, and culture to succeed in PDR projects.

The engagement of parties in some cases was restricted in PDR projects; therefore, formulation of legislation is required to avoid those issues through a better understanding of the culture of disaster affected community (Alexander, 2010).

According to Jaygasu (2002), the decision making of PDR projects should allow women's participation, and also it should be encouraged in the reconstruction process. When considering the risk experience of disaster, women may have a different level of experience compared to men; therefore, the development of PDR will improve by detailing women's risk experience when decision making (Ariyabandu and Wickramasinghe, 2003).

3. METHODOLOGY

In order to achieve the aim of the research through proper data collection method and data analysis method, there should be a well-structured condition to the research process (Kothari, 2004). This research was initiated with a comprehensive literature review which included basic concepts of PDR strategies and their shortcomings from the global and Sri Lankan contexts. A qualitative research stance was used for the proposed research as it requires in-depth inquiry into the PDR strategies. As the main data collection method, 6 semi-structured interviews were used. Deciding on the resettlement locations, layouts of the houses, infrastructure facilities and constructing buildings are done by government organizations such as National Building Research Organization (NBRO), Disaster Management Centre (DMC), and Ministry of Disaster Management. Therefore, semi-structured interviews were carried out with policymakers related to PDR strategies development from those organizations. From the policymakers, the factors they consider when developing PDR strategy, the shortcomings they have witnessed, and the possible ways of developing appropriate PDR strategies were inquired. Table 1 provides the summary of respondents who participated in the primary data collection process.

Table 4: Summary of respondent's profile

Respondent	Discipline	Industry Experience	Ability to Contribute to the Study
R1	Senior Scientist	13 years	NBRO
R2	Project Coordinator	10 years	DMC
R3	Scientist	08 years	NBRO
R4	Disaster Management Officer	05 years	DMC
R5	Structural Engineer	05 years	NBRO
R6	Quantity Surveyor	07 years	NBRO

The outcomes were evaluated by comparing findings through the literature survey to identify the suitability of the PDR strategies for the Sri Lankan context. According to Braun and Clarke (2006), a qualitative approach is used to get opinions and behaviours according to the subject matter. When getting those opinions, it considers a group of people and gets their individual responses to the topics highlighted in the research (Yin, 2013). Therefore, the content analysis was selected as the qualitative analysis method to investigate the suitability, shortcomings and improvement techniques of PDR strategies.

4. RESEARCH FINDINGS

Professionals in the disaster management industry were selected as resource persons for collecting information. Therefore, semi-structured interviews were carried out with policymakers related to PDR strategies development such as NBRO, DMC, and the Ministry of Disaster Management. They provided their idea on the importance of the development of PDR strategies in Sri Lanka. Further practicability of identified strategies to improve project success of PDR projects in Sri Lanka was discussed. Shortcomings when implementing strategies, improvement methods of strategies, and implementation levels of strategies within PDR projects were collected under each strategy.

4.1 IMPORTANCE OF THE DEVELOPMENT OF POST-DISASTER RESETTLEMENT STRATEGIES TO SRI LANKA

Different ideas were discussed with different respondents on the importance of the development of PDR strategies to Sri Lanka. According to R1, the risk areas from disasters can be divided into different types of levels such as medium risk areas, high risk areas etc. Medium risk area has a non-active risk from disaster. It has the risk, but still, it is not activated, and risk mitigation will be done for those areas to reduce the vulnerability to disaster. Different techniques such as soil nailing can be used for mitigation in medium risk areas. R3 mentioned, *"Risk mitigation is not suitable for high-risk areas, and resettlement is required to those areas as the last step when there are no mitigation or* *solution for disaster"*. Further, he explained that the complexity of the resettlement is the main reason for that. Therefore, the development of PDR strategies is important to Sri Lanka. R4 identified the PDR projects must be designed according to the factors that affect the project, such as social factors, economic factors, political factors etc. Research and studies must be conducted very carefully before making the decision for PDR projects because the PDR projects are very sensitive to human lives. All respondents stated that community involvement is not at a good level. Although government provide lands and compensation, the community do not want to resettle in another area. It happened because of some shortcomings of PDR projects. R2 identified the resettlement lands were in the mountain areas, and there were no proper access roads to the lands. R1 stated that one land was near the rubber factory and bad smell and non-protection from insects were the reasons for the unsuccess of the PDR project. Therefore, all respondents confirmed that the development of PDR strategies for success in the PDR project is important to Sri Lanka. Those strategies will overcome and minimize the above identified problems of unsuccessful PDR projects.

4.2 PRACTICABILITY OF STRATEGIES TO IMPROVE PROJECT SUCCESS OF PDR PROJECTS IN SRI LANKA

In this study, seven strategies for success in PDR projects were identified under literature synthesis. These strategies were assessed during the data collection procedure for achieving the aim of the research. During the data collection process, another five strategies were identified in the Sri Lankan context. Altogether, twelve strategies were identified to succeed in PDR projects in Sri Lanka.

4.2.1 Strategy 1 - The Required Knowledge about PDR Projects should be Shared among Professionals and Other Stakeholders Involved in the Project

According to Jigyasu (2002), all parties who engage in PDR projects must acquire the knowledge and information about the project. All respondents agreed with the implementation of this strategy in PDR projects in Sri Lanka. R4 mentioned, *"There are a lot of stakeholders who participated in PDR projects, and they must start the project with their own goals that build together with one final goal of PDR project"*. Further, he stated that all stakeholders must have an idea about what will be done in the project. Therefore, the knowledge sharing about the final goal must be a starting point for PDR projects. R2 identified the main areas of knowledge sharing as policies about the PDR project, design of the buildings, specification of mitigation strategies, and structural requirements. Those areas must have their own criteria, specifications, standards, and designs to share among parties. R3 opined that *"Stakeholders of the project build a completed team for PDR projects that include architects, researchers, engineers, funding organizations etc. Although that was a single team, all those separate parties will go through the design and specifications to review the feasibility of the project and the benefits from the project to their organization"*. Therefore, it required knowledge sharing for the PDR project. Lack of knowledge sharing among professionals and other stakeholders involved in the project was identified as the starting point of the disputes in PDR projects by R6. One respondent presents an example of this problem. *"In order to reduce the vulnerability of single-storey houses, concrete structural columns should be incorporated into the design. However, a contractor in a PDR project decided to build the single-storey houses without columns, creating disputes between the involved parties."*. According to R1, organizing workshops and supervising throughout the project are required to improve this strategy. Resistant to communicating with others was the main shortcoming of this strategy. Therefore, PDR projects need a proper process to share the knowledge among professionals and other stakeholders involved in the project parties.

4.2.2 Strategy 2 - Involving Disaster-Affected Communities in the Development of PDR Projects in a Socially and Culturally Acceptable Manner

The issues that arise when conducting PDR projects can be minimized by involving the affected communities throughout the project by analysing real practices with theoretical proposals (Davidson, et al., 2007). According to R1, this is the best strategy to succeed in PDR projects in Sri Lanka. Highly inflexion of traditional cultural patterns to the livelihood of the community was identified as the main reason for the requirement of this strategy. R5 stated that *"The ideas of the community must be heard from the policy level and must continue throughout the project"*. Further pointed out the unnecessary involvement of the community and the consuming time will be a shortcoming of this strategy. The community will fail in providing ideas when consulting structural features and technology features. Therefore, R3 proposed proper training to the community about the PDR projects through workshops. The community must enable the project by providing technical knowledge about the project and its features. R4 stated they want to work with disaster affected communities and get their requirements and ideas of them. Therefore, according to respondents, involving the disaster-affected communities in the development of PDR projects was a suitable strategy for the Sri Lankan context.

4.2.3 Strategy 3 - Using Innovations and Technologies that are Implemented with Local Knowledge under Local Conditions and Policies

Although Twigg (2006) identified using local knowledge under local conditions and policies will cause the success of PDR projects, it was partially accepted by respondents. According to R4, if Sri Lanka is not a technologically well-developed country, therefore, this strategy will be completely suitable for Sri Lanka. Sri Lankan PDR projects should use mix approach when considering technology because of Lack of required new technology. R6 stated that *"There may be new technologies to speed up the project, and there may be innovation that reduces vulnerability by using them in PDR projects"*. Sometimes technologies used in Sri Lanka will speed up the project. Further, he stated the combined implementation of foreign technologies and locally available technologies should be needed. Sometimes locally available technologies may become costly when implemented, and it was identified as a shortcoming by R2. R5 proposed to review innovative products from Sri Lanka and get support from them to improve this strategy. Further, he said the research on innovative products should be presented in symposiums and conference venues to increase the applicability in PDR projects.

4.2.4 Strategy 4 - Local Resources that are Familiar with the Community must be Allowed to use in PDR Projects

According to Jayaraj (2008), identification of old building materials, which can still be useful for projects and using those for projects, would mainly reduce the cost with minimum wastage of materials. R1 stated, *"Resettlement is changing the whole life of the affected community, but at least their houses must be familiar with them"*. Further, he identified that most of the resettlement was processed through new technologies that were not familiar to the affected community. According to the R6, the high cost of materials and time-consuming process decreases the ability to use local resources for PDR projects. R2 proposed to start research to identify cost-effective materials and designs because

PDR projects should end up with the available budget. Further, he stated that the making process and construction methods related to local resources should be implemented within the scheduled time frame without consuming time. Because disaster affected communities spend the worst time of their life during the period that PDR implements. Therefore, according to all respondents, local resources that are familiar with the community must be allowed to use in PDR projects within the available budget and within the scheduled time frame.

4.2.5 Strategy 5 - Utilization of Local Skills by Giving Livelihood Opportunities to the Community Affected by Disaster

According to Hayles (as cited in Prasad, 2005), PDR can succeed through indigenous technology as the adaptation of hazards is well maintained in indigenous technology. R3 identified most PDR projects were completed with a unique traditional approach. Projects were designed by authorities and built by the contractor. The affected community were isolated to the rescued area, and they were not engaged in the PDR project. R5 stated that *"Affected community can be used as local skilled resources for PDR project through proper knowledge sharing but the lack of experience and knowledge was the main shortcoming of this strategy"*. Therefore, according to all respondents, the utilization of local skills of disaster affected communities will help succeed in the PDR project by giving benefits to the community.

4.2.6 Strategy 6 - Formulation of Legislation to Avoid Issues Through a Better Understanding of PDR Projects

The engagement of parties in some cases was restricted in PDR projects (Alexander, 2010). Therefore, proper policy arrangement will cause the success of the PDR projects within designed boundaries as per the views of respondents. According to the R1, disaster affected communities have options when they resettle after a disaster. They can provide some alteration to their houses, they can make a design for their houses within given limitations, or they can accept the given house through the resettlement process. However, R6 stated that *"The community will propose alterations that will not be suitable for PDR projects. Although the community have a lot of options available, they will request alterations that are not suitable for the proposed programme"*. Therefore, according to R2, alteration from the community for the PDR project should be governed by legislation. It will succeed the PDR project through community participation within the proposed programme, pre-designed features, overall budget and time frame. On the other hand, R1 stated that professionals who enrolled in PDR projects must govern through legislation to get familiar with culture and community by conducting proper studies. Further, he identified that those restrictions by legislation would badly affect professionals and disaster affected communities, because of enforcement. Sometimes professionals want to engage the problems and solve them with the affected community, but policies restrict their involvement in that. Therefore, according to all respondents, the formulation of legislation should be implemented in a proper approach that will not enforce the professionals and disaster affected community to avoid the issue in PDR.

4.2.7 Strategy 7 - Encouraging the Women's Participation in the Decision Making and Reconstruction Process

Although Jaygasu (2002) stated the decision making of PDR projects should allow women's participation, according to the respondents, this strategy will partially be suitable for Sri Lanka. Further, R6 stated that participation of both men and women require for success in PDR projects in Sri Lanka. R4 identified that the high involvement of women in the PDR process decreases the ability to resettle in other area. The main reason for that was the lack of technical knowledge about construction projects. On the other hand, R3 stated, *"The women's participation will increase the feasibility of features in the project and then PDR project can process with features that highly required to the livelihood of disaster affected community"*. Further, he identified the sensitive mind of the women as the main shortcoming that together with culture, will create a resistance to changing the place of the living. Therefore, as the idea of all respondents, women's participation is required for the PDR project as same as men's participants. Therefore, encouraging women's participation in decision-making, and reconstruction should be implemented with proper knowledge sharing about technology.

4.2.8 Strategy 8 - Encouraging the Host Community's Participation in the Decision Making and Reconstruction Process

PDR projects are about relocating disaster affected communities to different locations. People who already live in the PDR relocation area are called as the host community. According to R1, the host community should relate to the PDR process. Further, he identified there were problems in previous relocating areas with the host community after resettlement. Those issues can be reduced if the host communities are engaged in the PDR projects. Therefore, encouraging the host community participation will help to succeed in the PDR project.

4.2.9 Strategy 9 - Restoration of Jobs with Vocational Training for Disaster Affected Community

R3 mentioned, *"The livelihood of people in the community depends on their living area, and they are working with available opportunities that are provided by their society"*. Their jobs will lose their jobs after relocating to new and different areas during the PDR process, making it hard for them to find opportunities that are suitable for their skills in the new area. Therefore, this strategy will improve by encouraging disaster affected communities for skill development by leading them to new ways related to the area. Arranging a vocational training programme will improve their skills and success in the post period of PDR projects.

4.2.10 Strategy 10 - Developing a Proper Approach to Improve Infrastructure Facilities in the Resettlement Areas

Scarcity of land for PDR projects is the main difficulty in Sri Lankan PDR projects. According to R4, *"After finding a land anyway, it will be a land that located in a rural area. Previous PDR lands were in isolated areas, where there are no sufficient infrastructure facilities. Therefore, PDR projects must be planned to build the resettlement so that the affected community can live happily"*. PDR must improve infrastructure facilities and other facilities to day-to-day requirements such as roads, schools, shops etc. Although the government is funding for PDR project, they allocate a very low budget to other facilities. That is the main difficulty when implementing it. Therefore, developing a proper approach to improve infrastructure facilities in resettlement areas will succeed in the PDR projects in Sri Lanka.

4.2.11 Strategy 11 - Arranging Counselling Programmes for Disaster Affected Community to Stable the Mentality

Disaster affects the community will badly fall in mentality, because they have lost their homes and their life was stuck. According to the R1, disaster affected communities should live happily after PDR to succeed in PDR projects. Therefore, the mentality of people should change, and they require counselling. Social analysis of disaster affected communities must need to be resettled before PDR. Therefore, arranging the counselling workshop to rearrange their mentality will succeed in the PDR projects.

4.2.12 Strategy 12 - Continuation of Dispute Resolution after PDR

There are a lot of disputes that will arise when PDR projects are implemented. R6 mentioned, *"dispute resolution is conducted among parties who are involved in the project while the PDR process is still going on"*. Therefore, the PDR process at the construction stage will become successful. After relocating the community, they will resist living there because of various issues. Therefore, ending the dispute resolution process right after the PDR process is concluded can be considered the main reason for that. If people leave the new places, the PDR would not be successful. Therefore, the respondent's idea is the continuation of dispute resolution after PDR will cause success in the PDR project.

Table 2 provides the summary of developed strategies throughout the research.

Table 2: Summary of developed strategies

Strategy	Identified from Literature Review	Suitability (According to the interviewees)	New Strategy (Identified from Data Collection)
The required knowledge about PDR projects should be shared among professionals and other stakeholders involved in the project	✓	Suitable	
Involving disaster-affected communities to the development of PDR projects in a socially and culturally acceptable manner	✓	Partially Suitable	
Using innovations and technologies that are implemented with local knowledge under local conditions and policies	✓	Partially Suitable	
Local resources that are familiar with the community must be allowed to use in PDR projects	✓	Suitable	
Utilization of local skills with giving livelihood opportunities to the community affected by disaster	✓	Suitable	
Formulation of legislation to avoid issues through better understanding of PDR projects	✓	Partially Suitable	
Encouraging the woman participation in decision making and reconstruction process	✓	Partially Suitable	

Strategy	Identified from Literature Review	Suitability (According to the interviewees)	New Strategy (Identified from Data Collection)
Encouraging the host community participation in decision making and reconstruction process		Suitable	✓
Restoration of jobs with vocational training for disaster affected community		Suitable	✓
Developing proper approach to improve infrastructure facilities in resettlement area		Suitable	✓
Arranging counselling programmes for disaster affected community to stable the mentality		Suitable	✓
Continuation of dispute resolution after PDR		Suitable	✓

5. CONCLUSIONS AND RECOMMENDATIONS

Ineffective resettlement results to find out new strategies to achieve the objectives of the PDR projects in Sri Lanka. The aim of the study was to identify and develop suitable post-disaster resettlement strategies for Sri Lanka. In this study, seven strategies for success in PDR projects were identified under literature synthesis. These strategies were assessed during the data collection procedure for achieving the aim of the research. During the data collection process, another five strategies were identified in the Sri Lankan context. Altogether, twelve strategies were identified to succeed in PDR projects in Sri Lanka.

As per the viewpoint of experts, eight strategies were identified as completely suitable for Sri Lankan PDR projects. Those strategies will highly affect the success of PDR. There are 4 strategies that were identified as partially suitable for the Sri Lankan context. Experts agreed that the involvement of disaster affected communities should implement within the predetermined limitations of the PDR projects without over-involvement of technical features and other structural strategies. Using local innovation and technologies should engage with foreign technologies as a mixed approach for speedup and success of the projects. The experts suggested that the formulation of legislation should implement in a proper approach that will not enforce the professionals and disaster affected community to avoid the issues in PDR. According to the findings, encouraging women's participation in decision making and reconstruction process should implement within limitations with proper knowledge sharing about technology.

Research findings confirmed that identified strategies should be implemented to succeed in PDR projects in Sri Lanka, and they can be used to overcome the current success level of Sri Lankan PDR projects and increase the satisfaction of disaster affected communities and all stakeholders in a project. The findings of this research will be beneficial for the policymakers and disaster management policy implementing organisations such as the Ministry of Disaster Management, National Building Research Organization (NBRO) and Disaster Management Centre (DMC), to increase the project performance in Sri Lankan PDR.

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DRIVERS AND BARRIERS TO IMPLEMENT GREEN BUILDING PRACTICES IN HIGHER EDUCATION INSTITUTES IN SRI LANKA

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ABSTRACT

Higher education institutes have a vast variety of humans, processes, and activities with significant waste generation, transportation, water and material consumption, and energy and electricity consumption. They have the potential to disseminate and lead future generations in the transition towards sustainability. Green buildings are designed, constructed, and operated by efficiently utilizing resources to provide a healthy and comfortable built environment while minimizing the life cycle cost. Higher education institutes across the world are several steps ahead of Sri Lanka in implementing green building practices. Thus, this research aimed to find approaches to increase the implementation of green building practices in higher education institutes in Sri Lanka. The research aim was approached through a qualitative case study. Accordingly, three cases were studied by collecting data through nine semi-structured interviews. Collected data were coded by using the NVivo 11 software and analysed using the cross-case analysis. Findings revealed that benefits associated with green buildings, leadership, specialization of the institute, institutional policy, and imposed regulations drive Sri Lankan higher education institutes to implement the green building practices. Lack of awareness, professional knowledge, skilled labour, and funds, political regime changes, poor planning, and stakeholder management were identified as barriers. The research outcomes guide the policymakers and management of the Sri Lankan higher education institutes to effectively implement green building practices. Further, the research outcomes will help to make strategies to reinforce the drivers and mitigate the barriers.

Keywords: *Barriers; Drivers; Green Building; Higher Education Institutes; Sri Lanka.*

1. INTRODUCTION

Sustainable Development (SD) was defined in the Brundtland Report as the "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). There are various tools and mechanisms to incorporate SD features into various industries (Boons and Ludeke-Freund, 2013). Green Building (GB) has been globally recognised as a means of incorporating sustainability into the construction industry (Shen, et al., 2018). World Green Building Council (2021) defined

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a GB as "a building that, in its design, construction or operation, reduces or eliminates negative impacts, and can create positive impacts, on our climate and natural environment". The GB concept is a catalyst that paves the way for sustainability by achieving 9 out of the 17 United Nations (UN) SD goals (Czerwinska, 2021).

As per Universities Act No. 16 of 1978, a Higher Education Institute (HEI) means a university, campus, open university, or university college established under the Act. Further, as per the Universities (amended) Act No. 7 of 1985, any institute or centre for higher learning and any degree awarding institute can be categorized as a HEI. Enriching the operations of HEIs with sustainable features become emphasized during the UN decade of Education for SD (2005-2014) (Qdais, et al., 2019). HEIs have the potential to disseminate and lead future generations in the transition towards sustainability (Corcoran and Wals, 2004). This has been recognised by the European Union SD strategy and the UN millennium development goals (Lukman and Glavic, 2007). Tennakoon (2017) and Anthony Jnr (2020) identified HEIs as the ideal places for introducing the GB concept with a futuristic view. Similarly, Fernando and Ariyawansa (2018) contended that developing and operating HEIs with green features significantly contribute to the nation's movement towards SD. Education and SD were first amalgamated by the Stockholm Declaration in 1972 (Grindsted, 2011). However, Tbilisi Declaration in 1977 laid the foundation for sustainability in higher education (Grindsted, 2011). Talloires Declaration assimilates sustainability and environmental literacy practices in teaching, research, and institutional operations (Association of University Leaders for a Sustainable Future, 2021).

HEIs across the world are several steps ahead of Sri Lanka in incorporating green concepts in operations, structures, and curricula (Lukman and Glavic, 2007). Moreover, greenness will be a key parameter in ranking universities globally in the future (Grindsted, 2011). Even though studies on sustainability in HEIs have increased in the recent past, only a few related studies have been conducted in the Sri Lankan context. By reviewing the literature base on the studies done on foreign green HEIs, Thennakoon (2017) proposed an agenda for Sri Lankan state universities in transforming into the green. On the other hand, Fernando and Ariyawansa (2018) developed a green rating system for new state university buildings in Sri Lanka by considering the criteria that affect sustainability. However, Fissi, et al. (2020) highlighted a research gap in empirical studies regarding the on-field realization of green HEIs. More importantly, Hoque, et al. (2016) highlighted the significance of studying the sustainability of HEIs in the South Asian context. On the other hand, Shen, et al. (2018) argued that more research should be done on identifying the barriers to implement the GB practices that are specific to developing countries. Moreover, the global trend of greening is knocking on the door of the Sri Lankan HEIs, leaving no option other than accepting (Tennakoon, 2017). Thus, it is important to understand the effective ways of implementing GB practices (Waidyasekara and Fernando, 2012). Hence, this research addresses the rising research question of "how the drivers and barriers affect the implementation of GB practices in HEIs in Sri Lanka".

2. LITERATURE REVIEW

2.1 DRIVERS TO IMPLEMENT THE GREEN BUILDING PRACTICES IN HIGHER EDUCATION INSTITUTES

Li, et al. (2011) identified two categories of driving forces of GBs namely market-led drivers and imposed drivers. Market-led drivers are the measurable benefits of GBs such as utility cost reductions and value addition to the brand name (Li, et al., 2011). A study that explored drivers of integrating sustainable practices in HEIs consolidated that by identifying reputation, image, goodwill, and credibility as driving forces (Blanco-Portela, et al., 2017). Imposed drivers are the rules and regulations that catalyse the adaptation. Dave, et al. (2014) identified environmental regulations as one of the top driving forces of GBs from 2018 to 2021. Declarations on sustainable higher education played a key role in developing monitoring tools for green HEIs (Grindsted, 2011). Anthony Jnr (2020) identified the ability of declarations and summits in higher education to foster sustainability attainment in HEIs in the Malaysian context. Stockholm Declaration, Tbilisi Declaration, and Talloires Declaration are the landmark declarations that initiated national legislation on sustainability in HEIs (Grindsted, 2011). However, the declarations were lacking in providing a framework on the critical GB practices that should be adopted by HEIs and thus not providing an interdisciplinary collaboration (Anthony Jnr, 2020). Beringer, et al. (2008) emphasized that merely signing declarations do not indicate the true sustainability efforts of the HEIs. For instance, researchers revealed that few signatory institutes of Talloires declaration in Atlantic Canada failed to reflect sustainability in institution policies (Beringer, et al., 2008).

Institutional commitments toward environmental conservation trigger the market demand for GBs (Shen, et al., 2018). The University of Florence realised the goal of being a green HEI by incorporating the green strategies into the institutional framework (Fissi, et al., 2020). Thus, sustainability became one of the basic strategic paths of the institute, and its mission and vision were defined accordingly (Fissi, et al., 2020). A study regarding Chinese HEIs concluded that the academic backgrounds of the staff members affect the institute's commitment to implement GB practices (Zhao and Zou, 2016). The study revealed that academic staff members from the environment, science, and technology backgrounds possessed greater abilities to contribute to the implementation of GB practices compared to members with backgrounds in art and sports. This was due to the ability to initiate platforms that increase active involvement via lectures or research on sustainability (Zhao and Zou, 2016). For instance, Tsinghua University developed China's first ultra-low energy building which was a platform for sustainability communication and increased the influence of green initiatives (Zhao and Zou, 2016). Similarly, Anthony Jnr (2020) highlighted the importance of the roles of academic professionals in related fields in pioneering the implementation of GB practices in respective HEIs in the Malaysian context. Moreover, Blanco-Portela, et al., (2017) identified that collaborative and interdisciplinary work between and among students, academic staff and external researchers as a unique driving force. A study regarding universities in Australia and England concluded that individuals who were committed to a more sustainable world would be a driving force that incorporates the green concept with university operations and activities (Ralph and Stubbs, 2014). Similarly, Shenyang University's green efforts project was driven towards success by the strong leadership who encouraged stakeholders to provide ideas and coordinated them effectively (Geng, et al., 2012).

Accordingly, the literature reveals that associated benefits of implementing GB practices, imposed rules and regulations, institutional policy, strong leadership, and specialisation of the staff in the environmental, science, and technological fields drive the HEIs to implement the GB practices.

2.2 BARRIERS TO IMPLEMENT THE GREEN BUILDING PRACTICES IN HIGHER EDUCATION INSTITUTES

Lack of professional knowledge slows down the development of green construction (Abidin, et al., 2012; Ametepey, et al., 2015; Karunasena and Thalpage, 2016). Qualified GB professionals are required to adopt advanced green technologies and materials. Scarcity of professional knowledge causes additional costs (Choi, 2009). Labour without proper training in green construction hinders ensuring the quality (Karunasena and Thalpage, 2016). Even being the centres of knowledge creation and sharing these barriers can still be seen in HEIs (Blanco-Portela, et al., 2017). On the other hand, rigid organizational structures discourage effective communication and knowledge sharing (Verhulst and Lambrechts, 2015). Malaysian HEIs experienced a lack of integrated information on GB practices which is required in attaining sustainability (Anthony Jnr, 2020). This results in a lack of effective leadership and creates a change resistance culture (Adams, 2013 and Horhota, et al., 2014). Portuguese HEIs had experienced a lack of commitment, engagement, awareness, and interest of the key stakeholders toward green construction as barriers (Verhulst and Lambrechts, 2015). Similarly, Anthony Jnr (2020) specifically identified a lack of interdisciplinary collaboration and communication among the stakeholders involved in GB projects in Malaysian HEIs. A study that explored barriers to integrating sustainable practices in HEIs identified lack of engagement, and roles and involvement of stakeholders as the worst problems (Blanco-Portela, et al., 2017). Similarly, Blanco-Portela, et al. (2017) contended that community involvement is fundamental for the effective implementation of GB practices.

The lack of incentives is another barrier. According to Olubunmi, et al., (2016), GB incentives are two folds; external incentives and internal incentives. External incentives are the extrinsic motivation factors provided by the government upon the fulfilment of stipulated conditions (Olubunmi, et al., 2016). According to the authors, there are two types of external incentives; financial incentives and non-financial incentives. Financial incentives are direct grants, tax incentives, rebates, and discounted development application fees (Karkanias, et al., 2010; Shapiro, 2011). A study which analysed the level of the greenness of Chinese HEIs identified government-based funding inequalities as a major barrier to implement GB practices (Zhao and Zou, 2016). Accordingly, top-tier HEIs which had sufficient funding reported notable progress compared to tier-2 HEIs which had less funding (Zhao and Zou, 2016). Similarly, Fissi, et al., (2020) identified a lack of sufficient funding as a major barrier faced by the University of Florence during the journey towards greening. Non-financial incentives are technical assistance, expedited permitting, business planning assistance, marketing assistance, regulatory relief, and guarantee programmes (Choi, 2009). Internal intensives can be defined as circumstances where people are poised to act out personal endorsement. The authors specified that human well-being related incentives are highly effective to promote GBs in HEIs. A study based at the University of Waterloo - Ontario revealed that the existing decision making process did not aim to reduce the long-term operating costs (Richardson and Lynes, 2007). The researchers further noticed that GBs were not prioritized even when the cost was the same as that of conventional buildings.

Accordingly, the literature reveals that lack of professional knowledge, lack of awareness and training, lack of interdisciplinary collaboration and communication, lack of finance, and lack of intensives act as barriers to implement the GB practices in HEIs.

3. METHODOLOGY

This study was intended an in-depth investigation with the aim of "finding approaches to increase the implementation of GB practices in HEIs in Sri Lanka". Kumar (2011) suggested using the qualitative approach when the study is about a particular situation, event, or emerging concept. On the other hand, it was impossible to go for a large sample due to the lack of implementation of GB practices in HEIs in Sri Lanka. The qualitative approach collects data from comparatively a lesser number of participants and analyses in-depth (Creswell, 2012). Hence qualitative approach was adopted for this research.

This study investigated the contemporary phenomenon of GB practice, within the real-life context of HEIs, in which the researcher had no opportunity to control or manipulate the behaviour. Moreover, context specific information was very important in this regard. Case studies provide a holistic view by deeply focusing on the context (Erickson, 2018). This research had a 'how' type research question. Yin (2014) recommended following the case study research strategy for the 'how' type research questions which are more explanatory. By considering all the above facts, the case study was selected as the research strategy. Since multiple cases reinforce the findings, more compared to a single case study, the researchers decided to go for three (03) cases. The number of cases was constrained by time and access limitations. According to Yin (2014) cases should be selected based on convenience, judgment, cost, and time limitations. Moreover, strategic selection of cases provides a competitive advantage over probability sampling (Patton and Appelbaum, 2003). Hence, judgemental sampling which allows selecting the cases that best suit the research question, was used. Accordingly, three (03) HEIs out of the universities, campuses, open universities, university colleges, institutes or centres for higher learning, and degree awarding institutes were selected based on the fact that having either rated GBs or GBs for which rating was pending. Profiles of the selected cases are presented in Table 1. Accordingly, GB practices were the unit of analysis and HEIs in Sri Lanka who involve in GB practices was the case boundary.

Table 1: Profiles of cases

Case	Description
C1	GBCSL gold rated building premises Constructed when the institute was relocating Institute established under the purview of the University Grants Commission (UGC) Established under the Ordinance No. 3 of 2000
C2	Green Mark gold certified building premises Degree awarding institute recognized by UGC Established under the State Ministry of Skills Development, Vocational Education, Research & Innovations

Case	Description
	Corporate entity incorporated under the Companies Act No. 07 of 2007 Sri Lanka's first HEI with rated GBs
C3	Pending GBCSL platinum rated building premises and non-rated building premises University established under the purview of UGC Established under the Universities Act No 16 of 1978

Interviewing is one of the most important data collection methods in the case study (Yin, 2014). In-depth interviews reflect interviewees' perspectives based on their experiences and understanding. Punch (2005) identified three (03) types of interviews namely structured, semi-structured, and unstructured. Semi-structured interviews, while being guided by a defined framework yet allow the researcher for situational questioning based on the responses. Yin (2014) recommended using a defined protocol when conducting multiple case studies yet inquire specific information becomes relevant during the data collection. Hence, semi-structured interviews were chosen for this research. Interviewees were selected within the case boundary based on their involvement and specialization in implementing GB practices. Accordingly, two (02) academic staff members and one (01) administrative staff member were interviewed in each case. All the interviews were conducted online via the Zoom platform due to the travel restrictions. The profiles of the interviewees are presented in Table 2.

Table 2: Profiles of interviewees

Case	Respondent	Description
C1	C1R1	Senior Lecturer (M.Phil., MSc, BSc in Engineering) Specialized in civil engineering
	C1R2	Lecturer (MSc, BSc in Engineering) Specialized in environmental engineering
	C1R3	Assistant Registrar (BSc)
C2	C2R1	Senior Lecturer (Chartered Architect) Research interests in minimal architecture and effective reusability of building spaces
	C2R2	Temporary Lecturer (BSc in Quantity Surveying) Research interests in GB and sustainability
	C2R3	Senior Manager (BSc)
C3	C3R1	Senior Lecturer (PhD, Master of Sustainability Science, MSc, BSc in Engineering) Member of Centre of Sustainable Solutions
	C3R2	Senior Lecturer (PhD, MBA, BSc) Accredited Professional-GBCSL Member of Centre of Sustainable Solutions
	C3R3	Assistant Registrar (BSc)

Interviewees were questioned under 4 major sections: the way of funding the GB implementations, factors/circumstances that drove the HEI to implement the GB practices, factors/circumstances that disturbed/hindered the implementation of GB practices within the HEI, and the ways of overcoming the challenges faced. Situational questions were raised to clarify and explore the details further and in response to literature review outcomes. Data analysis is the way of linking collected data with the literature and the research question (Yin, 2014). Data was analysed through cross-case synthesis which is the dedicated data analysis method for multiple case studies (Yin, 2014). NVivo 11 software was used to code the data.

4. RESEARCH FINDINGS

4.1 DRIVERS TO IMPLEMENT THE GREEN BUILDING PRACTICES IN HIGHER EDUCATION INSTITUTES IN SRI LANKA

In case 1, implementing GB practices was a combined decision of the client's project director and the contractor. The client's project director was a renowned professional in the Sri Lankan construction industry with decades of multi-faceted experience. Thus, he not just initialized but also effectively coordinated and drove the project towards success. The client's project director's technical knowledge and managerial and administrative skills immensely helped to leverage the project through several challenges such as rigid government decision making processes. Being an institute of technology, which provides higher education in engineering and technological fields, case 1 was rich with expert knowledge in sustainable construction. The in-house experts visited and explored several recently constructed buildings of HEIs around the country to enrich the planning process. On the other hand, in case 1, the majority of the contractor and consultant professionals were alumni members of the institute or the affiliated university. It caused stakeholder collaboration much more convenient and smoother. C1R1 further elaborated it by mentioning that "*everybody enjoyed the success of the project with the 'our' feeling*". Further, C1R2 mentioned that effective stakeholder management of case 1 during the project period was a benchmark in the field. On the other hand, C1R2 stated that at the previous location case 1 had no burden of paying utility bills as it was settled by the affiliated university. Since it was going to be settled by case 1 itself at the new premises it was essential to reduce the forecasted operational costs. Thus, associated benefits of GBs such as energy cost reduction drove case 1 to implement the GB practices. Additionally, sustainability related modules were included in the programme curricular and civil engineering programmes exclusively discussed GBs. Thus, the requirement to practically implement the theories and allow the students to experience the sustainable built environment drove the implementation of GB practices. However, C1R1 emphasized that conducting academics through online platforms due to the COVID 19 pandemic prevents gaining the true benefits out of the implemented GB practices.

In case 2, the principal driving factor to construct the country's first rated green HEI was the client's project director's requirement to develop a fully-fledged HEI which stands out from the rest. The underlying factors which drove the implementation of GB practices were associated benefits of GBs such as indoor environmental quality, reduced utility costs, and reputation. Commenting about the long-term planning C2R3 mentioned that "*the planning process started from the mind of our visionary leader-the project director, who thinks 4-5 steps ahead. Without that, I don't think this journey would have been possible*". The client's project team visited renowned HEIs such as Harvard University and the Massachusetts Institute of Technology to get the inspiration to develop an iconic green HEI which would be compatible with the 21st century's demands. Further C2R2 mentioned that there were no doubts about implementing GB practices for phase 2 of the projects due to the success achieved from initial implementations. Phase II was already underway with several GB practices. On the other hand, in case 2, the implementation of GB practices was driven by the corporate sustainability policy of the institute. The policy and a dedicated management framework institutionalised the green concept and ensured feasible and effective sustainability initiatives. Through that, the environmental considerations had been prioritised in future planning and day to day operations. In case 2, various state and semi-state organisations were involved in the project and all the stakeholders treated the project as of national importance. In addition to that, the visionary leadership of the client's project director enriched with vast experience in leading organizations and wide social networks played an immense role. C2R3 emphasized that the rapport among the key players: client, contractor, and financier highly determined the project's success. This was achieved by developing a team working culture with a common goal. Similarly, stringent project management and quality assurance ensured project success.

In case 03, the environmental policy of the institute drove the implementation of GB practices. Case 3 had taken several significant steps to institutionalise the green concept. The policy contained frameworks for environmental management, assessing and monitoring environmental impacts, and setting and reviewing environmental objectives and targets. Most importantly mission of the Centre of Sustainable Solutions (the dedicated centre that leads the implementation of the environmental policy within the institute) was to become the leading green university in Asia. In addition to those discussions were conducted with the International Cooperation Division of the Global Environment Centre Foundation on organizing collaborative programmes to implement the green concept at the university. Case 3 had experienced the benefits of GB practices before initiating the decision of constructing the pending GBCSL platinum rated GB premises. Case 3 had implemented GB practices such as solar energy generation, biogas generation, and organic waste recycling. Most importantly, in 2016 the institute was nominated for the UNESCO-Japan Prize for Education for SD considering the efforts to educate the youth by being an example through greening. In addition to that, the institute secured 259th place in GreenMetric World University Rankings in 2017 and 253rd place in 2016 while securing first place among Sri Lankan universities. In 2021 the institute held the 247th position. The main intended benefit of pending GBCSL platinum rated GB premises was to reduce the life cycle cost. C3R2 stated that "*the Building Energy Index of a typical higher education building is around 200 and we expect to maintain it around 100 in this premises*." Similarly, the institute intended to provide better indoor environmental quality for students and hire the auditorium for the outsiders and promote the landmark exceptional GB. Additionally, as mentioned by C3R1, sustainable technology is one of the specializations of degree programmes offered by the faculty and thus there was a requirement to enable the students to have a real-life experience in sustainability in a built environment. During the planning and designing stage of the new premises, case 3 got inspired by the net-zero energy buildings at Norfolk State University. On the other hand, for the new building premises for which the green rating was pending, constructing a rated GB was a condition stipulated by the funding agency.

Table 3 summarises the factors which drove each case to implement the GB practices.

Table 3: Drivers of each case

Drivers	Case 1	Case 2	Case 3
Associated benefits of implementing GB practices	√	√	√
Outstanding leadership	√	√	
Institutional policy		√	√
Specialised in environment, science, and technology	√		√
Imposed rules and regulations			√

All three cases evidenced the findings of Li, et al. (2011) and Blanco-Portela et al. (2017) regarding how the associated benefits drive the HEIs to implement the GB practices. In case 2, the client's project director was certain about how the GB practices were beneficial in developing a HEI which stands out from the rest. In case 1, the client's project director and the in-house experts had that understanding. On the other hand, in pending GBCSL platinum rated GB premises of case 3 and the second phase of case 2, the institutes had already enjoyed the benefits of GB practices and those experiences drove the further implementations. Thus, the findings revealed that in order to be driven by the associated benefits, firstly, the HEI must identify the benefits of the GB practices and secondly, must be aware of how the benefits are advantageous in achieving the desired goals. Evidencing the experiences of Shenyang University's green efforts project, in case 1 and case 2, strong leadership had driven the implementation of GB practices. The roles played by the client's project directors in both cases substantiated the findings of Ralph and Stubbs (2014) about committed individuals' ability to drive the green concept within the HEIs.

Prioritizing GB practices from the institutional policy can be seen in case 2 and case 3. Evidencing the findings of Fissi et al. (2020) regarding the University of Florence, case 3 had the clear mission of becoming the leading green university in Asia. A policy ensures continuous commitment to the green concept. Similarly, policies and frameworks guide the institutes towards a defined goal by integrating the implementation rather than the isolated implementation of GB practices. Findings were strongly in line with that of Zhao and Zou (2016) regarding the abilities of the institutes with the strong environment, science, and technology backgrounds to contribute to the implementation of GB practices. On the other hand, imposed regulations had driven the implementation of GB practices only in case 3. As argued by Beringer, et al. (2008) this can be explained by the fact that the law always set the minimum requirements and by nature people try to comply with the law just to avoid being subject to the remedies of non-compliance.

4.2 BARRIERS TO IMPLEMENT THE GREEN BUILDING PRACTICES IN HIGHER EDUCATION INSTITUTES IN SRI LANKA

The most significant challenge that case 1 faced was the 2015 political regime change. Even though the new government stopped funding many ongoing projects the project team with the support of the alumni of the institute built up healthy relationships with the government and made sure the project was funded uninterruptedly. In case 1, designing while ensuring minimum cut and fill was challenging due to the sloping nature of the ground. Thus, architects and structural engineers together with other professionals evaluated the designs together to choose the best one. As per the unique design, level zero floor (entering floor) of the main building was connected to every building and floors were named Z0, U1, U2, U3, U4 for upwards, and D1 for downwards. However, the subcontractor did not agree to customize the buttons inside the elevators accordingly. Hence client had to go for another subcontractor. Case 1 had a closed wastewater treatment plant that was processed through an activated sludge process by using a patented material for bacteria growth. However, using the material was arguable as the subcontractor did not will to reveal it. Hence, regardless of being a turnkey project weekly progress review meetings and discussions were conducted. On the other hand, installing solar panels was not in the initial plans and changing the design later when it was required was costly. Similarly, the proposal made during the operational phase to install solar panels was not approved due to a lack of funds. It was noted that the awareness of the direct stakeholders about the implemented GB practices was very low. Even some people in senior administrative positions did not know that case 1 was a rated GB. Some of the academic staff members who were lecturing in related fields got to know about the institute's green rating from a plank demonstrated in the director's office.

Major challenges faced by case 2 during the 5 years project period were inflationary conditions, long spells of incessant rain, skilled labour shortage, and most importantly the 2015 political regime change. However, the evolving socio-political conditions were tactfully managed by the institutional leadership by using the vast experiences and social and professional network. The natural rock boulders in the land challenged the designers and thus, the design was done by incorporating them instead of removing. Initially, it was hard to convince that the location would be preferred by the potential students. As a result, obtaining funds was also challenging. Later case 2 managed to obtain a treasury guarantee and a loan facility from a local bank through the guarantee. On the other hand, the project obtained Board of Investment status and was carried out under stringent project management and quality assurance which ultimately resulted in lesser than the estimated cost per square foot. However, the project was slightly delayed than estimated.

In case 03, the major challenge was the lack of thorough understanding of the professionals about the GB concept. As a result, green features such as using rainwater for toilet flushing had to be partially removed. C3R1 argued that it was hard to convince the designers that using harvested rainwater for toilet flushing was required to get a higher rating score. The challenge had been mitigated through frequent monitoring, negotiations, and introducing some other green features to collect the lost points. C3R2 claimed that designers sometimes merely focused on getting the points without any clear idea about the outcome. She substantiated that "*once they tried to fix only a few CO2 sensors for the sake of getting the points instead of focusing on the indoor environmental quality*". The consequences were mitigated through weekly progress review meetings, acknowledging the project team about the green features and the point allocation, and organizing pre-evaluation visits of GBCSL.

Table 4 summarizes the barriers faced by each case when implementing the GB practices.

Table 4: Barriers faced by each case

Barriers	Case 1	Case 2	Case 3
Lack of awareness and commitment	√		
Lack of understanding of the professionals			√
Lack of skilled labour		√	

Barriers	Case 1	Case 2	Case 3
Lack of funds	√	√	
Political regime change during the project period	√	√	
Sloping nature of the land	√	√	
Natural rock boulders located in the land		√	
Stakeholder management	√	√	√
Lack of proper planning	√		

Similar to Portuguese HEIs, Case 1 experienced a lack of commitment, engagement, awareness, and interest of the key stakeholders. Even though case 1 had in-house experts and sustainability related modules included in the curricular, there was no proper mechanism for stakeholder collaboration during the operations phase. Obtaining the green certification should not be sufficient, especially when allowing the students to experience the sustainable built environment was an intended benefit. As contended by Blanco-Portela et al. (2017), it prevented case 1 from the effective and efficient implementation of GB practices. Substantiating the literature findings case 3 experienced a lack of professional knowledge while implementing the GB practices and evidencing the findings of Choi (2009) resulted in additional costs. As identified by Karunasena and Thalpage (2016), case 2 experienced a lack of skilled labour.

Cases had different experiences regarding the availability of funds. Case 1 suffered from a lack of funds to install a solar energy generation facility. Whereas, case 2 initially had to face various hardships in securing funds. In case 3, pending GBCSL platinum rating building premises was funded by a grant for GB construction and had not faced a lack of funds. Findings revealed that stakeholder management was critical and challenging in each case. This was identified in the literature as a lack of interdisciplinary collaboration and communication. Case 2 received BOI concession as a financial incentive and case 3 got technical assistance from GBCSL such as pre-evaluation visits. Thus, a lack of incentives could not be identified as a barrier to implement GB practices in the HEIs in Sri Lanka. Barriers faced by case 1 due to lack of proper planning can be referred to as a lesson learnt.

Case study findings revealed few barriers which had not been identified in the literature. Political regime change became a barrier due to the country's political culture, where the successor regime criticises and stops supporting the projects started by the previous regime. However, in both cases, funds and government support were secured by strategically managing the socio-political behaviour. It was possible due to the social networks and the experience of the client's project directors and especially in case 1 since the alumni members of the institute were there in top positions in the government. Barriers arise due to the sloping nature of the lands and the existence of rocks were project specific but not common. However, barriers related to political regime changes can be commonly expected in the Sri Lankan context.

5. CONCLUSIONS

Only a few studies related to sustainability in HEIs have been conducted in the Sri Lankan context. Thus, this paper attempts to fill the research gap of empirical studies regarding green HEIs in Sri Lanka. Accordingly, three (03) Sri Lankan HEIs which had either rated rating pending GBs been selected for the case study.

Associated benefits of GBs drive the HEIs to implement the GB practices. In order to be driven, firstly, the HEI must identify the benefits of the GB practices and secondly, must be aware of how the benefits are advantageous in achieving the desired goals. Strong leadership backed with technical skills in related fields, social networking, and managerial skills drive the implementation of GB practices within the HEIs. Prioritising GB practices from the institutional policy is also a driving force. A policy ensures continuous commitment to the green concept and guides the institutes towards a defined goal by integrating the implementation of GB practices. Institutes with a strong environment, science, and technology backgrounds have competitive advantages over others in implementing GB practices. According to the findings, in the Sri Lankan context, the ability of imposed rules and regulations to drive the implementation of GB practices within the HEIs is less compared to other drivers. Obtaining the certification should not be sufficient. There should be a proper mechanism for stakeholder collaboration during the operations phase. Lack of commitment, engagement, awareness, and interest of the key stakeholders prevent the effective and efficient implementation of GB practices. The lack of professional knowledge and skilled labour are barriers to implement GB practices in HEIs in Sri Lanka. Lack of funds will be a barrier depending on the source of funds and the objective of the financer. Case study findings identified political regime change during the project period as a barrier to effective implementation of GB practices in the Sri Lankan context. It became a barrier due to the country's political culture. Barriers arise due to the sloping nature of the lands and the existence of natural rocks were project specific but not common. Lack of proper planning is also identified as a barrier. Findings did not identify a lack of incentives as a barrier to the effective implementation of GB practices in the HEIs in Sri Lanka. The empirical findings will be beneficial for the administrators, and policy makers of HEIs in Sri Lanka to effectively implement the GB practices. Research outcomes aid them to align the institutional strategies in a way that strengthens the drivers and mitigates the barriers. Similarly, the research findings can be referred to as lessons learned for future implementation projects. However, since the study is based on three (03) cases and all of them are located in the western province of Sri Lanka, the results cannot be generalised. Similarly, data collection interviews were limited to three (03) in each case and only two (02) members of the academic staff and one (01) member of the administrative staff were interviewed. These limitations should be addressed in future research by conducting quantitative studies which enable to generalise the findings. Similarly, data collection can be expanded to students of HEIs as well.

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ECONOMIC PERFORMANCE OF GREEN WALLS: A SYSTEMATIC REVIEW

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ABSTRACT

Green walls are becoming an interesting solution to address the potential issues due to loss of greenery in the urban built environment. Even though green walls offer numerous benefits, the application pace of this concept seems slow in many parts of the world including Sri Lanka, which could be primarily due to the perception that the construction of green walls may involve additional costs compared to conventional walls and due to lack of awareness of its performance. This has driven the recent researchers to investigate the economic performance of green walls. However, those studies are limited to given local contexts, thus, the knowledge is scattered. Therefore, this paper aims to explore the economic performance of green walls in the global context collectively using a systematic review towards understanding the differences. Filtering the search for the period of 2010 to 2022 offered 15 out of 103 research articles suitable for the analysis. The cost data extracted shows high variability related to different characteristics of green walls, building envelopes, and climatic conditions. According to the review, the maintenance stage accounts for the highest portion of the Life Cycle Cost (LCC) in any type of green wall. The direct green façade is the cheapest option with lowest LCC compared to the indirect and living wall types while the living wall is the expensive type due to presence of more components. The review further confirms that in most instances, the economic benefits of green walls; increase property value, façade longevity, tax incentives, and energy-saving tend to offset the cost of green walls. It is expected that this collective review outcome would better guide the decision-making process of green wall implementation in a given context.

Keywords: *Benefits; Costs; Economic performance; Green walls; Systematic Review.*

1. INTRODUCTION

With the increment of population growth and the rapid development of urbanisation, environmental issues have drawn worldwide attention (Chuai, et al., 2021). According to the United Nations (2018), urban population may rise 60% by 2030 and accounts for 60–80%, 75%, and more than 60% of global energy consumption, carbon emissions, and resource use, respectively. Furthermore, if there are no alterations to improve the energy efficiency of buildings, the demand will be increased by 50% for global building energy from 2018 to 2050 (US Energy Information Administration [USEIA], 2019). In addition to the energy crisis, global warming, climatic changes, health problems, loss of biodiversity and rising risk of natural disasters are a few of the many challenges that

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current society facing, giving rise to the integration of natural vegetation into the built environment (Olubunmi, et al., 2016). Therefore, rain gardens, street trees, urban drainage systems, green roofs, and green walls are effective solutions for mitigating and avoiding those issues in urban areas (Teotonio, et al., 2021). Green roofs and green walls can be considered as the most preferred solution than others due to the scarcity of land and the numerous benefits in terms of environmental, economic, and social aspects (Manso, et al., 2021). Of them, green walls have a greater potential to yield positive outcomes than green roofs because the surface area of the walls of a multi storey building is greater than the area of roof (Olubunmi, et al., 2016).

Green walls are referred to as all forms of vegetated wall surfaces and can be classified into two main categories as green facades and living wall systems based on their method of construction (Manso and Castro-Gomes, 2015). Green facades are based on a climbing plant directly attached to the wall (Direct green facades) or supported by structures such as steel cables or trellis (Indirect green façade) (Manso, et al., 2021). The living wall system is more complicated with a prefabricated or pre-vegetated system on a modular panel that contains growing media with balanced nutrients (Huang, et al., 2019). Green walls provide multiple services to three sustainable pillars: environment, economy, and society. In terms of environmental benefits, absorption of air pollutants, and improved air quality (Teotonio, et al., 2021), urban noise absorption, mitigating urban heat island effect (Manso, et al., 2021), provide habitats for small insects and birds, and urban wildlife protection (Silva, et al., 2018) are prominent. From the perspective of economic benefits, green walls enhance buildings' performance by increasing property value (Dong and Huang, 2021) and building durability (Almeida, et al., 2020). Furthermore, reduce the energy consumption for heating, ventilation, and air conditioning by maintaining the heat transfer between internal and external environments through plants (Zazzini and Grifa, 2018). In addition to environmental and economic benefits, social benefits comprise of providing quality and healthy life, spaces for recreational use (Teotonio, et al., 2021), and improving aesthetics (Rosasco and Perini, 2018).

Although benefits which green walls offer, the wider application of this concept is hindered by several factors: high initial and maintenance cost, lack of public awareness on the green wall concept, high technology, and breading unwanted pests, etc. (Naumann, et al., 2011). Amongst these barriers, the high initial and maintenance cost of green walls compared to conventional walls is evident as a major concern. For example, Chew and Conejos (2016) noted that lack of awareness and the high initial cost are major barriers that limit the widespread application of the green wall concept. Similarly, a survey carried out to identify the possible reason for the low adoption of green walls concluded that most people hold onto the perception that the high initial cost of green walls is relative to conventional walls (Wong, et al., 2010). Therefore, a through account and a proper evaluation of the economic performance of the green wall concept will help to encourage the green wall application.

The foregoing review confirms that much work has been done on the economic performance of the green wall concept in the global context over the last decade. However, those studies are limited to a specific region, climate, or context. Hence, reviewing the available literature will help to identify the global trends with respect to the economic performance of green walls and whereby it can assure the developers and investors on deciding on the application of green walls. Therefore, this paper aims to explore the changes in the economic performance of green walls in the global context using a systematic review approach.

2. RESEARCH METHODS: SYSTEMATIC REVIEW

The systematic review technique was used to carry out the literature search in this study as it is widely practiced among several methods. Rather than selecting random literature, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method was adopted to improve the quality of the study. According to Benachio, et al. (2020), the PRISMA guideline consists of a four-phased flow diagram where it passes through the phases of identification, screening, eligibility, and inclusion.

2.1 SEARCH STRATEGY

Initially, the research question of "What is the level of the economic performance of green walls in the global context?" was developed using the PICO (Population, Intervention, Comparator, and Outcome) search strategy tool (Cooke, et al., 2012). Since the research question focuses on economic performance, which is more towards quantitative outcomes, the PICO search strategy enables defining a quantitative research question and search terms, laying the pathway for a systematic search strategy (Schardt, et al., 2007, as cited in Cooke, et al., 2012). Accordingly, the PICO elements of the research question formulated for the study were identified: global context as the study population, green walls as the intervention, and economic performance as the expected outcome. As the study intends to systematically explore the concept of green walls where it is not necessary to consider an alternative to the identified intervention, i.e., green walls, the comparator element was eliminated from the study (Cooke, et al., 2012). Following, a basic logic grid was developed to perform an initial search to identify the relevant key and index terms to include in the comprehensive search strategy. Table 1 provides the basic logic grid alone with the alternative terms identified for the PICO elements. Here, the term global context was not included in the logic grids as the intention is to retrieve publications covering the whole world.

Table 1: Logic grid with identified keywords added

Population	Intervention	Outcome	
Global context	Green wall	Economic	Performance
	Green façade	Cost	Capability
	Vertical greenery system	Cost?benefit	Feasibility
	Living wall	Life?cycle?cost	Appraisal
	Green garden	Lifecycle?cost	Analysis
		Financial	Evaluation
			Assessment
			Sustainability
		Sensitivity analysis	

As indicated in Table 1, wild cards such as question mark (?) were introduced to several terms to maximize the search results in literature databases. When developing the final search strategy, quotation marks were used to get the exact term and the Boolean operator "AND" was used to combine the PICO elements while "OR" was used to link synonyms identified for each element. Once all the search terms were identified and finalised, the final search string was developed as follows.

> (("green wall" OR "green facade" OR "vertical greenery system" OR "living wall" OR “green garden”) AND (“economic performance” OR “economic capability” OR “economic feasibility” OR “economic appraisal” OR “economic analysis” OR “economic evaluation” OR “economic assessment” OR “economic sustainability” OR “cost performance” OR “cost capability” OR “cost feasibility” OR “cost appraisal” OR “cost analysis” OR “cost evaluation” OR “cost assessment” OR “cost?benefit performance” OR “cost?benefit capability” OR “cost?benefit feasibility” OR “cost?benefit appraisal” OR “cost?benefit analysis” OR “cost?benefit evaluation” OR “cost?benefit assessment” OR “life?cycle?cost performance” OR “life?cycle?cost capability” OR “life?cycle?cost feasibility” OR “life?cycle?cost appraisal” OR “life?cycle?cost analysis” OR “life?cycle?cost evaluation” OR “life?cycle?cost assessment” OR “lifecycle?cost performance” OR “lifecycle?cost capability” OR “lifecycle?cost feasibility” OR “lifecycle?cost appraisal” OR “lifecycle?cost analysis” OR “lifecycle?cost evaluation” OR “lifecycle?cost assessment” OR “financial performance” OR “financial capability” OR “financial feasibility” OR “financial appraisal” OR “financial analysis” OR “financial evaluation” OR “financial assessment” OR “financial sustainability” OR “sensitivity analys?s”))

2.2 STUDY SELECTION

Within systematic reviews, when searching for relevant references, it is advisable to use multiple databases. However, searching databases is laborious and time-consuming, as syntax of search strategies are database specific (Bramer, et al., 2017). Given the time and resources constraints and the optimal combination of databases, the current study performed systematic searches in three databases: Web of Science, Scopus, and Science Direct, as those comprised of high-ranking and indexed scholarly journals and conference proceedings. Furthermore, a manual search was also conducted to identify any other remaining seminal works which satisfied the research question of this study. Once the systematic searches were conducted in above-mentioned bibliographic databases and manually, the search string was further refined by introducing relevant filters given in Table 2.

Table 2: Filters assigned for the literature search

Criteria	Filters	Rationale
Search fields	Title, Abstract, Keywords	To extract all possible and relevant records
Publication year	From 2010 to 2022	Avoiding out of date results
Subject/Research area	Environmental science, Engineering, Social science, Material science, Decision Science, Economics, Econometrics and Finance	Research areas related to construction and built environment
Document type	Article, Proceedings papers	-
Language	English	English is the international and the universal language

Finally, all the records were imported to the Mendeley software for screening and systematic analysis.

2.3 DATA EXTRACTION

The PRISMA flow diagram (see Figure 1) was used to present the process that adapted to extract the relevant data from the records retrieved via structured searches performed in bibliographic databases and manually (Liberati, et al., 2009).

The complete search found 103 records: 11, 27, 56, and 9 journal articles and conference proceedings from the Web of Science, Scopus, Science Direct, and manual search citation, respectively. From these records, 24 duplicate records were removed. The remaining 79 records were screened using the titles, keywords and abstracts and found 53 of them to have no relevance to the research question of this study. Subsequently, the remaining 26 records were sought for full-text; full-texts were re derived for all records; thus all 26 publications were forwarded for the in-depth review. Of 26, 11 publications were excluded as they are not dedicated to the economic performance of green walls which resulted in 15 included studies. Along with, the geographic location, methodology, and publication year of the filtered studies were also considered to derive conclusions of the current study.

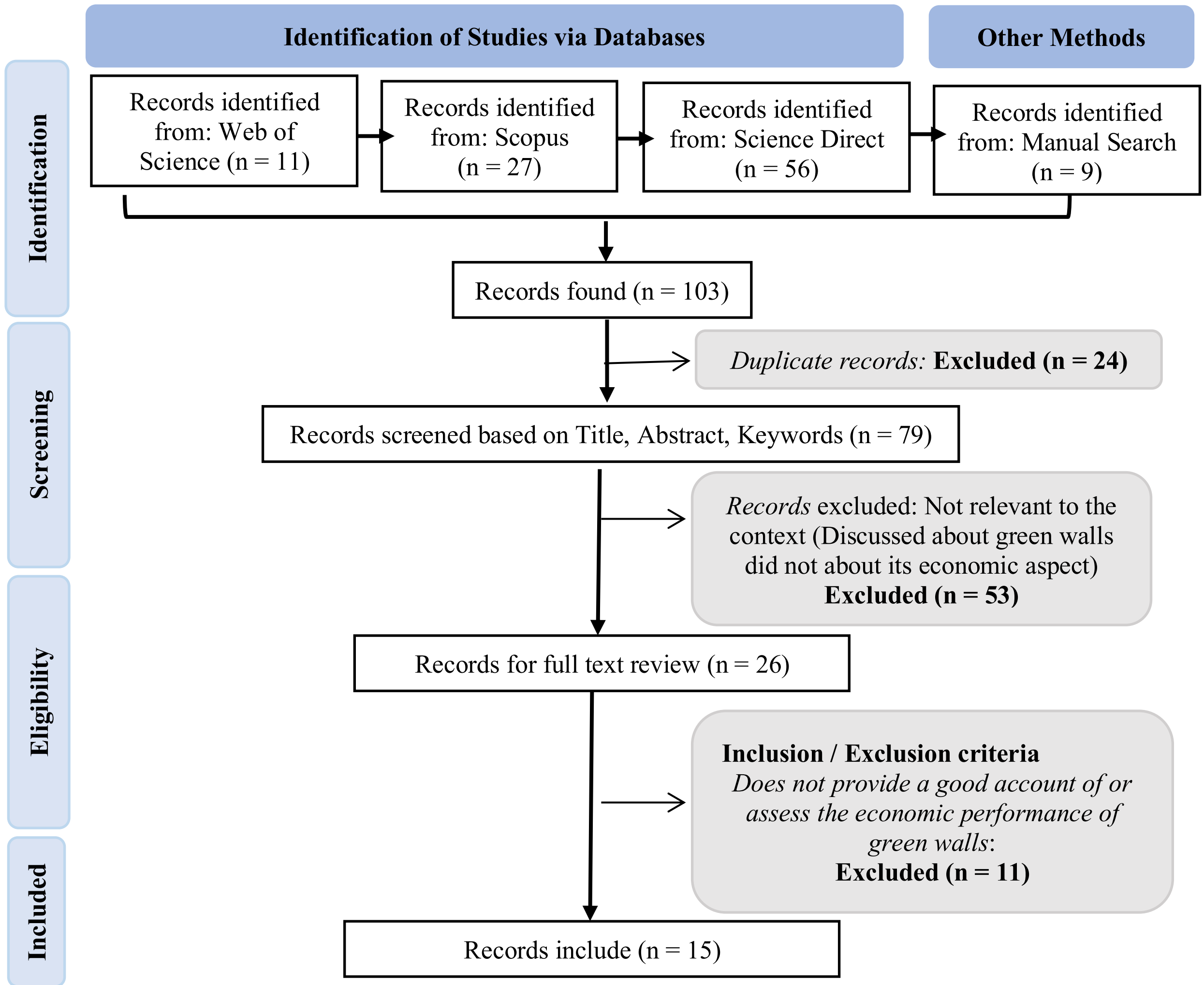

Figure 1: Flow diagram of study selection

The 15 articles filtered are journal publications. Classification of the study selection based on their year of publication is presented in Figure 2.

As observed in Figure 2, there have been increased publications in recent years, 2018, 2019, and 2021. This seems to indicate that the investigations into the subject area in concern are emerging in the recent past.

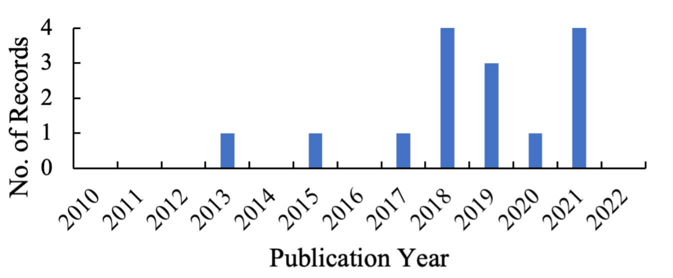

Figure 2: Analysis of the selected research contributions

3. RESULTS AND DISCUSSION

The key focuses discussed in the articles collected are summarised Table 3.

Table 3: Summary of key focuses of the selected research articles

Area	Sources		
		No.	%
Economic benefits of green walls	(Teotonio, et al., 2021; Rosasco, 2018; Manso, et al., 2021; Santi, et al., 2019; Shazmin, et al., 2017; Zazzini and Grifa, 2018; Rosasco and Perini, 2018; Almeida, et al., 2020; Perini and Rosasco, 2013; Haggag and Hassan, 2015)	10	67%
Economic performance comparison among different green wall types	(Huang, et al., 2019; Almeida, et al., 2020; Silva, et al., 2018; Perini and Rosasco, 2013; Dong and Huang, 2021)	5	33%
Economic performance assessment		7	47%
LCC Analysis	(Huang, et al., 2019; Dong and Huang, 2021; Silva, et al., 2018	3	20%
CBA	(Rosasco and Perini, 2018; Almeida, et al., 2020; Perini and Rosasco, 2013; Haggag and Hassan, 2015)	4	27%

As observed from Table 3, 10 out of 15 papers, which is the highest number of studies have researched about economic benefits of green walls. 7 out of the 15 papers have assessed the economic performance of green walls using LCC (3) and CBA (4) methods. Of those researches, 5 papers have compared the economic performance of different green wall types while the rest of them have focused only on one particular type of green wall. As the next step of the systematic review, the search results were further analysed and synthesized their contents to extract the knowledge on (1) life cycle stages and respective cost components of green walls and (2) the economic benefits of green walls. The outcome of this analysis is presented in the following section.

3.1 LIFE CYCLE COST STAGES AND COST COMPONENTS OF GREEN WALLS

Of the reviewed papers, 7 out of 15 papers have discussed the life cycle stages of green walls along with their cost components that can be considered in the assessment of economic performance. Table 4 illustrates the life cycle stages and the respective cost components referred in the studies.

Table 4: Life cycle cost stages and components of green walls used in different studies

Sources	LCC Stages	LCC components
Perini and Rosasco, (2013)	Initial	Plants, Pot, panels, support system, irrigation system, installation, transportation
	Maintenance	Pruning, cladding renovation, irrigation, plants replacement, pipe replacement, panels replacement
	Disposal	Green layer disposal
Haggag and Hassan (2015)	Initial	Plants, growing media, installation, irrigation system
	Maintenance	Irrigation
Rosasco and Perini (2018)	Installation	Panels, supporting system, plants, transport, construction
	Maintenance	Pruning, plants replacement, pipe replacement
	Disposal	Disposal
Silva, et al. (2018)	Construction	Not specified the cost items further
	Maintenance	
	Demolition	
Huang, et al. (2019)	Initialisation	Structure, plants, pot, panel, growing media, irrigation system, drainage system, fertilizers, electricity, water, manpower
	Installation	Transport, installation, electricity, water, manpower
	Operation & Maintenance	Replacement cost of materials, mainly for plants and irrigation systems, fertilizer, electricity, water, manpower
	Disposal	Transport, manpower
Almeida, et al. (2020)	Installation	Not specified the cost items further
	Maintenance	
	Replacement	
Dong and Huang (2021)	Design	Design and strategic planning
	Construction	Cost during the construction, including labour and material
	Maintenance	Project operation, maintenance, updates, replacement, and disassembly
	Finance	Project financial support

Perini and Rosasco (2013) and Rosasco and Perini (2018) have indicated that the Life Cycle Cost (LCC) of green walls can be broadly classified into three categories as initial, maintenance, and disposal. Similarly, Huang, et al. (2019) also have identified three (03) stages where the initial stage was divided into two subcategories: (1) initialisation (off-site preparation) and (2) installation (on-site preparation) while other two (02) stages included operation and maintenance and disposal. In the case of operation and maintenance, there was no clear separation of operational cost items and maintenance cost items identified. In another instance, Haggag and Hassan (2015) have carried out a cost-benefit analysis where authors considered only two stages which are initial and maintenance while Silva, et al. (2018) considered the LCC of green walls in terms of three components: construction, maintenance, and demolition. Almeida, et al. (2020) used the term replacement as the last LCC stage. However, the LCC stages considered by Dong and Huang (2021) are slightly different from the above-mentioned studies. The stages include design, construction, maintenance, and finance.

According to the above review the three main LCC stages of green walls can be identified as initial, maintenance, and end life and the cost components belonging to each stage are given in Table 5.

Table 5: Summary of the life cycle cost stages and components of green walls

	LCC Stage	Cost component
Initial	**Initialisation (off-site preparation)**	Taking care of plants, support system, structure, plants, pot, panel, growing media, irrigation system, drainage system, fertilisers, electricity, water, manpower
	Installation (on-site)	Transport to the site, installation on-site, electricity, water, manpower, design
Maintenance		Pruning, cladding renovation, irrigation, plants replacement, pipe replacement, panels replacement, electricity, water, manpower
End life		Green layer disposal, transport, replacement, manpower

(Sources: Perini and Rosasco, 2013; Haggag and Hassan, 2015; Rosasco and Perini, 2018; Silva, et al., 2018; Huang, et al., 2019; Almeida, et al., 2020; Dong and Huang, 2021)

3.1.1 Initial

Initial costs of green walls can be computed through the Bills of Quantities or obtained from green wall suppliers. According to Perini and Rosasco (2013) who examined the initial cost of different green wall systems in Italy (Mediterranean climate), the initial cost of green walls varies with the green wall type. The initial cost of the direct green facade is between 30 and 45 €/m2 and it is the cheapest option in terms of the initial cost. When considering the initial cost of the indirect green façade made of High-Density Polyethylene (HDPE) is about 125 €/m^2 while steel based is about 216 €/m^2. If an indirect green façade is combined with the planter boxes, then the initial cost further increases. However, a living wall can reach a cost of 315 €/m2, the most expensive type, amongst all types. Similarly, Dong and Huang (2021) examined the LCC of a green facade (not specified whether direct or indirect) and four different types of living walls (Blanket, Pocket style, Hanging containers, and Modular containers) in China and revealed that the green façade accounts for less initial cost compared to all types of living walls considered. Furthermore, the initial cost of living walls is increased with the material involvement; Hanging containers, modular containers, pocket style, and blanket, respectively. It was further evidenced by Silva, et al. (2018) that the initial cost of living wall considered in the study is fifteen times the initial cost of green façade (not specified whether direct or indirect) in Portugal. Similarly, Almeida, et al. (2020), concluded that the initial cost of a green façade in both indoor and outdoor are less compared to the living walls installed in both indoor and outdoor. Conversely, Huang, et al. (2019) researched about three types of green walls which are mostly available in Singapore and showed that the cost involved in the initial stage is 15%, 18%, and 25% of the total cost in carrier system (Living wall), planter system (indirect green façade with pot), and support system (indirect green façade with frame and mesh), respectively. This could be due to the material involvement of the different green wall systems.

Hence, it can be concluded that the initial cost of the green walls mainly depends on the geographical location, type of plants species used, materials used for the structural support, and system (direct, indirect, living wall). In terms of green wall types, a green façade; direct or indirect, is less expensive in terms of initial cost compared to a living wall. However, with the types of materials used in the different green wall systems, especially indirect and living wall types, the initial cost contribution can change. Direct green façade accounts for low initial cost as it consists of less components contributing to costs of green walls.

3.1.2 Maintenance

As observed from Table 4, pruning, cladding renovation, plants, pipe, and panel renovation are some of the main cost components in the maintenance stage. Generally, climate conditions and plant selection are the two main factors that determine the maintenance conditions (Rosasco, 2018). Some climatic conditions require more irrigation and re-planting than other conditions. However, choosing native plant species can reduce the irrigation needs and other associated costs. In the initial years, green walls need more irrigation and re-planting due to plant adaptation (Huang, et al., 2019). In addition, time intervals for each maintenance activity affect the whole maintenance cost. As per the maintenance cost considered by Perini and Rosasco (2013) for different green wall systems in Italy, the maintenance cost of green walls is varied with the system. The maintenance cost of a direct green façade mainly consists of the cost of pruning; hence the cost is less compared to other types. In addition to pruning, the indirect green façade system needs the replacement of materials used for the support structure. However, in the living wall system due to vegetation density and diversity, more material involvement can be seen and thereby responsible for high maintenance costs as well. The above authors further added that in any case, maintenance cost contributes significantly to its LCC, on average 51%-78%. The findings of Almeida, et al. (2020) indicated that the maintenance cost of a living wall is twelve times higher than the green facade while Silva, et al. (2018) stated that it is sixteen times higher. Similarly, Huang, et al. (2019) indicated that the operation and maintenance cost together contribute significantly to the LCC of green walls, 84%, 81%, and 74% respectively for the carrier system (Living wall), planter system (indirect green façade with pot), and the support system (indirect green façade with frame and mesh).

The foregoing review concludes that direct green façade has less maintenance cost than the living wall system due to the types of materials used. However, irrespective of the types of green walls, the maintenance cost consumes the largest part of the LCC of any green wall system.

3.1.3 End Life

End life cost of green walls normally includes the removal of all plants, substrate, support layers, and transportation (Perini and Rosasco, 2013). As per Perini and Rosasco (2013), the disposal cost of green walls also depends upon the green wall type. For example, direct green façade, indirect green façade (HDPE), indirect green façade (Steel), indirect green façade (HDPE with planter boxes), indirect green façade (Steel with planter boxes), and living wall account for the disposal cost of about 31 € / m^2, 198 € / m^2, 200 € / m^2, 203 € / m^2, 206 € / m^2, and 219 € / m^2, respectively. Similarly, Huang, et al. (2019) stated that the living wall system involves high disposal cost compared to the indirect green façade system (Planter and support systems). This higher disposal cost of living walls could be due to the diversity of the materials involved in living walls (Radiac, et al., 2019). However, in any type of green walls, the end life cost contribution to the whole life cycle cost is about 1%.

3.1.4 Total Life Cycle Cost

As discussed above, having considered the cost at each stage of the life cycle, Perini and Rosasco (2013) concluded that the direct green façade is the cheapest green wall type in Mediterranean climate mainly due to it contains a smaller number of components. The authors further stated that the living wall systems have much higher LCC compared to indirect and direct green façades. Similarly, Huang, et al. (2019) identified the living wall system as an expensive green wall type compared to indirect green façade in hot and humid climate in Singapore. This is due to the high installation, maintenance, and disposal cost of living walls with its additional cost elements compared to the other two types. It was further evidenced in Portugal (Silva, et al., 2018) and China (Dong and Huang, 2021) that the total Net Present Value (NPV) of the living wall is higher compared to the green façade.

When considering the indirect green façade type, the LCC varies with the material involvement. For example, as per the result of Perini and Rosasco (2013) study in Italy, the LCC of indirect green façade made by steel is higher than the indirect green façade made by HDPE. In case, if the indirect green façade is combined with the planter boxes, the total LCC further increases. Similarly, Huang, et al. (2019) considered two indirect green façade systems; (1) planter system and (2) support system and found that the planter system results in higher Net Present Value (NPV) than the support system in Singapore.

Thus, in considering the total LCC, the living wall involves higher costs compared to other two types and the direct green façade is the cheapest option.

3.2 ECONOMIC BENEFITS OF GREEN WALLS

From the reviewed papers, 10 out of 15 papers have discussed the economic benefits of green walls. Out of 10 studies, 4 studies have quantitatively assessed the economic benefits in their CBA calculations (Refer Table 3). The remaining 6 studies qualitatively identified and presented the economic benefits of green walls. As per the review, there are five (05) economic benefits: enhancing property value, increasing building/facade durability, rental saving, tax incentives, and energy savings for heating and cooling purposes.

Enhancing property value and energy savings for heating and cooling purposes are the mostly assessed benefits in CBA studies while other benefits are rarely assessed.

According to Perini and Rosasco (2013), the economic benefits of green walls differ with green wall types. For example, in Italy, the annual energy saving in direct green façade, indirect green façades made of HDPE and indirect green façades made of steel are equal (1,164 €/year) while indirect green façades made of HDPE & planter boxes and indirect green façade made of steel & planter boxes are equal (980 €/year) but the cost of these two types of indirect green facades (later) is less than the direct green façade and former indirect green façades (HDPE and Steel). The living walls contribute to energy saving of 1,870 €/year, the highest saving potential type of green wall. When considering the benefits of façade durability and enhancing property value cost of this study, it is gradually increased with the green wall types of direct, indirect (HDPE and steel), indirect (HDPE + planter boxes and steel + planter boxes), and living wall, respectively. Similarly, Almeida et al. (2020) study results showed that there is a higher property value increment with living walls than with green facades.

Although Haggag and Hassan (2015) and Rosasco and Perini (2018) considered the energy-saving benefit, there was no comparison between green wall types. The studies focused only on living walls. However, those two studies also evidenced that the living walls account for energy saving, rental saving, and enhancing property value. Furthermore, According to Rosasco and Perini (2018), tax incentives of green walls play an important role in the economic assessment of green walls. When tax reduction is introduced, the net results (i.e. NPV) become positive and thereby can increase the number of investors engaged in green wall implementation.

As evidenced the amount of benefit offered by the green wall types differ from context to context. Since there were limited CBA studies, it is difficult to conclude about the extent of potential benefits of types of green walls. However, the findings of previous studies considered evidence that the costs of green walls can offset the economic benefits. For example, Haggag and Hassan (2015) showed that the cost of a living wall is 58US$/m^2 while the total cost of benefits offered (reduction of cooling load, rental saving and increase property value) by a living wall is 67.23US$ through CBA. It was further evidenced by Perini and Rosasco (2013) and Rosasco and Perini (2018), with positive NPVs (that is when income prevails on cost).

4. CONCLUSIONS

This paper has presented the results of the systematic review carried out on the available studies regarding the economic performance of green walls. The systematic review determined that the annual maintenance cost of green walls consumes a large share of the LCC of any type of green wall and most of the time annual benefits of green walls offset the cost incurred from initialisation to disposal of a green wall system. Compared to maintenance cost of the system, contribution of initial and disposal costs is less. The analysis further revealed that among the green wall types, direct green façade is economical in terms of LCC while living walls are most expensive. This is due to materials involved in the construction of a direct green façade is comparatively less than the living walls. However, with the variation of the materials involved in the different green wall systems, especially indirect and living wall types, the total cost can change. Though the cost of green walls increases with direct, indirect, and living walls, as per the reviewed papers, living walls are responsible for gaining more economic benefit compared to direct and indirect green façades. As per the systematic review, it seems to be most of the studies that discussed the economic performance of green walls belong to

Italy and Singapore context. Since the costs and benefits of green walls could vary with climatic condition, variety of plant species used, materials used for the support structure, etc. It is expected that the future studies would perform a comprehensive assessment of costs and benefits of green walls with respect to the climatic condition, plant species used, materials used for the support structure, etc.

5. ACKNOWLEDGEMENT

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EFFECT OF COVID-19 ON THE SMALL-SCALE CONSTRUCTION COMPANIES: THE CASE OF COLOMBO DISTRICT, SRI LANKA

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ABSTRACT

COVID-19 is a global pandemic that has wreaked havoc on the lives of many individuals and has had a severe impact on the global economy. During this crisis, small and medium-scale businesses suffer the most and are the least prepared among all companies as per the previous studies done in other parts of the world. The majority of the small-scale construction firms in Sri Lanka act as subcontractors and generate job opportunities for a considerable number of people and are able to create a multiplier effect on the whole economy. However, it was observed that they are more vulnerable to the adverse impact of the pandemic. Thus, the principal goal of this research is to explore possible survival strategies to overcome critical financial issues of small-scale construction companies during the ongoing COVID-19 pandemic in Sri Lanka. A mixed-method approach was adopted to gather the data for the study. A comprehensive literature review was carried out to identify the impact of COVID-19 on both global and local construction industries. The data for this study was gathered using semi-structured interviews and a comprehensive questionnaire survey with small scale construction company owners and construction industry professionals. The findings highlighted the key financial issues faced by the small-scale construction companies due to the pandemic including delays in client payments, supply chain management issues, frequent price escalation of construction materials, and inability to repay loans. The respondents suggested creating partnerships with financially strong companies, reduction of unwanted expenses, modifying supply chain channels and agreements, and ensuring business continuity plans as the strategies to be used to overcome the financial burden that occurred due to the pandemic.

Keywords: *Construction Firms; COVID-19; Financial Issues; Small-scale Construction Companies; Strategies.*

1. INTRODUCTION

The impact of the COVID-19 pandemic on the construction industry is unprecedented (Fairlie, 2021). It extends over 216 nations and territories worldwide, causing the worst economic collapse since the great depression (Aladejebi, 2020). Many nations' economies were caught off guard by COVID-19, which wreaked havoc on a variety of industries, including construction. Even though many sectors have embraced online job execution, building projects cannot be completed online since employees must be present on-site to

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achieve productivity (Amoah, et al., 2021). In order to minimize the spread of this disease, several government restrictions and laws have been implemented, which unfortunately has a negative influence on the construction sector. Interruption of the supply chain and resources, project quarantine because of positive cases of COVID-19, project delays, and terminations are only a few of the consequences (Hansen, et al., 2021). Construction projects all over the world are expected to be delayed or cancelled due to this unexpected pandemic. Shortened construction operations and late clearances by associated agencies are affecting project time frames. Further, the project's functioning has been hampered by a lack of trained labourers and materials, as well as logistical problems (Zamani, et al., 2021). The study further pointed out that the global economic crisis is producing higher inflation, with long-term consequences. Although the outbreak's economic impact is still being felt and is becoming increasingly unpredictable, it is evident that the situation in developing economies will deteriorate before improving. In a recent analysis, the World Bank forecasted that South Asia's economy will experience its worst performance in 40 years, with half of the countries entering a serious recession (Shafi, et al., 2020).

The Sri Lankan construction industry comprises few large contractors and a number of small and medium scale contractors. As per the local industry landscape, large-scale construction companies could survive in a pandemic without much disturbance, while small-scale players face deadly circumstances for their survival. They encounter challenging situations and the majority of them will face the risk of bankruptcy, as this has a direct impact on the business revenue. The pandemic situation compelled many small-scale construction companies to abandon or temporarily shut down their ongoing construction projects. Funding new projects is the challenge faced by many clients, which has an impact on their budgets, while contractors were not compensated for their work done. This is aggravated since contractors are required to compensate their permanent staff, despite many financial challenges. Further, the construction sites have to be properly managed according to certain health and safety procedures approved by the government. This involves unexpected cost, which was never foreseen by those small-scale construction companies. Due to the above-mentioned reasons, the majority of small-scale construction companies are facing financial difficulties, especially in managing their cash flow. Even reopening construction projects after temporary closure will be a difficult decision for those companies. These companies have to adapt to new procedures and pre-plan to face a pandemic situation without getting bankrupt.

Therefore, this study aimed to identify appropriate strategies to overcome the financial problems that emerged due to COVID-19 on the small-scale construction companies in Colombo district, Sri Lanka. In order to fulfil the aim of the study, a few research objectives were developed such as exploring the impact of the COVID-19 pandemic situation on the Sri Lankan Construction industry with special emphasis on small scale construction companies in the Colombo District, to identify the cash flow problems that arise in small scale construction companies in the Colombo district due to the pandemic, to identify and critically analyse the strategies used by those companies to overcome above problems and to propose appropriate strategies to be followed by small scale construction companies to overcome challenges posed by a pandemic situation in future.

2. LITERATURE REVIEW

One of the main engines of the national economy in Sri Lanka is the construction industry (Kawmudi, et al., 2021). In 2021, GDP from construction climbed to LKR 1,147,487 million, up from LKR 1,015,706 million which is the annual GDP from construction of year 2020 (Department of Census and Statistics - Ministry of Finance in Sri Lanka, 2021). According to Pathirana (2021), the majority of existing projects have been suspended or postponed, while local clients and contractors are operating their companies with insufficient financial reserves, putting them in a difficult position and exposing their market shares to rivals. Author further pointed out that the substantial depreciation of the local currency against the US dollar signalled the economic impact of the pandemic on Sri Lanka. This has negatively affected the industry as it has added an extra cost to the stakeholders to bear with. Contractors, material suppliers, and clients play important roles in the industry, and the current situation has forced all three parties to deal with issues such as completing projects on time, expecting supplies on time at the right price, and, most importantly, ensuring that the final product or finished project meets set goals (Pathirana, 2020). The construction industry has traditionally had lengthy payment waiting lines, which will be further aggravated due to economic instability, and the COVID-19 crisis will be a reason for this (Kawmudi, et al., 2021). Furthermore, as a result of the pandemic's dangers, the sector faces extra risks such as losses, bankruptcy, damage to existing materials, payment to workers who are unable to work, rental costs for office buildings and rented plants and machinery, and the potential of claims and payment delays by clients (Vithana, et al., 2020).

The industry classification of construction companies spans from large-scale, medium scale to small-scale. During the crisis, small and medium-sized businesses suffer the most and are the least prepared of all companies (Aladejebi, 2020). The importance of small and medium-sized enterprises (SMEs) in any country's economy cannot be understated, in terms of the number of industry players, as a share of the total market, and their inward and outward linkages with the rest of the economy. SMEs are critical for the success of the local economy, particularly in terms of employment creation, economic growth, and poverty reduction (Aladejebi, 2020). This is not an exception in Sri Lanka, and there are more than 188,877 construction workers in the Colombo area, and 90% of the work has been temporarily halted because of the pandemic (Pathirana, 2020). However, owing to the COVID - 19 crisis, all the projects were halted, and the majority of the employees were trapped inside Colombo. Due to the limited crossing over between districts, most construction companies had trouble retaining their employees. Contractors had a difficult time paying wages and meeting basic requirements (Pathirana, 2020). Although there is high uncertainty over whether these companies' shutdowns will be permanent or otherwise, each month of inactivity has an impact on these firms' revenue, income, and workers (Fairlie, 2021). Project suspensions, rising unemployment, shortage of manpower, time overruns, funding issues, financial losses, supply and material scarcity, legal problems, and work schedule disruptions are among the issues identified by Gamil and Alhagar (2020) in their study on the impact of COVID-19 on the construction industry.

3. METHODOLOGY

In order to achieve the research objectives, a mixed-method approach was utilized as the research technique, comprising both qualitative and quantitative approaches. Since the novelty of the research problem warrants a thorough investigation, the goal is to perform a detailed exploration of the phenomenon under the study. The COVID-19 pandemic is a relatively new occurrence in the world, hence studying how this current phenomenon impacts small-scale contractors in the local construction industry, is a worthy exercise. A mixed-method study is best suited for achieving the study goals.

Since it is challenging for the researcher to reach the whole population, sampling is used to choose predefined participants from a bigger network. As for the sampling method, a purposive sampling method is used. According to Kumar (2011), the most important factor to consider in purposive sampling is judging who can give the most information to help reach the study's goals. In order to achieve this, 30 small-scale construction firms which have an annual turnover of less than LKR 10 million, were chosen from the Colombo district using the Construction Industry Development Authority (CIDA) grading system. The study sample represents owners of 30 small scale contractor companies for semi structured interviews, and 34 number of construction professionals were selected from key professional categories namely Engineers, Project Managers and Quantity Surveyors from the small-scale construction companies as participants for the questionnaire survey. The criteria for selecting participants for the study were based on research findings by Fei and Khan, (2015) who listed the following qualities and tangible criteria for experts:

1. Age should be 19-60 years.
2. A minimum of 1-year experience and participation in the construction industry is needed.

Based on that scenario, participants were selected above the age of 19 years and with more than 1 year of experience in the construction industry.

Semi-structured interviews and questionnaire surveys were utilized as data collecting tools for this study. The questionnaire contained both open-ended and closed-ended questions. The data gathered were analysed through thematic analysis and statistical analysis methods. Conducting face-to-face interviews was not practical during the pandemic, hence the interviews were planned to be conducted through phone calls and emails.

Statistical techniques were used to analyse quantitative data. Since Microsoft Excel has proven its robustness as a useful tool in data analysis, advanced data analysis functions of Microsoft Excel and the features of the same were utilized to perform relevant calculations. The qualitative data was evaluated using thematic content analysis. Thematic analysis is a popular method for evaluating qualitative data on unexplained phenomena (Maguire and Delahunt, 2017; Creswell and Poth, 2018). 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 to come up with clear conclusions and outcomes (Vaismoradi, et al., 2013). Accordingly, thematic content analysis was performed under four main themes.

4. RESEARCH FINDINGS AND DISCUSSION

Study findings were evaluated under two aspects: namely, quantitative, and qualitative aspects. A comprehensive online questionnaire was distributed among key construction industry professionals namely Engineers, Project Managers and Quantity Surveyors who have considerable exposure in the selected small-scale construction companies in the local construction industry. The collected data was analysed using descriptive statistics such as mode, mean and standard deviation. Thirty-four responses were collected, and 3 responses were eliminated from the further study as those respondents claim that they were not impacted due to the pandemic. The research sample for further analysis includes only the small-scale companies that were affected by the COVID-19 pandemic. Data collection for the qualitative findings was done through semi-structured interviews with 30 owners of selected small-scale construction companies in the Colombo district. The gathered interview data were analysed using thematic analysis. Participants were asked to describe how the COVID-19 has affected their company in selected aspects. Those aspects were selected as an outcome of a thorough literature review. The characteristics of the interviewers are listed in the table below. All the companies are grade C7 companies whose annual turnover is about LKR 5-10 million. More than 80% of the respondents are in the building construction sector while the rest is in the water supply and sewerage construction sector in the Colombo district. All the companies were established before the pandemic and all the company owners had experiences in the construction sector parallel to the pandemic issue. Characteristics of the participants are presented in Table 1.

Table 1: Characteristics of participants

Style Name	Company Grade	Participant	Position
Building Construction	C7	P1, P2, P3, P5, P6, P7, P9, P10, P11, P13, P14, P15, P16, P18, P19, P20, P21, P23, P24, P25, P26, P28, P30	Company Owner
Road Construction	C7	P4, P27, P29	Company Owner
Water Supply and Sewerage Construction	C7	P8, P12, P17, P22	Company Owner

4.1 CASH FLOW PROBLEMS OCCURRED IN SMALL-SCALE CONSTRUCTION COMPANIES DUE TO PANDEMIC

4.1.1 Theme 1 - Financial Impact

The data gathered by conducting interviews with the company owners indicated that the COVID-19 pandemic has severely affected the small-scale construction company's finances. In March 2020, the first COVID case was identified and from there onwards, the government has imposed crucial restrictions and island wide curfews from time to time. As a result, the majority of the construction projects were closed or delayed. Thus, many companies could not be able to engage in new projects and it adversely affected their finances. For instance, one company owner (P1) reported that they had made a loss due to less work during the shutdown. Clients also find it difficult to raise funding for projects, which has an impact on their company's cash flow. Contractors weren't paid for the work they did, and they had to pay the permanent employees with their own funds. This was also admitted by P3, P4, P7, and P11. The Central Bank of Sri Lanka (CBSL), which is the financial sector regulator in the country, has built up a whole new relief package to assist businesses and self-employed people who were affected by COVID-19 in March 2020. Under this scheme, small business owners were given a 6-month debt moratorium on bank loans and the period was further extended later. Also, CBSL provided working capital loans up to a total of LKR 50 billion for Small and Medium Enterprises (SMEs) in the country, but P9 revealed that they did not get an opportunity to have this facility. All the respondents claimed that worker absence and fewer workers at project sites slowed project development. It severely affected the financial aspect of the company since it led to project delays. Since the district borders were closed, owners admitted that they had to incur more costs to bring their workers from the rural areas. Many of them stated that travelling restrictions limit transportation to Colombo, forcing many firms to close, resulting in declining funds. Project delays, cost overruns, labour shortages, and financial losses have all been mentioned. Comments made by participants on financial impact are summarised in Table 2.

Table 2: Summarised comments of thematic analysis performed on financial impact

Participant	Thematic Analysis Comment
P1	Day-to-day operations are severely affected because of the unplanned expenses and payment delays of clients.
P3	Labour shortage due to the restrictions prevailed in the Colombo district.
P8	Delay of payments from clients especially in the government projects has strongly affected.
P9	Too many expenses due to increase in the health and safety precautions (PPE).
P12	Cannot pay for the bank loans since the delay of projects.
P25	Clients are hesitant to give the advance payment.

4.1.2 Theme 2 - Company Cash Inflow

Findings revealed that the cash inflow and payment schedules of those companies were affected adversely due to the pandemic. The majority of those small-scale companies are sub-contracting companies. P2 and P24 stated that when the main contractors shut down their projects due to various reasons associated with the pandemic, it directly affects the cash inflow of their company since they were not paid for their work done. All the participants admitted that they experienced payment delays from the client. More than 75% of the participants are involved in government projects. P4, P8, P9, P13, P21, and P26 clearly stated that government projects are heavily affected since the government was hesitant to make the payments on time. Thus, the projects were postponed until the contractor received payments. Even though it has been almost 2 years since the start of the pandemic, client funding for most of the government projects are not released. For instance, P6 and P23 admitted that their companies have not started government projects even though the agreements were signed during the first half of 2020. The stated reason was that the "government funds have not yet been released" due to the economic breakdown of the country. Also, P25 further stated that even private clients were reluctant to do the payments; especially the advance payment and they now prefer to pay for the value of work done. However, P5 indicated that their company had both ongoing private and government projects. Although the payments were delayed in government projects, they did not stop the projects, since they were able to slowly manage the same by doing private projects. Table 3 presents some excerpts of participant opinions.

Table 3: Summarised comments of thematic analysis performed on company cash inflow

Participant	Thematic Analysis Comment
P2	Payments are delayed since the main contractor halted the project.
P4	Payments from the government clients were completely stopped.

Participant	Thematic Analysis Comment
P5	Payments are very slow from the private clients since he could not raise funds.
P13	Had to halt projects which client is the government. Also, we (contractors) cannot claim for delayed payment from the government. It heavily affected our cash flow.
P18	Delay in certification of IPAs.
P28	Even though we have started our daily operations, the payments from the clients are still delayed.
P30	As a result of the payment delay, the projects were not completed on time.

4.1.3 Theme 3 - Payment Schedules

A delay in payment by a party involved in the payment process may have an impact on the entire payment chain (Abdul-Rahman, et al., 2011). P6 stated that payment issues at the top of the hierarchy cause a major cash flow problem for the whole contract chain. Also, P4, P12, and P26 admitted that they encountered issues in paying the salaries of the permanent employees. P12 admitted that employees got half-payments for two months. Even though the country's situation in terms of the pandemic is improving, all the participants indicated that as company owners they are still unable to give bonuses and rewards to the employees. Further, all the participants pointed out the increase in construction material prices due to the economic downturn. P2 stated that they cannot cope with the price increase, and they are on the verge of bankruptcy. Also, P5 revealed that even in Colombo, which is the commercial capital of the country, there is a scarcity of construction materials such as iron, aluminium, cement, etc. in the market and also the price increase of those materials was dramatic during the recent past. Furthermore, P14 admitted that the sudden price escalation of construction materials after the third wave of COVID-19 severely affected the estimated tender costs and their company profit margins. Findings further revealed that 25% of the company owners have loans to pay in monthly instalments. Even though they received some concessions at the start of the pandemic, the economic downturn after the third wave of COVID-19 compelled them to pay their debts regularly. P16 revealed that now they had to allocate more funds for health and safety, which directly affected their cash flow. Furthermore, P20 admitted that they have stopped operations completely for 1 month since 90% of the employees were tested covid positive. They further revealed that the company had to bear all the costs of quarantining laborers, PCR tests, food, sanitation, etc. P12 admitted that even though the projects were progressing, the company is not making profits, since the expenses are high compared to the cash inflows. The findings indicated that the number of workers on the building site was reduced in order to comply with the social distancing guideline, and also there was a reduction in overall project output and schedule delays, as well as cost escalations. Table 4 presents some examples of participant opinions.

Table 4: Summarised comments of Thematic analysis performed on payment schedules

Participant	Thematic Analysis Comment
P1	Supply chain is disturbed as material prices are very high.
P4	Our cash outflow is higher than the cash inflow because of the pandemic.

Participant	Thematic Analysis Comment
P8	We cannot start new projects until these delayed ongoing projects are completed since we cannot cope with rising expenses.
P14	There is a shortage of materials, and the prices are very high.
P19	Small scale companies cannot survive if the material prices rise daily.
P22	Cannot pay for the bank loans since the delays of projects and client payments.

4.2 STRATEGIES USED BY COMPANIES TO OVERCOME CASH FLOW PROBLEMS

Meanwhile, the survey respondents were asked to choose cost-cutting methods that their companies followed to reduce the impact on cash flow disruptions as a result of COVID-19. The results were analysed using the descriptive statistical method (Eq. 01).

$$Percentage = \frac{No.of\ responses\ for\ a\ particular\ method}{Total\ valid\ responses}\ x\ 100\% \qquad (Eq.\ 01)$$

The majority of the respondents (58%) indicated that they have reduced their operational costs like electricity, water, Wi-Fi, etc of the company to maintain their cash flow at this moment. 52% of the respondents stated that companies have reduced giving bonuses and rewards to the employees while 48% of the companies have completely stopped recruiting new employees which will be an extra expense for them at this moment. Unfortunately, 16% of the respondents admitted that they have dismissed employees as a cost-cutting method. Furthermore, 6% of the respondents acknowledged that they have not taken any cost-cutting measures to manage the cash flow. Findings are presented in Figure 1.

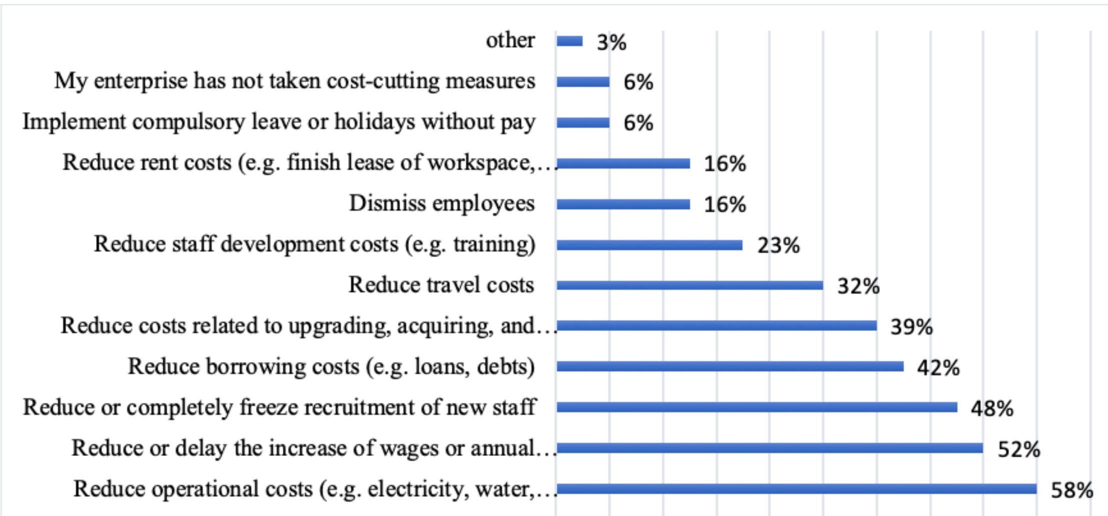

Figure 1: Cost cutting measures taken by companies

Lastly, the interviewees were asked about the strategies they are willing to use to overcome the financial problems that occurred during the pandemic. Six strategies, which were identified through a comprehensive literature study were given to choose from while there was an open option for them to comment on any new strategy which was used by them. And “modifying supply chain agreements” was the most preferred strategy of the respondents among them. While doing the study, it was evident that small-scale companies are in the most vulnerable situation due to this pandemic. The main financial issue emphasised was payment delays by clients. Material shortage during the pandemic also led to rapid change in material pricing and the payment delays hence lack of liquidity compelled many companies to modify supply chain arrangements (81%). Forty-five percent (45%) of the respondents admitted that they are willing to create partnerships with other enterprises in order to reach more clients. This illustrates the risk of bankruptcy of small-scale companies due to COVID-19. Thirty-five (35%) percent of the respondents acknowledged that business continuity planning can be used as a strategy to overcome cash flow problems, while 23% of the respondents chose to diversify markets/reach new clients as a strategy. Many respondents stated that government projects were halted due to a lack of payments. According to the study, diversifying markets will be the best option they have at present. The least selected strategies are decreasing the price of selected products and changing distribution channels like online purchasing etc. (19%). Summary of findings on strategies used to overcome the financial issues are presented in Table 5.

Table 5: Strategies used to overcome those financial issues

Strategies Used	Frequency	Percentage
Decrease price of selected products or services	6	19%
Change distribution channels (e.g., online purchasing)	6	19%
Diversify markets (e.g., operate in different locations or with new clients)	8	26%
Ensure business continuity planning	11	35%
Create partnerships with other enterprises or develop loyalty plans to reach more clients	14	45%
Modify supply chain agreements (e.g., source from other suppliers, negotiate with suppliers)	25	81%

Majority of the participants admitted that they had to reduce the number of temporary workers of the company in order to control salary issues. P20 admitted that they had to dismiss permanent employees to manage their cash flow. Furthermore, P7, P10, and P13 admitted that to cover the delay in cash inflows from government projects they had to engage with small-scale private projects. Also, P27 revealed that as a strategy they reduced their operational costs such as electricity, water, Wi-Fi, etc. P2, P8, P15, and P29 also admitted the same. Furthermore, P6 and P11 indicated that they completely stopped new recruitments since they had no capacity to pay any other employees without getting funds from the clients. Also, many participants agreed with the reduction of bonuses and rewards to employees which was a practical strategy that can be implemented in such a situation. P10 revealed that borrowing from banks or financial institutions will not be the right decision in a situation like this. With the drastic increase in material prices, many companies not only face payment delays but also supply chain disturbances. Thus, the majority approved modifying the supply chain as one of the key strategies that can be used in a pandemic situation. Furthermore, P16 and P22 admitted partnering with a capable alliance company is another strategy to survive during this period.

Table 6 presents some excerpts of participant opinions.

Table 6: Thematic analysis comments on strategies used

Participant	Thematic Analysis Comment
P1	Modifying supply chains is the only strategy we implemented.
P9	Reduce operational costs as much as we can in the company and completely stop new recruitments.
P11	Changed some of our suppliers because material prices vary from one supplier to another.
P16	Stopped new recruitments and stopped hiring temporary workers to the site.
P17	Reduced giving bonuses and rewards for the employees for the time being.
P22	Arranging partnerships with a capable company.
P26	Reduced upgrading costs for plants and machines.

4.3 SUMMARY OF THE ANALYSIS

This research is mainly focused on problems encountered in the cash flow of small-scale construction companies in the Colombo district and the strategies used to overcome those problems. According to the participants, the main issues they had to face were payment delays from the clients, especially from the government clients, and a sudden increase in expenses. The economic downturn experienced in the country due to the third wave of the COVID-19 has severely affected small-scale construction companies. Also, the data analysis elaborated that small-scale construction companies failed in cash flow management because of these problems which have led many companies to the verge of bankruptcy. As strategies, participants mentioned reduction of rewards and bonuses, reduction of temporary labour, completely freezing new recruitments, modifying supply chains, and reduction of operational costs. Creating partnerships with financially strong companies and creating business continuity plans were the proposed possible strategies recommended by the participants. The first objective of the study is covered by the literature review and the rest of the objectives are covered through the finding's discussion of the study.

5. CONCLUSION

The majority of the small-scale construction firms in Sri Lanka work as subcontractors and generate job opportunities for a considerable number of people. Therefore, the country's economy will be threatened if the small-scale construction companies face difficulties in their future operations. This study mainly focuses on small-scale construction firms in the Colombo district and the impact of COVID-19 on the cash flow of those companies. A mixed-method approach was adopted as the research technique. The study strengthened the view that the small-scale construction companies were heavily affected by COVID-19 in terms of their financial aspect which is mainly the cash flow of the company. Both the cash inflows and the outflows were severely disrupted due to the financial issues that occurred due to the pandemic. Moreover, supply chain disruptions, termination of contracts, project delays, inability to pay loans, shortage of labour, and changes in health and safety precautions directly affected the cash flow of those small-scale construction firms. Further, the study revealed that disruption of the cash flow significantly affected the survival of those small-scale construction companies and during the peak of the pandemic, the majority of small-scale construction firms were unable to benefit from various government programs. As a result, some companies faced severe financial difficulties, leading them to bankruptcy or closing down the business. According to the findings, most of the companies have resumed operations with major disruptions to workflow and progress of projects. The most often agreed-upon response by company owners was the decrease in revenue as a result of the pandemic, indicating that COVID-19 has had a negative impact on revenue. As per the data, many businesses did not pay their employees their full salaries throughout the shutdown, and even after the shutdown bonuses and rewards were still not paid. Also, companies stopped recruiting new employees, reduced their operational costs of projects, and reduced upgrading plants and equipment at present to cope with the pandemic. Also, due to the prevailing economic crisis after the third wave of COVID-19, the construction material prices increased drastically. This led company owners to modify their supply chain agreements. According to the participants, the cash outflow was higher compared to the cash inflow in which the owners unintentionally failed to manage the cash flow of the company. Based on the data, this study suggests a few strategies to overcome financial problems that occurred due to the pandemic. Freezing new recruitments, reduction of temporary workers, reduction of operational costs, and curtailing bonuses and rewards were the strategies used by those companies to manage cash flow problems. Furthermore, it will help reduce the financial burden of small-scale construction firms if they are willing to create partnerships with financially strong companies. This is a practical strategy suggested by the participants of the research. Moreover, this study recommends modifying supply chain channels and creating business continuity plans as other strategies that can be used by small-scale construction firms in such a situation in order to lessen their financial burden.

6. ACKNOWLEDGEMENT

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EFFICIENT WORKPLACE PLANNING AND DESIGNING STRATEGIES TO REDUCE WAITING TIME IN THE OUTPATIENT DEPARTMENTS (OPD) OF GOVERNMENT HOSPITALS IN SRI LANKA

D.P.I.M. Pathirana[1] and Nayanthara De Silva[2]

ABSTRACT

The waiting time is a major challenge for government hospitals around the world, particularly in developing countries, due to inefficient design and limited facilities. This waiting time causes long queues, especially in service providing facilities. Hence, queuing is considered a key performance indicator when evaluating the performance of healthcare facilities. The outpatient department (OPD) is the main division of a hospital that handles a large number of patients daily. This research aimed to provide solutions for minimising waiting time in OPD premises through efficient planning and designing strategies. This study applied the queuing theory for two case studies to analyse the waiting time of the patients at the OPD. Hospital records and field observations were used to gather data. Further solutions for minimising the waiting time were identified using semi-structured interviews with hospital management and a questionnaire survey with patients at OPD. Field observations revealed that there were long waiting queues and long waiting times at the registration counter and the consultant rooms. Due to increased demand for OPD services, unnecessary arrivals, a lack of resources, and patients' ignorance of OPD procedures were identified as causes of overcrowding. Further, to minimise waiting time at the OPD, it should leverage the efficient designs with properly placed inquiry counters, walkways, and directions; provide adequate facilities such as a spacious waiting area, and restructuring should be implemented. The findings of the research mark valuable insights into government hospitals, and the proposed solutions will be useful for hospital management.

Keywords: *Government Hospitals; Out-Patient Department (OPD); Planning and Designing; Queues; Queuing Theory; Waiting Time.*

1. INTRODUCTION

Hospitals typically provide emergency services, secondary care facilities, and tertiary medical services, while primary care and some basic treatment or first aid are provided by health centers under the government and private hospital categories. In a hospital facility, there are several departments such as inpatients wards, outpatient department (OPD), emergency or accident wards, clinical area, laboratory, and pharmaceutical area. Among those facilities, OPD servicers are significant tasks that provide diagnostic,

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curative, preventive, and rehabilitative services to a large number of the patient charter (Mital, 2010). Further, patients visit to take numerous facilities for OPD within the hospital system, such as primary treatments and consultations, tests, emergency treatments, health education, and family planning (Al-Zain, et al., 2019). OPD is a facility where patients receive healthcare services on an outpatient basis for conditions of minor illness that can be treated without admitting them to the hospital.

According to a health bulletin (Ministry of Health, 2020), the total number of government hospitals in Sri Lanka is 776 excluding temporary covid treatments units, offering free service for over 5 million patients. However, to ensure easy access to the nearest hospital in all areas by limiting patients coming from another region or district, a greater number of hospitals are required. Further, most Sri Lankan government hospitals face many problems because of lacking facilities, insufficient staff, and improper infrastructure (Dasanayaka and Sardana, 2011).

The healthcare sector in Sri Lanka operates in 03 levels for medical services, namely primary, secondary, and tertiary care institutions. The central dispensaries, maternity homes, rural hospitals, peripheral units, and district hospitals come under primary health care institutions. The base and provincial hospitals are secondary care institutions. The teaching and special hospitals come under tertiary care institutions. They operate in inadequate spaces with limited facilities in built environments, but at a satisfactory level as a free service. Those built environments create overcrowded places resulting in long queues and waiting times (Benevento, et al., 2019).

The waiting time of an OPD patient includes the time spent from arrival time at the OPD until the patient leaves the OPD with the treatments obtained and prescribed medicines from the OPD drug counters (Munavalli, et al., 2017). Furthermore, the same authors mentioned that waiting time in queues is the key reason for complaints and patient dissatisfaction and thus plays a crucial role in quality assurance in hospitals. The waiting time in queues can be taken as a major waste of time cost, social cost, customer cost as well as employee costs (Barlow, 2002). This waiting time can impact patients in different ways such as loss of their time, increased suffering from illness, limited consultation time (risk of inaccuracies in diagnosis), and deterioration of the condition (maybe due to delay in treatment or due to stress and anxiety developed by prolonged waiting) (Benevento, et al., 2019). The impact is not only for patients but also for hospital staff mainly doctors and nurses who may over-stress and in turn, it may cause inefficient service delivery (Willoughb, et al., 2010).

The queuing theory has increasingly been used as a decision-making tool in the service-providing sectors in developed countries to enhance the service delivery process efficiency (Fomundam and Herrmann, 2007). Government hospital can consider essential workplace in Sri Lanka which provides vital service to the public. Thus, this research is focused to use queuing theory to identify waiting time in OPD and address proper workplace planning and designing strategies to reduce the long waiting time in OPD. Efficiency planning of queues, computerised administration work, and work procedure chart was proposed through this queue analysis. The objectives of the study are to derive a "queuing model" to calculate the waiting time and propose efficient strategies to reduce waiting time in government hospitals OPD.

2. LITERATURE REVIEW

OPD is the gateway to every health care facility and OPD care represents the total quality of treatment in the hospital (Haldar, et al., 2008). The OPD serves the following functions (Dilrukshi, et al., 2016);

1. General OPD section - This section treats mainly medical and surgical patients. General OPD also provides Anti-Rabies Vaccine (ARV), Dressings, Tetanus toxoid, and other injections.
2. Admission Section - This section is functioning round the clock and patients' admissions are done through this section.
3. Emergency Treatment Unit (ETU) - Seriously ill patients are resuscitated and kept under observation here before being sent to the wards.
4. Operation Theatre - Minor operations are performed in OPD Operation Theatre.
5. Clinics - Specialist clinics are held in the clinic sections of OPD. They include Medical, Neurology, Surgical, Thoracic, Skin, and Psychiatric.

As per the OPD procedure, registration of patients is done at the registration counters and directed to consultation rooms with a registration number to approach an available doctor.

2.1 WAITING TIMES AT THE OPD

Government hospitals in Sri Lanka provide vital free services for the whole society without assessing a patient's status, income, or assets, as the country believes that health is a prerequisite for a nation's overall economic and social growth (Jayasekara and Schultc, 2017). However, patient waiting time is one of the major reasons for complaints and patient dissatisfaction over this vital service. For instance, even in a normal situation with a smaller number of patients, they have to wait for at least 2 to 3 hours for taking treatments and collecting laboratory reports at the OPD of the National hospital in Colombo (Dilrukshi, et al., 2016). Further, the annual health bulletin in 2021 reported that there is an increment of 3.3% in the waiting time from 2018 to 2019. It is outpatient attendance per 1000 population. Similarly, many other developing countries face the same problem (Bittencourt, et al., 2016). According to (Puri, et al., 2011), in India, patients have to wait in OPD for more than 45 minutes to have at least a five-minute consultation. Further in developed countries link Japanese, a study by (Zhang and Oyama, 2016) revealed that overall, among all Japanese hospitals 40% have to wait less than half an hour before they met the doctor. Overall, 35 % of patients wait 30 to 59 minutes for taking medicines from the hospital and the other 25% of patients have to wait one hour or more. In Hong Kong, the average waiting time for OPD patients from 2014 to 2016 was around two hours (Tsui and Fong, 2018).

2.2 ADVERSE EFFECTS OF LONG WAITING TIME

Waiting time affects patients as well as the employees of the hospital (Tsui and Fong, 2018). The heavy workload and low incentives are often attributed to shortages of employees due to the high turnover rate of frontline health care workers in government hospitals and that turnover, will result in overcrowded circumstances (Puri, et al., 2012). That situation is compounded by other external factors from private hospitals, including attractive remuneration packages and greater opportunities for clinical development (Ishtiaq, 2014). As well as the large number of patients at OPD, the staff allocates very less time per patient. Most OPD doctors see between 60 to 80 patients in their six-hour shift, and they could spend on average 5 minutes for the treatment as well as for a referral (Mathugama, 2015). Therefore, always patients feel dissatisfied with government healthcare facilities.

2.3 QUEUING THEORY MODEL

Queuing theory involves analysing queues or waiting lines in mathematical terms to measure performance (Hiller and Liebeman, 2019). The queue is the flow of service customers and is defined by the highest number of acceptable customers that may be included. (Benevento, et al., 2019). The basic queuing process assumed by most queuing models is as follows:

1. An input source or calling population generates customers requiring service.
2. A member of the queue is chosen for service by a rule at certain times.
3. The service required is then performed by the service mechanism for the client.
4. Customers exist or return to the queue (Mathugama, 2015).

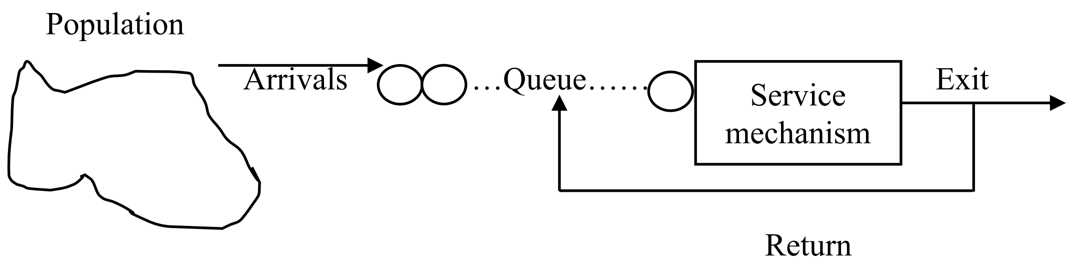

Figure 1: Basic queuing process

Customers who arrive for service, wait for service, and leave after getting service can be defined as a queuing system (Mital, 2010).

A queuing system can be described by:

- Input sources - The group from which arrivals arise is referred to as the calling population. Its population size is one parameter of the input data. The size is the total number of patients from time to time who may need service. It may be finite or infinite in size.
- Arrival process - The arrival process contains four parts.
    1. Pattern - Whether it is controlled or not.
    2. Grouping - The way customers occur
    3. For example, customers arrive singly as well as in groups.
    4. Time between arrival statistics - Mean, variability, and distribution of successive arrivals.
    5. Degree of impatience - Whether customers leave before being served.
- Physical Characteristics of Queue - This means a number of queues (one or more) It can be defined as a number of service channels and the length of the queue (limited or unlimited capacity).
- Queue discipline - This means the way a customer is selected from all those awaiting service for service. Those disciplines can introduce as FIFO - First-In-First-Out, LIFO - Last-In-First-Out, JSQ - Join the Shortest Queue, SIRO - Service e-In-Random-Order, Favourite server specified (in barbershops), Priority queue

- Service mechanism - Service systems are generally categorized according to their number of service channels (servers).

3. RESEARCH METHODOLOGY

The research design reveals the path to answering the research problems through specific research strategies (Millet, 2009). Three main research approaches including quantitative, qualitative, and mixed are used by researchers. The research process based on clear evidence and records is known as the quantitative approach (Naum, 2007). The qualitative approach, on the other hand, is a subjective process consisting of exploring the participants' attitudes and opinions (Dawson, 2002). The mixed approach is adopted when quantitative or qualitative approaches alone do not produce satisfactory results (Johnson and Turner, 2003). Due to the availability of data mixed philosophical approach that combines elements of both pragmatism and interpretivism was adopted in this research. A case study and quantitative research strategy were adopted to design an efficient workplace and proving solutions to enhance the operation of OPD by minimizing waiting time. The mixed approach was taken as the best way of proving quantitatively the number of patients in the queue reference concerning the time while interview outputs prove the quality of the hospital service.

In queuing theory (Mital, 2010) the following equations were used to calculate the waiting time of a patient at OPD.

- Waiting time in the queue $Wq = Lq/\lambda$
- λ - average arrival rate
- Lq - Average number of patients waiting for service.
- $Lq = \frac{P_0(\frac{\lambda}{\mu})^s p}{s!(1-p)^2}$
- p - Server utilization $p = \lambda/_{\mu}$
- P_0 –the probability that the number of patients in the OPD
- $p_{0=} \left\lfloor s^{-1}\sum n = 0 \frac{(\lambda/\mu)^n}{n!} + \frac{(\lambda/\mu)^s}{s!} + (\frac{1}{1-p})^{-1} \right\rfloor$
- s - number of channels (servers)
- μ - average service rate at each channel (service)
- n - number of patients

Data were collected from two case studies (i.e., two base hospitals located in Colombo). Within the case studies questionnaire survey, observations, semi-structured interviews, and reviewing of internal records such as patient's attendance logbooks, staff attendance sheets, doctor's and nurser's working rosters were carried out to gather appropriate data. The questionnaire survey was conducted using a sample of 50 patients at the OPD at the time of data collection. Data obtained from the questionnaire survey were used to analyse the real waiting time of patients. In addition, hospital records were reviewed to identify staff attendance, and daily patient's attendance. Further, a work procedure chart was introduced to manage OPD premises efficiently.

Semi-structured interviews were conducted with OPD doctors and administrative staff who are having a greater exposure and knowledge of OPD operation to obtain data such as current practices of the OPD, service time of the OPD, staff capacities, and their opinions regarding waiting time and related design drawbacks for inefficient OPD operations. Detailed profiles of the interviews were tabulated in Table 1.

Table 1: Profile of the interviewees

Case Name	Respondent	Designation	Experience
Case A	Respondent - 1	OPD Consultant Doctor	08 years
	Respondent - 2	OPD Medical Doctor	05 years
	Respondent - 3	OPD Nurse	03 years
Case B	Respondent - 1	OPD Consultant Doctor	10 years
	Respondent - 2	OPD Medical Doctor	4 years
	Respondent - 3	OPD Nurse	05 years

4. RESEARCH FINDINGS AND DATA ANALYSIS

4.1 CASE A

According to collated primary data, Monday is the most crowded day of the week, and the patient number is counted as 1520 (average based on working hours; from 6 a.m. to 4.30p.m). In case A, OPD has a single queue for both consultation rooms while having multiple service channels. Thus, average arrival rates (λ) and the number of service channel(s) are considered for fed input data for the queuing model. In front of the consultation rooms, there was not enough seating facility. Most of the patients standing near the queue. That is a very pathetic situation for a healthcare-providing organization. Those situations decrease the quality of their service. In addition to the consultation queue, there was a separate queue at the registration counter to get a registration number. But this study considered only the consultation queue for the queue model.

The average service rate is calculated as 12 (patients/minutes) of consultation. This implies that 12 patients can be seen per hour by a doctor. In both cases, the service rate for all channels was assumed to be the same. In case A, the highest and lowest number of arrivals can be seen around 10-11 a.m. and 1-2 p.m. respectively, according to collected data. In cases A and B there was a barrier to collecting data for patients' attendance on hourly basis due to a lack of records. Therefore, queuing model analysis including server utilization (P), the probability that the number of patients in the OPD (P0), the average number of patients waiting for service (Lq) and waiting time in the queue (Wq) parameters were calculated by changing the number of channels after the average one-month patient arrival data. As the number of channels increases, the length of the queue and the waiting time decreases. These channels indicate the service points in the consultation rooms.

Table 2 shows the calculations for the consultation on average monthly data from 6 a.m. to 10 a.m. Currently, six consultation channels are operated in case of A, with 81 patients in the queue with 32 minutes of waiting time. The service's required number of channels has been increased to 8 channels after calculations. The inefficient situations are indicated by the empty columns in front of the occupied columns in each row. Those channels were indicated as inefficient because 1 to 5 channels were unable to cater to all the current patients. It is proved in the 06th channel still there are 81 patients in the queue (Lq= 81). When the server utilization (P) exceeds one with the available number of channels, inefficient situations occur. On the other hand, cost factors should be considered. Non-cost-effective situations are indicated by the empty columns after the occupied columns in each row. Because of the cost factors, the calculation was stopped when the length of the queue (Lq) was less than or equal to one. And also, there is no point in increasing the number of channels further because in the 08th channel there is only one patient in the queue (Lq=0.041). The number of channels can be expanded even more. But it is more additional cost for hospital staff requirements.

Table 2: Calculation of queuing parameters for case A

Parameters	No of channels									
	1	2	3	4	5	6	7	8	9	10
p						0.8625	0.546	0.29		
P_0 (%)	INEFFICIENT					0.0111	0.024	0.028	NOT COST	
Lq(patients)						81.12368	53.21	0.0.41	EFFECTIVE	
Wq(minutes)						32.44947	25.631	0.075		

4.2 CASE B

OPD opens from 6.30 a.m. to 4.30.p.m. providing their service for 10 hours per day. According to collated primary data, Wednesday is the most crowded day of the week, and the patient number is counted as 2235 (average based on working hours; from 6 a.m. to 4.30p.m). In case B, OPD has a single queue for both consultation rooms while having multiple service channels. In case B, the highest and lowest number of arrivals can be seen around 8-9 a.m. and 2-3 p.m., respectively, according to collected data.

Table 3 shows waiting time with reference to increasing service channels in order to minimise the number of patients in the waiting queue and waiting time in OPD.

Table 3: Calculation of queuing parameters for case B

Parameters	No of channels														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
p							1.428571	1.111111	0.909091	0.769231	0.666667	0.588235	0.2395		
P_0 (%)							0.0009	0.0005	0.0001	0.00111	0.00015	0.000002	0.000001	NOT COST	
Lq(patients)	INEFFICIENT						10.852	7.528	5.348	4	2.381	1.532	0.002	EFFECTIVE	
Wq(minutes)							5.5	4	2.5	2	1	0.5	0.004		

As same as case A the empty columns which are in front of the occupied columns in each row showing an inefficient situation. Beyond the occupied columns after 13 channels were not cost-effective implementation.

After analysing queuing theory models with the current practice of OPD it consists of 7 channels in the OPD, and it will result in the average number in the queue (Lq) of 11 patients and the average time in queue (Wq) of 5.5 minutes. With the 08 channels, it gives the average number in the queue (Lq) 7 patients and the average time in queue (Wq) 4 minutes. Changing into 09 channels provides the most effective performance of the system by giving values as an average number in the queue (Lq) 5 patients and the average time in queue (Wq) 2.5 minutes. The change from 7 channels to 09 channels reduces the average number in the queue (Lq) from 11 patients to 5 patients Similarly, the average time in the queue (Wq) drops from 4 minutes to 2.5 minutes, respectively. 09 channels considering as an effective approach because of its server utilization amount (p). It is 0.909091 and that proves that it is an efficacy system operating according to queuing theory models P < 1. This means that patients spend less time in the queue with the above factor. Again, it is essential thing to consider cost aspects such as this kind of marginal change. Increasing channels into 13 were identified as the zero queues with zero waiting time.

4.3 Planning and Designing Strategies for Reducing Waiting Time in OPD Premises

4.3.1 Introduce Work Procedure Chart

The work procedure chart is presented in Figure 1.

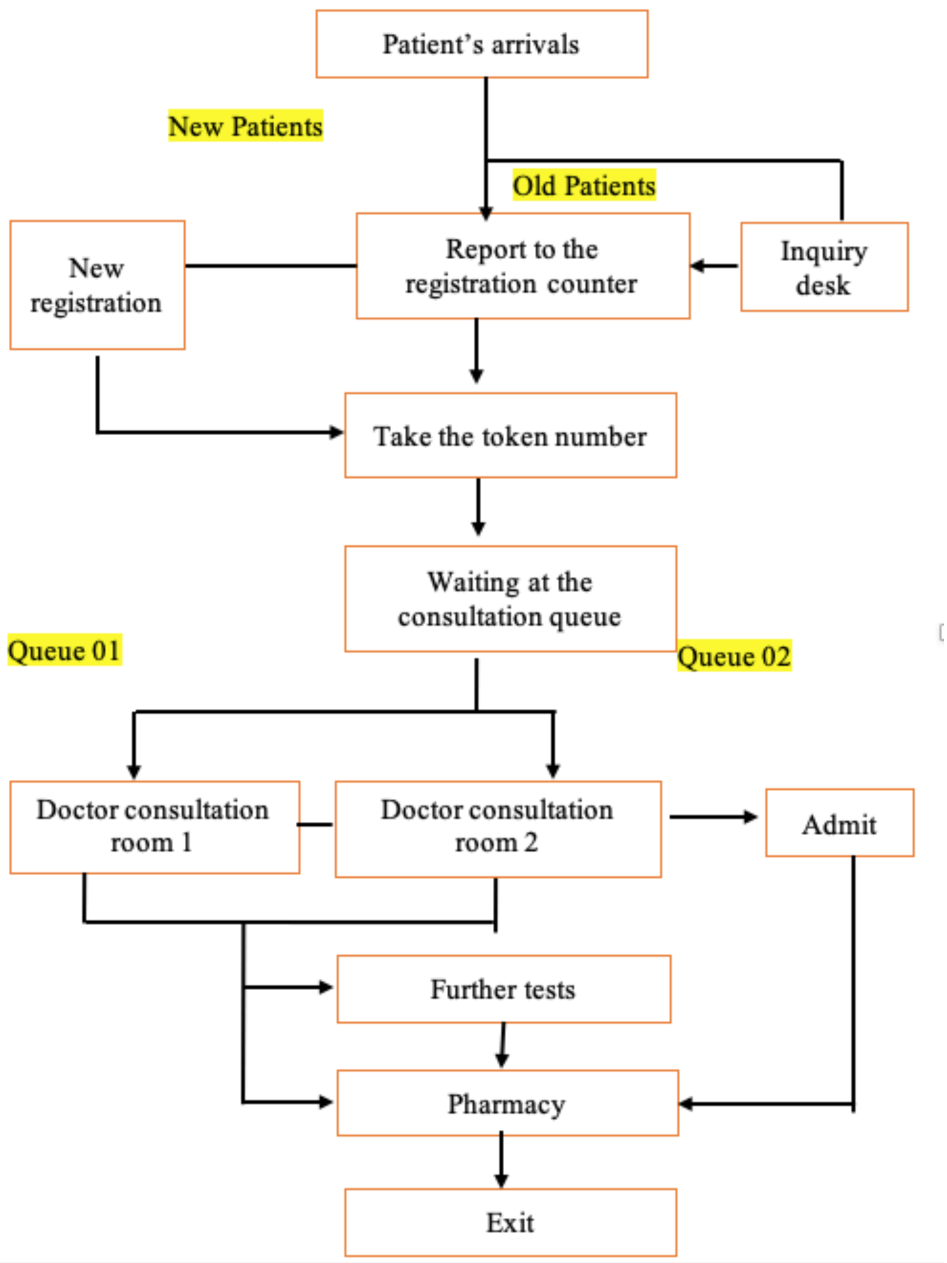

Figure 1: Work procedure chart

Both cases included two consultation rooms having a single queue model with First Comes First Serve. Instead of one queue for both consultation rooms, separate 2 queues can be introduced. It helps to increase doctors' efficiency and decrease doctors' stress levels, as well as, implementing 2 queues helps to reduce the anxiety and impatience of patients. Because patients have not to wait in long queues after implementing two queues. With the proposed work procedure chart number of patients is divided into two queues which help to reduce the long queue in front of the consultation room. In addition to that, it is suggested to create an inquiry counter for further convenience of patients.

In this system person who arrived first at the OPD can go for the patient's queue number 1 and the second person can go for the patient's queue number 2 likewise a third person can go to queue number 1 and the fourth person can go to queue number 2. According to this order, long waiting queues in front of consultation rooms can be reduced. Providing an inquiry desk, helps to provide accurate information for the patients as well as it can direct patients to the correct locations. As a result, that decreases patients' nervousness and reduces their spending time on OPD. This inquiry desk may help in finding relevant counters and other operational information from it.

Apart from the above suggestions summary of the interviewee's responses was that no major renovation was done for the OPD premises during their service period. Both respondents 1 and 3 of case A stated that they have been facing insufficient staff and facilities in the OPD unit compared to the high number of patients. As suggested respondent 1 comments on providing more staff such as more nurses and sisters. And also, further commented on providing more facilities to doctors to save time such as more investigating beds, sanitary equipment, and changing shifts considering patients' demands. According to responded 2, space utilization is not at a satisfactory level. He commented that though there are 2 consultation rooms those 2 rooms are not utilized efficiently. That is why this new work procedure chart is proposed by the researcher. And also, he proposed that overloaded documentary activities consume more time in OPD for that he is proposing a computerized system for admirative and managing processes.

4.3.2 Computerisation of the Administrative Work

These hospitals' general outpatient departments use two consultation types: old patients and new patients. The new patients are those who are coming to the hospital for the first time for treatment, while the old patients are those who have been there before. This computerized system enables old patients for getting queue tokens quicker than new patients. It's because patients' folders are sorted and a tally with a serial number is issued based on arrival time for old patients, and new patients must first register with the hospital, then a file will be created before a token is issued. That registration process takes 5 to 10 minutes. By issuing a serial-based hospital card that time can be saved.

Increasing service efficiency is one of the main suggestions for reducing the waiting time of the patients. For providing more efficient service may occur high cost. Without considering the cost this study is proposing computerized system in order to manage daily work in the OPD. Respondent 3 of Case B commented on the computerized system can increase the server efficiency and helps to speed the patient's admission process. Further patient information such as demographical information, medical history, test reports, prescribed medicines, etc., can be computerised for quick access. Further, it can be used as a database that would reduce administrative work.

4.3.3 Increased Resources

Delay at every point of service will affect the total final waiting time. Therefore, increasing overall system efficiency is one way of reducing waiting time in the OPD. It was a suggestion of case B respondent 2. Respondent 2 proposed that providing more hospital resources with modern technology, evaluating staff, giving awareness to patients, and targeting settings for staff are major activities that can be introduced. According to respondent 3 of Case B, the service capacity or service channels can be altered according to the arrival pattern of the patients. The OPD doctor of Case B reviewed that severe efficiency can be improved by enhancing the built environment. For instance, providing more equipment, doctor's tables, chairs, examine beds could be considered.

4.3.4 Signage and Direction

Respondent 3 of case A stated that proper direction boards should be created and pasted on the walls which will help to properly guide the patients. If not when a new patient comes into the OPD that patient feels nervous and has to ask for every information from the inquiry counter. It takes more time for the patient and sometimes the patient may fall into other troubles when getting information from the wrong person. Therefore, implementing information boards using standard colours, and symbols will help to patient's convenience.

5. CONCLUSION

Empirical findings prove that waiting time is one of the major issues that can see in Sri Lankan government hospitals. As a patient, time is a more significant factor when considering their perspectives. Therefore, this study's purpose is to minimize patient waiting with new strategies concerning two different government hospitals' OPDs in Sri Lanka. In this effort is further established that the theory and modelling of queuing is an efficient instrument that can be used to create decisions on staff requirements regarding queuing challenges for optimum performance of hospital OPD. Properly designed internal space, computerized systems, and other managerial changes proposed based on the model outputs in each hospital, enable to minimize of the number of patients in the queue and the average waiting time in the queue. Planning and design teams could have a role to play in minimizing the waiting time of patients in hospitals.

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ELECTRICITY GENERATION THROUGH MUNICIPAL SOLID WASTE IN SRI LANKA: DRIVERS AND BARRIERS

T.A.D.C.D. Karunarathna[1], P. Sridarran[2] and M. Gowsiga[3]

ABSTRACT

The rapid increase in population and urbanisation has led to an increase in per capita consumption and the generation of waste. Thus, the need of having improved management strategies for Municipal Solid Waste (MSW) has aroused. Waste to Energy (WtE) was a concept that came up as a solution for waste management and as an ideal solution for energy crises as well. WtE is a process of generating energy mainly in terms of electricity and heat by giving MSW as the input where it will become the fuel for this process. Most countries like Denmark, England, Australia, etc. use this as a successful Municipal Solid Waste Management (MSWM) strategy and as a sustainable energy producing mechanism too. But, in Sri Lankan WtE has become unsuccessful in many instances due to the influence of barriers to implementing WtE mega-scale projects. Thus, this study aims to explore existing barriers in light of expanding WtE projects in Sri Lanka. In addition, it proposes strategies to mitigate those barriers. Data was collected through expert interviews and manual content analysis was used for data analysis. Some identified key barriers and strategies in the frame of political, economic, social, technological, legal, and environmental are lack of having government infrastructure, high initial investments, social burdens, lack of technical knowledge on WtE, disposal of bottom and fly ash as barriers and providing infrastructure by the government, introducing debt financing, social awareness, getting foreign technical experts, using bottom ash and fly ash to produce some necessary bi-products as strategies.

Keywords: *Barriers and Strategies; Drivers; Municipal Solid Waste (MSW); Municipal Solid Waste Management (MSWM); Sri Lanka; Waste to Energy (WtE).*

1. INTRODUCTION

Rapid urbanisation and human population expansion accelerate the capacity of Municipal Solid Waste (MSW) in urban areas in the global context and it will grow by 2.6 million tons per day by 2025 from 2012 (World Bank, 2012). The generation of MSW is considered an issue of global concern (Khajuria, et al., 2010), and MSW will prove to be one of the challenges ahead and thus contribute significantly to global warming and climate change (Li, et al., 2011). Thus, due to the adverse effects of MSW generation,

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Municipal Solid Waste Management (MSWM) becomes a key challenge. MSWM can be defined as the selection and implementation of appropriate technologies, techniques, and management programs to achieve the objectives and targets of waste management (Tanskanen, 2000). The main aim of MSWM systems is to safeguard environmental health and human by reducing the adverse effects of waste and seeking some beneficial consequences for it (Melosi, 2000). MSW is well known as a source of renewable energy due to its nature (wood or food) as a biomass material (Ryu, 2010). As one of the most common solutions, Waste to Energy (WtE) incineration helps to reduce landfill MSW (Monni, 2012). WtE technology can be seen as a great waste management strategy since it is not only utilising the recycling potential of degradable organic solid waste created by various activities but also offers renewable energy sources (Kothari, et al., 2010). WtE technologies can be addressed in the terms of thermal treatment technologies (incineration, pyrolysis, and gasification), biological treatment technologies (anaerobic digestion technologies), and biorefineries (waste to by-products) and landfill gas utilisation (Moya, et al., 2017).

WtE incineration is not only capable of dealing with the rapidly increasing amount of MSW, likely due to population growth, but can also meet energy demand by heat and electricity (Pavlas, et al., 2011). In this way, including MSW in an energy system will become active in pulling off the goals of a 20% reduction in CO2 emission and 20% renewable energy for the year 2020 (Munster and Meibom, 2011). Modern WtE installations convert the chemical energy embodied in MSW into heat and/ or electricity (Brunner and Rechberger, 2015). WtE technology can be seen as an effective industrial device to eliminate dangerous organic compounds, recover resources (Electricity) and materials and save landfill spaces (Vehlow, 2015). WtE plants are capable of destroying fully hazardous organic materials, eliminating risks due to pathogenic microorganisms and viruses, and storing both useful and harmful metals in certain fractions (Brunner and Rechberger, 2015). Currently, since there are plenty of waste management strategies, WtE technology can be seen as a successful process thus having several strategies, and many countries around the world already applying this technology.

In Sri Lanka MSW can be seen as a serious issue and haphasard disposal of solid waste accelerates this serious socioeconomic and environmental issue further and waste generation increased due to the rapid urbanisation, population growth, development, migration, and keep going with consumption pattern changes and industrialisation (Hikkaduwa, et al., 2015). Furthermore, the composition of solid waste collection through different councils is, 49.5% (1696 Mt) by municipal councils, 33.1% (1133 Mt) by Peradeniya sabha councils, and 17.4% (594.5 Mt) by urban councils. On average, in Sri Lanka, about 0.62 kg of solid waste is generated per day per person (Visvanathan and Trankler, 2003 cited by Chathumini, et al., 2019). At present MSWM, collection and treatment in Sri Lanka are not proceeding at an acceptable level due to incomplete collection of total generated solid waste by local authorities (Gunaruwan and Gunasekara, 2016). As a developing country, Sri Lanka is in a catastrophic situation on waste management due to the lack of a proper management strategy. As a solution Sri Lankan government recently approved the plan to construct the first WtE plant in the Karadiyana landfill (one of the waste dumping sites in Colombo) (Alwis, 2019). Thus, in Sri Lanka, the generation of electricity through this process took the lead and seems to be a trending and proper solution for MSW. the second WtE site under construction in Muthurajawela. The volume of MSW can be reduced after the functioning of these two sites while adding

20 megawatts of electricity to the national grid (Kamanthi, 2019). Furthermore, the author stated that WtE operations will be limited to these two projects since the government of Sri Lanka has decided not to extend WtE in Sri Lanka due to the moist condition of Sri Lankan waste which makes government incur additional Rs. 3000/= to produce electricity from one ton of waste. This is going to be a serious challenge for the government and this study focus on eliminating these challenges by investigating and proposing solutions while making the applicability of WtE in Sri Lanka at an optimum level.

Hence, this study aims to explore existing barriers in light of expanding WtE projects in Sri Lanka. The structure of the paper starts with the research methodology and is followed by research findings and discussion. Finally, the paper is concluded with conclusions and recommendations for this research.

2. RESEARCH METHODOLOGY

This study aims to explore existing barriers in light of expanding WtE projects in Sri Lanka. To achieve the research goal, this research requires more detailed qualitative and in-depth information. This research was therefore conducted under the qualitative approach, taking into account its advantages over the quantitative approach. Accordingly, the case study strategy was selected as one of the most appropriate tools for an in-depth analysis of this research. Since there are only 2 sites that will be going to function as WtE sites in Sri Lanka in near future have been selected under the case study approach in conducting data collection.

- Case A: The treatment plant would decrease the amount of waste transported to landfills by as much as 90% by volume and 80% by mass. A total of 83,000,000 kWh of electricity per year will be generated by the project and this is enough to meet the demands of 40,000 households. Furthermore, the plant will produce liquid and solid fertiliser with 40,000 tons per year an energy of 12 MW will be generated by this facility and the remaining electricity will be transmitted to the national grid (Ceylon Electricity Board) following the use of electricity for the plant consumption.
- Case B: This was implemented by private cooperation monitored by Megapolis and CEA (Central Environmental Authority). In the Colombo municipal sector, the project will recycle solid waste to produce a power of 11.5 Megawatts by transforming 500-700 MTs of MSW into electricity. Using the 700 metric tons of fresh waste from the Colombo municipal council district, this WtE power plant will run approximately 7,500 hours per year while automatically providing a waste disposal solution in Colombo. It provides the Colombo garbage clearing with a permanent solution and then offers the national grid with green energy.

Semi-structured interviews were conducted with experts who have experience in waste management and WtE sectors. Three (03) expert interviews were carried out with selected experts on WtE from each selected case. The details of the respondents are presented in Table 1.

The data was analysed using manual content analysis and data analysis techniques as there are only 02 mega-scale WtE projects available in Sri Lanka.

3. RESEARCH FINDINGS

This section consists of three sub-sections such as drivers for initiating a WtE mega-scale project in Sri Lanka, barriers for initiating a WtE mega-scale project in Sri Lanka, and suggested strategies to overcome the barriers to initiating WtE mega-scale projects in Sri Lanka.

Table 1: Details of Interviewees

Case	Code	Designation	Experience
Case A	RA-1	Chief technical officer	9
	RA-2	Manager - Regulatory Compliance and local affairs	10
	RA-3	Chief compliance officer	10
Case B	RB-1	Managing director	20
	RB-2	Site director	5
	RB-3	Deputy project director	12

3.1 Drivers for Initiating a WtE Mega-Scale Project in Sri Lanka

Most the countries including developed and developing are using these WtE techniques to generate electricity and other energy sources like heat while giving a better solution to the garbage crisis as well. In the Sri Lankan context, most industries are tending to reuse their waste to generate electricity through small-scale WtE plants. Thus, apart from the traditional waste management options Sri Lankan government focused on substitutional waste management options. WtE was such a waste management option that came forward. With the use of case study facts, it can be demonstrated that in addition to the waste management issue there are some other drivers for implementing WtE mega-scale projects in Sri Lanka. The responses of the respondents that have been interviewed about the drivers that let them implement WtE projects in Sri Lanka are discussed below using the PESTLE analysis. Table 2 provides the responses given by the respondents on drivers for initiating WtE mega-scale projects in Sri Lanka.

Table 2: Responses on drivers for initiating WtE mega-scale projects in Sri Lanka

No	Drivers	Responses
	Political	
1	Need of reducing the increment of solid waste	6/6
2	Capable of extending landfill lifetime and energy recovery from waste	6/6
3	Elimination of public health-related issues associated with MSW	5/6
4	Having many side benefits instead of managing MSW	5/6
5	Strengthening public-private partnership goals	4/6
6	Tending towards green energy concepts	2/6
	Economic	
1	Deriving job opportunities in many fields due to having WtE projects	5/6
2	Generation of electricity and needful byproducts	5/6
3	Direct and indirect cost reductions in waste management	4/6
4	Creation of investment opportunities	4/6

No	Drivers	Responses
5	Reduce land scarcity by allowing minimum space for open dumping	3/6
6	Reduction of costs associated with public health and disasters due to poor waste management options	3/6
	Social	
1	Creation of new job opportunities	6/6
2	Public pressure	6/6
3	Increment in urbanisation and generation of waste	6/6
4	Mitigation of social externalities	4/6
5	The need for the general public to have a viable waste management solution	3/6
6	Social acceptance of technology	2/6
7	Supporting hand for electricity generation	1/6
	Technological	
1	Technological developments	6/6
2	Different energy recovery technologies are available for different types of waste	4/6
	Legal	
1	Complimentary legislations	3/6
	Environmental	
1	Negative impacts due to open dumping and landfilling	6/6
2	High dependency on imported coal in energy generation	5/6
3	Reduction of carbon dioxide emissions	5/6
4	Capacity to generate renewable energy sources due to having scarcity of available non-renewable energy sources	3/6
5	Environmental issues like climate changes	2/6

Political drivers: Accordingly, a major influencing driver towards the initiation of WtE mega-scale projects in Sri Lanka was the increment in the garbage disposal and open dumping. This was clarified by the RB-2 as "*the Sri Lankan government is facing huge problems with open dumping in different perspectives. For example, people died due to the collapsing of the Meethotamulla garbage pile, and the government has searched for a way to get rid of those stacks of waste"* So, the pressure built up by the general public towards the government has become a strong driving force towards WtE implementation. In addition, RA-2 stated that, "the *government also mainly focused on reducing public health-related issues that have happened as a result of open dumping*." Sri Lankan public especially around the Colombo area had to face several adverse effects of this open dumping like respiratory diseases, uncomfortable odour, and disasters (Meethotamulla pile collapse). In addition, adverse effects like aesthetic discomfort, and the use of large-scale lands for open dumping also happened. Thus, the elimination of such social externalities has become a key political driver. On the other hand, having additional benefits through WtE sites has been identified as another key driver. RA-1 stated that "*generation of electricity by giving MSW as the primary fuel is the main additional benefit except reducing MSW"* Within WtE plants they used MSW as the primary fuel for generating electricity. So, this can be a solution to the energy crisis in Sri Lanka as well. Directors of both the projects have mentioned that they are going to deliver some amount of electricity to the national grid. "*Apart from generating electricity bottom ash from the incineration process can be used as a building material for construction projects like road constructions*" detailed by RB-1. This can be a critical advantage thus; Sri Lanka is going through large-scale development and construction projects. The responses of the respondents this was another critical political driver for initiating WtE mega-scale sites in Sri Lanka. It is also identified as a catalyst to tend more toward the sustainable alternatives to energy production because of the expenses that government has to bear to import coal.

Economic drivers: One of the main economic drivers was the creation of new large-scale investment opportunities in the Sri Lankan economic sector. Four out of six respondents mentioned, "*Sice the ca and case B WtE projects are establishing in large scale, this will affect positively on Sri Lankan economy as a considerable amount of money has been invested on these two projects."* Implementing these projects will open the path toward job opportunities in many fields. Further, RB-1 especially highlighted that a "*considerable amount of job opportunities will be coming into the action as these sites are comprising of a huge number of tasks and processes."* The reduction of cost components linked with typical waste management techniques that were followed by the Sri Lankan government also become an economic driver for WtE implementations. According to the respondents in both the cases, it is summarised that the "*Sri Lankan government has mainly followed open dumping for waste management. So, they have to bear a different type of costs in doing this like transportation costs, sorting costs, handling costs, etc."* Although the government followed daily there was poor management of waste because they were not able to reduce or eliminate the collected waste properly. As a result, the waste piles were created day by day. So, this has become an economic driver for WtE implementation. Most all the respondents have listed that, "*WtE is a process which is addressing the issue of waste while giving solutions to some other emerging issues as well*." Within this WtE process, MSW will be used as the input, and electricity and heat will be generated as the output. Since electricity can be generated through WtE this can be used as a process to address the energy crisis in Sri Lanka to some extent as well. An additional income will be created by selling the generated electricity to the national grid. If the waste was piled up, the government has to bear additional costs, and sometimes, they have to compensate the public as in the Meethotamulla situation. Through WtE it will reduce the waste and also generate electricity, through that creating additional income. In addition to that, the reduction of land scarcity has become one of the mentioned economic drivers. Open dumping will lead to inefficient waste management and land scarcity. By implementing WtE projects these waste piles can be removed and lands can be used for development projects to pull up money.

Social drivers: One of the key social drivers highlighted by all the respondents is "public pressure" for initiating WtE mega-scale sites in Sri Lanka. This driver has an interrelationship with all other drivers listed and discussed above.

Technical drivers: Although the WtE concept is still novel in Sri Lanka, both cases suggested that the main technical factor for the implementation of WtE projects was technological growth. The RA-1 explained, "*the non-availability of sufficient technologies was historically the biggest barrier for waste treatment, but WtE technology was gradually enhanced to the extent where most organic waste was both safely and* *efficiently incinerated to produce electricity"*. At present, there are many WtE technologies like incineration, gasification, anaerobic digestion, pyrolysis, etc. to generate electricity from waste. But, in the early stages, WtE has become unsuccessful due to having negative environmental impacts due to technical failures like emissions. According to the respondents these emissions and other negative environmental impacts have been controlled at present for safe generation of electricity from waste. RB-1 further added that "*there are emission control systems, fly ash control systems, bottom ash control systems, leachate treatment systems, wastewater treatment systems have been introduced to mitigate toxic emissions and negative environmental impacts*." Hence, the mentioned factors have become technical drivers for implementing WtE projects in Sri Lanka.

Legal drivers: As WtE is fresh in Sri Lanka, the respondents did not give favorable responses on the legal aspect because there is no separate legal framework established for the WtE sector. But Sri Lanka is now providing favourable regulations to promote the adoption of WtE in the Sri Lankan context.

Environmental drivers: Due to the environmental concerns caused by most of Sri Lanka's existing waste management activities, environmental drivers have also been a big force for the initiation of WtE mega-scale sites in Sri Lanka (For example; negative impacts due to open dumping and landfilling as discussed under social drivers). In addition, most of the respondents have mentioned the minimisation of air and water pollution as the main driver. Moreover, WtE which is having a very low level of emissions came forward instead of typical landfilling and open dumping. Although the respondents mentioned "High dependency on imported coal in energy generation" and "Capacity to generate renewable energy sources due to having scarcity of available non-renewable energy sources" as two different drivers, there is an interrelationship between those two drivers. Due to the scarcity of non-renewable energy sources like coal, people tend to generate sustainable renewable energy sources. Since coal can be identified as a scarce resource for generating energy it should be controlled and should move to generate renewable energy sources. Also, due to rapid population increment and urbanisation the generation of garbage never getting ends and can continuously supply the primary fuel in WtE sites to generate electricity. So, the above-mentioned factors are the ones that are mainly highlighted by the respondents in initiating WtE mega-scale projects in Sri Lanka as environmental drivers. However, the successful adoption of WtE plants is depending upon the proper identification of barriers to its implementation and proper strategies to overcome the identified barriers, thus the next section is discussing the barriers to implementing WtE projects in Sri Lanka.

3.2 BARRIERS TO INITIATING WTE MEGA-SCALE PROJECTS IN SRI LANKA

It is important to develop a clear understanding of the barriers that may arise through the implementation process to ensure the successful implementation of WtE projects and to decide on strategies to deal with such barriers if they arise. In the Sri Lankan context, barriers have been aroused from different perspectives. The results of the interviews revealed several obstacles faced by project participants through the PESTLE analysis, although the problems arising from the respondents of each case differ from the wording used, most of the problems seemed to be similar in the two cases. The initiation of WtE mega-scale sites in Sri Lanka has been influenced by barriers considerably. Table 3 provides the responses to barriers highlighted by the respondents.

Table 3: Responses on barriers to initiating WtE mega-scale projects in Sri Lanka

No	Barriers	Responses
	Political	
1	Lack of infrastructure from the government	6/6
2	Taxes on the machinery imported from other countries	6/6
3	Lack of awareness of the benefits of WtE projects	6/6
4	Burdens on gaining approvals for WtE project proposals	4/6
5	Political inertia of moving towards new mechanisms of MSWM from typical methods	3/6
6	Lack of national strategies	2/6
	Economic	
1	Need for high capital investment to initiate WtE projects	6/6
2	High operation and maintenance costs	6/6
3	Having long-run payback periods	6/6
4	Nature of the waste	4/6
5	High cost for EPC (Engineering, Procurement, and Construction) contractors	4/6
6	Projects are implemented through subordinates of real developers	2/6
	Social	
1	Segregation of waste: people show resistance to sorting their waste at home	6/6
2	Attitudes and habits of the general public	6/6
3	Having protests against the projects	4/6
4	Excessive noise during the construction phase	3/6
5	Odour and nuisance from the sites	3/6
6	Noise burdens along transportation routes to the sites	3/6
7	Sound pollution during the operational phase	3/6
	Technological	
1	Lack of expert knowledge on WtE technologies for such implementations	6/6
2	The high moisture content of waste available in Sri Lanka	4/6
3	Fewer technicians and their knowledge on performing operations and doing maintenance of WtE plants	6/6
4	Processing of hazardous substances	3/6
5	Segregation of waste	2/6
6	Poor maintenance activities performed on equipment	2/6
7	Availability of heavy metals	2/6
	Legal	
1	Absence of a regulatory framework	6/6
2	Difficulties in getting permissions and license	6/6
3	Difficulties in getting a power purchasing agreement from CEB	4/6

No	Barriers	Responses
4	The action laws and regulations of the national environment act	2/6
5	Absence of permitting protocol	2/6
	Environmental	
1	Disposal of fly ash and bottom ash	6/6
2	Controlling of leachate	6/6
3	Controlling air pollutants	6/6
4	Strict environmental regulations	4/6

Political Barriers: Respondents of both cases highlighted that, "*taxes imposed for imported items and machinery*" as the main political barrier, RA-3 mentioned that, "*as WtE is new to Sri Lanka, most of the equipment and related machinery have to be imported from other countries. So, the project developers are demotivated by the very high amount of taxes*" Similarly, all 3 respondents of case A highlighted that, since the government is not aware of the long-term advantages that can be gained through these types of projects it will demotivate the project developing parties in initiating WtE projects in Sri Lanka. In addition, RA-2 stated that "*typical political ideas are arising when concerning on this type of projects. They are only focussing on the high amount of capital budget for implementing this type of projects"*. Furthermore, RA-3 mentioned that "*political people are not interested in focussing long term benefits of this kind of project*". Instead of calculating long-term benefits and cost savings, political people always focus on high capital budgets and show inertia regarding these types of projects. In addition, respondents from both the cases have mentioned that, the process that project developers have to follow on gaining required approvals to initiate a WtE mega-scale site and the lack of national base strategies for initiating these types of projects as they are modernist in Sri Lanka as political barriers as well.

Economic barriers: All revealed that the "*requirement of high capital investment is a critical economic barrier for WtE project implementation*". This is due to spending high costs on machinery and services that are required for implementing WtE projects. Highlighting the same fact, the RB-2 stated that, "a high cost has to be paid for EPC contractors for their service." This is since WtE is modernist in Sri Lanka the expert knowledge is lacking in this type of project. So, the service of EPC contractors who are responsible for designing and constructing WtE plants must be granted. In addition, RB-3 mentioned that "*the operation and maintenance phase will be contracted to some outside contractors who are delivering operation and maintenance services at high rates*". Moreover, the respondents pointed out that WtE projects are usually taking long-run payback periods to recover their capital investment. RB-3 explained that "in Sri Lanka, WtE projects have a poor return on investment when comparing with other countries which follow these projects due to the lower return from these projects." It was disclosed that CEB agreed to purchase the generating electricity from WtE sites at a very low rate per one unit. RA-2 stated that "usually WtE plants are working 24/7/365 leading to high operational costs." This is the main burden on covering capital costs within a short period. The nature of waste which are processed in WtE plants to generate electricity is an economic barrier in Sri Lanka. RA-1 mentioned that "*high moisture content of waste is a burden for incineration process*". Since Sri Lanka's waste composition consists of a high percentage of organic waste (high moisture content) they must be pre-treated before sending for incineration. If not the efficiency of incineration will become less due to the partial burning of waste which is leading to inefficient electricity generation.

Social barriers: According to RB-1, many MSWM projects including WtE projects become failed due to the high influence of social barriers themselves. The main reason was the waste segregation problem. Case A identified this as a key barrier because it comprised of a hybrid plant consisting of an incinerator and an anaerobic digestion plant which required biodegradable and non-biodegradable waste separately. In addition to that, odour and nuisance from the sites are important social barriers. RB-3 stated that "*odour from the sites consists of some chemical compounds like ammonia (NH3) and hydrogen sulphide (H2S)*". As a result, this will create a bad odour combined with air pollution as well. Moreover, all the respondents highlighted that "*attitudes and habits of the general public towards social welfare*" are also a major social barrier. At this point, the typical philosophy of the Sri Lankan public is "not in my backyard" coming forward. People are just caring about themselves rather than considering social burdens. So, the push toward these types of projects becomes less. According to RA-2 and RB-3, "*public protests have a major impact on WtE projects in general as a social burden, but such issues have not been raised for our projects".* As per the RA-1, "the *main reason for these types of public protests against WtE projects due to less awareness of these types of projects and its long-term benefits*". So, the social barriers have much influence in initiating WtE sites in Sri Lanka.

Technical barriers: Since WtE is a modernist technology for Sri Lanka many technical issues are interrelated with the implementation of these types of projects. Deficiency in expert knowledge and specialisation in WtE was identified as one of the key technical barriers and RB-1 added that "*there are no trained or expert people for handling the operations and performing maintenance activities in WtE plants*". As a result of not having enough people for WtE operations and maintenance, the expected outcomes from WtE plants cannot be generated. Also, with poor maintenance of machinery and equipment, machine breakdowns, and machine wear and tear will appear frequently. As discussed in economic barriers, high moisture content and low calorific value in waste will cause inefficient energy output. With the case study results, it was identified the amount of energy that is released when 1Kg of waste is burnt in the presence of Oxygen (calorific value) available in Sri Lanka lies between 6500-7500 KJ/Kg (Kilo Joules per Kilogram). Segregation of waste which was identified as a social barrier before was identified as a technical barrier as well by RA-2 and RB-3. This is because MSW is comprised of heavy metals like mercury and hazardous materials like chemicals. If these are burnt inside an incinerator this will cause negative impacts. This fact was confirmed in both cases.

Legal barriers: All mentioned that the lack of a regulatory framework for WtE has become the key legal barrier, RB-3 mentioned that "*Sri Lanka is not delivering a separate regulatory framework for WtE projects, hence discouraging the project developers*". Also, RA-2 highlighted that "*getting approvals from government organisations for WtE projects has become a considerable barrier where several approvals have to be taken*". Apart from that getting the power purchasing agreement from CEB was also identified as a legal barrier. RB-1 stated that "*there are many requirements to be fulfilled to get power purchasing agreement like energy permit, letter of intent, grid connection permit, etc*". Moreover, RA-2 added that "*there are some regulations to be fulfilled like national* *environment act, provincial council, hazardous waste regulations, and local government ordinance*".

Environmental barriers: One of the major environmental barriers identified was the generation of fly ash and bottom ash as alternatives. RA-1 mentioned that, "*the decomposition of fly ash and bottom ash is the main environmental impact from WtE sites*" and RB-1 added that, "*according to the estimations an amount of 5-6 MT/day of fly ash and 40-60 MT/day of bottom ash will be generated*". Moreover, both the cases highlighted the controlling of leachate which is identified as an environmental pollutant and an environmental-related barrier. The estimated amount of leachate per day will be 50-100 m3. According to the RA-3, "leachate is considered as an environmental pollutant which is causing groundwater contaminations and soil pollution." The respondents affirmed that there are air pollutants from WtE plants. This is due to the combustion process inside incinerators. As per the respondents of both cases, "strict environmental regulations" have become considerable environmental barriers as well.

Concluding, through the case studies twenty-eight (28) drivers and thirty-five (35) barriers were discussed. From both the literature findings and collected data, the magnitude of barrier forces seems to be greater than the driving forces. This is because Sri Lanka is still in its infant age in terms of WtE technologies and their adoption. But most of the respondents highlighted that due to the presence of well-built driving forces the applicability of WtE in electricity generation through MSW can be empowered by coming up with strategies to weaken the barrier forces. Hence, the next section is on suggested strategies to overcome the barriers identified.

3.3 SUGGESTED STRATEGIES TO OVERCOME THE BARRIERS TO INITIATING WTE MEGA-SCALE PROJECTS IN SRI LANKA

Drivers can themselves be the strategies for applicability of WtE in electricity generation through MSW in Sri Lanka. But separate strategies were discussed as suggested by the interviewees in terms of political, economic, social, technical, legal, and environmental as follows.

Political barriers: All the respondents highlighted the fact that the government of Sri Lanka should provide "incentives like tax downturns for the machinery and equipment that has to be imported for initiating WtE sites". Simultaneously all the required infrastructure like access roads, electricity, water, etc should be given. In addition, respondents proposed "a separate national base WtE initiation plan by implementing clear approval procedures". This should be achieved using an acceptable approach by convincing the government of the benefits of having WtE projects.

Economic barriers: The respondents suggested introducing debt financing as high capital investment is required. Through this, there will be more funders for a WtE project. Furthermore, guarantees can be given by the government. As an example, if CEB is willing to buy the electricity that is going to be generated through WtE sites then financial institutions will offer loans for project developers. The operation and maintenance costs can be reduced through proper maintenance and utilisation of the plants as per the respondents. As a solution for spending high costs for EPC contractors, Sri Lanka can find and train people within the country.

Social barriers: The best strategy that could be done as per the respondents is "having awareness programs to convince the public on the importance and long-term benefits that can be obtained from initiating WtE projects". The main reasons for public protests against WtE projects can be mitigated by "facilitating proper waste storage within the sites, using better machinery were emitting less sound and vibrations, going for low noise designs like noise-proof buildings, using shortest routes for transportations and selecting sites in areas where having less volume of residents".

Technical barriers: Deficiency in expert knowledge in Sri Lanka for configuring and operating WtE sites was identified as one of the key technical barriers. The respondents provided a two-way strategy for this barrier. The respondents were therefore advised, "either to receive professional knowledge from foreign organisations or to implement a separate WtE module to local universities were conducting WtE related training programs as well". Waste should be stored inside a bunker for 6-7 days before sending for incineration to prevent the high moisture content and low calorific value, so the leachate that is coming from the waste will be eliminated and the moisture level will be reduced. To prevent burning hazardous waste inside the incinerators like e-waste, clinical waste, etc. the respondents suggested having agreements not to accept such types of waste. To solve the waste segregation, issue the respondents suggested that there should be more tough laws on waste segregation at the source.

Legal barriers: The key recommendation for resolving regulatory barriers was to provide an "approval system where all the approvals required for these types of projects can be obtained from one place". Through this, the approval process can be facilitated in an appropriate way where project developers will not get discouraged. Moreover, the respondents mentioned that there should have a proper regulatory framework with proper approval protocol.

Environmental barriers: It was proposed for bottom ash "to be used as a secondary aggregate in building sites or to dispose as an inert waste to a particular landfill or to be used in the manufacture of lightweight payment bricks". In terms of fly ash that could be accumulating using an ash silo. A proper leachate treatment plant can be installed within the site to solve the problem of leachate. Installation of a proper framework to monitor air pollution, monitoring system, measurement system for gas concentration, emission measurement system, and Flue Gas Desulfurization (FGD) systems have been proposed.

4. CONCLUSIONS

At present MSW has become a major crisis in Sri Lanka causing many negative impacts on the public as well as on the environment. This is due to the rapid generation of MSW as a result of the increasing population and urbanisation. Also, there is an imbalance in the demand and supply of electricity generation is one of the major issues in Sri Lanka. Thus, WtE is such a MSWM solution and it delivers alternative sources like electricity by addressing waste problems. It has been adopted in many countries already, but in the Sri Lankan context, this is still a newborn technology. Thus, to derive the adoption of WtE technology, mainly the drivers and barriers to such implementations have been identified. Even though the literature provides a smaller number of drivers (13) than the drivers that were highlighted through interviews (28) for the implementation of WtE projects under PESTLE analysis. However, through the case studies, thirty-five (35) barriers were identified which include twenty-one (21) new barriers. This study made a significant contribution to awareness by identifying how WtE projects in Sri Lanka can be successfully implemented as an efficient waste management strategy and renewable energy generation technology. Moreover, the following recommendations have been suggested by the authors such as governments should promote the implementation of such projects by offering incentives and loan schemes as these are because expensive expenditure, "one roof system" that would enable the taking of all approvals at one location through the members of each company as necessary approvals and permits to consume more time and challenging, the WtE principles and their benefits be made known to the public through awareness campaigns.

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ENABLERS TO FACILITATE INDUSTRIAL SYMBIOSIS FOR BETTER WASTE MANAGEMENT OF 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, Industrial Symbiosis (IS) concept was raised as a suggestion for WM in IZs through resource optimisation. IS concept being a sustainable solution focuses on waste elimination by creating a network of firms for the purpose of exchanging waste, by-products, utilities, infrastructure, and knowledge. Sri Lankan IZs still have not yet established a proper method to manage IW, which has led to heaps of waste. Since IS is an effective and timely solution for this issue, this paper was intended to analyse the enablers which will be vital in facilitating the application of the concept of IS for better WM of IZs in Sri Lanka. Despite the abundant research on IS concept, a gap in literature could be identified when it comes to exploring enablers to adapt 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 enablers were extracted through the analysis of case findings using an abductive analysis. The empirical findings revealed 34 enablers under environmental, economic, social, regulatory, organisational, technology, and market categories. Reduction of environmental deletion, reduction of WM cost, public pressure, environmental regulations, social relationships, availability of technology and recognition from buyers were some of the key enablers identified in this study. The knowledge generated through this research can be used by respective industry practitioners in Sri Lanka in adapting IS concept for better WM of IZs in Sri Lanka.

Keywords: *Enablers; Industrial Symbiosis; Industrial Zones; Waste Management.*

1. INTRODUCTION

Industrialisation and urbanisation resulted in the generation of massive amounts of Industrial Waste (IW), which is a key social issue (Karunasena and Kannangara, 2012). Kaza, et al. (2018) predict a 70 percent increase in the current generation of global waste by 2050 while waste generation will rise by more the double of its current waste stream in South Asia. Industrial Zones (IZ) can be identified as the most visible morphological

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form of industrial facilities (Sacirovic, Ketin and Vignjevic, 2019) and it has become a common concept around the world where their functions create adverse impacts on human health, environment, and communities through higher pollution, safety problems, loss of biodiversity, and increase in cost associated with social externalities (Geng, et al., 2008). Similarly, IW is generated massively in Sri Lanka where IZs have been accountable for a higher proportion of IW (Karunasena and Kannangara, 2012). Unpleasant surroundings, loss of property values, increased flooding possibilities, creating health and safety issues for the public, spreading diseases, soil pollution and degradation of other natural resources are identified as environmental consequences of improper Waste Management (WM) (Bandara and Hettiaratchi, 2010).

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). Industrial Symbiosis (IS) concept 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 and Laybourn, 2012).

In the process of facilitating and developing a robust IS network, it is increasingly important to have a greater understanding of enablers applicable to the development as it plays a critical role in the context (Chertow and Park, 2016). Enablers can be considered an important attribute of industrial symbiosis, which directly affects to the success of developing IS networks where there is a data deficit about the enablers (Rahman, Islam and Islam, 2016). This implies that there is a necessity in investigating the enablers for the successful application of the IS concept as a solution, which has a knowledge gap in the Sri Lankan context. This paper aimed in bridging this knowledge gap to facilitate the successful application of IS concept for better WM of IZs in Sri Lanka.

2. LITERATURE REVIEW

2.1 WASTE MANAGEMENT OF INDUSTRIAL ZONES

IZs are one key area where a huge amount of IW is generated (Karunasena and Kannangara, 2012). Industrial activities have a significant environmental impact which has the potential to harm the environment (Duflou, et al., 2012). In IZs, improper and isolated WM procedures cause more environmental problems and spread diseases (Karunasena and Kannangara, 2012). Furthermore, the authors stated that public nuisances like soil pollution, unauthorised dumping, and inland water pollution have been created due to poor WM procedures in IZs. Discharge of industrial wastewater into storm water drains and surface water sources, and improper discharge of solid waste containing hazardous materials into open dumps directly contribute to the degradation of the quality of the water resources (Bandara, 2003). According to Van-Berkel, et al. (2009), recycling can be identified as the most common and favourable WM mechanism in use. Handing over to scavengers, landfilling, reuse, recycling (Geng, Zhu, and Haight, 2007) incineration, export, co-disposal with municipal waste and on-site storage (El-Fadel, et al., 2001) are some existing WM mechanisms in IZs. Resource eco-efficiency, cleaner products, eco-designs, life cycle assessment (Mohamed, 2009), Pay as a throw, polluter pays principle, 3R strategy, green purchasing, and extended producer responsibility are novel concepts applied in WM in IZs (Karunasena and Kannangara, 2012). According to Guerrero, Maas and Holand (2013), existing WM approaches capture only a limited proposition of actual waste generation which routes to various issues. Mohamed (2009) shows that the increasing pace of industrialization produces massive amounts of waste, signalling the need for a new approach to WM in IZs.

2.2 INDUSTRIAL SYMBIOSIS CONCEPT

In the past 150 years, production and consumption patterns of the industrial economy followed the Linear Economy (LE) concept (Wautelet, 2018). LE is based on taking, make, consume, and discard principle (Drljaca, 2015). This linear system consumes large volumes of resources which creates negative impacts on the environment and people (EMF, 2017). Even though the LE has been successfully implemented in industrial nations up to the 20th century, it is forecasted that it will affect negatively in near future (Sariatli, 2017). The Circular Economy (CE) concept has become a key solution for achieving economic growth while ensuring environmental sustainability due to the limitations and challenges of the LE concept (Lieder and Rashid, 2016). In this metabolism organisations are interacting together to create IS where energy and materials flowing out from one organization or process are used as inputs for another (Ashton, 2008). According to Bocken, et al. (2016), IS concept enables industries to shift from a linear model to a circular model where waste generated from one organization is transformed into another organization as its feedstock and vice versa. The emergence of IS concept has been highly demanded due to the negative impacts of LE.

2.3 ENABLERS FOR APPLICATION OF INDUSTRIAL SYMBIOSIS CONCEPT

Enablers can be considered as an important attribute of IS which directly affect to the success of developing IS networks (Rahman, Islam and Islam, 2016). Hence, it is important to have a considerable concern on enablers in the application of IS concept for WM of IZs. Table 1 summarises the enabling factors of IS network development under environmental, economic, social, regulatory, and organisational categories. This was based on the previous studies, which have been conducted by many researchers in the same area.

Table 1: Enablers of IS network development

Enabler category	Enabling factors
Environmental enablers	• Reduction of natural resource depletion • Reduction of waste outflow • Reduction of environmental impact
Economic enablers	• Reduction of input resource cost • Creation of new areas of revenue • Increased turnover • Spatial proximity
Social enablers	• Pleasant and cleaner environment • Creation of new employment opportunities • Satisfaction of cooperate social responsibilities

Enabler category	Enabling factors
Regulatory enablers	• Environmental policies • Pollution control regulatory framework • Supportive initiation policies and laws • Facilitated IS programmes
Organisational enablers	• New partnership opportunities • Enhance organizational sustainability • Trust, reciprocity, short mental distance, positive attitudes, social ties, common vision • Diversity of participants

[1] Domenech, et al. (2019); [2] Haq, et al. (2020); [3] Aparisi (2010); [4] Chertow and Park (2016); [5] Lin (2020); [6] Paquin and Howard-Grenville (2009); [7] Liu, et al. (2018)

However, when it comes to the Sri Lankan context, enablers of IS network development have not been discussed in literature yet. Thus, in bridging this knowledge gap, this paper intends to discuss the enablers of IS network development. The next section discussed the research process adopted in bridging this knowledge gap.

3. RESEARCH METHODOLOGY

This study aims to analyse enablers which are vital to ensure the success of the application of IS concept for WM of IZs in Sri Lanka. Thus, the research question of the study was as follows:

> ***RQ.*** "How the IS concept can be successfully applied for waste management of Industrial Zones in Sri Lanka?''

Yin (2015) 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 (Yin, 2015) 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. Since the research area is broad and not limited to a certain industry as it focuses on IZs where a variety of industries are operated, it is necessary to compare several cases to derive a more accurate output. Therefore, multiple case study was selected and limited to two (02) case studies based on the literal replications and theoretical replications (Yin, 2015) expected through the study. The profile of selected cases is given in Table 2.

Table 2: Profile of the selected cases

Case	Area (in acres)	Number of Factories	Number of workers	Main categories of factories operated	Estimated waste generated per year
A	531	86	39000	Hi end apparel, rubber production, electronic production	21,328 tonnes
B	450	77	26000	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 practised 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 with six personnel from each case were used as the data collection technique (refer Table 3). The number of interviews was decided based on the data saturation and was limited by the fact that there are no experts on IS network development as there have not been practical applications yet in the Sri Lankan context. The interview guideline focused on 18 enablers identified through the literature review. Respondents were requested to elaborate their answers as per the current exposure to the aforementioned enablers.

Data analysis was carried out using code-based content analysis. It is vital to have an in-depth understanding of the enablers, which is vital to ensure the success of the application of IS concept for WM of IZs in Sri Lanka. However, so far, there has been no systematic academic analysis of the application of IS for WM in IZs in Sri Lanka. Thus, to investigate enablers, this paper applies the categorisations of Environmental’, ‘Economic’, ‘Social’, ‘Regulatory’, ‘Technological’, ‘Marketing’ and ‘Organisational’ to analyse the macro-environment of the IS application in IZs of Sri Lanka. Similar categorisations have been widely used for such purposes all around the world (Aparisi, 2010; Domenech, et al., 2019). According to Domenech, et al. (2019), the use of such categorisations provides a multifaceted approach to assess big-picture forces for better understanding the enablers in a broader view and to assist in making considered and informed decisions. The enablers under were extracted through analysis of case findings using an abductive analysis.

Table 3: Profiles of respondents

Case	Years of experience	Interviewee code	Designation
A	6 years	CA-I1	Senior Manager – Environmental Sustainability
	5 years	CA-I2	Assistant Manager – Sustainability
	3 years	CA-I3	Executive – Sustainability
	3 years	CA-I4	Executive – Compliance and Sustainability
	3 years	CA-I5	Executive – Environmental Sustainability
	4 years	CA-I6	Executive – Environmental Safety and Health
B	4 years	CB-I1	Executive – Compliance and Sustainability
	5 years	CB-I2	Executive – Environmental Safety and Health
	3 years	CB-I3	Executive – Compliance and Sustainability
	5 years	CB-I4	Factory Engineer – Head of Engineering
	4 years	CB-I5	Assistant Manager – In charge of Operation
	5 years	CB-I6	Manager – Facilities and Administration

4. CASE STUDY FINDINGS

The case study findings of enablers to facilitate IS to manage waste in IZs are discussed and presented under environmental enablers (Section 4.1), economic enablers (Section 4.2), regulatory enablers (Section 4.3), social enablers (Section 4.4), organisational enablers (Section 4.5), technological enablers (Section 4.6), and market enablers (Section 4.7) as below;

4.1 ENVIRONMENTAL ENABLERS

Findings generated through the case study analysis revelated that almost all the enablers under the environmental category directly or indirectly contribute to the reduction of environmental impact. Amongst the all-environmental barriers, 'reduction of environmental impact (En/E6)' was identified as the main enabler by all the respondents from both cases. 'Reduction of natural resource depletion (En/E4)' and 'reduction of waste outflow (En/E5)' are environmental enablers reasoning reduction in the institutional and public pressure on the organisations. Reduction of external pressure as a result of reduced use of raw materials and reduced waste disposal encourages organisations to involve in IS networks. Further, 'Reduction of water contaminations (En/E1)' and 'waste dumps (En/E2)' encourage organisations to involve in IS network which prevents water pollution and enhances land usability. In addition, CA-I4 stated that IS provides solutions to scarcity of resources where scarcity has been a major issue in the current industrial system which is another environmental enabler of IS. A summary of Environmental enablers of IS network development has listed in Table 4.

Table 4: Summary of environmental enablers

Code	Enabler
En/E1	**Reduces effect on water bodies by waste contaminations***
En/E2	**Reduces waste dumps on lands***
En/E3	**Control scarcity***
En/E4	Reduction of natural resource depletion
En/E5	Reduction of waste outflow
En/E6	Reduction of environmental impact

En/E - '**En**vironmental/**E**nabler'

Note: *Findings that are identified <u>only</u> from the analysis of cases.

4.2 ECONOMIC ENABLERS

'Reduction of input resource cost (E/E5)', 'reduction of waste processing cost (E/E1)' and 'creation of new areas of revenue (E/E6)' are the most highlighted economic enablers where CA-I4 stated that "*alternative use of waste reduces the raw material cost for buying participants and generate revenue to selling participants and also it reduces the waste outflow from the network which reduces waste processing cost*". 'Spatial proximity of the participant organisations (E/E8)' is identified as an economic enabler by all respondents, where it reduces the cost on transportation and infrastructure. CA-I1 added that "*close proximity of organisations enables the use of immovable properties in a shared basis and reduces cost on movements*". Shared cost on utilities and infrastructure (E/E2)' was identified as an economic enabler where CB-I5 stated that "*IS enables participants to* *share the cost associated with initiation, operation, and maintenance of utility and infrastructure projects*". 'Innovative production opportunities (E/E4)' are an economic enabler too as per case study findings. It was further evident through the perspective of CB-I3 where he stressed that "*IS provides huge exposure to novel and innovative knowledge where new production applications open up new income generation paths".* In addition, increment in turnover (E/E7)' and 'financial strength to enter new initiatives (E/E3)' were recognised as economic enablers of IS by respondents. Table 5 shows the economic enablers of IS network development.

Table 5: Summary of economic enablers

Code	Enabler
E/E1	**Reduction of waste processing cost***
E/E2	**Shared cost on utilities and infrastructure***
E/E3	**Financial capabilities to enter new initiatives***
E/E4	**Innovative production opportunities***
E/E5	Reduction of input resource cost
E/E6	Creation of new areas of revenue
E/E7	Increased turnover
E/E8	Spatial proximity

E/E - '**E**conomic/**E**nabler'

Note: *Findings that are identified <u>only</u> from the analysis of cases.

4.3 SOCIAL ENABLERS

A summary of social enablers of IS network development are listed in Table 6.

Table 6: Summary of social enablers

Code	Enabler
S/E1	**Social recognition***
S/E2	**Goodwill***
S/E3	**Public pressure***
S/E4	Pleasant and cleaner environment
S/E5	Creation of new employment opportunities
S/E6	Satisfaction of cooperate social responsibilities

S/E - '**S**ocial/**E**nabler'

Note: *Findings that are identified <u>only</u> from the analysis of cases.

'Creation of pleasant and cleaner environment (S/E4) is a major social enabler which was accepted by all the respondents from both cases. According to CA-I5, "*IS prevents improper waste disposal and social externalities associated with WM of IZs where it creates a pleasant and cleaner environment*". Many respondents highlighted that 'creation of employment opportunities (S/E5)', 'satisfaction of cooperate social responsibilities (S/E6), social recognition (S/E1) and 'goodwill (S/E2)' are social enablers which are interconnected. CB-I4 stated that "*creation of employment opportunities through new projects satisfy the cooperate social responsibilities where it creates a good image to the organisations*". Further, finding generated from the analysis of both cases revelated that complaints and objections on public nuisance (i.e., 'public pressure (S/E3)') tends organisations to apply more sustainable WM approaches" which was raised by other respondents as well.

4.4 REGULATORY ENABLERS

All the respondents identified 'implementation of environmental policies (R/E3)' and 'pollution control regulations (R/E4)' as regulatory enablers where it demands more sustainable WM solutions. CB-I6 stated that "*IS provides solutions to reduce environmental pollutions where an organisation may involve with IS network to adhere to rules and regulations"*. 'Restrictions on non-renewable resources (E/E1)' and 'imposing taxes on non-renewable resources (R/E2)' are considered as regulatory enablers of IS as "*it provides alternatives to non-renewable resources which reduces tax cost and provide solutions to limitations of using non-renewable resources"* CA-I2 said. A summary of the regulatory enablers of IS network development are listed in Table 7.

Table 7: Summary of regulatory enablers

No.	Enabler
R/E1	**Restrictions on non-renewable resources***
R/E2	**Imposing taxes on non-renewable resources***
R/E3	Implementation of environmental policies
R/E4	Pollution control regulatory framework

R/E - '**R**egulatory/**E**nabler'

Note: *Findings that are identified <u>only</u> from the analysis of cases.

4.5 ORGANISATIONAL ENABLERS

All responses from case study shows that 'trust, reciprocity, short mental distance, positive attitudes, social ties, and common vision (O/E5)' are individual factors of participants which enables to initiate synergies in an IS network where CA-I3 further strengthen this fact as "*trust, reciprocity, short mental distance, positive attitudes, social ties and common vision creates strong relationships among participants which enhance sustaining synergies*". 'Diversity of participants (O/E6)' and 'new partnership opportunities (O/E3)' are co-related organisational enablers where both provide synergistic possibilities. CB-I2 stated that a "*higher number of synergistic possibilities occur with the diversity of participants which tempt participants to enter the IS network*". Knowledge of participants on the benefits of IS act as an organisational enabler. Executive – Compliance and Sustainability from Case B stated that "*organisations with proper knowledge on IS initiatives involve in IS network as there are vast a number of benefits to participants*". Also, 'enhancement of organisational sustainability (O/E4) and 'positive influence by management (O/E2)' were identified as organisational enablers. A summary of organisational enablers of IS network development are listed in Table 8.

Table 8: Summary of organisational enablers

Code	Enabler
O/E1	**Knowledge of participants***
O/E2	**Positive influence by management***

Code	Enabler
O/E3	New partnership opportunities
O/E4	Enhance organizational sustainability
O/E5	Trust, reciprocity, short mental distance, positive attitudes, social ties, common vision
O/E6	Diversity of participants

O/E - '**O**rganisational/**E**nabler'

Note: *Findings that are identified <u>only</u> from the analysis of cases.

4.6 TECHNOLOGICAL ENABLERS

'Availability of technological knowledge (T/E1) is an enabler to IS, which was identified by all respondents where it provides a greater understanding on the application and operation of the network. Executive – Compliance and Sustainability from Case B stated that "*IS network development demands higher-level technological expertise as it requires novel and innovative thinking*". 'Availability of advanced equipment and machinery (T/E2) was identified as another enabler of IS. CA-I5 stated that "*IS network is a complex network which needs critical decision making and advanced process handling which require automated operations where availability of advanced technologies enhance the performance of the network*". A summary of Technological enablers of IS network development are listed in Table 9.

Table 9: Summary of technological enablers

Code	Enabler
T/E1	**Availability of technological knowledge***
T/E2	**Availability of advanced equipment and machinery***

T/E – '**T**echnical/**E**nabler'

Note: *Findings that are identified <u>only</u> from the analysis of cases.

4.7 MARKET ENABLERS

'Recognition by buyers (M/E1)' and 'matching to international market requirements (M/E2)' were identified as market enablers by respondent from both cases. CA-I1 stated that "*sustainable overlook of the organisation increases the recognition, which creates new market spaces*" where CA-I5 also stated a similar view. "*Buyers who are looking for sustainable products increase the demand for the products and many developed countries concern highly on sustainable production where new market opportunities in international market arise by involving in IS operations*", CA-15 said. A summary of Market enablers of IS network development are listed in Table 10.

Table 10: Summary of market enablers

Code	Enabler
M/E1	**Recognition by buyers***
M/E2	**Matching to international market requirements***

M/E - '**M**arket/**E**nabler'

Note: *Findings that are identified <u>only</u> from the analysis of cases.

5. DISCUSSION

By reviewing the existing literature, altogether 18 enablers were identified (refer Section 2.3). These findings were in general and are not specific to Sri Lanka. However, these enablers are almost similar to the Sri Lankan context according to case study findings, except for two enablers. The formation of "supportive initiation policies" and "facilitated IS programmes" should be raised with the involvement of a governing body, which has a long-term vision of the process. Since the IS concept is a novel concept currently not practicing in Sri Lanka, the governing bodies do not involve in such initiations due to a lack of expertise knowledge and risk attached to initiations. Moreover, in addition to the five enabler categories found through the literature (i.e., environmental, economic, social, regulatory and organisational), four enablers were revealed through the case studies under another two categories, namely; technological and market. Sri Lanka is being a developing country, technological enablers and market enablers need to be considered because, in the technological sense, Sri Lanka is been reluctant to adopt new technologies and most of the techniques are not affordable to implement. Thus, it is obvious that, identification of its enablers and how those enablers could assist in such context is utmost important.

Altogether, 18 enablers were solely identified from the case studies including 03 environmental (refer Section 4.1); 04 economical (refer Section 4.2); 03 social (refer Section 4.3); 02 regulatory (refer Section 4.4); 02 organisational (refer Section 4.5); 02 technological (refer Section 4.6); and 02 market (refer Section 4.7) enablers, which are required for the application of IS to manage waste in IZs successfully in Sri Lanka. The recent studies by Domenech, et al., (2019) and Haq, et al., (2020) highlighted in their studies that reduction of environmental impact as a foremost enabler. A similar perception was observed in Sri Lanka as per case study findings. Moreover, Domenech, et al., (2019) disclose environmental, economic, social, regulatory, and organisational enablers (refer Table1). These findings were applicable to the Sri Lankan context as well.

Reduction of input resource cost, reduction of waste processing cost and creation of new areas of revenue are the most highlighted economic enablers identified through the case studies. These findings are almost similar to the findings of the studies by Domenech et al., (2019) and Aparisi (2010). The creation of a pleasant and cleaner environment is the major social enabler which was solely identified through the case studies. Though the concept of IS is new to Sri Lanka, it is believed that a pleasant and cleaner environment could be generated through the implementation of IS concept in IZs of Sri Lanka. Case study findings further revealed that this finding could be generalised to other countries as well. Organisational barriers identified in this study are almost the same as the findings by Domenech, et al., (2019), Aparisi (2010), Lin (2020), Paquin and Howard-Grenville (2009); On a slightly different note, trust, reciprocity, short mental distance, positive attitudes, social ties, and common vision, knowledge of participants are the foremost organisational enablers in Sri Lanka in comparison to the findings by same researchers. These foremost enablers in Sri Lanka facilitate to initiate synergies in an IS network and let the implementation process be accelerated, as per case study findings.

6. CONCLUSIONS

Management of IW is becoming a decisive problem mainly in IZs in Sri Lanka. Except for sewer treatment plants which are established in IZs, there are no other proper treatment techniques adapted to manage the waste generated. Therefore, instead of going for an open industrial system, which disposes of waste after consumption of energy and materials for production, should be replaced with a cyclic industrial system which is effective and efficient in resource flow. IS is such a concept, which can be adapted to manage IW successfully in an effective manner. However, the concept of IS being a novel concept to Sri Lanka, identifying its enablers is vital to get a better understanding of the concept and to accelerate the implementation process of IS in IZs for better waste management. Thus, this research was intended to analyse the enablers which will facilitate the successful implementation of IS concept for WM of IZs in Sri Lanka. Altogether, 34 enablers including 06 environmental, 08 economic, 06 social, 04 regulatory, 06 organisational, 02 technology, and 02 market enablers were identified in this study. Reduction of environmental deletion, reduction of WM cost, public pressure, environmental regulations, social relationships, availability of technology and recognition from buyers were the key enablers identified in this study. Understanding of these enablers will streamline the future adaptation of IS to manage IW in Sri Lanka. Overall, the knowledge generated through this research would be favourable for relevant industry practitioners i.e., policymakers, industry practitioners, investors, government bodies and researchers to make informed decisions on the implementation IS concept to initiate a centralised WM mechanism in IZs.

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ENHANCE THE COLLABORATIVE INVOLVEMENT OF STAKEHOLDERS THROUGH CLOUD-BASED BIM IN THE SRI LANKAN CONSTRUCTION INDUSTRY

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ABSTRACT

The construction industry relies on the collaboration of stakeholders for a successful outcome, as most the stakeholders are from multidisciplinary organisation to achieve a particular goal. In addition, information in the construction industry must be more accurate and on time to increase the project performance. Even though cloud-based collaboration can be a useful tool for working with the stakeholder, is not being used widely yet. Therefore, it is required to analyse the feasibility of collaborative stakeholders' participation on cloud-based Building Information Modelling. Hence, this paper outlines: the level of stakeholder collaborative involvement in cloud-based Building Information Modelling; the benefits of stakeholder collaborative involvement through cloud-based Building Information Modelling; limitation for the cloud-based Building Information Modelling; as well as strategies to overcome these limitations. Findings of the study indicated that even though, the benefits derived from the stakeholder collaboration are high, the collaborative involvement level in cloud-based Building Information Modelling is very low due to several limitations. therefore, this study propose some strategies to overcome the limitations such as: the government can provide training and awareness programmes; formulate regulations allowing for electronic-data processing to lower tax; develop Building Information Modelling execution plans with assistance from the Construction Industry Development Authority; and improve Building Information Modelling Execution plans with the technology.

Keywords: *Building Information Modelling (BIM); Cloud-Based; Construction Industry; Sri Lanka; Stakeholder's Involvement.*

1. INTRODUCTION

The construction sector, which is highly individualised with people and information for the construction process, makes a major contribution to a country's Gross Domestic Product. (GDP). (Fathi, et al., 2012; Afolabi, et al., 2018). Sri Lanka's construction industry generates around 7% of the country's GDP. (Central Bank of Sri Lanka, 2020; Central Bank of Sri Lanka, 2021; Central Bank of Sri Lanka, 2022). The Architecture, Engineering, and Construction (AEC) field is fragmented, covered with a network of data

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and involves a large number of various professionals and organisations throughout the lifetime of the construction outputs (Beach, et al., 2013). As a result, stakeholder might be classified as internal or external depending on their engagement or project scope. (Sutterfield, et al., 2006). Based on this, the primary difficulty in the construction industry is the effective involvement of stakeholders to accomplish specific objective with a substantial impact (Fathi, et al., 2012a). Due to that, many organisation encounter multiple difficulties in managing information safety procedures, and quality of the project for the construction stakeholders (Chung, et al., 2008). Therefore, the efficient collaboration of stakeholders is an important thing for the communication and awareness in the project activities to complete the project in an efficient way (Barthelmess, 2003). Furthermore, stakeholders in the construction industry wants to share the knowledge efficiently and effectively to improve the coordination among the stakeholders (Lang, et al., 2002). In the current world, the generation of information should be more accurate and real-time to get better performance from the construction stakeholder (Afolabi, et al., 2018), the construction firms should move on to the Information Technology (IT) sector to fulfil their day-to-day activities in the construction process (Kumar, et al., 2010). Therefore, the demand for cloud computing (CC) becomes a rapidly changing platform of IT and it allows construction firms to change the resources according to the demand of the construction environment (Shawish and Salama, 2014).

One of the creative techniques for the construction sector to achieve successful stakeholder engagement is the deployment of CC collaboration (Fathi, et al., 2012b). There are several applications (apps) available for stakeholder participation, including;

Building Information Modelling (BIM) is an innovative technology in the construction industry that enables better collaboration among stakeholders during construction processes including design procurement, prefabrication, construction, and post construction (Ma, et al., 2018; Cao, et al., 2017; He, et al., 2017).

In the construction industry, combining BIM and CC is far superior to utilizing BIM as a single product because the integration of BIM and CC provides an excellent platform for the working process and communication. (Wong, et al., 2014; Abanda, et al., 2018). In addition to that, the integration of CC and BIM (here in after Cloud-Based BIM) enables the stakeholder to easily tracking facilities of the building from the design stage to maintenance stage, which covers operations, facility management, energy management and maintenance of the building (Wong, et al., 2014; Amarnath, et al., 2011). Based on that, the development of CC based BIM is an effective and collaborative project management tool (Zhang, et al., 2017; Chu, et al., 2018). In the construction industry, the stakeholder can employ cloud-based applications to get an efficient outcome in the construction process; at the same time, the stakeholder rarely utilises to use the cloud-based applications and technologies during the day-to-day activities in the construction process (Afolabi, et al., 2018). Likewise, the cloud-based BIM collaboration can reduce the issues among the stakeholder collaboration during the construction process, but there is a requirement to check the feasibility of cloud-based BIM collaboration of stakeholders practically (Alreshidi, et al., 2016). Furthermore, there is a shortage of stakeholders' cooperation via cloud-based BIM and future researchers wish to focus the stakeholder involvement level via cloud-based BIM to help the construction stakeholders in obtaining an efficient outcome in the construction process (Wong, et al., 2014; Chu, et al., 2018). According to that, there have been some disagreements regarding the collaborative involvement level of stakeholders through cloud-based BIM, which has been pointed out by many researchers. So, the gap of this research identified that, the lack of stakeholder involvement through cloud-based BIM in the construction industry.

Hence, this research aims to investigate the stakeholder involvement level and mitigating strategies that accelerate stakeholder involvement in the construction industry. The remainder of this article is structured as the literature review followed by the research methodology. Then, the prime part of the paper is research analysis and findings. Finally, the conclusions and recommendations are provided.

2. LITERATURE REVIEW

This research is a continuation of the prior study (Mohanaraj, et al., 2021). The factors that are required for this study is just summarized and used to further this study. The factors that were used in this study are listed in Table 1.

Table 1: Factors identified from previous research

Drawbacks in the conventional method of stakeholder collaboration	Collaborative Features through cloud-based BIM	Benefits come from the collaborative involvement through cloud-based BIM	Limitation for the collaborative involvement through cloud-based BIM
Inadequate exchange of information	Document management	Easy communication	Hesitation
Inefficiency of data	Contract management	High storage capacity	High implementation cost
Poor coordination	Design management and drawing	Backup and recovery	Changing of organization culture
Low transparency	Real-time management	High collaboration	Data security and protection
Limited communication	Project life cycle management	Real-time monitoring	Legal uncertainty
Decision-making path critical	Efficient communication	No need for a physical location	Higher requirement of computer resources
Collaboration among stakeholder very low	Supply chain management	Data transfer quality and productivity improvement	Unpredictability of performance
	Finance management	Trust development	Trust related issues
	Tracking features	Low cost	The limited size of document sharing
	Sophisticated reporting	Resource sharing	Data ownership
	Task assignment		Lack of awareness
	Procurement		
	Time management		

3. RESEARCH METHODOLOGY

This research aims to investigate the stakeholder involvement level and mitigating strategies to accelerate stakeholder involvement through cloud-based BIM in the Sri Lankan construction industry. This study was developed based on the practical view of the research gap on the stakeholder collaborative involvement level through cloud-based BIM. The data collection was carried out using a mixed-method approach, which was directed in two ways such as questionnaire survey and semi-structured interview. The questionnaire survey was circulated among the fifty (50) professionals in the construction industry to rank the level of involvement through cloud-based BIM. According to the respondent percentage, 76% of respondents responded to the survey. The sample comprised of directors, engineers, architects, project managers, and quantity surveyors, the sample selection was done using the convenience sampling method. They were chosen from both consultant and contractor organisations, although, with the majority of respondents working in consultancy organisations and having experience in the construction industry between eleven to fifteen years. The criteria identified in the literature study were scored using a five-point Likert scale and the survey results were analysed using descriptive statistical analysis method through SPSS V20 software.

According to the findings of the questionnaire survey, the semi-structured interviews were undertaken among the ten (10) interviewees, who are experienced and practice CC and BIM in their day-to-day activities. During the interview, questionnaires were clarified, such as whether or not the collaborative elements in the traditional method and cloud-based BIM technique are the same. The interviewees responded that the Characteristics of any approach are nearly same, with the only variable being the efficiency level. If we employ the most recent approach for the stakeholder participation, the efficiency and accuracy levels increase. The semi-structured interview includes 17 questions divided into two sections for each respondent, and all findings are based on the questionnaire survey for the collaborative involvement through cloud-based BIM as collaborative features, benefits, and limitations for the involvement of stakeholders through cloud-based BIM. The species of the interviews are elaborated in Table 2.

Table 2: Details of the interviewees

Code	Profession	Organisation type	Designation	Experience
I-1	Charted Quantity Surveyor	Contractor	Contract Manager	13 Years
I-2	Charted Architect	Consultancy	Chief Architect	18 Years
I-3	Charted Architect	Consultancy	Project BIM coordinator	14 Years
I-4	Charted Architect	Consultancy	Director	20 Years
I-5	Charted Quantity Surveyor	Consultancy	Director	14 Years
I-6	Structural Engineer	Contractor	Structural Engineer	18 Years
I-7	Quantity Surveyor	Contractor	Project Quantity Surveyor	20 Years
I-8	Charted Architect	Consultancy	Charted Architect	17 Years
I-9	Quantity Surveyor	Consultancy	Project Quantity Surveyor	15 Years
I-10	Engineer	Contractor	Project Manager	23 Years

During the analysis of the factors through SPSS V20, the mean value was used to determine if the factor influence each cluster positively or negatively, ranking was done according to the mean value. According to the thumb rule or general rule, the number three on the five-point Likert scale is regarded ta decision-making point. According to that, values more than three are regarded to positive impact factors, while values less than three are considered negative effect factors.

4. RESEARCH FINDINGS AND DISCUSSION

The section consists of research findings from the questionnaire survey and semi-structured interview.

4.1 QUESTIONNAIRE SURVEY

In addition to the findings from the literature (section 2), some additional factors were identified during data collection and Table 3 elaborates the drawbacks of the conventional collaboration of stakeholders in the construction industry and mention the method of ranking or the basis on which the ranking was done.

Table 3: Drawbacks of the conventional collaboration of stakeholders in the construction industry

Code	Factor	Mean	Rank
A1.	Collaboration among stakeholders	3.82	1
A2.	Decision-making path is critical	3.74	2
A3.	Performance efficiency	3.71	3
A4.	The conflict between the department	3.66	4
A5.	Manipulation of data	3.61	5
A6.	Exchange of information among stakeholders	3.58	6
A7.	The efficiency of handling data	3.55	7
A8.	Coordination among stakeholder	3.53	8
A9.	Communication among stakeholders	3.53	8
A10.	Transparency of data	3.45	10
A11.	Wrong decision-making path	3.26	11
A12.	Security issues	3.26	11

As a result, the ranking order of the factors from the previous studies and the questionnaire survey findings are contradict. For instance, we consider the factor *"exchange of information among the stakeholder*" most authors pointed out that this is a high impact factor the conventional method of collaboration, while respondents stated that, this factor is not very essential the conventional method of collaboration. In this way, we evaluate "*collaboration among stakeholders*" most of the authors indicated that this is not a significant element in the conventional method, respondents highlighted that, this factor has a significant impact on the conventional method of collaboration. Moreover, according to the responses, these elements have a favourable influence on the conventional method of stakeholder collaboration in the construction industry. Those factors also have a positive impact on the conventional method of collaboration.

The collaborative features for the stakeholder involvement through the conventional method and cloud-based BIM found and graded using a literature study. Document management, contract management, design management, real-time management, project life cycle management, efficient communication, supply chain management, finance management, tracking features, sophisticated reporting, task assignment, procurement, time management, and scheduling are some of the factors to consider (Mohanaraj, et al., 2021). Table 4 depicts the collaborative involvement features available via cloud-based BIM.

Table 4: Collaborative involvement through cloud-based BIM

Code	Factor	Mean	Rank
B1.	Efficient communication	3.05	1
B2.	Tracking features	2.89	2
B3.	Time management	2.89	2
B4.	Finance management	2.82	4
B5.	Document management	2.79	5
B6.	Supply chain management	2.79	5
B7.	Scheduling	2.76	7
B8.	Real-time management	2.66	8
B9.	Sophisticated reporting	2.61	10
B10.	Task assignment	2.55	11
B11.	Project life cycle management	2.53	12
B12.	Design management	2.42	13
B13.	Contract management	2.39	14
B14.	Procurement	2.39	14

According to the findings, collaborative involvement in the cloud-based BIM has a negative impact, indicating that stakeholder rarely use cloud-based BIM to benefit the construction industry. Furthermore, the stakeholder collaborative involvement, features were assessed individually in terms of theory and practice. In this approach, the authors emphasized the significance of collaborative features through cloud-based BIM, however in practice; the intensity of involvement differs from the theory. For instance, the authors claimed that "*contract management*" is an important thing in collaborative involvement, but the respondents pointed out that the involvement level in cloud-based BIM collaboration is too low. In this sense, "*efficient communication*" is not so crucial in the authors' opinion, but respondents claimed that this aspect is extremely important in the collaboration of stakeholders via cloud-based BIM.

Furthermore, the benefits of stakeholder collaborative involvement through cloud-based BIM were discovered and assessed through literature review. Table 5 explains the benefits of collaborative involvement through cloud-based BIM.

As per the findings, all the respondents believed that collaborative involvement through cloud-based BIM had a positive impact on the construction industry. It elaborates that the collaborative involvement of stakeholders through cloud-based BIM is an efficient thing in the construction industry for the stakeholder to make efficient and effective collaboration. However, the significance of the advantages changes from the research review to real situation. For example, while the literature considers real-time monitoring to be the most essential advantage stakeholder collaborative involvement through cloud-based BIM, in the industry, accuracy is the critical component that comes from the stakeholder collaborative involvement through cloud-based BIM. Through a literature analysis, the limitations for collaborative engagement through cloud-based BIM were discovered and rated appropriately. Table 6 depicts the constraints of stakeholder interaction using cloud-based BIM.

Table 5: Benefits of collaborative involvement through cloud-based BIM

Code	Factor	Mean	Rank
C1.	Accuracy	4.53	1
C2.	Minimise the practical difficulties of design	4.5	2
C3.	High collaboration	4.45	3
C4.	No need for a physical location	4.45	3
C5.	Easy communication	4.39	5
C6.	Backup and recovery	4.39	5
C7.	High storage capacity	4.37	7
C8.	Real-time monitoring	4.32	8
C9.	Transferring of data	4.29	9
C10.	Document handling	4.24	10
C11.	Trust development among the stakeholders	4.24	10
C12.	Data transfer quality and productivity improvement	4.16	12
C13.	Resource sharing	4.13	13
C14.	Project cost reduction	4.11	14

Table 6: Limitation for the collaborative involvement through cloud-based BIM

Code	Factor	Mean	Ranking
D1.	Hesitation	4.08	3
D2.	High implementation cost	4.05`	4
D3.	Changing of organisation culture	4.21	2
D4.	Data security and protection	4.03	5
D5.	Legal uncertainty	3.58	9
D6.	Higher requirement of computer resources	4.26	1
D7.	Unpredictability of performance	2.97	12
D8.	Trust related issues	3.39	10
D9.	Limited size of document sharing	3.71	8
D10.	Data ownership	3.39	10
D11.	Lack of awareness	4.03	5
D12.	Lack of skilled professionals	4.03	5

According to the data survey results, respondents said that the limitations for the stakeholder collaborative involvement through cloud-based BIM in the construction industry had a positive impact. Based on this the conclusion was made that, these limitations have an influence on the collaborative involvement of stakeholders through cloud-based BIM. When it comes to rating theory vs practice, there is not much of difference in either situation. The amount of stakeholder participation in the construction sector was explored using questionnaire data, and to complete this research, a semi-structured interview was conducted, as will be explained Below.

Based on the findings, which come from the above table 3 the conclusion was made that, the stakeholders face many challenges during the conventional involvement of stakeholder. In addition to that, the collaborative involvement level through cloud-based BIM is considerably negative impact, which was presuming through table 4, as well as Table 5 pointed out that, the collaborative involvement though cloud-based BIM is highly beneficial. In this way, the benefits come from the collaborative involvement through cloud-based BIM has a positive impact, but the involvement level through cloud-based BIM is considerably low. According to that, there is a requirement to analyse the reasons for the negative impact in the stakeholder collaborative involvement through cloud-based BIM.

4.2 SEMI-STRUCTURED INTERVIEWS

The mani goal of semi-structured interviews is to figure strategies for limiting stakeholder collaborative involvement using cloud-based BIM. During the interview, most of the interviewees highlighted some important strategies for reducing the limitation to the collaborative involvement through cloud-based BIM, such as training sessions, initiating BEP plans, changing government regulations and taxes, providing a BIM centre with the help of CIDA and renting it out, and making technical knowledge a piece of key knowledge for employees during the recruiting process. Furthermore, I-1 predicted that, “if the client demand to do the work with the specific set of software, the stakeholders cannot avoid it”, while I-5 and I-8 suggested “running pilot project under the overhead cost of organisation and checking whether the project is running properly or not within the particular period with the estimated amount”. All except I-1 stated that obtaining government concessions to make a favour and decrease taxes to offer the organization purchasing power to purchase software and resources. In addition to that, I-2 and I-9 suggested to purchasing software rather than individually to avoid high-cost problems, although the collective purchasing have security problem”, and I-3, I-4, I-7, and I-9 mentioned strategies such as providing training and awareness programs to improve the awareness of the stakeholders. I-5, I-7, I-10 stated that, once employees are trained, they should be involved in the pilot project within the organisation and see how it works in terms of time, cost, and quality and then prepare a manual and distribute it throughout the organisation to make employees aware of the importance of using technology in their day-to-day activities”. I-5, I-7, and I-9 explained, “CIDA and government engage in software purchasing jointly and construct a BIM centre to an open environment for stakeholders to rent and utilize”. Accordingly, the following table 6 summarises the strategies to reduce the limitation for As a result, Table 6 summarizes the techniques for reducing the limitations for cloud-based BIM in the construction sector.

Table 6: The strategies to reduce the limitations for cloud-based BIM in the construction industry

Factor	Strategies
Hesitation	• Involvement of the higher management • Client demands the stakeholder to do in a specified system • Government support and purchase power of the organisation • Proper training and awareness programme about the technology • Provide work programme and knowledge sharing programme • Develop a proper framework for the technology • Give education from level 1 for the university students
High initial cost (Implementation cost)	• Provide BIM centre with the help of CIDA, then professional rent it out for their work • Support by the Government by reducing taxes • Purchase power of the organisation • Allocate budget for the purchasing and training the employees
Change organisation culture	• Proper training will reduce this issue • Educate and promote these technologies free of charge • If the organisation reduces the hesitation, then this issue can be shorted out automatically • Develop a proper BIM Execution Plan (BEP) programme within the organisation to interconnect the stakeholders • Recruit the employees with proper technical knowledge
Data security and protection	• Recruit proper Information Technology (IT) concession, people • Regular checking of the system • Develop proper BEP and data security plans within the organisation • Bring proper protection tool which is available in the market and check the system regularly
Legal uncertainty	• Proper BEP plans and amends the contracts to use the technology • Clearly define the rules and regulations for the stakeholders • Government makes laws with the help of CIDA • Relevant authorities implement laws to accept Electronic Data (E-data)

Factor	Strategies
Higher requirement of computer resources	• Development of BIM centre • Use own computer for the work and processing work will be done in the higher speed computer • Purchase power of the organisation • Support by the Government by reducing taxes • Purchase as a group not as individual • Allocate budget within the organisation
Unpredictability of performance	• Make proper BEP plans • Have some backup system to backup data • Under the overhead cost of the organisation run, the pilot project checks its works or not
Trust related issues	• Proper BEP plan and mention the roles and responsibilities for the stakeholders • Define the rules and responsibilities in the supplementary agreement • Provide training programmes • Improve legal background and security background • Provide access for the required person • Maintain data library through the stakeholder system and share with a link through the model
Limited size document sharing	• Purchase power of the organisation again sort out the higher implementation cost it can be sorted out • Purchase space in the cloud for the storage and pay for it annually
Data ownership	• Make proper BEP plans and address responsibilities of the stakeholders clearly and agreed by all of them • Recruit proper IT concession people • Improve the awareness of the stakeholders • Improve the legal background

Factor	Strategies
Lack of awareness	• Make awareness programme • Proper training programme from the university level and Continuous Professional Development (CPD) • Do workshops with the help of the software companies • Based on the top management's decision to give proper education about the system • Allow budget for training the employees • Make the knowledge of the technology a requirement for the employees when recruiting them.
Lack of skilled professionals	• Make awareness programme • Proper training programme from the university level and Continuous Professional Development (CPD) • Do workshops with the help of the software companies • Based on the top management's decision to give proper education about the system • Allow budget for training the employees • Make the knowledge of the technology a requirement for the employees when recruiting them. • Initially train one set of people and evaluate how they work, then they become experts and train another set of people

5. CONCLUSIONS AND RECOMMENDATIONS

This study evaluates the extent of cloud-based BIM involvement in the construction industry as well as mitigation methods to improve the collaborative involvement through cloud-based BIM. According to the data collection findings, the collaborative involvement of stakeholders through cloud-based BIM is at a low level, even though stakeholders encountered several challenges in the conventional method of collaboration and advantages from stakeholder collaborative involvement are high. The key disadvantages of conventional methods include: lack of stakeholder's collaboration, a lack of involvement in crucial decision-making process, and performance inefficiency. At the same time efficient communication, tracking features, time management, money management, and document management have been accomplished through cloud-based BIM in effective and efficient manner. However, several constraints influence the extent of collaborative involvement through cloud-based BIM such as lack of skilled professionals, high implementation cost, hesitation, and data security and protection are some key contraints. Some strategies mentioned by interviewees to increase stakeholder collaborative involvement level through cloud-based BIM are: providing a training session for the staff; collaborating with the government to make regulations and reduce taxes; collaborating with CIDA to provide BIM centre and rent it out to construction firms; making technology knowledge a mandatory thing during the recruitment time; and improving BEP plans to use the technology. Furthermore, the collaborative involvement through cloud-based BIM is not appropriate for smaller-scale projects since the initial cost for cloud-baes BIM is greater than the overall contract sum of the project. When it comes to the Sri Lankan construction industry, cloud-based BIM is a cutting-edge technology and only few construction firms are involving the cloud-based BIM in the early stages or up to a certain point including construction process, however, they cannot use it throughout the entire project. Furthermore, this study suggest that in the Covid-19 pandemic situation, the stakeholder collaboration through cloud-based BIM is beneficial to increase the progress of the project, because of the travel restrictions all over the island and, therefore, it is helpful to the stakeholder to investigate the progress of the project and maintain the records without any issues and anyone can assess and get the detail easily to get a status of the project. According to this, the collaborative involvement through cloud-based BIM is a good approach for stakeholders to involve in the project efficiently and effectively.

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ESTABLISHING THE ROLE OF BIM TOWARDS MITIGATING CRITICAL PROJECT RISKS ASSESSED USING A FUZZY INFERENCE SYSTEM

Sulakshya Gaur[1] and Abhay Tawalare[2]

ABSTRACT

Risk management is an essential process for the successful execution of the project, and it is pertinent in achieving the project objectives and leading to its successful outcome. The nature of the construction industry, which is full of uncertainty and high capital investment, makes it notably more critical to address and manage the risks promptly. The most important part of the risk management process is identifying and assessing risks. However, the traditional Probability (P)-Impact (I) matrix used in their evaluation fails to account for the uncertainties witnessed in the determination of both P and I. This paper, therefore, uses a fuzzy approach to develop a risk assessment model. Further, the results of the generated model are compared with the conventional P-I matrix to show the effectiveness of the adopted fuzzy system. The data for the model development was collected from one of the metro-rail projects through a questionnaire. Subsequently, semi-structured interviews were conducted to identify the advantages of BIM in the project. The recognized BIM advantages were then correlated with the critical project risks to present it as the process for mitigating these risks. The study findings present the use of FIS to overcome the uncertainty in the risk management process, followed by the applicability of BIM as a risk mitigation tool. Establishing the role of BIM in the risk mitigation process can help in its wider acceptance in the construction industry.

Keywords: *Building Information Modelling (BIM); Construction project; Fuzzy Inference System (FIS); Megaproject; Risk Management.*

1. INTRODUCTION

The distinctive nature of construction projects which accounts for process complexity, involvement of multiple stakeholders, substantial capital investments, and other external factors, make it a highly risk-prone industry (Siraj and Fayek, 2019). Risk is defined as “an uncertain event or condition that, if it occurs, has a positive or negative effect on a project’s objective.” (PMI, 2017). If the adverse risks are not addressed timely and properly, it can lead to the problems of time and cost overrun (Wu, et al., 2018) along with the complete scrapping of the project in highly adverse conditions. Therefore, it

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becomes essential that a thorough risk management approach be practiced in such projects that can lead to their successful execution.

The first and the essential part of the risk management process is their identification, followed by their assessment (Yazdani-Chamzini, 2014). This is particularly important to devise a risk response strategy efficiently. Although numerous studies have been done in the space for risk assessment, it is still heavily dominated by the adoption of a probability (P) and impact (I) matrix for their evaluation (Qazi and Dikmen, 2019). However, using the P-I matrix for risk assessment has its fair share of limitations. Its most critical limitation is handling the uncertainty around the estimation/determination of both probability and impact of the identified risk. Although the project expert can provide their opinion to model the uncertainty, it becomes difficult for them to quantify their knowledge to estimate that uncertainty (Yazdani-Chamzini, 2014). Also, obtaining the requisite accurate data for the efficient implementation of the methods is a complex and challenging task (Winch, 2010). Therefore, to overcome this, a suitable measure needs to be adopted that can efficiently employ linguistic terms to model the uncertainty witnessed for the process or a sub-process. Obtaining the information regarding the risk importance is important as it can help formulate a response strategy.

Creating a risk response strategy to cope with all the identified risks is generally difficult due to several reasons, such as the budget constraint, the existence of process risk factors under different sub-processes, and situational demands that require control over some process in a specific subprocess (Wu, et al., 2018). Therefore, to facilitate the process of risk mitigation, it becomes essential that new approaches be undertaken that can help overcome some of the critical challenges. The adoption of building information modeling (BIM), although not entirely, complements the strategies adopted for the mitigation of project risks. The improved design visualization, collaboration, and information exchange brought in by BIM (Gaur and Tawalare, 2022) in the projects help to overcome certain key risks witnessed in the projects. The risks account for project designs, frequent design changes (Luo, et al., 2019), government interventions, and risks related to information transfer and availability (Taylan, et al., 2014) can be efficiently dealt with by using BIM. The ability of BIM models to provide an improved level of collaboration (Jin, et al., 2017) followed by the swift relay of information (Ganbat, Chong and Liao, 2020) among the stakeholders can help in dealing/mitigating some of the critical project risks.

Therefore, the aim of this paper is two-fold. Firstly, it aims to provide a method for risk assessment that can cater to the uncertainties witnessed in estimating the probability and impact of risk. The second aim is to present the applicability of BIM as a tool in the risk mitigation process.

2. LITERATURE REVIEW

The major challenge with developing an efficient risk assessment approach is to deal with the uncertainty (Wang, et al., 2012). The accurate assessment of the risks requires complete information regarding the consequence and the frequency of their occurrence (Jaderi, Ibrahim and Zahiri, 2019). However, achieving these is challenging due to a lack of knowledge, incompleteness, and inaccuracy in its measurement (Yaqiong, Man and Zhang, 2011). Moreover, obtaining the definite values for risk assessment can be highly resource-intensive and sometimes impossible due to the sheer uncertainty in its estimation (Urbina and Aoyama, 2017). Several methods like the alien eyes' risk model developed by Wang, Dulaimi and Aguria (2004), the use of TOPSIS grey and grey numbers for risk assessment by Zavadskas, Turskis and Tamošaitiene (2010), combined fuzzy logic and AHP in construction project risk assessment by Mohammadi and Tavakolan (2013), etc. have been posited to assess project risks by overcoming the shortcomings of the conventional risk assessment process. Still, among them, fuzzy logic is considered the best approach for assessing the risks (Jaderi, Ibrahim and Zahiri, 2019). 'Fuzzy logic' is defined as a set of mathematical principles established to represent knowledge deriving its dependence on the degree of membership instead of classical binary logic (McBratney and Odeh, 1997, Grosan and Abraham, 2011). When dealing with the imprecision inherent in many problems, using a fuzzy membership function (MF) for risk will help cater to the ambiguity or uncertainty witnessed in the decision-making (Kumar and Maiti, 2012). Fuzzy logic considers the use of linguistic terms rather than the numerical values as the variables for the application in the fuzzy sets (Hatefi, Basiri and Tamošaitienė, 2019).

2.1 FUZZY INFERENCE SYSTEM (FIS)

The fuzzy inference system (FIS) is defined as receiving output based on the input through the use of fuzzy logic (Alidoosti, et al., 2012). An essential advantage of FIS is its ability to use linguistic terms to provide an inference framework for modeling complex problems. Several previous studies have used fuzzy logic to develop FIS to assess risks in varied projects. In the study conducted by Yazdani-Chamzini (2014), the authors developed and used a FIS to evaluate the risks associated with the tunneling project. Similarly, Jaderi, Ibrahim and Zahiri (2019) developed a fuzzy risk-based maintenance model that used the FIS for risk analysis in the petrochemical industry. The development of the FIS system is based on the essential formulation of If-Then rules. All the previous studies have used various numbers of if-then rules for developing the inference mechanism in the FIS. Therefore, devising the correct number of such rules and their accurate writing is integral to the FIS (Hatefi, Basiri and Tamošaitienė, 2019).

Although the use of FIS for the assessment of risk serves as an initial step toward the risk management process, specific strategies need to be developed to mitigate assessed risks. The improvement and enhancement of the communication between the stakeholders (Yang and Zou, 2014), followed by maintaining and encouraging close collaboration with the associated stakeholders (Goh and Loosemore, 2017), and the use of information technology tools to facilitate the additional requirement of coordination, and collaboration (Hwang, Shan and Looi, 2018) are some of the strategies that have been presented as the mitigation measures for various types of risks in previous works. However, achieving these independently is not easy as the mitigation process is highly resource-intensive and sometimes proves to be very costly. Therefore, to make the mitigation process efficient, BIM as a process needs to be looked into. The usage of BIM helps overcome certain risks by improving collaboration and relaying complete project information among the stakeholders. It also tends to have an implication on the overall efficiency of the projects.

The previous studies have independently looked into risk assessment and mitigation measures based on the above discussions. Although there have been established advantages of BIM, they need to be looked into in detail concerning their implications in the risk mitigation process. Moreover, the perceived benefits of using a fuzzy approach to deal with the uncertainty in decision-making need to be extensively adopted in the risk assessment in construction projects.

3. RESEARCH METHODOLOGY

The study adopted a combination of methods to identify and assess the risk and how the BIM favored their elimination or mitigation. Initially, a thorough systematic literature review was undertaken to determine various significant risks faced in the construction projects. This was followed by data collection to assess the influence of the identified risks. Data was collected by using a case study-based research methodology. A single case was selected because BIM is being utilized in the project. A metro project in one of the cities of Central India was selected as the single case for collecting the requisite data. The project has an estimated completion cost of US$4.0 billion (30,000 crores) and has adopted the use of 3-D BIM with the LOD500 (level of development). Primary data was collected through expert interviews. Ten project participants from the design, planning, quality control, and safety departments were interviewed for the data collection process. Initially, the participants were presented with a questionnaire where they were asked to rate a particular risk on the 'level of their impacts to effect the project' and 'it is chance of occurrence/probability.' A five-point Likert scale was used to obtain their responses. The adopted scale for data collection is presented in Table 1 below. Column 2 in the below table shows the 5 levels of parameters classified to judge the impact and probability of a particular risk. Column 3 of the table shows the adopted scale having a crisp (i.e., a definite integer value) value in relation to the impact and probability parameters (linguistic) of risks mentioned in column 2. This was used to judge the risk influence level based on the conventional approach of the P-I matrix. Further, to account for the uncertainty witnessed in the human decision-making process, fuzzy ratings were developed and presented in column 4 of the table. Instead of adopting a definite integer value, Fuzzy rating takes a range to address the parameters of impact and probability. This range was obtained based on the adopted Gaussian membership function for the input values (i.e., impact and probability of risk) presented in Figure 1.

Table 1: Scale adopted for risk assessment

S.No.	Linguistic Scale		Crisp Scale	Fuzzy Rating
	Impact (I)	Probability (P)		
1	No Impact (Negligible)	Very Unlikely to Occur (1-10%)	1	$1 < (P, I) \leq 2.5$
2	Low Impact (Marginal)	Unlikely to Occur (11-40%)	2	$1 < (P, I) \leq 3.5$
3	Medium Impact (Moderate/Tolerable)	May occur about half of the time (41-60%)	3	$1.5 < (P, I) \leq 4.5$
4	High Impact (Critical)	Likely to occur several times (61-90%)	4	$2.5 < (P, I) \leq 5$
5	Very High Impact (Catastrophic)	Very likely (frequent) to occur (91-100%)	5	$3.5 < (P, I) \leq 5$

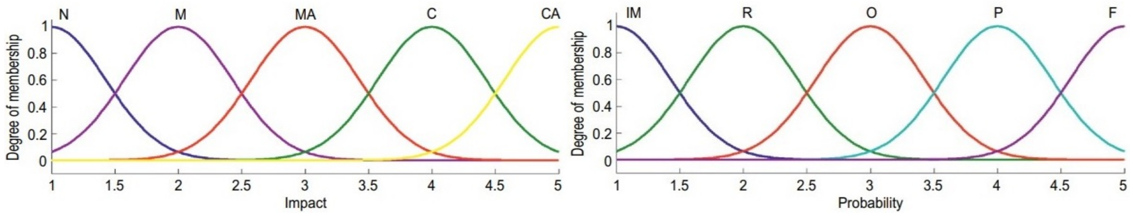

Figure 1: Adopted membership function for input variables

A dual approach based on the determination of risk Probability (P) - Impact (I) index and the risk assessment using a developed fuzzy model was adopted to assess the influence of identified risks. Since the quantification of expert knowledge is a difficult task, the fuzzy model was used to model the system's complexity through linguistic terms. Fuzzy logic can handle and express the ambiguity of human thinking and rationale into data that can be easily computed (Yazdani-Chamzini, 2014). Several FIS have been developed to model both the linear and non-linear behavior of the system. However, the Mamdani fuzzy model is the most popular mechanism for modeling problems related to uncertainty and complexity (Yazdani-Chamzini, 2014). There are various features associated with the Mamdani fuzzy model that makes it a preferred choice for dealing with complex problems (Wang, 1994): 1) the use of real-valued input and output makes it suitable for the engineering system, 2) A natural framework is made available for incorporating fuzzy *if-then* rules from experts, and 3) there are numerous choices and freedom to choose fuzzifier, inference engine and defuzzifier. The developed fuzzy inference system model (FIS) replaced the risk index with the risk assessment function and is presented in Figure 2.

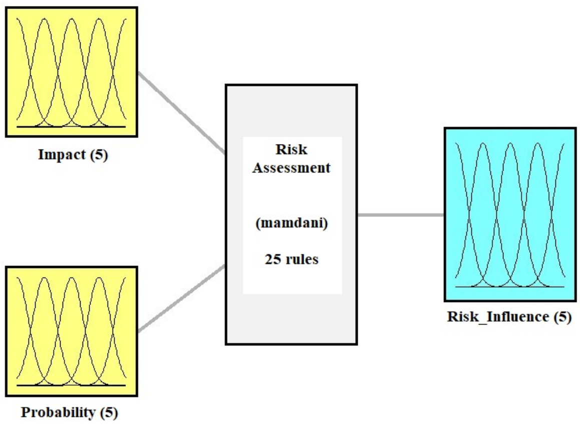

Figure 2: Structure of the used fuzzy model

The developed FIS model consists of four parts, i.e., fuzzification, knowledge base, inference engine, and defuzzification. The input and output relationship can be easily understood using a 3-dimensional plot, also known as a control surface. The developed FIS surface model is presented in Figure 3. The centroid method was used for defuzzifying the output in this study. The FIS model was developed and analyzed using MATLAB.

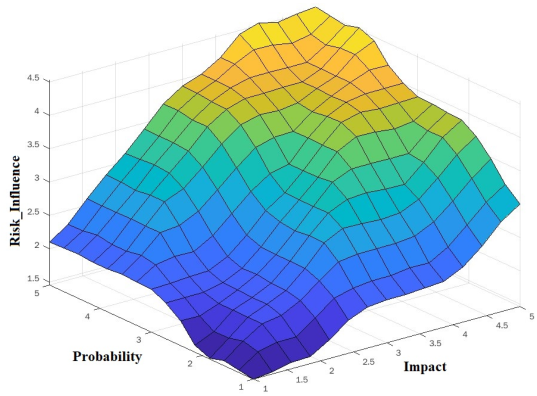

Figure 3: FIS surface diagram of the risks

The assessment of the risks was also done using the traditional P-I matrix, where the risk influence (R) was calculated as the product of P and I. Based on this calculation and the output of the FIS model, the risks were categorized into five categories. Their linguistic classification and the crisp scale and fuzzy scale (fuzzy output based on gaussian membership function) are presented in Table 2.

Table 2: Scale developed for determining the risk influence (Yazdani-Chamzini, 2014)

S.No.	Linguistic Scale	Crisp Scale (R = P X I)	Fuzzy Rating
1	Risk is Insignificant and can be tolerated without devising any mitigation measures	1 - 4	$0 < R \leq 2.5$
2	Risk is tolerable and requires partial mitigation measures	5 - 8	$0 < R \leq 3$
3	Risk influence is substantial and mitigation might be required	9 - 12	$1 < R \leq 4$
4	Risk is significant, and proper mitigation measures should be adopted to reduce the risk.	13 - 16	$2 < R \leq 5$
5	Risk is intolerable, and mitigation measures that reduce the impact of the risk should be adopted.	17 - 25	$3 < R \leq 5$

Further, the participants were asked questions about the advantages of BIM they witnessed during the project. This was achieved through the conduction of semi-structured interviews with the participants. The interview data were analyzed using NVivo 10. NVivo is a computer-assisted qualitative data analysis software used to code and analyses qualitative data. It analyses the data and helps in transcribing, storing, and cataloging these data. The advantages witnessed in the project and enumerated by the respondents were coded as nodes. These nodes were then categorized based on the percentage of articles coded for a particular BIM advantage. The % of articles coded was calculated based on the number of articles that cited a specific advantage over the total number of interviews conducted. The impact of these advantages was then correlated with the mitigation of certain critical risks witnessed in the project.

4. RESULTS AND DISCUSSIONS

The influence of the identified risks was determined using both the P-I matrix and the FIS model. The risk influence through the traditional P-I matrix was calculated on the scale of 1-25 and the FIS model on 0-5. The determined risk influence through both models is presented in Table 3.

Table 3: Influence of the Identified Project Risks

Risk	Risks	Risk Influence (P-I Matrix)	Rank	Risk Influence (FIS)	Rank
R1	Adverse impact on the Environment due to project.	9.99	13	3.25	13
R2	Project personnel unavailable due to external constraints	4.76	17	2.40	16
R3	Improper allocation of roles and responsibilities	8.25	15	3.06	14
R4	Improper document management and cataloguing	10.88	9	3.42	11
R5	Frequent design modification and improper designs	16.65	1	4.09	1
R6	Improper project scheduling and forecasting	13.94	4	3.88	5
R7	Inefficient planning and management of resources	13.53	5	3.76	6
R8	Inefficient and improper monitoring and management of project assets	10.2	12	3.42	11
R9	Poor project supervision	10.8	10	3.52	9
R10	Lack of planning of budget and cash flows	8.46	14	3.33	12
R11	Lack of provisions for site safety	12.6	6	3.60	7
R12	Lack of provisions to protect IPR	6.2	16	2.84	15
R13	Logistical issues in material and component delivery	10.5	11	3.52	9
R14	Inefficient decision-making process	15.91	3	4.07	2
R15	Unclear communication between project participants	16.28	2	3.97	4
R16	Poor quality control parameters and measures	11.44	8	3.50	10
R17	Tangled and lengthy approval process	16.28	2	4.01	3
R18	Unsatisfied external stakeholders	12.54	7	3.58	8

The developed FIS model aims to overcome the most critical shortcoming of the conventional P-I matrix. The P-I method ranks the risk at the same level of importance, having a varied set of P and I. This leads to the basic assumption of considering both probability and impact as equally important in the risk assessment through the conventional method. For instance, assume two different sets of risks having a value of 4, 2, and 2, 4. The traditional approach would provide the influence values as 8 and consider them equally important. However, in actual circumstances, the implications of both risks may be different. This is where the use of FIS provides a considerable difference. The FIS model accounts for the uncertainty computed based on the membership function.

For instance, the ranking of R4 and R8 through the conventional method comes out to be 9 and 12, respectively. However, through the FIS model, both the risks show an equal influence level as an output of 3.42 and a ranking of 11. Also, the risks R15 and R17 were ranked in 2nd place by the conventional risk matrix and were ranked in 4th and 3rd place, respectively, through the FIS model. The individual parameters, i.e., P and I values for both these risks, were 3.7 and 4.4, which gave them an equal value of influence, but through the FIS model, it was found to be 3.97 (for R15) and 4.01 (for R17).

The results of the traditional risk assessment are also presented with the help of a risk P-I matrix in Figure 3, where the entire matrix was distributed in four quadrants. The four quadrants comprised ‘high impact-low probability’; ‘low impact-low probability’; ‘low impact-high probability’; and ‘high impact-high probability. The HI-HP quadrant of the risk matrix represents the ‘significant’ and ‘intolerable risk’ as categorized in Table 2. The 8 risks under the quadrant of HI-HP are considered to have a significant impact on the project and need to be addressed timely before leading to some undesirable consequences. Table 3 also shows a general agreement among the influence levels of these 8 risks based on their ranks from both the analysis methods. Although there is a slight variation in the ranks of these eight risks, they still constitute critical based on their influence levels calculated from the respective models.

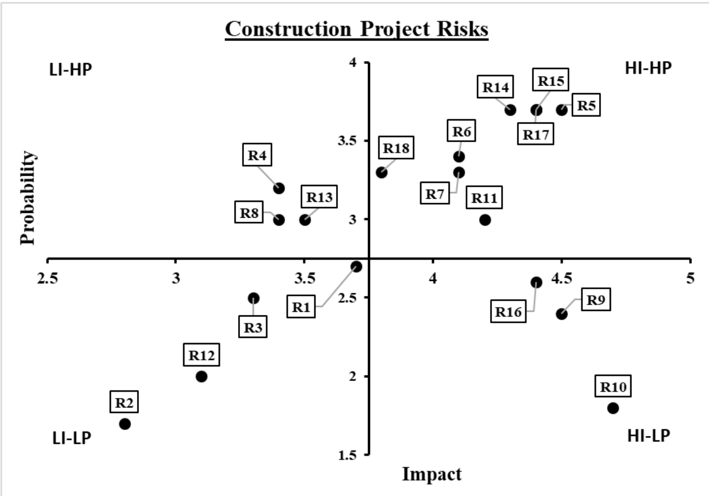

Figure 3: Risk P-I matrix

Once the critical risk was identified, the next step was to correlate them with the BIM advantages for suitable mitigation. The developed/incorporated mitigation measures here are presented as the advantages of BIM witnessed in the projects. The advantages coded in more than 50% of the interviews are only taken as mitigation measures and considered for subsequent discussions. These advantages are grouped under two constructs design optimization and efficient decision-making for the discussions.

4.1 EFFICIENT DECISION MAKING

This construct of the BIM advantages comprised ‘better collaboration for obtaining coherent design solutions’ as the most coded advantage (in 90% of interviews), followed by the ‘ease in the communication of designs to approving authorities’ (80%) and ‘reduction in the number of change orders/RFIs’ (60%). These advantages show the implication they can have in overcoming certain risks. For instance, the improved collaboration between the civil and systems contractors brings various designers and contractors on the same platform to obtain an optimized design solution. This helps overcome the issue of frequent design changes at the later stage of the project, which is found to be an important risk in the works of Luo, et al. (2019). In this project specifically, the primary issue was efficiently managing the number of involved contractors and subcontractors. BIM allowed them to work together in tandem by analyzing their independent models with the complete project design by providing a digital workspace. The coming of civil contractors with the systems contract associated with installing HVAC systems and other essential utilities achieved the desired outcome in a specified time frame.

Improved collaboration and coordination between the stakeholders also help them relay complete project information. Apart from enhancing the collaboration between the stakeholders, the BIM models can efficiently store and share large chunks of data between the stakeholders. The digital storage and transfer of project data reduces the information loss from one stakeholder to another leading to the complete relay of information between them. The transfer of complete project information within the teams and groups is critical for improving the efficiency of any process (Taylan, et al., 2014). The improved project visualization, coupled with real-time data transmission among the participants, allows them to efficiently plan for the resources required in the project activities. The 3-D models, when integrated with the time, provide a better visualization to the management team to plan for the project's schedule. Moreover, the real-time information transmissibility provided by the BIM models conveys necessary information regarding the project schedule to the associated stakeholders, allowing them to suitably plan for further action.

The BIM models can convey the critical project data through the 3-D models. This eases the understanding of the project information and designs among the stakeholders. The most important implication of improved visualization through the developed BIM models is reflected in the communication of drawings to the approving authorities. This helps improve the efficiency of the approval process, which otherwise delays the design time and is an important risk in the work of Siraj and Fayek (2019). One of the reasons for this can be the approving authority's inability to comprehend project designs. A thorough understanding of such intricate designs can be time-consuming, making the whole approval process highly complex. The availability of the 3-D models, as opposed to the drawings, tend to improve this comprehension by providing visual cues. This facilitates understanding of the intricate details of the design through the generated models, leading to a reduction in the approval time. This improved understanding brought in by 3-D models also improves the communication with the external stakeholders if required. This can, in a way, keep them informed and content with the project, thereby improving their satisfaction levels with the project. Moreover the improved design visualization and better information transfer reduce the change orders or the request for information, leading to the mitigation of risk associated with the design modifications, which was found to be important in the works of Chatterjee, et al. (2018).

4.2 DESIGN OPTIMIZATION

This construct of BIM advantage consisted of clash detection as the most coded advantage (90%), reduced waste generation and better design visualization (both coded from 70% of the interviews). Clash detection refers to the identification and elimination of clashes between the building components during the design stage itself so that there is reduced or no rework during the execution stage. Clash detection is thought of as a subset of improved collaboration. Bringing the various stakeholders together during the design stage allows them to look into multiple alternatives through the available 3-D models. This tends to improve coordination between them, which is an important risk in the work of Siraj and Fayek (2019). This enables them to identify any clashes in the models and designs beforehand. The most crucial benefit of prior clash detection is reducing the reworks during the project execution, which is found to be an integral part of design risk in the works of Chatterjee, et al. (2018).

The thorough clash detection between the designs improves the communication and collaboration between the stakeholder group. An efficient inter or intra-organizational information sharing is essential for maintaining operational efficiency in the event of joint operations (Keers and van Fenema, 2018). This was particularly important in the studied project because of the underground nature of the project. Since the project was completely underground, the placement of utilities in the cramped space was brought in by the efficient collaboration between the different contractors (civil and MEP contractors). A better design solution devoid of any clash also reduces the transfer of improper designs to the execution team during the project execution phase. Identifying and eliminating any clashes in the design stage can reduce or remove reworks in the project. This helps save construction costs and time on the ground of reworks and, most importantly, helps reduce the generation of construction wastes. The reduction in construction waste minimizes the project's impact on the environment, which serves as an essential impetus for improving the satisfaction of external stakeholders.

Identifying and visualizing clashes also enables the team to efficiently plan for on-site safety measures. For instance, the better information availability regarding the overhead utilities and equipment through the improved visualization brought in by the BIM models enables the team to place cautionary signs regarding the area to improve the safety at the project site. Moreover, the use of BIM models results in the generation of as-built models that also helps in conveying critical information about the built facility to the stakeholders, especially the O and M teams. This leads to improved decision-making during the O and M stage of the project.

5. CONCLUSION

This study used the conventional risk assessment approach and the FIS model to evaluate the risks associated with a construction megaproject. Further, it presented BIM as a tool for mitigating certain key risks by establishing a correlation between its advantages and the witnessed risk. A discussion with an expert group from a metro-rail project was undertaken. The expert group was initially asked for their opinions on the probability and impact of the identified risks based on the developed linguistic scale. Subsequently, the obtained data were used in the fuzzy toolbox of MATLAB to create a FIS model for risk assessment. The obtained data were also analyzed using the crips values through the P-I matrix. A combination of both the employed methods served to compare the obtained results. The results favor the rigorous process employed by the fuzzy system to evaluate the risks. The most important advantage of this was witnessed when the risk had the same values of both P and I. The traditional matrix fails to differentiate or distinguish between the risk levels; however, the FIS model can differentiate between the influence levels of both the risks, thereby catering to the uncertainty around the determination of P and I value.

The risks were categorized under five categories i.e., insignificant, tolerable, substantial, significant, and intolerable, based on the influence levels. Through the results obtained from the P-I matrix and the FIS model, 8 risks belonging to the category of (HI-HP quadrant of the risk matrix) significant and intolerable were chosen as the critical risk, which needs specific mitigation measures. The mitigation measures were provided as the advantages of BIM, obtained from the interview conducted within the expert panel. The BIM advantages were classified under two significant constructs efficient decision making and design optimization. For instance, the collaboration among the stakeholders provided by BIM listed under the construct of efficient decision-making helps overcome the most critical risk, i.e., the frequent design modification and improper designs obtained through risk assessment methods. The findings of this work aim to overcome the uncertainty around the estimation of risk indexes and present BIM as an essential tool that can be used to mitigate key project risks. This helps present BIM as a critical process to improve the project's overall efficiency. It can, therefore, help in its wider adoption in the architectural, engineering, and construction (AEC) industry.

This work has a few limitations. First, since the research work used a retrospective case study of a metro rail project, the findings of this work need to be established by conducting similar studies on other types of projects. This will help ascertain the findings and the actual role of BIM along with the varied project types. Secondly, the identified risks are primarily focused on the design aspect of the project. Thus, there is a need to consider varied risk categories for establishing BIM as a tool for complete risk mitigation. Moreover, the project used in this study used a 3-D BIM. Therefore, other projects need to be studied employing higher dimensions of BIM to reach a conclusive finding on the applicability of BIM as a risk mitigation tool.

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EVALUATION OF CONSTRUCTION WORKERS MENTAL HEALTH DURING COVID-19 PANDEMIC IN NIGERIA

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ABSTRACT

The need to ensure construction workers have good mental health is imperative because poor mental health has an economic cost that impacts individuals, companies, and nations. The aim of this study is to evaluate construction workers' mental health during the COVID-19 pandemic in Nigeria. To achieve this aim, a survey questionnaire was developed and administered online to building environment professionals working on construction sites. The results show that stress, feeling overwhelmed, feeling unusually confused, fatigue, being unpredictable and anxiety were the top mental health challenges during the COVID-19 pandemic. The result also revealed that training on mental health and the symptoms, awareness week activities, flexible working, and working from home policies were the top support provided by organisations for mental health wellbeing during COVID-19. The study concludes that difficulty in adapting to the challenges brought about by the deadly virus and its effect on the economy makes construction workers more susceptible to mental health challenges as it impaired their work life and thereby increasing their mental pressure.

Keywords: *Accident; Fatigue; Stress; Suicide.*

1. INTRODUCTION

Construction workers are subjected to strenuous physical and psychological pressures, which are linked to an increased risk of physical and mental illness. The construction industry's psychological anguish is not confined to labourers; a web-based study of construction managers in the United Kingdom found that 68.2 percent of construction professionals reported severe stress, anxiety, or depression connected to their employment (Campell, 2006). Mental illness affects one in every three persons worldwide, accounting for 13% of disease, and affects 450 million people (World Health Organization, 2013, Mnookin, et al., 2016). Children and teenagers (20%) are also impacted by mental illness, resulting in human sorrow (Mnookin, 2016). According to Herrman and Jane-Llopis (2012) physical health, human behaviour, and quality of life are all linked to mental health. It is imperative to guarantee that mental health is addressed

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internationally, given the strong links between mental health and decreased harms, healthy relationships, and reduced use of alcohol and hard drugs.

Mental illness is a result of socioeconomic challenges in Nigeria, with worrisome figures (Oyewunmi et al., 2015). According to Oyewunmi et al. (2015), there is a need for cultural re-engineering in the Nigerian workplace regarding mental health and the promotion of the psychosocial environment. This necessitates research into workplace solutions, as Nigeria's growing economy relies largely on the engaged workforce to maintain growth and development. Nigeria, like other countries, requires a health and safety plan before construction projects may be approved. However, the strategy focuses on improving physical working conditions in order to prevent injury and accidents (Dodo, 2014), rather than laying out plans to address other mental distress risk factors (Ibem, et al., 2011; Ojo, et al., 2019). As a result, in Nigeria there has been a lack of strategic moves to emphasise mental health and well-being of construction professionals by implementing strategies to reduce work-related stress, resulting in reported feelings of melancholy, hopelessness, and anxiety (Oladinrin, et al., 2014). It is critical to maintain excellent mental health since illness has a financial cost to both businesses and individuals, and it has an impact on production, turnover, interpersonal relationships, physical health, and social living (liang et al, 2021).

COVID-19 has a massive, complicated, and sophisticated impact on the construction industry, just as it does on other important economic sectors. More than 80% of construction workers utilise hazardous materials and components on the job, are exposed to harsh weather, work at heights, move or transfer heavy materials and components, operate in unsanitary circumstances, and have poor health and safety standards. Construction projects were halted, with the exception of those deemed absolutely important for national security concerns, and construction site workers were directed to stay at home and work on stage. The worldwide construction industry faces a significant problem as a result of the lockout. Insufficient site labour, factory closures, low morale among site operatives, low productivity, shortages of materials, failure to handover projects on time, shortages of plants and materials, border closures, delays or inability to obtain required permits, and changes in the work culture on the sites were among the challenges faced by the global construction industry. All of COVID-19's negative effects on the construction industry have a direct influence on construction employees' mental health. In light of this, the purpose of this study is to assess the mental health of construction workers during COVID-19. In the context of this study construction workers is refer to as those who are directly involved in construction work from inception to completion stage.

2. LITERATURE REVIEW

Mental illness comes in a variety of forms and degrees of severity; the most prevalent (depression and anxiety) are known as common mental disorders (CMD) (World Health Organization, 2014). According to the World Health Organization (2017), CMD encompasses a wide spectrum of anxiety and depressive symptoms that result in significant health and functional impairments.

CMD is a collection of distressing moods that include sadness and anxiety (Risal, 2011). Depression and anxiety are the leading causes of disability worldwide (World Health Organization, 2017). Sadness, poor self-worth, guilt, sleep disturbances, loss of appetite, and difficulties concentrating are all symptoms of depression. It also has an impact on a person's capacity to operate normally at work and cope with day-to-day life (Li, et al., 2017). Anxiety can be an emotional state or a personality feature, whereas dread disorder is a collective term for mental illness characterised by anxiety and fear (Saju, et al, 2019). Depression and anxiety affect roughly 20% of Americans, 10% to 20% of Europeans, 6.6 percent (3.9 percent depression, 2.7 percent anxiety) of Nigerians, and 7.3 percent (4.2 percent depression, 3.1 percent anxiety) of Chinese people (World Health Organization, 2017). Depression and anxiety can have a significant impact on one's health, work capability, and quality of life (Bar-Sela, et al., 2015; Saneei, et al., 2016). When depression and anxiety symptoms go untreated, they can lead to chronic physical illness, suicidality, and mortality (Li, et al., 2017, Pavičić Žeželj, et al., 2019).

Mental health is increasingly becoming an important concern in the workplace, according to Joyce et al. (2016). According to studies, occupational stress causes a significant prevalence of depression and anxiety among workers (Kamardeen and Sunindijo, 2017; Zhang, et al., 2018; Pavičić Žeželj, et al., 2019). Workplaces and labour have been highlighted as important socioeconomic determinants of health (Joyce, et al., 2016). In comparison to the general working population, construction workers had a higher risk of suicide. Construction workers, for example, have the second highest suicide rate of all major professional occupational groups in the United States, trailing only the hunting and fishing industry (Peterson, et al, 2018), and construction workers in England have a suicide rate three times the national average among males. Construction workers had higher rates of substance misuse and sleep issues than other occupational categories, in addition to disproportionately high rates of psychological anguish and suicide (Office for national statistics). At the workplace, risk factors and associated poor mental health contribute to absenteeism, presenteeism, low productivity, high safety claims, and employee turnover (Roche, et al, 2016; Milner, et al., 2017; Nwaogu, et al., 2019; Kotera, et al., 2020). Furthermore, poor mental health has an economic cost that impacts individuals, companies, and nations (Nwaogu, et al., 2019). Because the working population spends roughly two-thirds of their time at work, it is an excellent arena for mental health promotion (Joyce, et al., 2016).

Those who have been through traumatic circumstances due to COVID-19 are more likely to have psychological disorders and mental health concerns. Confusion, frustration, worry, anger, irritation, fatigue, and depression are common sentiments among construction workers (Ekpanyaskul and Padungtod, 2021). They may also feel defeated, have sleeplessness, have trouble concentrating, and/or be exhausted. If such stress is not managed properly, it might lead to alcoholism, smoking, as well as other drugs abuse (Karthick, et al., 2021). Salaries, working time, workload, psychological stress, interactions with coworkers and managers, even accessibility to periodic vacation have all been impacted by COVID-19, some of which may have a significant influence on the physiological as well as mental health of employees, their relations, and their societies (Jahan Nipa, et al., 2020). Social distance has compounded the issue since everyday meetings with colleagues and friends, which are a vital element of maintaining positive mental health, are lacking, and workers become socially alienated (Rouhanizadeh and Kermanshachi, 2021). Many individuals, whose employment had been terminated during COVID-19 are also dealing with mental health issues, as they are worried about finding another work and meeting their financial commitments (Woolley, et al., 2020). The outcomes of Pamidimukkala and Kermanshachi (2021) study demonstrated that an absence of a secure environment at work, excessive workloads, family problems, and worries regarding job security frequently lead to stress, despair, and even suicide. According to Choudhari (2020), during India's lockdown, and other COVID-19 imposed measures left workers without the monetary capacity to cover daily food costs, and quarantine rules all contributed to extreme anxiety, which led to morally reckless actions and nervousness among internal migrant workers. Internal migrant workers are experiencing significant levels of anxiety and panic as a result of the COVID pandemic, and they require supportive care. The fast-expanding COVID 19 epidemic has elicited a slew of negative cognitive processes and emotions in the vulnerable populace. As a result, the COVID-19 pandemic has the potential to induce chronic psychological symptoms such as despair, anxiety, phobias, and psychosomatic symptoms, adding to the negative impacts on physical health (Qiu, et al., 2020; Tandon, 2020).

Mental illness affects everyone; therefore, it is critical to improve mental fitness in order to maintain mental health. Despite the high prevalence of psychological discomfort, substance abuse, and sleep issues among construction workers, their mental health is poorly studied.

3. METHODOLOGY

Although mental health has received considerable attention in the construction management literature, the literature on the construction workers mental health during COVID-19 is nascent globally. Therefore, this research is set to answer the following questions, How often do construction workers suffer different mental health challenges during COVID-19? What support does organization offer for mental health during COVID-19? To achieve this a cross-sectional survey research strategy was used to solve the research problem in order to attain the study's goal. According to Bryman (2016), this is a quantitative research technique in which a researcher distributes a survey to a representative sample or the entire population in order to identify the population's opinions, thoughts, behaviours, or characteristics. Convenience sampling was used to collect the primary data. When sufficient information on population size and sample frame is not available, the approach is appropriate. While the results may not be generalizable, the conclusion can be typical of a large group of people. This follows from the central limit theorem (CLT). According to the CLT principle, the distribution of sample means approaches a normal distribution as the sample size grows (Olanrewaju and Idrus, 2020). A sample size of 30 or more is statistically required for the CLT principle to be valid. This study adopted a convenient sampling method because information on the total number of construction workers in Nigeria is not readily available as there is no database capturing the number of construction workers. A well-structured, closed-ended questionnaire was prepared and distributed online to built-environment experts working on construction sites in order to collect data. The survey was open from November 15, 2021, through February 4, 2022. Respondents were asked to rate how often they suffered from mental health challenges before and during COVID-19 on a six-point scale, with "6" denoting "extremely often," "5" denoting "strongly often," "4" denoting "moderately often," "3" denoting "less often," "2" denoting "least often," and "1" denoting "not at all." During the COVID-19, they were also asked to rate the level of mental health support their organisation currently provides on a six-point scale, with "6" denoting "extremely frequent," "5" denoting "strongly frequent," "4" denoting "moderately frequent," "3" denoting "less frequent," "2" denoting "least frequent," and "1" denoting "not at all." The acquired data was analysed using descriptive statistical tools such as means and standard deviation. For interpretation purpose a mean score of 5.01-6.0 indicates extremely frequent/often; 4.01-5.0 indicates strongly frequent/often; 3.01-4.0 indicates moderately frequent/often; 2.01-3.0 indicates less frequent/often; 1.01-2.0 indicates least frequent/often, and 0-1.0 indicates not at all. Statistical package for social science (SPSS) 23.0 was used for the analysis.

4. ANALYSIS AND DISCUSSION

Table 1 contains basic information about the respondents.

Table 1: Respondent profile

Position in the company	Frequency	Percent	Academic background	Frequency	Percent
Construction Manager	13	24.1	Architecture	4	7.4
Contractor's architect	3	5.6	Building Technology	14	25.9
Contractor's engineer	8	14.8	Civil Engineering	13	24.1
Contractor's quantity surveyor	5	9.3	Construction Management	3	5.6
Engineer	2	3.6	Electrical engineering	1	1.9
General worker	3	5.6	Mechanical Engineering	7	13.0
Safety Officer	2	3.7	Quantity Surveying	12	22.2
Site supervisor	18	33.3	**Total**	**54**	**100**
Construction Manager	13	24.1	**Academic qualification**		
Contractor's architect	3	5.6	Bachelor’s degree	21	38.9
Total	**54**	**100**	Diploma	16	29.6
Years of experience			HND	1	1.9
11-15 years	16	29.6	Master’s degree	13	24.1
16- 20 years	7	13.0	PGD	1	1.9
5-10 years	24	44.4	PhD	2	3.7
Less than 5 years	6	11.1	Bachelor’s degree	21	38.9
More than 20 years	1	1.9	**Total**	**54**	**100**
Total	**54**	**100**	**Type of organization**		
Number of safety officers			Developers	8	14.8
1.00	25	46.3	Main Contractors	22	40.7
2.00	13	24.1	Sub-contractors	20	37.0
3.00	2	3.7	Suppliers	4	7.5
4.00	4	7.4	**Total**	**54**	**100**
5.00	1	1.9			
None	9	16.9			
Total	**54**	**100**			

Table 1 revealed that the respondents cut across different positions on the construction site. This implies that the results of the findings can be generalised for construction workers. It can also be deduced that 88.9% of the respondents have more than 5 years of experience in construction work.

This is an indication that their responses can be more reliable since they are based on their experience. Similarly, it can be deduced that 83.3% of the respondents have at least one safety officer on their construction site. This also indicates that the respondents have knowledge of mental health and hence can answer the questions correctly. The table also revealed that the respondents had their academic background across different professions in the built environment. This also allows the result to be more reliable as it represents the opinion of built environment professionals. Likewise, the table revealed that the respondents cut across different organizations. Finally, it was deduced from the table that the least academic qualification of the respondents was a diploma. This is also an indication that all the respondents were academically qualified to fill out the questionnaire correctly.

Figure 1 shows that 9.3% of the respondents indicated that compliance with health and safety standards of procedures SOPs due to the COVID-19 will reduce the progress/productivity of projects on sites by 30% or less, while the remaining 90.7% indicated that project progress/productivity will be reduced by over 30%. This is also in line with the findings of Olanrewaju et al. (2021), which revealed that, on average, site productivity had been reduced by about 50%.

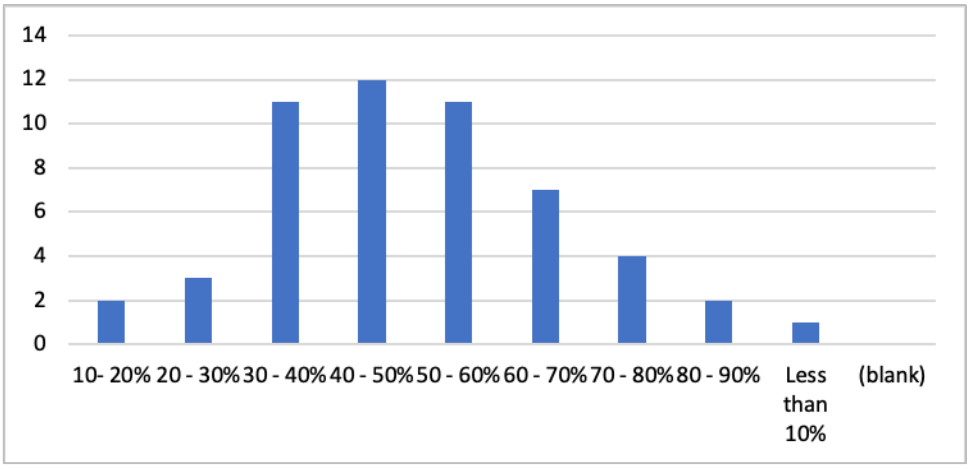

Figure 1: The extent to which compliance to health and safety standard of procedures SOPs due to COVID-19 reduces the progress/productivity of project on sites

Figure 2 shows that 6.1% of the respondents indicated that they suffer from mental health issues extremely often, while 31.3% indicated that they suffer from mental health issues strongly often.

Meanwhile, 28.6% indicated that they suffer from mental health moderately often. 12.9% indicated that they suffer from mental health less often, 7.5% indicated that they suffer from mental health least often, and the remaining 13.6% indicated that they do not suffer from mental health at all.

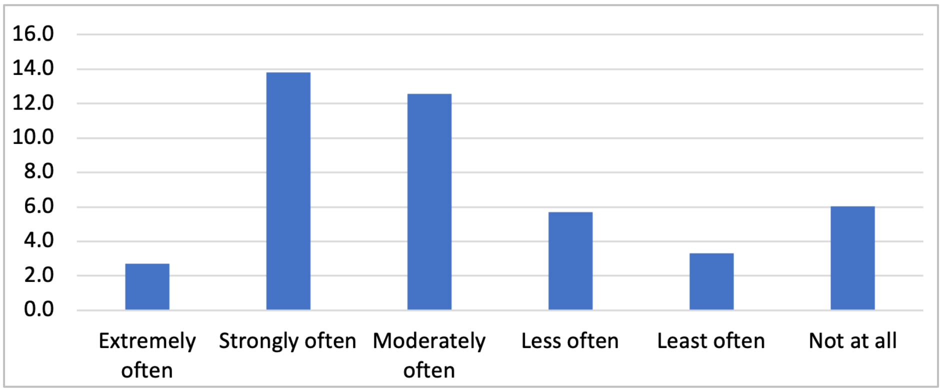

Figure 2: Summary of respondent's answers to all the identified mental health issues

It can be deduced from the figure that a higher percentage of the respondents suffer from mental health issues than average, which implies that mental health issues are prevalent among construction workers during COVID-19. Furthermore, Table 2 contains the mean and standard deviation of a respondent's opinion on the 35 identified mental health issues.

Table 2: Descriptive statistics of different mental health challenges

Factors	Mean	Std. Deviation	Rank
Stress	4.13	1.29	1
Feeling overwhelmed	4.09	1.31	2
Feeling unusually confused	4.05	1.51	3
Fatigue	4.04	1.33	4
Unpredictable	3.91	1.36	5
Anxiety	3.89	1.71	6
Persistent thoughts	3.86	1.53	7
Eating too much or too little	3.86	1.39	7
Having unexplained aches and pains	3.84	1.4	9
Depression	3.84	1.65	9
Feeling unusually worried	3.82	1.42	11
Poor concentration	3.82	1.42	11
High absenteeism	3.8	1.42	13
Inability to take care of family members	3.77	1.57	14
Inability to get to work on time	3.76	1.3	15
Experiencing severe mood swings that cause problems in relation	3.75	1.48	16
Feeling helpless or hopeless	3.73	1.5	17
Thinking of harming others	3.7	1.65	18
Feeling unusually forgetful	3.7	1.5	18
Feeling unusually upset	3.69	1.28	20
Sleeping too much or too little	3.68	1.34	21
Feeling unusually scared	3.68	1.41	21
Irritability	3.68	1.36	21

Factors	Mean	Std. Deviation	Rank
Inability to perform daily tasks	3.64	1.51	24
Hearing voices or believing things that are not true	3.64	1.42	24
Yelling at colleagues/others	3.64	1.48	24
Lack of self-confidence	3.63	1.59	27
Fighting with family and friends	3.61	1.6	28
Using drugs more than usual	3.61	1.63	28
Lack of emotion	3.61	1.53	28
Drinking more than usual	3.59	1.53	31
Violent	3.57	1.58	32
Having low or no energy	3.53	1.31	33
Smoking more than usual	3.47	1.5	34
Suicidal thoughts	3.43	1.65	35
Total	**131.06**	**51.46**	

Table 2 revealed that 11.4% of the variables have their mean within strongly often while the remaining 88.6% have their mean within moderately often as discussed in the methodology. This is also in line with the result shown in figure 3. The table also revealed that all the variables have a standard deviation that is not too high, which is an indication that the responses are clustered around the mean. The average of the total mean and standard deviation was 3.74 and 1.47, respectively. This implies that mental health problems were moderately common. Therefore, because of space constrains, only variables that have a mean above the average total mean will be discussed in this study.

Stress, which is the feeling of emotional or physical tension and also our body's response to pressure, was not surprised to be ranked first on the table. This is because construction work is characterised by numerous stressful activities coupled with the measures put in place to curb the spread of COVID-19 such as wearing nose masks in conducive and inconducive weather. This is also in line with the findings of Zhang, et al. (2018), which identified stress as the source of other prevalent mental health challenges among the working population. Next to this is feeling overwhelmed, which occurs when the intensity of one's feelings outmatches his or her ability to manage them. During this period, a worker will become temporarily unable to think clearly due to their emotional feelings, making them experience too much distraction. This may be as a result of sadness, anger, frustration, amazement, joy, shock, or a combination of these and other emotions and feelings which are all peculiar to construction work due to job insecurity and working away from home (Peterson, et al., 2018). Next on the table is feeling unusually confused. Confusion is when there is a change in mental status in which a person is not able to think with his or her usual level of clarity. Frequently, confusion leads to the loss of the ability to recognise people and or places, or tell time and the date. Feelings of disorientation are common in confusion, and decision-making ability is impaired. This is also common on construction sites, especially when a worker is faced with a daunting task. Next to this is fatigue. This is a feeling of constant tiredness or weakness and can be physical, mental, or a combination of both. The physical nature of construction work such as block setting, concreting, and plastering, coupled with a long working hour, also makes this common among construction workers. This is also in line with the findings of Oladinrin, et al.

(2014), which identified fatigue as a stressor on construction sites. Next is unpredictable. This means a person may likely change suddenly and without any reason and therefore cannot be predicted. This is particularly common among unskilled workers who are liable to drug abuse in order to relieve stress. Next is anxiety. This is the body's natural response to stress. It's a feeling of fear or apprehension about what's to come. It is also an uncomfortable feeling of nervousness or worry about something that is happening or might happen in the future. This is also common among construction workers due to the nature of construction work. For example, a worker tends to be anxious when he/she is approaching the deadline of a given task without any assurance of completing the task. This is also in line with WHO (2014), which identified anxiety as one of the most common mental health disorders. Next is persistent thought. These are thoughts that seem to become stuck in the mind. They can cause distress since the nature of the thought might be upsetting. They may also reoccur frequently, which can make the concern worse. Persistent thoughts may be violent or disturbing. This may also arise as a result of job insecurity, little or no social gathering as a measure to reduce COVID-19 spread on construction sites, among other things. Next is eating too much or too little. This can also be referred to as an eating disorder. It is characterised by a persistent disturbance of eating or eating-related behaviour that results in the altered consumption or absorption of food that significantly impairs physical health or psychosocial functioning. This may also be a result of stress or anxiety. When a worker is stressed or anxious, they may either lose their appetite for food or eat beyond their measure. Next is having unexplained aches and pains. This happens when the muscles, tendons, joints, and other connective tissues hurt. This ache can also be in the fascia, which is the soft tissue between the muscles, bones, and organs. This type of pain is usually experienced after a long working hour and as a result of stress and fatigue. Next is depression. This is a mood disorder that causes a persistent feeling of sadness and loss of interest and can interfere with your daily functioning. When depression and anxiety symptoms are not attended to promptly and adequately, they may lead to chronic physical illness, suicidality, and mortality (Li, et al., 2017; Pavičić Žeželj, et al., 2019). Next is feeling unusually worried. This can also be a major symptom of Generalized Anxiety Disorder, a common anxiety disorder that involves tension, nervousness, and a general feeling of unease that colours the whole life. This may also occur as a result of an inability to meet the target or a long time away from family and friends due to work or distance. Next is poor concentration. This is the inability to focus on a task. A person who is unable to concentrate easily is easily distracted. This may be due to depression or persistent thoughts. When a worker has many things going on in his/her mind, that worker may tend to lose focus on the task at hand and may eventually end up making a mistake. Next is high absenteeism. This is a habitual pattern of absence from work without good reason. Generally, absenteeism refers to unplanned absences. Absenteeism has been viewed as an indicator of poor individual performance as well as a breach of an implicit contract between employee and employer. When a worker is facing one or two mental health issues, that worker may not be coming to work regularly. Next is the inability to take care of family members. This is when a worker is no longer living up to his or her responsibility towards family. This may also be due to depression. When a worker is depressed, it will become difficult for such a worker to take care of family members. Next is the inability to get to work on time. This is when a worker is arriving after the planned, expected, usual, or necessary time. Last but not least, experiencing severe mood swings that cause problems in relationships, which is characterised by a sudden or intense change in emotional state. During a mood swing, a person may quickly switch from feeling happy and upbeat to feeling sad, irritable, or angry.

Table 3 contains the mean and standard deviation of a respondent's opinion on the identified mental health support provided by their organization. The table revealed that all the variables have their mean within strongly frequent as discussed in the methodology. The table also revealed that all the variables have a standard deviation that is not too high, which is an indication that the responses are clustered around the mean. The average of the total mean and standard deviation was 4.56 and 1.13, respectively. This implies that the frequency of mental health support provided by the organizations was strong.

Table 3: Descriptive statistics of different mental health supports

Factors	Mean	Std. Deviation	Rank
Training on mental health and the symptoms	4.8	1.06	1
Awareness week activities	4.65	0.96	2
Flexible working	4.62	1.18	3
Work from home policy	4.57	1.14	4
Additional external support - e.g. counsellors, occupational psychology	4.55	1.1	5
Mental Health First Aids	4.53	1.16	6
Fatigue management plans	4.47	1.04	7
Switch-off policy - e.g. Policy against checking your phone/emails	4.43	1.41	8
Scheduled meetings	4.43	1.14	8

The first place on the ranking table went to mental health and symptom training. This is a teaching and learning activities that are carried out with the primary goal of assisting members of an organisation in acquiring and applying the information, skills, abilities, and attitudes required for a certain job and organisation (Oni, et al, 2019). It's the method by which people acquire knowledge and/or skills for a specific purpose. The importance of training cannot be overstated, since it is beneficial not only now but also in the future. It is considered that if you are not informed, you will be deformed, thus training allows employees to learn more about their mental health and how to better manage it. Next is awareness week activities, awareness which is the state of being aware of something, or "the ability to immediately know and experience, to feel, or to be attentive of happenings." The goal of these programmes is for employees to learn more about mental health and how it affects them. The activities of awareness week assist in enlightening personnel, particularly those who are not captured during a formal training. Flexible working is the next, this refers to alternative arrangements or schedules to the typical working day and week. Employees have the option of working a modified schedule to accommodate personal or family obligations. Employers, on the other hand, may create a variety of timetables to satisfy the needs of their customers. This arrangement allows workers to better manage their time and complete their tasks at a more convenient time, which in turn helps them manage their stress and anxiety while also allowing them to have a work-life balance. This is also in line with the findings of Nwaogu, et al (2021), who identify flexible employment as a key component of improving construction worker mental health. Then there's external help like counsellors, occupational psychologists, who are persons who have been trained to offer advice on personal or psychological issues. Allows workers to get care for their mental health needs as needed. This contradicts the findings of Roche, et al (2016), who found that mental illness is prevalent among construction workers because of the inability to get required support.

After that, there's mental health first aid. A person who is developing a mental health problem, suffering a worsening of an existing mental health condition, or in a mental health crisis receives mental health first aid. First aid is administered until expert assistance is obtained or the problem is resolved. It improves awareness of mental disorders and their treatments, as well as knowledge of proper first-aid procedures and confidence in administering first aid to people with mental illnesses. It's a skills-based training programme that teaches people about mental health and substance abuse. The next is creating a fatigue management plan, which identifies the fatigue hazards at work and specifies how they should be addressed. Depending on the project kind and size, developing a plan might be easy, complicated, or somewhere in between. For this plan to be effective, it must first be developed as a draught, then tested for a few weeks before being revised. This is followed by Switch-off policy e.g Policy against checking your phone/emails, this policy forbids worker from checking phones/emails during working hours. Studies have shown that the constant urge to check phones/emails is one of the most stressful daily activities for workers. Last on the table is scheduled meeting, this is a formal gathering between the workers and the management team, The essence of a meeting, in most cases, is to get feedback from workers; hence, in this case, it allows workers to table their challenges and also seek additional support where necessary.

5. CONCLUSION

The study evaluates the mental health of construction workers during COVID-19. The study revealed that construction workers suffer more mental health problems during COVID-19 due to the nature of construction work coupled with the challenges brought by the outbreak of the deadly virus such as total/partial lockdown, mandatory social distance, using hand sanitizer, using nose masks, among others, which are difficult for construction workers to adapt to as it impairs their usual work life, hence increasing their mental pressure. The study also revealed that efforts have been made by the organisations to put several measures in place to support construction workers' mental health during COVID-19 and that all of these supports have been offered frequently. The practical implication of this study is that it helps construction stakeholders to be more informed about mental health and the type of support required to improve or manage it. It is important to note that this study is an excerpt from comprehensive research that compare the mental health of construction workers before and during COVID-19 in Nigeria. Notwithstanding the result of this study, further research needs to be conducted on the mental health of unskilled/labourers on construction sites.

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EXPLORING THE LESSON LEARNT BY IMPLEMENTING E-TENDERING: A REVIEW OF LITERATURE

Kavitha Kajendran[1]

ABSTRACT

For the success of a construction project, the selection of the most suitable contractor is vital. The process of selecting the most suitable contractor is called tendering. Unexceptional to other industries, the construction industry all over the world is also being urged to move to advanced information technologies to compete in the global market. Addressing globalization along with the introduction of Building Information Modelling (BIM), it becomes crucial for the tendering process to move from traditional to electronic tendering (e-tendering). This study identifies the application of e-tendering in different countries and the outcomes and readiness of Sri Lanka to accept e-tender through an extant literature review. It was concluded that e-tendering benefits through high transparency and accountability, less corruption, less cost, time and paperwork, and easy evaluation of submitted tenders if rightly implemented addressing the challenges such as legal and security issues, resistance to change, less investment in Information Technology, unawareness of the process of e-tendering and non-identical software and formats. Further, considering Sri Lanka's readiness in adopting e-tendering, the country's government has considerably progressed towards e-government but not has been fully implemented. This study would be beneficial for the government and private clients who are willing to practice e-tendering.

Keywords: *Construction Industry; E-tendering; Sustainability.*

1. INTRODUCTION

In developed countries, e-tendering has been implemented many years back and applied in a wide range. As per Hui and Yang, 2011, the United States is the pioneer to carry out e-government and many state governments over there have been practicing e-procurement platforms. They have developed an innovative system of public procurement and tendering through government procurement websites. Further, other developed countries such as Singapore, Denmark, Japan, and Australia have implemented e-procurement with a greater level of success. (Neupane, et al., 2012). Not only, developed countries but also some developing countries have originated e-procurement and started to gain benefits through it. As per the report produced by the United States Agency for International Development (USAID) in 2017, the Government of Sri Lanka also has commenced work to institutionalize e-procurement in 2010 but has not yet fully launched an e-procurement system.

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This study aims on exploring the lessons learned in the implementation of e-tendering in different countries, the benefits experienced, the limitations identified, and how they are being mitigated. Further, this study examines the readiness of Sri Lanka in adopting e-tendering for their construction business.

2. RESEARCH METHOD

To fulfil the research's goal, a thorough literature evaluation was conducted. Data was collected using the desk study method. As a result, literature on the experience of implementing e-tendering has been gathered from journal articles from various nations, government publications, websites, newspaper stories and other published reports. Hence, the awareness and readiness of Sri Lankan construction professionals to adhere to e-tendering and the critical grounds of the limitations in implementing e-tendering will be identified and recommendations to overcome the barriers and paths of smooth transferring from traditional tendering to e-tendering will be formed through an interview survey with the industrial experts.

3. E-TENDERING

E-tendering has been redefined with a modern explanation of "an electronic platform/s includes all the project stakeholders and carries and facilitates all the tendering communications, documentation and transactions from the project initiation till the handing over" (Alyahya, 2017). The success of E-tendering highly depends on user-friendliness. Sunmola and Shehu (2021) identify key seven factors which influence the frequency and satisfaction of internet-based platforms self-initiative, commitment, content, availability, speed, aesthetics, ease of use, and effectiveness. While transforming from the traditional tender to e-tendering, above mentioned factors are to be tackled aptly, therefore the users will be adopting the change pleasantly and completing tasks. Their satisfaction can be expressed through feelings of acceptance, happiness, relief, excitement, and delight.

4. CHARACTERISTICS OF E-TENDERING

Before discussing the characteristics of e-tendering, it is important to learn the process of e-tendering. Royal Institute of Charted Surveyors (RICS) has defined distinct stages of the e-tendering progress in a ten-point plan (refer Figure 1).

Figure 1: The tendering ten-point plan

Source: RICS (2010)

While following the provided ten- point plan process, there are several characteristics of e-tendering that have been identified as benefits by the practitioners if rightly utilized.

4.1 HIGH TRANSPARENCY AND ACCOUNTABILITY

The main benefit of e-tendering shall be the increased transparency and accountability of the procurement process. This factor is highly lacking in the traditional tender. Especially, most of the developing countries are suffering a high level of corruption in the planning process of the public sector construction projects. The higher authorities might be working on hidden agendas on the approval of projects, disclosing some confidential details, or adding unnecessary scopes considering their benefits. However, when it comes to e-tendering, it discloses all information related to tendering, makes the process more transparent and accountable, and prevents any malpractices. Further, there might be unethical practices that happen during the selection of the contractor due to the paper-based traditional tendering. Even, the influential contractors might stop the participation of other qualified tenderers, by threatening. Since e-tendering reduces face-to-face interaction, there are minimal chances for bribing (Neupane, et al., 2012).

However, Hashim, et al. (2020) argues that still, certain stages of the e-tendering process remained hidden to the public, which leads to another fear for ethical issues. It was evidenced with the cases reported in Madhya Pradesh, India, that e-tendering was being exploited as a tool for extortion, depravity, and fraudulence.

Further, regarding integration, Hui and Yang (2011) highlight that the e-tendering platform needs to be designed to accommodate different organizations together, if not, the expected integration will not be achieved due to unified planning and coordination.

As per the above findings, there are still loopholes in e-tendering when it is implemented. They reveal that appropriate designing of e-tendering is vital to achieving high transparency and accountability unless it will lead to more confusion or abounded.

4.2 LESS COST, TIME, AND PAPERWORK

As Sydorenko (2017) annotates e-tendering cut down tender cost and get rid of bureaucratic obstacles. Since e-tendering saves the time that the traditional method usually spent on repetitive and worthless tasks such as re-keying of information. Hence, the organizations could handle a larger amount of work at once and the highly qualified staff could focus on more laborious tasks to enhance their values. Further, it is explained, that the paperwork is reduced and this will minimize human errors such as incomplete information in the documents, insufficient number of copies, a disorder of documents, leakage of information, a large volume of documents, and others. Also, this will reduce the need for storage places for bulk paper documents. Arslan et al. (2006) evidence this as the paper-based tendering took an average of 16 days from the time of receipt of tender documents and completion and submission of tenders whereas e-tendering took an average of between 24 and 48 hours for the process to be completed. The authors further elaborate, around 87% of the time was saved and approximately 98% of the cost was saved through e-tendering.

Moreover, this is beneficial unexceptionally for the tenderers. Since, all documents are to be submitted by tenderers, in soft copies in the provided e-tendering web base, no need to print bulk documents and sort them or produce and submit various items like presentation materials, brochures, and estimating resources. Yet, the expenses associated with packing and delivering the hard copies through postal or transportation will be nil. In addition, the online submission will avoid the tender getting unqualified due to unnecessary postal delays. Further, the tenderers can upload any time before the deadline from anywhere, even after office hours and holidays (Patil, et al., 2016). As per the latest research by e-Market Services, an organization engaging in electronic procurement could cut procurement costs by 8 to 15% (Omran, 2020).

Nevertheless, the legal systems are not being updated along with the technology. Therefore, the lagging in the legal system will cause the organizations to maintain both soft and printed documents to address any legal issues (Sydorenko, 2017). The participants might not be confident in the legal acceptance of electronic communications. This will automatically destruct all the benefits of e-tendering. As this is an external barrier, which cannot be controlled by the organizations but the government could.

In addition, the security of the e-tendering platform might be a threat in case of any cyber-attacks or system crashes (Sydorenko, 2017). This might make it difficult to retrieve the data saved. Also, Eadie et al. (2010) and Khalil and Waly (2015) noticed that people were concerned about persons making unauthorized and unfair modifications of tender documents (document tampering), while others have expressed fears over the integrity and confidentiality of data in e-tendering systems. Due to such an insecure feeling, the organizations tend to have printed hard copies as backup plans.

As an outcome, the governments must accelerate the process of enforcing the digital laws, which will encourage the organizations to move towards e-tendering and restrict cybercrimes.

4.3 EVALUATION MADE EASY

Since the analysis of submitted tenders is automatically generated. (Sunmola and Shehu, 2021), it would be time-saving, accurate, and refrain from any human interference or malpractices.

5. CHALLENGES IN E-TENDERING IMPLEMENTATION

Even though, it is evident that e-tendering addresses the shortcomings of the traditional tender, there are some challenges in implementing successful e-tendering. Without eliminating such challenges, the benefits cannot be accomplished. It is not surprising that there is hesitation to enforce e-tendering in action even though lots of discussions done on its benefits (RICS, 2010).

5.1 RESISTANCE TO CHANGE

There might be resistance among organizational staff who are opposing the technical advancement (Sydorenko, 2017). In addition, some employers might not be willing to risk themselves by introducing or investing more money into new technologies in their projects. In such cases, they should be made aware of the benefits of e-tendering over the traditional method by the practitioners and make them feel comfortable in adopting new systems. According to the study done by Hashim, et al. (2020), in Malaysia, the resistance to change ranked as the major challenge.

5.2 LESS INVESTMENT IN IT

Most of the entrepreneurs are not willing to invest in new Information Technology due to the high cost and are not confident regarding the outcome that could be achieved. Still, if the government of the country initiates e-tendering for public projects, the entrepreneurs will be herded to move towards e-tendering naturally. Conjointly, the government of the country could encourage the pioneers through providing necessary training, awareness programs, offering awards, and tax exemptions.

5.3 UNAWARENESS OF THE PROCESS OF E-TENDERING

In accord with Budianto, et al. (2020) contractors' unawareness of the process of e-tendering was the main cause for the e-tender failures in Jakarta, Indonesia. As per the study, the main issues identified are submitted tender documents were incomplete and complex prequalification requirements. He further outlines that the employees with sufficient knowledge of IT need to be recruited and the competency levels of tender administration and IT knowledge of the existing staff to be increased through training.

5.4 NON-IDENTICAL SOFTWARE AND FORMATS

Patil, et al. (2016) identify different software currently used in e-tendering in India such as Coupa Procurement, E Bid e Xchange, Panacea, Promena e-Sourcing, Sourceit, Bid Sync e Procurement, Web Req, Buyer Quest e Procurement, Procurement Software and e Invoicing and Basware Procurement. Since different organizations tend to use different software, it might be hard to synergize the outcomes in a common platform minding the supportability of different software. Furthermore, Hui and Yang (2011) point out non standardized formats of documents such as the form of the internet files, the process of e-tender, evaluation method, and others is one of the major issues in China when it comes to the application of e-tendering.These could be eliminated by making sure that the tenderers applying are made aware of the preferred software, formats, and process by including in the tender invitation itself.

Table 1 summarises the analysis of benefits and limitations of e-tendering as per the several studies done in different locations. It is known from these studies that, among other benefits, cost and time savings, transparency, less paperwork, and reduced delivery issues are considered the most important advantages, while security, legal difficulties, not ready to invest on IT and resistance to change are the most common barriers to e-tendering in construction. As per the literature reviewed, it could be summoned as the e-tendering is fruitful if rightly implemented.

6. READINESS OF THE SRI LANKAN CONSTRUCTION INDUSTRY FOR E-TENDERING

USAID conducted the electronic Government Procurement (e-GP) readiness assessment conducted in Sri Lanka in 2017. As per the results, there is a favourable alignment of essential factors to support a successful transition to e-GP. Information and Communication Technology (ICT) infrastructure and online services have been dramatically grown and are now in a position to successfully support a range of e-Government services including e-GP. Nonetheless, there are still several readiness gaps that have been identified that need to be bridged timely and orderly to allow a successful transmission towards e-GP (refer to Figure 2).

Table 1: Summary of the analysis of benefits and limitations of e-tendering as per the several studies done in different locations

	Researcher/s	**Sunmola and Shehu, 2021**	**Gupta, et al., 2020**	**Omran, 2020**	**Hashim, et al., 2020**	**Sydorenko, 2017**	**Ibem and Laryea, 2017**	**Patil, et al., 2016**	**Tan and Suhana, 2016**	**Neupane, et al., 2012**	**Townsend, 2018**	**Hui and Yang, 2011**
	Origin	Hertfordshire, UK	New Delhi, India	Lattakia, Syria	Malaysia	Kyiv, Ukraine	South Africa	Malaysia	Malaysia	Toowoomba, Australia	Melbourne, Australia	Xuzhou, China
	Benefits											
B.1	Less cost	√		√		√	√	√	√	√		√
B.2	Increases transparency of the procurement process		√	√		√	√			√	√	√
B.3	No delivery issues	√	√	√		√	√	√	√			
B.4	Less paperwork	√		√		√	√	√	√			
B.5	Less time	√		√			√	√		√		√
B.6	Improved process of evaluation and decision making	√		√		√		√		√		√
B.7	Less corruption	√					√	√			√	√
B.8	Clear communication	√		√		√	√		√			
B.9	Less labour intensive	√				√	√		√			
B.10	Security of information						√	√	√	√		
B.11	Wider market	√		√			√					√
B.12	Easy submission					√	√	√				
B.13	Less human errors	√				√	√					
B.14	Increase competition	√					√			√		
B.15	Reduced collusion	√									√	√

	Researcher/s	**Sunmola and Shehu, 2021**	**Gupta, et al., 2020**	**Omran, 2020**	**Hashim, et al., 2020**	**Sydorenko, 2017**	**Ibem and Laryea, 2017**	**Patil, et al., 2016**	**Tan and Suhana, 2016**	**Neupane, et al., 2012**	**Townsend, 2018**	**Hui and Yang, 2011**
	Origin	Hertfordshire, UK	New Delhi, India	Lattakia, Syria	Malaysia	Kyiv, Ukraine	South Africa	Malaysia	Malaysia	Toowoomba, Australia	Melbourne, Australia	Xuzhou, China
B.16	Consistency			√			√			√		
B.17	Less waste	√						√				
B.18	Automation							√		√		
B.20	Best quality		√							√		
B.21	Less storage	√										
B.22	Single source of information					√						
B.23	Increases productivity					√						
B.24	A key strategy to develop different electronic procurement system					√						
B.25	Reduce bureaucratic obstacles					√						
B.26	Monitor and tracking											√
B.27	Effective market mechanism	√										
B.28	Control and collaboration									√		
	Limitations											
L.1	Security			√	√	√	√	√	√			
L.2	Legal difficulties	√		√		√	√		√			
L.3	Less investment in IT	√			√	√	√		√			
L.4	Resistance change				√		√		√			

	Researcher/s	Sunmola and Shehu, 2021	Gupta, et al., 2020	Omran, 2020	Hashim, et al., 2020	Sydorenko, 2017	Ibem and Laryea, 2017	Patil, et al., 2016	Tan and Suhana, 2016	Neupane, et al., 2012	Townsend, 2018	Hui and Yang, 2011
	Origin	Hertfordshire, UK	New Delhi, India	Lattakia, Syria	Malaysia	Kyiv, Ukraine	South Africa	Malaysia	Malaysia	Toowoomba, Australia	Melbourne, Australia	Xuzhou, China
L.5	Unawareness	√				√						√
L.6	Adopting changes	√				√	√					
L.7	Limitations of the information shared											√
L.8	Different standards											√
L.9	Not using identical software					√						
L.10	Concerns of interoperability	√										
L.11	Company culture	√										

Assessment Components	Readiness Levels
Leadership and Strategy	3
Human Resource Management	2
Policy	2
Planning and Management	2
Legislation and Regulation	2
ICT Infrastructure and Online Services	3
Standards	2
Private sector integration	2
Environmental Influence	3
OVERALL READINESS RATING	2.5

Figure 2: e-GP readiness assessment in Sri Lanka (USAID, 2017)

USAID has developed the e-GP readiness roadmap by the objectives of the ongoing Public Finance Management reform and in support of the Sri Lankan Government's strategic general goals, namely: cascading good governance to all strata of society, increasing government revenue through more effective tax collection, rationalizing unnecessary government expenditure, achieving higher economic performance, digitalizing the economy, enhancing investment and business climate in the country as a result of good governance, exploring the possibility of entering into free trade agreements with countries, following more transparent market-oriented policies, and fostering the development of Micro/Small and Medium Enterprises. Table 2 presents the progress of e-GP readiness in Sri Lanka since 2004.

Table 2: Progress of e-GP Readiness in Sri Lanka since 2004 (USAID, 2017)

Year	Progress
2006	Procurement Guidelines were released by the government, which becomes a standard to be adopted by all parties in the public sector. Further, it has been mentioned in the document that the advertising process, publishing of procurement invitations, an inspection of pre-qualification applications and tendering documents, and interaction with procurement officers for obtaining clarification can be done through online services.
2009	Information and Communication Technology Agency of Sri Lanka (ICTA) published "e-Government Policy". This legal framework includes a range of crucial components that directly impact e-GP i.e., as electronic transactions and data protection. Further, covering procurement procedure, ICT technical evaluation committee, budget and procurement plan, contractual issues in procurement, and intellectual property rights.
2011	ICTA published a concept paper titled "e-Sri Lanka: An integrated Approach to e-Government Case Study", presenting a high-level and strategic view for e-Sri Lanka.
2015	An amendment to the Constitution of the Democratic Socialist Republic of Sri Lanka, where Chapter XIX.B establishes the foundation and main function of the National Procurement Commission (NPC)
2016	The budget law was introduced by an official speech that is publicly available on the parliament's website including some announcements on the establishment of a Central Procurement Secretariat, which will oversee the awarding of tenders and

Year	Progress
	will handle all purchases over a specific value; b) appointment of a committee to provide education and guidance to companies and contractors.

ICTA is engaged in enabling digital laws since 2003 such as Electronic Transactions Act, Digital Signature and Authentication Regime, Computer Crimes Act, Data Protection Legislation, Cyber Security Act, and Intellectual Property Rights (ICTA, 2022).

In addition, each year, ICTA encourages the start-ups through the Tech Start-up Support Program called "Spiralation" and provides seed funding of 5000USD per start-up along with training by industry experts. A tender alert services website has been benefited through this program (ICTA, 2016) and it indicates the interest of the government is moving towards e-tendering.

The development of Artificial Intelligence (AI) is another measure of the government's readiness towards the advancement of ICT. A national AI strategy creates a unified definition of ambitions and priorities for AI in a country in response to the cross-sector, cross-departmental opportunities and challenges that AI presents. Figure 03 shows the AI strategies globally, which indicates that there are more Asian countries and African countries that are lagging behind the global AI strategies (Oxford Insights, 2021).

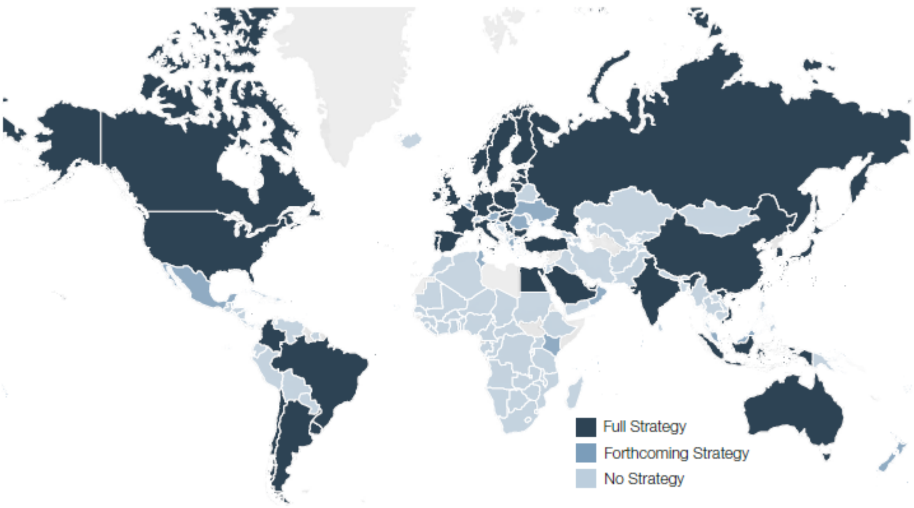

Figure 3: National AI strategies

Source: Oxford Insights (2021)

According to the Government AI Readiness Index released in 2021 by Oxford insights, Sri Lanka has gained 41.12 out of 100, which is below the global average of 47.42. India leads the countries in South and Central Asia with 56.11 (refer Figure 3). The United States capture the first rank (88.16) in the global position, whereas Singapore, one of the Asian countries ranks second (82.46) as a result of its institutional strength and government digital capacity.

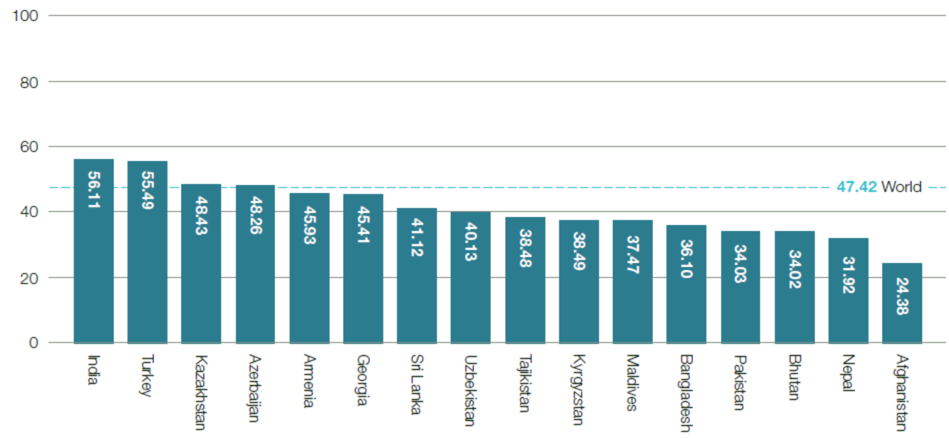

Figure 3: Government AI readiness index - South and Central Asia

Source: Oxford Insights (2021)

As per the survey on the E-participation index (EPI) done by United Nations (2020), Sri Lanka has been categorized under the high EPI level category. A country's EPI reflects the e-participation mechanisms that are deployed by the government as compared to all other countries. The E-Participation Index (EPI) is derived as a supplementary index to the United Nations E-Government Survey. It extends the dimension of the Survey by focusing on the government's use of online services in providing information to its citizens or "e-information sharing", interacting with stakeholders or "e-consultation" and engaging in decision-making processes or "e-decision-making".

In addition, Dhayalan and Davidrajuh (2005) recommend some micro-projects (refer Figure 4) to improve the e-readiness of the country minding the e-readiness of the Norwegian government.

As per the author's opinion, it is highly believed that COVID-19 Pandemic was one of the major causes, which forced Sri Lanka to move towards online services. Due to the self-quarantine and isolation, the suppliers were not able to meet the consumers physically. Online services became a medium to communicate among suppliers and consumers starting from basic commodities such as food, groceries, all home need goods, medicine, furniture, electronic goods, nursery plants, medical consultations, medical reports, banking, education, online travel visa, government services including obtaining vehicle license renewals, and more. The government and suppliers had to initiate websites with appropriate systems to address the users' needs. Even though this is not directly connected with construction e-tendering, this made lots of the citizens to get aware of online systems which would encourage the construction to move towards online services indirectly. Adding to this Amarapathy (2013) indicates that this transition is highly an economic and political challenge rather than a technical or a technological challenge, therefore this cannot be overcome without strong commitment at the highest political level.

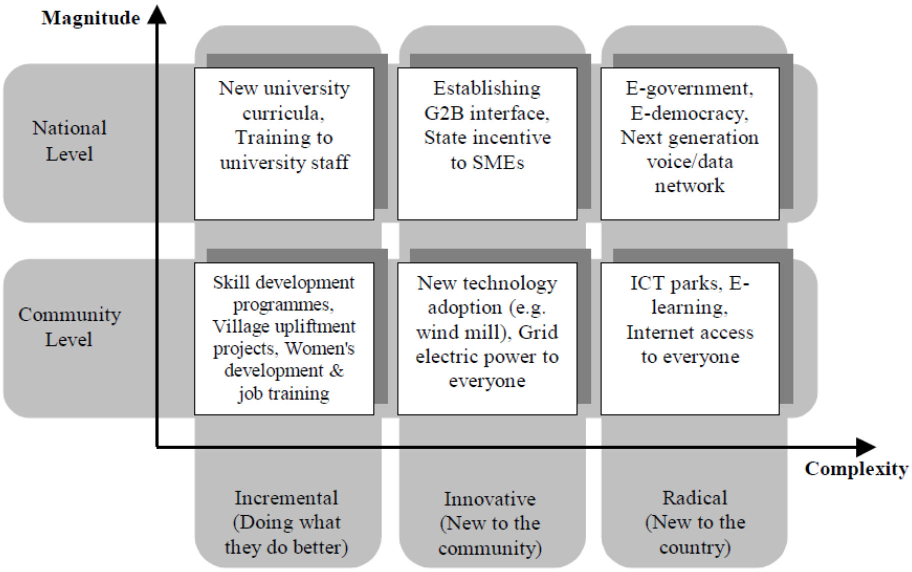

Figure 4: Classification e-readiness improvement projects for Sri Lanka

Source: Dhayalan and Davidrajuh (2005)

7. CONCLUSION AND THE WAY FORWARD

One of the milestones of adapting the advanced information technology in construction is implementing e-tendering in construction. Several developed countries and some developing countries have already started practicing e-tendering at a greater level of success. The stakeholders in the construction industry globally are embracing e-tendering for its high transparency and accountability, less corruption, less cost, time and paperwork, and easy evaluation of submitted tenders. Meanwhile, there are challenges in e-tendering implementations due to legal and security issues, resistance to change, less investment in Information Technology, unawareness of the process of e-tendering, and non-identical software and formats. This reveals that e-tendering is fruitful if rightly implemented addressing all these challenges.

Further, considering Sri Lanka's readiness in adopting e-tendering, the country's government has considerably progressed towards e-government but not has been fully implemented. However, a strong commitment at the highest political level is necessary in order to progress further. The study could be a way forward by investigating the barriers to implementing e-tendering and paths of smooth transferring from traditional tendering to e-tendering in the Sri Lankan construction industry.

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FACTORS AFFECTING CONSTRUCTION TIME PERFORMANCE IN HIGH-RISE BUILDING PROJECTS IN SRI LANKA

K. Kilintan[1], B.A.K.S Perera[2] and P. Kajavathani[3]

ABSTRACT

On-time completion is one of the most important criteria for recent successful construction projects. High-rise building projects face significant risks and time constraints due to the complexity and dynamic nature of their environments. Demand for high rise buildings has been fuelled by economic advancements, rapid suburbanization, and increased consumer spending in Sri Lanka. High-rise building developments require a large amount of funding, permissions and procedures, advanced construction methods, and collaboration between many project participants. Delays have been observed regularly in high-rise buildings, yet studies on factors affecting construction time performance (CTP) are scarce in the Sri Lankan context. Therefore, this study focused on the factors affecting CTP in high-rise building projects in Sri Lanka. If the factors were identified at early stages, they could be minimised or even mitigated and the chance of future occurrences can be minimised. The study used a qualitative approach. Factors affecting CTP were identified through the literature review. The required data were collected from a series of semi-structured interviews identified from purposive sampling. The data were analysed using manual content analysis and validated for high-rise building projects using semi-structured interviews. Fifty-four factors were identified under six categories, including owner, contractor, consultant, contract, contractual relationships and external factors. New additional factor mismatches between the design and budgets are identified. Further, interviewees endorsed 49 factors that were considered as factors that significantly affect CTP. The study would help raise awareness to improve CTP in high-rise building projects.

Keywords: *Construction Time Performance (CTP); Factors affecting CTP; High-Rise Building Projects.*

1. INTRODUCTION

Time is a traditional metric for project success that is usually measured using schedules (Gonzalez, et al., 2013). On-time completion is one of the most important criteria for recent successful construction projects (Hamzeha, et al., 2020). Construction time performance (CTP) is the rate of construction expressed as the ratio of the period planned for completion to the actual time taken to complete the project (Walker and Shen, 2002).

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If a project is delayed, time extensions will be required consequently, resulting in litigation, fines, increased costs due to inflation, and delayed damages (Dolage and Pathmarajah, 2015).

Sri Lanka's construction industry has grown significantly in recent years, notably in the property development sector (Saparamadu and Kumanayake, 2021). Demand for construction in the forms of housing, high rise buildings and condominiums has been fuelled by economic advancements, rapid suburbanization, and increased consumer spending in Sri Lanka (Saparamadu and Kumanayake, 2021). High-rise buildings are still the most common type of buildings in urban areas as land scarcity promotes high-rise building construction (Leung and Tam, 2003). Citizens have also moved from single houses to apartments, single workplaces to commercial buildings, and so on, to save up land space and make better use of resources (Saparamadu and Kumanayake, 2021). As a result, the number of high-rise building projects being built in Sri Lanka has increased (Saparamadu and Kumanayake, 2021). High-rise buildings will continue to be an inevitable housing trend in the real estate market of large cities (Nguyen, et al., 2020). High-rise building projects face significant risks and time constraints due to the complexity and dynamic nature of their environments (Basari, 2017; Perera, et al., 2020). Further, high-rise building developments require a large amount of funding, permissions and procedures, advanced construction methods, and collaboration between many project participants (Santoso, et al., 2003). In addition, the financial and economic risks associated with high-rise building projects can jeopardize the success of the project of time, cost and quality (Perera, et al., 2020).

According to Widowati and Rachmawati (2020), it is crucial to identify factors that influence project cost and schedule performance, which influence the overall project performance. A lot of studies have been focused on project completion time (Le-Hoai, et al., 2013). In addition, several studies have analysed CTP in building projects and multi-unit residential projects in different developing countries (Durdyev, et al., 2017). The resources, environment, and management are the major factors that affect construction time performance (Widowati and Rachmawati, 2020). Contractor-related delay factors have for long been identified as one of the main causes of schedule delays in construction projects (Famiyeh, et al., 2017). Some factors are outside the control of construction participants (Fashina et al., 2020). Despite the above-identified factors, factors affecting CTP have rarely been investigated in the case of high-rise building projects in Sri Lanka. According to Dolage and Pathmarajah, 2015, if delays are avoided, the contractor's revenues may increase, allowing them to expand their business and contribute to the country's economic growth. Delays have been observed regularly in high-rise buildings, yet factors affecting CTP have not been analyzed in the Sri Lankan context. Therefore, this study focused on the factors affecting CTP in high-rise building projects in Sri Lanka.

2. LITERATURE REVIEW

2.1 IMPORTANCE OF CONSTRUCTION TIME PERFORMANCE IN HIGH-RISE BUILDINGS

High-rise buildings face more risks than conventional buildings (Perera, et al., 2020). A high-rise building is one of the most complicated projects, involving many stakeholders over a long period (Basari, 2017). These projects reflect the most modern industrial and technological advancements, making their design and construction difficult and time-consuming (Dwijendra, et.al., 2021). They are also beset by time and expense overruns as a result of their unique characteristics and massive investment demands. (Shoar, et al., 2022). Leung and Tam (2003), stated that completing the structural frameworks is vital to the overall program's success. The number of critical routes available in high-rise buildings is higher than in horizontal buildings (Fedorov, et al., 2018). If there is any delay in one floor or particular area, it will automatically impact the remaining floors and lead to an overall project delay (Fedorov, et al., 2018). High-rise construction projects require intricate services, security, vertical circulation systems and construction logistics more than low-rise construction projects (Juan, 2018). In addition, high-rise buildings are associated with heavy machinery, and vertical MEP works (Fedorov, et al., 2018).

Time Performance is one of the key measures of the project's success in a high-rise building project, as they are the operating platforms of other forms of businesses (Zhang and Zuo, 2016). Further, extensive pre-planning and effective project management are required to make a high-rise building project successful. All construction industry stakeholders have recognized the need to improve construction project performance and are increasingly seeking efficiency in project execution (Meeampol and Ogunlana, 2006). Due to the dynamic nature of the construction industry, the stakeholders of the high-rise building projects are exposed to more risks than ever before, which have a significant impact on the projects' success (Perera, et al., 2020). CTP will be crucial to any construction project (Olawumi and Chan, 2019). Several elements emerge during the project implementation process, many of which have an impact on the project timeline (Le-Hoai, et al., 2013). Further, the repercussions of building delays are not limited to the construction industry; they can have an impact on a country's total economy.

2.2 FACTORS AFFECTING CONSTRUCTION TIME PERFORMANCE

It is not simple to complete a high-rise building project (Do, et al., 2021). Numerous factors can contribute to project delays. Fifty-four project delay factors were identified and categorised as those caused by the owner, contractor, consultant, contract, contractual relationships and external factors (Haslinda, et al., 2018). It is heavily reliant on human elements in addition to science and technology (Do, et al., 2021). Further, Organizations and individuals involved in the project must be fully aware of their roles and responsibilities, as well as have the essential knowledge and competence to perform a specific role. Many high-rise building projects have been proven to be inefficient, with delays, cost overruns, poor quality, lack of safety, unsatisfactory aesthetics and negative reputations of contractors and subcontractors (Basari, 2017).

Many previous researchers have identified that financing and payments made for completed work, slow decision-making on the part of owners, variations and unrealistic contract durations are the major owner-related delay factors affecting CTP in high rise buildings (Famiyeh, et al., 2017; Haslinda, et al., 2018). The majority of owners seek a quick project completion; nonetheless, they must carefully undertake appropriate research to determine the contract duration (Zidane and Andersen, 2018). Another major cause of delay is the owner's failure to hand over the construction site to the contractor at the inception of the (Assaf and Al-Hejji, 2006). Furthermore, the owner must ensure that funds are made available on schedule (Assaf and Al-Hejji, 2006; Hwang and Low, 2012). Furthermore, consultants and contractors must ensure that the site is given over on schedule for the parties' cooperation to be successful (Do, et al., 2021).

Contractor performance is critical to the success of any construction project because contractors are responsible for transforming the design into practical reality (Juan, 2018). Improved contractor performance leads to higher customer satisfaction, a boost in contractor reputation, and hence increased market competitiveness (Ajibade, 2006). Contractor-related delay factors have long been acknowledged as a primary cause of construction delays (Famiyeh, et al., 2017). A project contractor has to complete the project within the allocated time and budget (Fashina, et al., 2020). Contractor-related delay factors can be grouped under four categories: materials, equipment, workforce and project management performance. The contract type and scope of work heavily influence how a contractor responds to various events (Gebrehiwet and Luo, 2017). Similarly, a contractor's ability to finish a project on time is contingent on resource availability and decision-making capacity (Ibironke, et al., 2013). Furthermore, the contractor's personnel are sourced through subcontracting or direct employment. It is critical for the contractor to regularly oversee the work performance of subcontractors to maintain a balance between the various construction activities (Zidane and Andersen, 2018). Contractor-related delay factors include improper project planning and scheduling, inexperienced contractors, frequent changing of subcontractors, outdated technologies, unsuitable construction methods, insufficient staff strength, poor communications and misunderstandings, mistakes made during the preliminary stages and rework due to errors (Zidane and Andersen, 2018).

Consultant-related delays do arise in the ideal situation during the preparation of drawings, acceptance of design drawings, endorsing designs from contractors and clients, verifying payment, and carrying out inspection procedures (Famiyeh, et al., 2017). These types of delays can be caused by a variety of factors, including unskilled consultancy staff, insufficient qualifications, the absence of consultant site staff, underestimation of project costs, insufficient communication and coordination skills, and poor planning (Braimah, 2013; Zidane and Andersen, 2018;). Some experts believe that during the construction process, consultant inquiries and inspections typically slow down the project's progress (Braimah and Ndekugri, 2009). The need to improve project performance has become apparent to all parties involved in the construction sector, and all stakeholders are increasingly seeking efficiency in project execution (Meeampol and Ogunlana, 2006). Further, the authors also stated that each project participant is expected to identify and implement effective management techniques that will help them achieve better results in their respective construction roles.

Some factors are beyond the construction participants' control including legal factors, weather conditions and external factors (Omar, et al., 2020). In harsh conditions, contractors may face several complications, which generally result in the declination of the construction process (Sheikh, et al., 2020). Also, building codes and regulations will affect the construction time performance of high-rise buildings (Fakunle, et al., 2020). Inflation in raw material prices or the exchange rate can also have a detrimental impact on a building project because it is a factor that is beyond the control of the owner and contractor (Durdyev, et al., 2017). External factors can also cause disagreements among construction stakeholders, increasing the project's cost and duration (Rauzana, 2016).

3. METHODOLOGY

Qualitative research is a process of understanding and exploring facts based on inquiry methodology, used to study a single environment or a small number of individuals or projects (Maxwell, 2005). The qualitative approach, focusing on a specific group of people, can be used for an in-depth study of a broad topic, and it allows broad latitudes in topic selection and represents the ideas and perspectives of people (Austin and Sutton, 2014). In this study, data on factors affecting CTP were collected and investigated. Recommendations are provided on how to increase the CTP in high-rise building projects considering the factors affecting CTP. Thus, the study had to use a fact-finding approach with the research question starting with the word "how." The study, therefore, selected the qualitative approach because it would encourage experienced industry professionals to share their construction knowledge with the researchers.

The interview is a guide for defining the direction of data collection and validating the results of the literature (Yin, 2011) and is one of the most common data collection methods used in a qualitative approach (Bacon-Shone, 2015). This research mainly focused on analysing the factors affecting the CTP. In order to focus Semi-structured interviews with purposive sampling, were used as the research technique in the study. It allows the researchers to control the sample size and provide a scope for discussing and recording the interviewee's opinions and views. Fifteen semi-structured interviews were conducted face-to-face with professionals, who had both theoretical and practical knowledge, employed in contractor organizations. The professionals were selected based on purposive sampling adhering to the criteria given in Table 1. Identified potential respondents were invited to the interviews via emails and telephone conversations, and then the interviews were conducted through online zoom meetings. The interview respondents had to have more than five (5) years of working experience in the construction industry and more than two (2) years of experience in high-rise building projects or should have at least two-year experiences in a similar research area and everyone should satisfy with C9. Also, the interviewee must satisfy at least three additional qualifications from Table 1. This sample has variant exposure levels to the areas which are related to that study. Importantly, the selected sample contended with different levels of industry practices also, therefore it helped necessary moments to increase the Contractor's construction time performance.

Each interview lasted for 60-75 minutes. The interviews were used to validate for high-rise building projects the information collected from the literature. The number of interviews was limited to 15 because data saturation was reached after 13 interviews. The data collected from the interviews were analysed using manual content analysis. The primary goal of content analysis is to correctly identify the data collected and highlight important opinions, features or findings (Hsieh and Shannon, 2015). Content analysis can be done manually or by using the software. In this study, the interview findings were analysed manually.

4. RESEARCH FINDINGS

4.1 IMPORTANCE OF CONSTRUCTION TIME PERFORMANCE IN HIGH RISE BUILDING PROJECTS

In any type of construction project, time is important. According to **I1**, time performance is a key measure of the success of a high-rise building project because the buildings are the operating platforms for businesses, for example, a delayed office complex will lose its potential lessees, while a delayed apartment complex will lead to liquidated damages. **I4** mentioned that CTP is crucial in the construction industry because the clients require on-time delivery. **I2** believed CTP was crucial in the construction industry because the work has to be completed within the contract period and milestones met as per the approved programme. **I3** stated that CTP will create a win-win situation for the parties involved.

Table 1: Interviewee profiles and selection criteria

Coding for Interviewees	Designation	Criteria								
		Compulsory qualifications (C1 and C2 or C3)			Additional qualifications (Interviewee must possess at least three qualifications)					
		C1	C2	C3	C4	C5	C6	C7	C8	C9
		Should possess at least 5 years of experience in contracting organization	Should possess at least 3 years of experience in high-rise building projects	Should possess at least two years of experience in the similar research area	Should possess a degree in quantity surveying	Should be employed as a high-level manager in a contracting organization	Should possess knowledge about construction time performance	Should be willing to provide services within a given time frame	Should be interested in construction time performance	Should be accessible
I1	Deputy Manager - Projects Monitoring	√	√	√	√	√	√	√	√	√
I2	Contract Administrator	√	√	√	√	√	√	√	√	√
I3	Senior Quantity Surveyor	√	√	√	√	√	√	√	√	√
I4	Senior Quantity Surveyor	√	√	√	√	√	√	√	√	√
I5	Chief Quantity Surveyor	√	√	√	√	√	√	√	√	√
I6	Chief Quantity Surveyor	√	√	√	√	√	√	√	√	√
I7	Quantity Surveyor	√	√	√	√	×	√	√	√	√
I8	Senior Quantity Surveyor	√	√	√	√	√	√	√	√	√
I9	Quantity Surveyor	√	√	√	√	×	√	√	√	√
I10	Senior Quantity Surveyor	√	√	√	√	√	√	√	√	√
I11	Contract Manager	√	√	√	√	√	√	√	√	√
I12	Quantity Surveyor	√	√	√	√	×	√	√	√	√
I13	Contract Manager	√	√	√	√	√	√	√	√	√
I14	Quantity Surveyor	×	×	√	√	×	√	√	√	√
I15	Senior Quantity Surveyor	√	√	√	√	√	√	√	√	√

According to **I3**, **I4**, **I6**, **I8**, **I9** and **I12**, the number of critical paths is comparatively high in high-rise buildings (vertical buildings) than in horizontal buildings. **I15** stated that in high-rise buildings, the time of completion of structural work on a floor has a direct impact on the time of initiation of the structural work on succeeding floors. In high-rise buildings, the number of simultaneous tasks that can be accomplished is limited. Thus, in high-rise buildings, time performance is becoming increasingly important. According to **I7**, among the three pillars in construction project management, namely cost, quality and time, time is the most critical element. Completing construction, of a project on time is a key factor that has to be satisfied to ensure the success of the project because otherwise the cost and quality of the project will be adversely affected and the overhead or prolongation cost of the project will increase. Endorsing the opinion of **I7**, **I1** stated, *"Time performance is the most critical component in a construction project because it cannot be compensated. Although cost can be reimbursed and quality issues rectified, any time elapsed cannot be compensated except through an extension".*

4.2 FACTORS AFFECTING CONSTRUCTION TIME PERFORMANCE

From the literature, 54 delay factors that could affect the time performance of a construction project were identified under six categories. During the interviews, respondents identified highly affecting factors among those 54 factors, and additional factors were given in bold letters. Table 2 implied the interviewee's opinion about the factors affecting the Contractor's construction time performance. The interviewees wanted the factors endorsed by more than 50% of them (approximately more than 8 interviewees) considered the most significant factors. Accordingly, 49 factors were considered as factors that significantly affect CTP which are highlighted in the table.

As Table 2 indicates, most of the interviewees accepted the factors identified in the literature. Most of the respondents have agreed with the factors that are stated in the literature. According to the above table, **I1** to **I15** contractor quantity surveyors agreed that poor communications, inadequate contractor experience, improper planning, poor site management, construction methods, insufficient number of staff, underestimation of project complexity, mistakes in the preliminary stage, financial problems, misunderstanding, poor procurement programming of materials, poor contract management, and problems with neighbours are the highly affecting factors to the Contractor's construction time performance in high-rise building projects.

Table 2: Factors affecting construction time performance

	Factors	Number of Respondents
Owner	Poor communications	15
	Variations (design changes/extra work)	14
	Unrealistic imposed contract duration	13
	Owner interference	13
	Finance and payment of completed work	12
	Slow decision-making by owners	11
	Poorly defined scope	9
	Poor feasibility and project analysis	7
	Obtaining permits from the municipality	6

	Factors	Number of Respondents
Contractor	Inadequate contractor experience	15
	Improper planning	15
	Poor site management	15
	Construction methods	15
	Underestimation of project complexity	15
	Financial problems (difficulty in accessing credit)	15
	Poor communications and misunderstanding	15
	Poor procurement programming of materials	15
	Mistakes during construction	14
	Mistakes in the preliminary stage (soil investigation)	14
	Shortage in material	14
	Labour productivity	14
	Equipment availability and failure	14
	Sub-contractor	13
	Outdated technology	13
	Low quality of material	13
	Labour supply	13
	Labour disputes	12
	Preparation and approval of drawings	10
	Escalation of material prices	9
	Delay of material delivery to site	8
	Rework	7
	Insufficient number of staff	7
Consultant	Poor contract management	15
	Poor communications	15
	Inadequate experience	14
	Slowness in giving instructions	14
	Delays in preparation and approval of drawings	12
	Absence of consultant's site staff	12
	Waiting time for approval of tests and inspections	10
	Delays in payments	10
	Underestimation of project cost	9
	Poor Quality assurance/control	8
Contract	Mistakes and discrepancies in contract documents	11
	Change orders	10
Contractual relationship	Lack of communication between the parties	12
	Major disputes and negotiations	11

	Factors	Number of Respondents
	Inappropriate overall organizational structure linking	9
External factors	Problems with neighbours	15
	Unforeseen ground conditions	14
	Work accidents	13
	Weather condition	12
	Regulatory changes and building Code	12
	Inflation	12
Additional factors	**Mismatches between design and the budget**	7

Most of the interviewees stated that finance and payment of completed work, slow decision-making by owners, variations, unrealistic imposed contract duration, poorly defined scope, poor feasibility and project analysis, sub-contractor, rework, outdated technology, mistakes during construction, preparation and approval of drawings, Low quality of material, shortage in material, escalation of material prices, labour productivity, equipment availability and failure, labour supply, labour disputes, delays in preparation and approval of drawings, waiting time for approval of tests and inspections, inadequate experience, slowness in giving instructions, delays in payments, mistakes and discrepancies in contract documents, weather condition, unforeseen ground conditions, regulatory changes and building code, work accidents, and inflation also will highly affect the Contractor's construction time performance in high-rise building projects.

I1, **I5**, **I6**, **I7**, **I8**, and **I15** have stated, that the escalation of material price is not directly affecting the Contractor's CTP. **I1**, **I3**, **I8**, **I12**, **I13**, **I14**, and **I15** mentioned the Mismatches between design and the budget also will highly affect the Contractor's CTP. **I7** argued that the outdated technology, labour disputes, inappropriate overall organizational structure linking, regulatory changes, and building code and work accidents are not highly affecting the Contractor's construction time performance in high-rise building projects. Poor financial and business management of the client, delay in valuation and certification of interim payment by the consultant, withholding of payment by the client, the invalid claim of the Contractor, inaccuracy of valuation for work done, insufficient documentation and information for valuation and delayed work by the sub-contractors are the main causes of delay by owners in finance and payment of completed work. The respondents clearly stated that variations always lead to poor time performance when introduced midstream during construction, whether client-initiated or consultant initiated. The most effective method for minimizing variations is a thorough, complete, and presented project brief from the clients. The clients should offer sufficient time for design consultants to produce the complete and detailed design and its documentation. A full understanding of the roles and responsibilities between clients and consultants at an early stage can ensure minimal changes from the original design because of non-compliance with the client's objectives and/or a design arising from a poorly derived brief.

Only six interviewees agreed that obtaining permits from the municipality is an important owner-related factor affecting CTP. Only seven interviewees agreed that rework and insufficient staff strength are important contractor-related factors. **I1**, **I5**, **I6**, **I7**, **I8** and

I15 were of the view that the escalation of material prices does not directly affect CTP. Poor contract management and poor communications are key consultant-related factors affecting the CTP of high-rise building projects. Only nine interviewees agreed that underestimation of project cost affects CTP, while only eight interviewees agreed that poor quality assurance/control affects CTP. Approximately 10 interviewees agreed that the contract and contractual relationships have an impact on CTP. Most of the interviewees endorsed the two external factors *problems with neighbours and unforeseen ground conditions*, while only a few endorsed the external factors of *weather conditions*, *regulatory changes and building codes and inflation*. **I4** introduced the new factor *mismatches between the design and budge*, which was endorsed by six other interviewees.

Most of the respondents stated, that unrealistic contract duration arises from the acceleration in the project schedule due to the delays in the construction activities and it may increase the expectations on labour performance and may cause frequent disruptions in site management due to the delays in tools, equipment, and material supply. High expectations on labour performance, which can be referred to as working overtime, can cause the following problems: labour's physical fatigue, which ultimately will demotivate due to poor mental attitude of the workforce. Eventually, all of this will not only be affecting labour performance level, but also the quality level of output due to the poor workmanship, which is therefore rework, project time, and cost overruns. Further, the subcontractors play a significant part in the success of any construction project and typically clients view them as an extension of the main contractor. Therefore, any delay originating from any of the appointed subcontractors can adversely affect the contractor's on-time project completion. Also, some respondents pointed out, that since high-rise building projects involve higher risk compared to horizontal buildings, before the show up of subcontractors at the construction site, they must be briefed about the scope of their work, which shows the significance of communication between the parties. Even if it will cost more, it is recommended to choose a subcontractor with better qualifications and experience, as the cheapest subcontractor may end up delaying the project. Accidents due to poor site safety can reduce the work rate and efficiency, which will lead to work disruption and ultimately to project schedule delay. This is because construction site accident causes loss of labour productivity. Due to the population growth and urbanization, high-rise buildings have higher demand than horizontal buildings. Respondents said new construction technologies are very important in high-rise building projects. The selection of proper construction methods is very important for high-rise building projects since those are involved higher risks.

4.3 DISCUSSION

Delays are the most common and widespread issue affecting both commercial and public building projects (Fashina, et al., 2020). The study findings reveal that the delayed delivery of a project will have a cost implication for the employer and that the contractor will have to take responsibility for the additional costs incurred due to the delay in project delivery. A project delay will have an impact on project costs. Thus, a project delay will have a major impact on the works and will lead to liquidated damages, prolongation costs and project disruptions. Time performance of a construction project is important for a QS because it directly influences project success. If a delay occurs on one floor or in a particular area of a building, it would cause the overall project to delay. High-rise buildings are mainly used for commercial purposes and condominiums. Thus, the buildings have to be sold early and money earned.

Fifty-four factors that affect CTP were identified from the literature under six categories. The interviewees introduced several new factors that had not been mentioned in the literature. Most of the interviewees agreed with the factors stated in the literature. The majority of owners seek a quick project completion; nonetheless, they must carefully undertake appropriate research to determine the contract duration (Zidane and Andersen, 2018). The manner a contractor responds to various events is largely determined by the contract type and scope of work (Gebrehiwet and Luo, 2017). All of the interviewees believed that poor communication is one of the most significant owner-related factors affecting CTP. Variations (design changes/extra work), unrealistic contract duration, owner interference, and pending payments were the other factors accepted by all the interviewees. Regarding contractor-related factors, all the interviewees agreed that inadequate experience of the contractor, improper planning, poor site management, poor construction methods, underestimation of project complexity, financial problems (difficulty in obtaining credit), poor communications and misunderstandings, and poor material procurement programs were the crucial factors affecting the CTP of high-rise building projects. Poor contract management and poor communications are key consultant-related factors affecting the CTP of high-rise building projects. Approximately 10 interviewees agreed that the contract and contractual relationships have an impact on CTP. Most of the interviewees endorsed the two external factors problems with neighbours and unforeseen ground conditions, while only a few endorsed the external factors of weather conditions, regulatory changes and building codes and inflation. I4 introduced the new factor mismatches between the design and budge, which was endorsed by six other interviewees. The interviewees endorsed 49 factors that were considered as factors that significantly affect CTP excluding poor feasibility and project analysis, obtaining permits from the municipality, rework, insufficient number of staff and mismatches between design and the budget.

5. CONCLUSIONS AND RECOMMENDATIONS

Sri Lanka's construction industry has grown significantly in recent years, notably in the property development sector. The number of high-rise building projects being built in Sri Lanka has increased. Economic progress, increasing suburbanization, and greater consumer expenditure in Sri Lanka have fuelled the demand for high-rise buildings. Among the three elements of construction project management, namely cost, quality and time, time is the most critical element. This study analysed the factors affecting CTP in high-rise building projects through an extensive literature review and semi-structured interviews. The study findings pave the way for a new era in the construction industry. Completion of a construction project on time is important because otherwise the project cost and quality would be affected. Time performance is a key measure of the success of a high-rise building project because high-rise buildings can serve as operating platforms for various businesses. The delay factors were validated in the semi-structured interviews. Fifty-four delay factors affecting CTP were identified under six main categories as those related to the owner, contractor, consultant, contract, contractual relationships and external factors. The interviewees also introduced several new delay factors. Forty-four of the factors were identified and highlighted. The study findings would help construction industry practitioners to increase CTP in high-rise building projects. They can also help review the delay factors that mostly affect CTP. However, the study was limited to high-rise buildings in Sri Lanka. If the factors were identified at early stages they could be minimised or even mitigated and the chance of future occurrences can be minimised. The study used a qualitative approach. Factors affecting CTP were identified through the literature review. The required data were collected from a series of semi-structured interviews identified from purposive sampling. The data were analysed using manual content analysis and validated for high-rise building projects using semi-structured interviews. Fifty-four factors were identified under six categories, including owner, contractor, consultant, contract, contractual relationships and external factors. New additional factor mismatches between the design and budgets are identified. Further, interviewees endorsed 49 factors that were considered as factors that significantly affect CTP. The improved CTP increase the contractor's revenues, allowing them to expand their business and contribute to the country's economic growth The study would help raise awareness to improve CTP in high-rise building projects.

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FUNCTIONAL CHARACTERISTICS OF AN EARLY WARNING SYSTEM TO MINIMISE THE RISKS OF DAM BREAKS IN SRI LANKA

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ABSTRACT

Dams have become a very important infrastructure that provides enormous benefits to the economy of the country. Even though dams are very important and significant structures within a country, their breaks can cause severe damage to the country's economy, society, and environment. Other than that, it can be impacted human life by causing deaths. As a come-up strategy, early warning systems can be used to reduce the severe impacts of dam breaks. Early warning systems (EWS) have been identified as a very important tool used to save lives and properties from disasters. Hence, this paper attempts to identify the functional characteristics of an EWS that can be used to reduce the impacts of dam breaks in Sri Lanka. An extensive literature survey was conducted to achieve the primary objective of this paper. Accordingly, the paper has identified the major purposes of dams, the causes for the dam breaks, and the impacts of dam breaks on the economy, society, and the environment. Then, the paper explores the functional characteristics of the EWS which is used for dam breaks. Finally, a conceptual framework has been developed with the key literature findings of the paper in order to minimise the social, economic, and environmental impacts created by dam breaks using early warning systems in Sri Lanka. As such, this paper will be a value addition to support the country's economy, society, as well as environment.

Keywords: *Causes; Dam Breaks; Early Warning System; Functional Characteristics; Impacts.*

1. INTRODUCTION

Dams can be identified as an obstruction created by steel, concrete, or earth to disturb or manage the flow of water by constructing across streams or rivers and can be defined as a structure used to create reservoirs (Manikowski and Strapasson, 2016). These engineering structures have a long history of application in general watershed restoration, erosion reduction, and soil conservation, and they are found in a wide range of locations around the world (Mekonnen, et al., 2015). Dams have always been associated with humanity's development process (Chen, et al., 2016). Hence, dams are classified as large or small, and this classification is directly related to the structure's intended purpose and

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use (Nascimento and Ribeiro Neto, 2017). Dams have served a variety of purposes over the years, and their widespread use is due to the scientific knowledge used in the design and safety of the structures (Martinz, et al., 2003). According to Lucas-Borja, et al. (2021) dams are used to manage soil erosion, moderate water, and sediment flows, and improve the land. Hence, dams serve a variety of purposes, regardless of their size; dams primarily provide energy production, and they are also used for flow control, navigation, agricultural supplies (mostly for small properties), and water accumulation (Nava, et al., 2021).

The collapse of an infinite or finite volume of fluid, particles, or their mixture onto a horizontal or inclined channel is referred to as a dam break (Chanson, 2006). According to Chanson (2006), it represents a wide range of practical problems with significant engineering implications. Among the most well-known examples are the collapses of water reserving dams and earth filling tailing dams (Di Cristo, et al., 2010). The failure of these dams could have disastrous consequences for both human life and property (Li and Zhao, 2018). Dam failure can be caused by a variety of factors (Gregoretti, et al., 2010). Further, Gregoretti, et al. (2010) asserted that the main causes of tail dam failure are unusual weather and poor dam management, whereas the stability of a landslide dam is influenced by reservoir level, seepage, dam material, and geometric dam configuration. Overtopping is the most common cause of dam failure, particularly for moraine dams and earthen embankments (Balmforth, et al., 2008).

As per Viseu and Almeida (2009), dam accidents, including structure failure, pose serious risks to people and property. Despite increased dam safety due to improved engineering knowledge and better construction quality, a completely risk-free guarantee is not possible, and an accident can occur due to natural hazards, human actions, or a dam's loss of strength capacity due to age (Chen, et al., 2016). Further, Chen, et al. (2016) highlighted that those all justify an increased focus on dam safety and valley management. Prospective dam failures, as well as public pressure for a safer environment, advocate dam risk assessment and reduction in downstream valleys in modern society (Green and Baird, 2020).

Climate change has increased the frequency of natural disasters such as flash floods, hurricanes, and landslides around the world in recent years (Hsiao, et al., 2021). Natural disasters have a significant impact on human society and can be caused by a variety of hazards (Chen, et al., 2016). Disasters lead to substantial casualties in terms of physical infrastructure, interruption of essential facilities, and harm to the means of livelihood in the affected areas (Rathnasinghe, et al., 2021). However, in a climate of increasing public security, it is becoming increasingly public scrutiny, and it is becoming increasingly inadequate to handle a single dam or a portfolio of dams in allocating limited resources for their operation, repair, or improvement (Li, et al., 2019). Even though the communities have the practice of identifying the risk of dam failures through environmental changes like water stream levels, there can be the risk of dam breaks due to non-environmental changes such as the aging of the dam, structure failures, etc. (Mehta, et al., 2020). The experts in dam authorities communicate about the dam failures through mathematical and scientific methods, however, communities cannot understand those due to their lack of knowledge on the causes and impacts of the dam failure as they adhered to assess the risk of dam failures through their self-assessments (Mehta, et al., 2020). Therefore, people are willing to have a pre-disaster risk identification method in order to increase the communication between communities and dam operators with the aim of reducing the hazard of dam breaks (Mehta, et al., 2020). As such establishing an early warning system (EWS) to indicate the dam failures is vital to manage the potential risks before the actual disaster occurs.

In Sri Lanka, there are dams of various sizes and types like gravity, embankment, arch, and arch-gravity dams (Navarathinam, et al., 2015; Manatunge, et al., 2009; Fujikura, et al., 2009). With the recent climate changes and the aging of the dams, Sri Lanka is at risk of dam breaks as highlighted by the Irrigation Department (Samarajiva, et al., 2006). Hence, it is high time to have an effective early warning system developed for dam breaks in Sri Lanka.

However as witnessed based on the scientific literature the EWSs that are developed mainly focused on flood risk management (Henriksen, et al., 2018), tsunami warnings (Rahayu, et al., 2020), and preparedness for other disasters (Collins and Kapucu, 2008; Leonard, et al., 2008). Hence, there is an inadequacy of research focusing on developing an EWS for the dam breaks. As the impact of dam breaks are significant, and the recent climate change can be one of the main causes of dam breaks, it is high time to research on the EWS for dam break. In this context, this study attempts to address the research gap by investigating the functional characteristics of effective EWS to reduce the disaster risks of dam breaks in Sri Lanka. The next section presents the research methodology. Then the analysis of the literature is presented followed by the conceptual framework that is developed for further research. Finally, conclusions and the way forward are provided.

2. RESEARCH METHODOLOGY

This research intends to answer the problem of "what are the functional characteristics of an effective EWS used to reduce the risk of dam breaks?" through a qualitative approach. Qualitative methods support to implement systematic analysis of evolving beliefs and are more suitable when the study has a trifling base of literature background (Naoum, 2007). Further, the qualitative method can be used to create new relationships with the variables to understand the complex processes and to illustrate the influence of society (Shah and Corley, 2006). Accordingly, an extensive literature review was conducted to address the research question. The review investigated the purposes of the dams, the causes and impacts of the dam breaks; and the functional characteristics of EWS. Based on the review of the literature a conceptual framework has been developed as a guide to steer through the problem with the contribution of primary data collection as the way forward.

3. REVIEW ON EWS FOR DAM BREAKS

This section intends to present the functional characteristics of EWS. First, it reviews the major purposes of dams and the causes and impacts of dam breaks followed by the functional characteristics of EWS. Finally, the conceptual framework developed based on the literature has been presented.

3.1 DAM CONSTRUCTION

As revealed by Youdeowei, et al. (2019) dams are introduced as engineering structures which are used for the storage, regulation, and diverting of water from rivers, and they are artificial man-made barriers built across the water. However, dams have become unique constructions all over the world (Chen, et al., 2016). According to the intended purpose and the usage, design strategies, and construction materials, various types of dams can be found in a wide range of locations around the world (Youdeowei, et al., 2019). Among them, earth dams, embankment dams, concrete dams, hydroelectric dams, tail dams, check dams, cascade dams, and arch-type dams are very popular (Nava, et al., 2021). The benefits of dam construction can be realised in the social systems, livelihood, and health of the people, and culture. Table 1 provides the direct and indirect purposes of dam construction.

Table 1: Purposes of dam construction

Main Purpose	Sub Purposes
Direct Purposes	Water supply for human activities
	Water supply for agricultural activities
	Water supply for industrial use
	Flood control
	Water storage
	Electrical energy production
	Changing the direction of rivers
	Control flow of sediments
Indirect Purposes	Preventing flood erosion
	Prepare barren lands for agriculture
	Depositing sand and clay near the river mouth
	Changing the flow of nutrients
	Increase food production
	Act as a centre for tourists
	Introduce new jobs
	Act as a source of fish

Adapted from: (Haghshenas, et al., 2016; Celic and Gul, 2021; Ribas and Pérez-Díaz, 2019; Hallouz, et al., 2018; Youdeowei, et al., 2019)

While serving a range of purposes in terms of social, economic, and environmental aspects, dam can be disastrous when they fail. The next section discusses the causes and impacts of dam breaks.

3.2 DAM BREAKS

Even though dams are constructed with well-improved engineering knowledge and construction qualities for different purposes, they can be broken and cause severe damage to humans and their properties (Haghshenas, et al., 2016). The overturning of the still water column in a reservoir as a result of the removal of the sluice gate will represent an ideal sudden dam break which can introduce a mechanism that involves creating and formulating rapid unsteady flow (Khoshkonesh, et al., 2019). Terrible damages may cause for both human life and the properties due to the failures associated with the dams (Li and Zhao, 2018). However, when compared to the dam constructions in the past more attention has been given to modern dam safety as modern dams are comparatively larger due to the industrialisation and increased density of population around the dams (Wang, et al., 2018). Therefore, it is vital to identify the causes and the negative impacts of dam break to create strategies to mitigate the risks associated with dam breaks.

3.2.1 Causes of Dam Breaks

Ribas, et al. (2021) have categorise the major causes involved in the dam breaks as internal and external causes. Despite the sophisticated engineering involved with dam construction, dam breaks can be caused due to internal causes such as design, technical, and management failures (Zhang, et al, 2009). The authors further highlighted that mechanical or electrical consequences and internal erosions can cause dam breaks. The key external cause is the climatic changes where the global warming that increases the atmospheric temperature can be a threat to dams as it will create floods due to the dissolution of glaciers and increased rainfall (You, et al., 2012). Besides, human actions such as man-made disasters are another major external cause of dam breaks (Ardeshirtanha and Sharafati, 2020). Figure 1 illustrates the main causes of dam breaks.

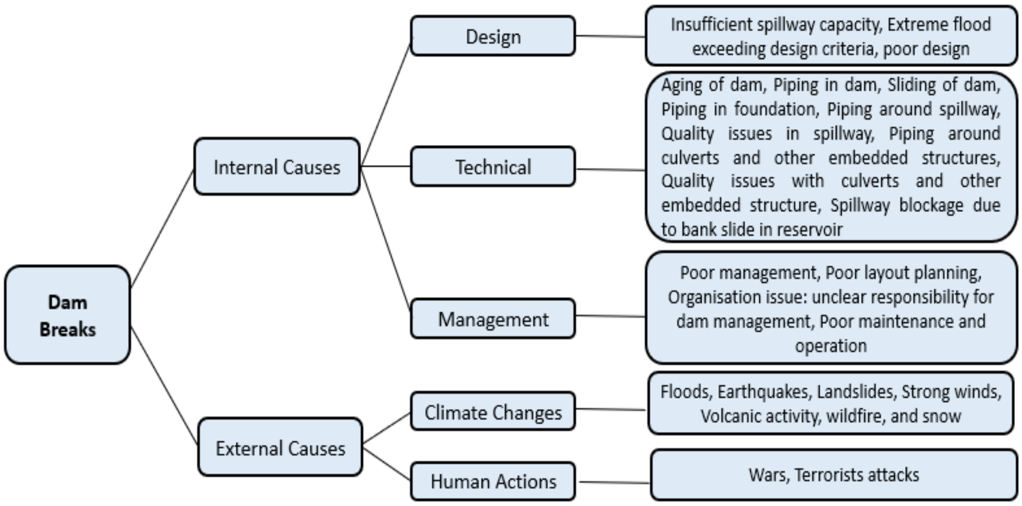

Figure 1: Causes of dam breaks

Adapted from: Zhang, et al. (2009); You, et al. (2012); Ribas, et al. (2021)

3.2.2 Impacts of Dam Breaks

The main impacts of the dam breaks can be classified as loss of human life, economic, social, and environmental losses (Wang, et al., 2018). Dam breaks adversely impact human life as it leads to the loss of human lives, their residencies, employment, and farming lands (Mehta, et al., 2020).

The economic losses caused by dam breaks can be divided into direct and indirect economic impacts (Zhang and Tan, 2014). The direct economic impacts are the financial impacts that can be directly measured in the flood-affected areas due to the reservoir dam break (Zhang and Tan, 2014). Basically, direct economic losses have been caused by agriculture (crops, fishery, forestry, animal husbandry), industry, commerce, and infrastructure (roads, railways, telecommunication, and tunnels) (Wang and Zhang, 2018). The direct economic loss has been measured as physical losses and income losses (Nigatu and Dinar, 2015). Physical losses are the physical value reductions in buildings, equipment, machinery, and all type of fixed or current assets which were affected by the dam break floods (Mo, et al., 2019). Mo, et al. (2019) further explored that the income losses are the profit losses that occurred due to the suspension of production and management activities as a result of the reservoir dam break and it mainly includes the agricultural income losses and industrial and commercial transport service losses. As revealed by Mo, et al. (2019) indirect economic impacts included the expenses of flood management efforts, losses from decreased agricultural production and factory production, and the rising costs of typical socioeconomic activities.

Like human life and the economy, dam breaks badly affect the environment and society too (Zhang and Tan, 2014). As such dam breaks affect the physical and mental health as a result of injury or stress, and a decrease in the quality of daily life (Zhong, et al, 2011). Other than that, damage to the cultural properties, art treasures, rare animals and plants, and even harmful political effects (i.e., national and social stability) can be identified as the social impacts due to the dam breaks (Mo, et al., 2019). The environmental and social impacts due to the reservoir dam breaks cannot be ignored as increased attention has been placed on the environment and society (Sun, et al., 2014). Accordingly, the effects on the channel morphology, living creatures and their habitats (including rivers, wetlands, topsoil, vegetation, and so on), and the cultural landscape, which cause significant damage to the environment through contaminations (e.g., River facilities and chemical storage facilities) can be identified as the environmental impacts caused with the reservoir dam breaks (Mo, et al., 2019).

Accordingly, there are severe impacts on humans, the economy, society, and the environment with the dam breaks (Lempérière, 2017). Hence, there is a vital need for an early warning system with the aim of reducing the risks of dam breaks.

3.3 EARLY WARNING SYSTEM (EWS)

An early warning system (EWS) is one of the most important tools used to prevent the impact of disasters (Zambrano, et al., 2017). Hence, EWS and risk communications are very important roles in the existence and recovery of the population impacted by the disasters (Fan, et al., 2018). According to Zambrano, et al. (2017), "early' refers to the prevention or reduction of disasters, potential damages, or hazards, "warning" describes the announcement given by describing the danger, and "system" is the component that puts all the information together. Therefore, EWS has been identified as a strategy used to save lives from disasters (Collins and Kapucu, 2008). Generally, EWS is a collection of abilities required to develop and transmit timely and relevant information in order for people, communities, and organisations endangered by hazards to plan and respond effectively having sufficient time to decrease the chance of injury or loss (UNISDR, 2009).

When developing an effective EWS, spatial and socio-cultural factors such as hazard and vulnerability mappings (Schlurmann, et al., 2011), community education and participation (Collins and Kapucu, 2008), indigenous and local knowledge (McAdoo, et al., 2008), and religious and language differences (Haigh, et al., 2020) should be considered. Other than that, the developers must have a solid knowledge and understanding of how to create effective warnings for the accurate risk scenarios associated with vulnerable people (Dutta and Basnayake, 2018). The authors further asserted that the effectiveness of the EWS can be achieved with the engagement of experienced experts to manage the system. Basically, EWSs are focused on the people (people-centric) by developing the risk knowledge, monitoring and warning service, dissemination of warning information, and public awareness and preparedness (Eckersley, et al., 2017). Hence, there are instruments and procedures connected with the

EWS which are coordinated by the international, regional, and national agencies (Fan, et al., 2018).

The installation of a variety of devices and technologies to guarantee early identification and monitoring of risks is typical of warning systems (Schlurmann, et al., 2011). As per Leonard, et al. (2008), EWSs are comprised of scientific and organisational capabilities for assessing acquired data to estimate the level of related risk exposure, potential consequences, and prompt notification mechanisms for people at risk. In addition to that, it is important to consider the coherency, capacity to convey timely predictions, efficient alarms, accurate detection, and warning messages, strong communication, reliable responses, and consistency in order to maintain the effectiveness of the EWS (Haigh, et al., 2020). Wehn and Evers (2015), also have further asserted that good risk communication has the ability to establish public confidence if it is based on honesty, clarity, comprehensiveness, and timeliness. Even though the major function of an EWS is to deliver the warning to the final destination (community level), the key concept behind that scenario is to filter the gathered information and translated them into recommended action through the technical process using the most suitable language in order to convey the warning in an understandable manner for the end-users (Hamza and Månsson, 2020). The next section explores the functional characteristics of an EWS.

3.4 FUNCTIONAL CHARACTERISTICS OF AN EARLY WARNING SYSTEM FOR DAM BREAKS

In order to achieve the goal of the EWS, there are five specific characteristics that must work in unison such as (i) Risk forecasting and evaluation, (ii) Detection and monitoring, (iii) Emergency response and action, (iv) Local dissemination, and (v) Public education (Samarajiva, et al., 2006).

Risk Forecasting and Evaluation

This is the system's scientific and technical dimension, which primarily relies on observation and prediction based on scientific expertise and advanced technologies such as mathematical modelling, remote sensing, etc. (Wu, et al., 2021). A significant amount of effort and resources have been invested on this characteristic, resulting in significant advances in EWS (Collins and Kapucu, 2008).

Many hazard warnings are prompted by local officials as well as affected local residents, alerting families, and neighbours (Delenne, et al., 2012). As a result, other than the experts, people also act as a valuable source of hazard detection information (Cools, et al., 2016). However, dam inspection staff, as well as villagers close to the dam, should always be trained to identify the dam breaks in a timely manner and to look for early signs of distress conditions such as unusually high-water levels in the canals or muddy discharge from seepage (Steenbergen and Willems, 2013). Therefore, when a villager identifies any hazard, they must inform relevant authorities to activate early warnings (Wattanasit and Khwannimit, 2021).

Detection and Monitoring

An accurate and dependable method of detecting hazards is the foundation of an effective and comprehensive public safety programme (Binder, 1979). As revealed by You, et al. (2012), in the field of dam safety, hazard detection begins with a thorough examination of the dam's physical integrity. An effective inspection/monitoring system must include the collection of relevant data to ensure that monitors receive accurate safety status indications, as well as timely data collection/sensing systems to allow authorities time to analyse data and issue warnings if necessary (Eckersley, et al., 2017). High tech extreme (considering complex factors) and low tech extreme (observations) are included in the routine inspections. However, due to structural and financial limitations, routine inspections are solely undertaken using low-tech extreme such as visual inspection (Fujikura, et al., 2009). This might lead to dam failures, for instance, Kantale dam failure (unusually heavy flow from a sluice barrel) was also first notified by a villager and informed to the Irrigation Engineer (Samarajiva, et al., 2006). Increasing the time lag between hazard detection and hazard events allows enough time to warn and evacuate vulnerable communities, as well as take mitigation actions to minimise property damage (Kim and Sanders, 2016).

Emergency Response and Action

The geographical impacts and the extent of inundation of the dam break impacts will be dependent on the location and the size of the dam (Duressa, 2018). As revealed by Duressa (2018) the data from the early warning systems are only sent to the local dam officers when only locals are impacted by the dam break and the data will be transmitted to all other locations to allow a region-wide coordinated response in case of a large dam break. Established protocols must be placed to allow dam engineers and local governments to make quick and efficient decisions (Wang and Zhang, 2018). If a dam-related hazard is discovered, dam operators should notify pre-designated emergency first responders in local government, community-level organisations, and the media (Samarajiva, et al., 2006). Disaster management plans must be tailored to the specific characteristics of the dam and its watershed area (Hardjosuwarno, 2014). The author further revealed that these plans must include instructions for on-site personnel on what steps to take to notify supervisors and warning disseminators. Further, these warning systems should play a dominant role while managing safety programmes and supplying information to the public in order to maintain public trust (Samarajiva, et al., 2006).

Local Dissemination

One of the most critical links in an early warning system is the ‘last mile”, which transports alerts and warnings to households in vulnerable towns and villages (Ardeshirtanha and Sharafati, 2020). Following the detection of a dam related hazard, warnings and alerts must be communicated to local authorities (police, local military, fire services, municipality), religious establishments (temples, churches, and mosques), community leaders (such as grama niladhari, farmer organisation leaders), grass-roots organisations (like Sarvodaya) (Samarajiva, et al., 2006). Therefore, the warning can be disseminated to each individual household at risk, allowing people at risk to take the necessary precautions (Zhu, et al., 2021). As revealed by Zhu, et al. (2021), this final component of warning or the instruction for protective measures is required to provide people with the best chance of avoiding serious harm.

Public Education

The general public must be educated on the nature of hazards and their consequences, who and what is at risk, how people will be warned, what the warnings mean, and what actions must be taken (Eckersley, et al., 2017). Warning systems must be tested on regular basis to ensure that they function properly and that the general public understands their purpose and messages (Martin and Rice, 2012). Samarajiva, et al. (2006) asserted that the success of a dam safety programme will be determined in large part by the public's ability to respond suitably to all authority's warnings, alerts, and instructions, both in the event of a dam risks and in the general and everyday use of dams and reservoirs. Finally, safety training should include information on potential risk warning signs (e.g., seepage or overtopping) as well as for instructions on how a local resident can contact the local dam operator and the central dam hazard unit (Eckersley, et al., 2017). As per the identified research gap, it is high time to develop an EWS including the key functional characteristics discussed above to minimise the risks of dam breaks in Sri Lanka. The following section presents the conceptual framework developed based on the literature review.

3.5 CONCEPTUAL FRAMEWORK

Based on the discussion above, a conceptual framework has been developed as shown in Figure 2. The purpose of the conceptual framework is to present how the functional characteristics of Early Warning Systems can support to minimise the causes and impacts of dam breaks.

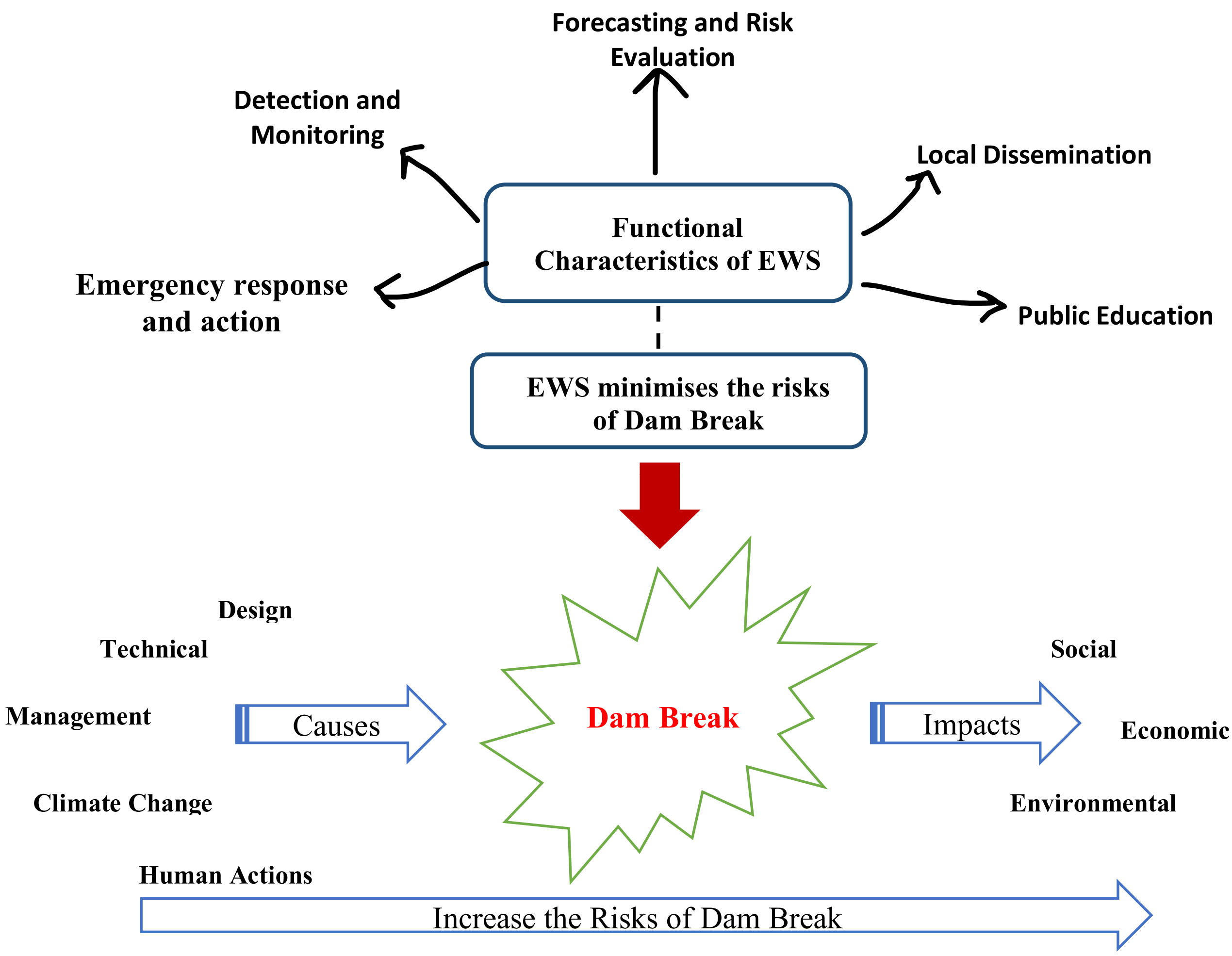

Figure 2: Conceptual framework

As shown in Figure 2, the dams are a very important infrastructure which gives enormous benefits. However, due to the identified causes, the risks of dam break will increase and create very disastrous consequences on social, economic, and environmental aspects. As illustrated in the conceptual framework, the EWS is the most suitable strategy to reduce the risk of dam failures during the construction, operation, and maintenance of the dams. The key functional characteristics of EWS are explored, as illustrated in the conceptual framework. How these functional characteristics will be utilised in the context of EWS for dam breaks in Sri Lanka is the way forward of this study. As the technology has developed and expanded worldwide, it can be used to enhance the characteristics of EWS in one platform (Fan, et al., 2018). Since all the theoretical information gathered on the dam breaks can be incorporated with the technology medium by sharing social, economic, and environmental information, technology will be a supportive platform to handle the different levels of information about the dam breaks by increasing the efficiency and effectiveness of EWS. As such this research will further analyse the utilisation of technological platforms to effectively evaluate and implement the functional characteristics of EWS for dam breaks in Sri Lanka.

Hence this conceptual framework will act as a basic guide to capture primary data in order to contextualise the functional characteristics of EWS to effectively minimise the risks of dam breaks in Sri Lanka.

4. CONCLUSION

Literature synthesis has been developed to summarise the existing knowledge on dams, dam breaks, and the EWS. Moreover, the availability of EWS for the disaster management industries will be a huge support to reducing the risk of dam breaks by enhancing the safety of humans as well as the properties. The conceptual framework has been developed by highlighting the key findings of the study. The causes that can increase the risk of dam breaks were categorised as design, technical, management, climate change, and human actions. The dam break will further create social, economic, and environmental impacts. To minimise such disaster risks due to dam breaks, EWS can be used as a strategy to ensure the safety of the communities affected by dam breaks during the construction, operation, and maintenance of the dams. As such, risk forecasting and evaluation; detection and monitoring; emergency response and action; local dissemination; and public education have been identified as the main functional characteristics of an EWS. EWS will be filtered all information collected through the risk analysis and communicate the warnings for recommended parties in a common language which can be understandable by all vulnerable parties within a lead time period. The conceptual framework will be used to gather primary data to enhance the efficiency of the functional characteristics of EWS in the context of the dam breaks in Sri Lanka. As a way forward, the research will also explore how technological platforms can facilitate to efficiently implement the functional characteristics of EWS for the dam breaks in Sri Lanka.

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GREEN ROOF AS A TECHNOLOGY TOWARDS SUSTAINABILITY: A PERSPECTIVE OF BENEFITS OFFERED

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ABSTRACT

Green roof is a building envelop embedded concept to compensate the consequences of green losses due to building constructions with its numerous benefits in all environmental, economic and social aspects. But the application of green roofs in Sri Lankan buildings is seemed to be limited due to the deficiency in comprehensive awareness of the benefits of the green roof concept among construction stakeholders. Though the global studies on green roof application are widespread among different green roof types, their results do not indicate any consistency between green roof application and climate. This warrants the current study to investigate the benefits offered by green roofs in the local context. A thorough literature synthesis had initially conducted to review the green roof concept, types of green roofs, and benefits offered. Subsequently, a preliminary investigation was performed to identify the green roofs available in Sri Lanka. Thereafter, the case study strategy was adopted to evaluate the benefits of intensive and semi-intensive green roof types through interviews. The collected data were analysed using manual content analysis. Analysis revealed that both intensive and semi-intensive type offers key benefits such as energy conservation, and stormwater run-off reduction in the Sri Lankan context. In addition, the intensive type offers benefits such as carbon emission control, and absorption of urbanized noise which can be aligned with the main criteria of sustainable sites, energy & atmosphere, and indoor environment quality of green rating systems. Therefore, the study suggests that an adequate recognition to green roof implementation in the green rating systems would enhance the green roof application and thereby contribute to achieving sustainability of buildings in terms of these criteria.

Keywords: *Benefits; Green Roof; Intensive; Semi-intensive.*

1. INTRODUCTION

The world is competing itself due to the rapid technological developments and population growth (Dareeju, et al, 2011). Even though growth and development are considered as unavoidable constraints, actions need to be made to minimize their negative impacts (Clark, et al., 2008). Climatic changes are considered as one of the key negative impacts which could be observed nowadays (Kompas, et al., 2018). Further, authors stated that it

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can affect economies of the countries physical and mental health of the Lack of green space is one of the leading causes of abnormal climatic changes (Hossain, et al., 2019). To this end, green roofing concept introduces a building envelope embedded green element which can be used to increase the green space (Mowla, 2010). A green roof can be considered as a roof area with soil and other layers which has vegetation on its topmost surface (Abass, et al., 2020).

A rapid urbanization can be observed in Tropical Sri Lanka (Halwatura, 2013). A higher rate of converting non-built lands into built lands can be observed in 2000s than 1990s (Subasinghe, et al., 2016). Halwatura (2013) stated green roofs could be a positive solution for forthcoming impacts on both environment and social due to rapid urbanization rates in Sri Lanka.

There are different green roof types as intensive, semi-intensive and extensive based on the soil layer depth and vegetation available (Fernandez-Cañero, et al., 2013). However, their benefits can differ with green roof types (Francis and Jensen, 2017). Furthermore, according to Semaan and Pearce (2016), there is no consistency is observed with the benefits of green roofs with climatic conditions and the location of they installed. Moreover, benefits offered by green roofs are comparable even with the same climatic conditions (Manso, et al., 2021). Hence, findings of global studies on green roofs cannot be adapted as it is for the Sri Lanka context.

To date, only a few studies have examined the different aspects of green roofs in the Sri Lankan buildings. Halwatura (2013) and Dareeju, et al. (2011) investigated the benefits offered by extensive green roof type while Nadeeshani, et al. (2021) assessed the life cycle carbon emission of an intensive green roofs based in Sri Lanka. However, other benefits offered by intensive type were not explored locally. Further, there is less attention given to the semi-intensive green roofs in the studies (Vacek, et al., 2017). This study therefore compares the benefits offered by each green roof type towards recommending the suitability of different green roof types as a sustainable technology.

2. LITERATURE REVIEW

2.1 INTRODUCTION TO GREEN ROOFS

A green roof can be described as a rooftop garden with natural or established vegetation embedded on the top of a soil layer and considered as a good vegetative solution for urbanization that provides value for money (Abass, et al., 2020). Composition of a green roof can vary upon climatic conditions and customer expectations (Bianchini and Hewage, 2012). However, the basic components of a green roof are vegetation, growth medium, filter layer, drainage layer and water proofing (Abass, et al., 2020).

2.2 TYPES OF GREEN ROOFS

According to Fernandez-Cañero, et al. (2013), intensive, semi-intensive and extensive are the three main types of green roofs where intensive type has the thickest growth medium. Further, extensive type can be considered as the modified version of early roof gardens with a thinner growth medium and minimum maintenance requirements while semi-intensive type has intermediate properties and characteristics of both other types (Vacek, et al., 2017) .

Figure 1 elaborates the longitudinal sections of intensive, semi-intensive and extensive green roofs highlighting the different growth medium thicknesses and different vegetation used (Fernandez-Cañero, et al., 2013). Further, Table 1 has tabulated the different features of each green roof type illustrated in Figure 1.

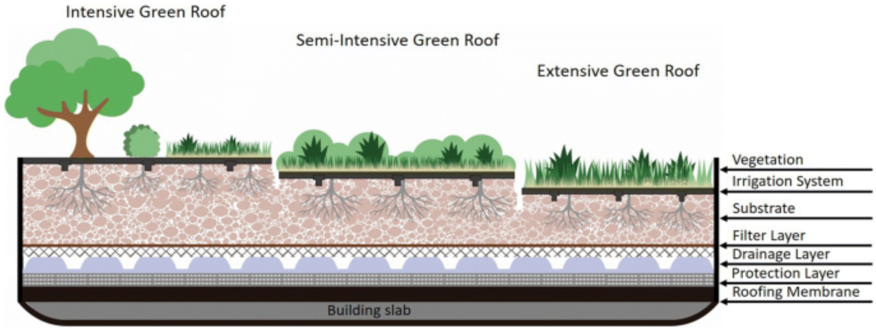

Figure 1: Longitudinal sections of each green roof type

Source: Calheiros and Stefanakis (2021)

Table 1: Features of green roof types

Roof type	Intensive	Semi-intensive	Extensive
Height	More than 20cm	12 - 25 cm	6 - 20 cm
Weight	200 - 500 kg/m^2	120 - 200 kg/m^2	60 - 150 kg/m^2
Vegetation	Trees, herbaceous plants, shrubs, coppices, grass	Shrubs, coppices, grass, herbaceous plants	Grass
Drainage	Separate layer	Separate layer	No separate layer
Irrigation	Required	Required	Not compulsory
Accessibility	Often accessible	Partially accessible	Often inaccessible
Maintenance	Regularly	Periodically	Rarely

Sources: (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL), 2002; Theodosiou, 2009; Fernandez-Cañero, et al., 2013; Abass, et al., 2020)

2.2.1 Benefits of Green Roofs

Green roof is considered as a convenient application of green technology for the urban green space increments and sustainable achievement which can tackle many issues and serves multiple benefits (Meulen, 2019). Those benefits could contribute in achieving economic, social and environment sustainability (Rosasco and Perini, 2019). Table 2 had identified benefits offered by green roofs under each identified sustainable category.

Table 2: Benefits of green roofs

	Benefit	Source
Economic	Energy consumption reduction	[1], [2], [3], [4]
	Enhancement of market value of building	[5], [6]
Social	Improvement of physical and psychological health of occupants	[7], [8]
	Enhancing aesthetic appearance of building	[9]
	Absorption of urbanized noise	[10]

	Benefit	Source
Environmental	UHI effect mitigation	[11]
	Carbon emission reduction	[4], [12]
	Air pollution mitigation	[13]
	Stormwater run-off reduction	[14]
	Expansion of eco and bio-diversity	[7]

Sources: [1] Aboelata (2021); [2] Halwatura (2013); [3] Jaffal, et al; [4] Nadeeshani, et al. (2021); [5] Bianchini and Hewage (2012); [6] Ichihara and Cohen (2011); [7] Hossain, et al. (2019); [8] Meulen (2019); [9] Mowla (2010); [10] Connelly and Hodgson (2013); [11] Razzaghmanesh, et al. (2016); [12] MacIvor, et al. (2016); [13] Velasco, et al. (2016); [14] Vacari, et al. (2019)

Energy consumption reduction is considered as one of the economic benefits of green roofs. According to Aboelata (2021), intensive roof saves more energy than extensive in Arid climate. Halwatura (2013) stated that extensive type saves more energy than conventional roof and the saving increases with the soil thickness of the roof. Further, Nadeeshani, et al. (2021) recorded a 89.95% saving in annual energy demand by an intensive roof compared to conventional roof.

The monthly rental value of a building can increase by 16.2% when a green roof is embedded to a building (Ichihara and Cohen, 2011). According to Bianchini and Hewage (2012), intensive and extensive green roofs can increase the property value by 5%-8% and 2%-5% respectively.

Hossain, et al. (2019) have identified green roofs as a successful solution to improve public health since the vegetation can clean their surroundings. The noise absorption and sound insulations of green roofs may improve the comfort of the occupants inside by reducing vibrations by 3 dB (Meulen, 2019).

A building receives significant attraction by embedding a green roof into its designs (Mowla, 2010). However, the impact of building aesthetic appearance is subjective (Everett and Lamond, 2019). Further authors stated that some people may not willing to see the vegetation on their rooftops. According to Meulen (2019), extensive type may have lesser attraction compared to other green roof types by their users.

According to Connelly and Hodgson (2013), a green roof can reduce noise level from 10-20 dB compared to a conventional roof. The vegetation type on green roof is significant in determining the ability of green roof in noise absorption (Peng and Jim, 2013). Vegetation embedded structures can address the Urban Heat Island (UHI) effect as vegetation can reduce air temperature through evaporation since green roofs accelerate the evapotranspiration of an area due to the availability of soil and trees on top of it in order to reduce UHI effect (Razzaghmanesh, et al., 2016). Nadia (2020) stated that only two intensive roofs used for the study were efficient in UHI effect mitigation while extensive type was more efficient in other cases. Energy consumption reduction ability of green roofs reduces fossil fuel combustion indirectly and reduces carbon emissions (MacIvor et al., 2016). Chenani, et al., 2015) concluded that life cycle carbon emission of green roofs is lesser than the conventional roofs. In the Sri Lankan context, Nadeeshani, et al. (2021) calculated 78.71 $kgCO_2m^{-2}$ annual carbon emission saving in intensive roof than a conventional roof.

Green roof is an innovative solution for the purification of polluted air since photosynthesis process of plants can reduce CO_2 concentration of the air (Velasco, et al., 2016). Further, the vegetation can absorb the fine dust particles of the atmosphere (Shafique, et al., 2018). However, trees are considered more prevalent in capturing dust particles than other vegetation types (Chen, et al., 2006). Hence, vegetation type on a green roof may vary the air pollution mitigation ability of that green roof.

Green roofs may successfully manage the stormwater runoff with their extensive capacity for water retention (Manso, et al., 2021). Further according to authors, intensive green roofs show higher water retaining ability compared to extensive type However, Nardini, et al. (2012) experienced similar retention capacity in both intensive and extensive roof types. According to the authors, that similarity could be due to the higher retaining ability of herbaceous modules than shrubs. Vacari, et al. (2019) stated that the maximum retention was observed in the lowest rainfall conditions in Brazil. Further, studies based on humid climates such as tropical rainforest and humid continental show deceleration in stormwater run-off reduction (Manso, et al., 2021). According to Hossain, et al. (2019), green roof vegetation promotes wildlife in the urban areas by allowing their access to the roof and providing habitats. It can be significantly involved in expanding eco and bio-diversity (Peng and Jim, 2013). Authors stated that it is difficult to quantify the effect of green roofs in that expansion.

The literature evidenced that studies had focused on different benefits offered by green roofs. However, most of the studies had not attempted to identify the existence and extent of each benefit based on the green roof type. Therefore, the results do not reflect any appropriate specific green roof type/s each of the identified benefits.

3. METHODOLOGY

Initially a preliminary investigation was conducted through internet survey, interviews with green roof contractors, regulatory bodies and site visits to identify the available green roofs in Sri Lanka. Accordingly, 5 intensive, 12 semi-intensive and 13 extensive green roofs application were identified. As evidenced in the literature, benefits of green roofs mainly depend on their location, function of the building, roof structure and number of stories. Of the 30 cases with green roofs, due to access restrictions, two case studies, an intensive and a semi-intensive green roof were selected for the study. Both roofs were located on top of car parks of apartment buildings. Intensive green roof was at Colombo while semi-intensive roof was at Galle, and both were in the similar climatic conditions. Key project participants involved in each green roof design, construction and maintenance were interviewed to identify the benefits experienced in the Sri Lankan context. Table 3 presents the profiles of the interviewees. As per the Table, interviewees included mostly architects and engineers of over 10 years of experience.

Table 3: Profiles of the interviewees

Roof Type	ID	Designation	Experience
Intensive	R1	Chief Architect	25 years
	R2	Landscape Architect	28 years
	R3	G Contractor - Managing Director/Design Head	22 years
	R4	Quantity Surveyor	22 years

Roof Type	ID	Designation	Experience
Semi-intensive	R5	Landscape Architect	15 years
	R6	Design Engineer	11 years
	R7	Maintenance Engineer	18 years

4. FINDINGS AND DISCUSSION

Identified participants were asked to comment on the benefits they experienced in the respective green roofs where they engaged, under the three main categories such as economic, social and environmental. Their views are summarised and presented in the following sections.

4.1 ECONOMIC BENEFITS

Energy consumption reduction

According to the opinions of all respondents employed in the intensive green roof building, a significant energy consumption reduction was achieved in the car park area due to the presence of green roof. There was no single ventilation mode installed for the entire car park area. The temporary site offices located below the car park area had installed some cooling units. However, R1 stated that "we have installed air conditioning machines only for air purification since the site offices are closed units, otherwise, the area is much cooler".

The respondents further expressed that the environment of the surrounding premises located at the same level as intensive roof also cooler than a typical same level building. Therefore, it was concluded that a substantial energy consumption reduction can be observed with the case of intensive roof.

In the cases of semi-intensive roof also, the car park area was not with any kind of ventilation. "The soil layer is adequate for our car park cooling premises" was added by R6. According to R6, even the vegetation on the semi-intensive green roof is lesser, the 450mm soil layer provides adequate insulation properties to the car park area. Therefore, semi-intensive roof also reduces energy consumption for cooling of the car park area.

Enhancement of market value of the building

1095 apartment units of the project are located at the peripheral of the green roof area. Having an intensive green roof was instrumental in selling all those apartments by adding value to the entire project. According to R2 respondent, the apartment units were sold in a shorter period of time. "Our marketing division specifically mentioned that the void period was lesser than in a typical apartment project. Customers were keen on the availability of green roof" added by R2 respondent.

According to respondents of semi-intensive green roof, the existence of green roof was not a market tool for the apartment units. The buyers/investors were more driven by the nearby coastal line than the presence of the roof area. R7 respondent highlighted that, "the less attractiveness could be due to the less accessibility and small roof garden area. Further, vegetation areas are inaccessible to the occupants". Therefore, it is considered that the green roof was not significant in enhancing the market value of the property.

4.2 SOCIAL BENEFITS

Improvement of physical and psychological health of occupants

One of the main benefits considered in designing an intensive green roof was improvement of physical and psychological health of the occupants. According to R1, respondent, urban migrations may affect migrators' children and old parents vulnerably. "Closing to the natural environment is essential to improve physical and psychological health of the children. As well, it helps to balance health conditions of adults. Hence, accessible garden areas are significant". Intensive green roof facilitates this requirement as it allows the occupants to play, walk, gather as recreational space.

However, according to respondents of semi-intensive green roof, it could not observe a significant contribution by green roof to the psychological and physical health improvement of the occupants. Occupants do not use the area as much as the designers expected. According to R6 respondent, limited access to roof area was the hindrance for this negative effect. "A non-green rooftop garden with more accessibility could be more effective than having a green area with limited accessibility" was added by R6 respondent. Hence, semi-intensive roof was not significant in regards of this benefit.

Enhancement of aesthetic appearance of the building

The respondents stated that the intensive green roof has been adding more calmness to the entire project. "Even though grass and shrubs are not visible to outside well, tress can be observed from far away" was mentioned by R2. Ultimately, this aesthetic appearance had boosted the selling rate of the apartment units also.

However, semi-intensive green roof is not visible to the outside. According to R5, "beauty of a green roof should not only visible for its occupants. If anyone can capture it at a glance, then it can consider as an additional aesthetic appearance". Further, the vegetation area also limited in the semi-intensive green roof and have not influenced the buyers' decisions.

Absorption of urbanized noise

According to R1, "plants can absorb noise through its stem, leaves, woods and branches. The availability of more plants absorbs more noise". The R2 elaborated the same further by adding "tree stems have special ability to reflect sound waves due to the rigidity of the stems. Sound waves might not able to vibrate more rigid stems and reflect back to its source". Therefore, the absorption becomes effective with the intensive green roof.

However, the respondents of semi-intensive green roof expressed that the sound attenuation of green roof is not considerable. There are no differences in building sound levels before the roof installation and after. Further, R5 commented that "the shrubs do not show any significance in absorbing the sound waves". Hence, this benefit was not identified in the semi-intensive green roof.

4.3 ENVIRONMENTAL BENEFITS

UHI effect mitigation

UHI effect mitigation could not be clearly examined in both intensive and semi-intensive green roofs. According to R3, *"the green roof is located comparatively at a lower height than to its surrounding apartment buildings. Apartment roof decks are not installed with any green roofs. Hence, the effect mitigation may not clearly visible in this green roof"*.

However, according to R6, *"the mitigation could be observed by the below car park area even though it is less significant"*. However, none of the participants could realize UHI effect mitigation ability of the selected green roofs.

Carbon emission control

According to R1, intensive green roof was used as a carbon emission controlling strategy. The green roof provides access to its occupants for recreational facilities. Further, trees provide shading to occupants and have been saving a large amount of fuel combustion and state resource depletion while reducing related carbon emissions.

In the semi-intensive green roof, carbon emission control ability was not identified clearly. According to R5, the roof area has limited access to its occupants. There were no any shadings caused by the roof vegetation. Therefore, the recreational facilities and the carbon emission control could be observed in a limited scale.

Air pollution reduction

The well-known process of air purification by plants is photosynthesis. According to R1, *"purifying atmosphere by photosynthesis is obvious. But the absorption of dust and other toxic particles and gases need to be evaluated further"*. None of the respondents was not definite on the air purification ability and capacity of the intensive green roof.

Respondents of the semi-intensive green roof were also not confident on the air purification ability and capacity of the green roof. R6 emphasized that *"even there are lesser trees in semi-intensive roof compared to intensive roof, a higher density of shrubs and turf may affect the photosynthesis and carbon sequestration processes significantly"*. However, purification ability was not able to be defined in semi-intensive type as well.

Stormwater runoff reduction

Both intensive and semi-intensive green roof are located in tropical rainforest climatic region. The respondents of intensive roof stated that stormwater is well managed by the permeable space of the green roof. Collection of water become limited due to soil layer and vegetation layer. The filtered excess water is transport through drain boards to the peripheral drain line. Hence, any stormwater overflowing cannot be observed.

According to the respondents of semi-intensive green roof, the roof is adequate enough to collect and transfer stormwater without any overflowing. R6 highlighted that, *"higher thickness (450mm) of the soil layer is the main reason for this proper stormwater management. Soil retains excess water and filter smoothly. Even vegetation is comparatively less, the adequate soil thickness provides better performances"*.

Expansion of eco and bio-diversity

There are numerous indigenous plants have been planted on the intensive roof. All respondents representing intensive roof opined that the expansion of both eco and bio-diversity are supported by the green roof. According to R1, *"even this area is highly congested, verities of species can be observed in the roof area. The human accessibility does not show any influence on the expansion of species"*. Further, R3 added *"controlled pruning helps to minimize the artificial nature of the trees, providing more habitats for the species"*. Hence, the expansion of bio-diversity also succeeded with intensive roof.

In the semi-intensive roof, the respondents identified expansion of eco-diversity as a benefit. However, the bio-diversity was not experienced by the respondents. According to R5, *"bio-diversity expansion was concerned in the design phase and it could not experience after installing roof. However, this could be due to the limited space of the roof area. The species may not get adequate security here"*.

Wind barrier

The plants of intensive roof are acting as a natural wind barrier of the area. According to R2representing intensive roof, *"we could experience a lesser wind blowing from the peripherals with trees. Scaevola plants were well resistant to the wind blowing since its early stages and protected other plants also"*. Therefore, it can be concluded that an intensive roof could act as a wind barrier.

In the semi-intensive roof, none of the respondents agreed with the action of vegetation as a wind barrier. Especially, R7 expressed that *"even it says shrubs can act as wind barriers, its performances can be varied according to its planting pattern. When the shrubs have planted as a hedge, it acts as a good wind barrier rather than single shrubs that had planted alone"*. There are no hedges of shrubs in the semi-intensive roof, but few shrubs together as bunches. Therefore, they cannot perform as a wind barrier.

Dust barrier

In the opinion of R1 representing intensive green roof, any kind of vegetation can collect dust at least up to a certain extent. However, the amount of dust collected could vary according to the type of the leaf, the number of leaves available and the surface area of the leaves. *"Evergreen, rough and hairy, fast-growing trees could be highly responsive to the dust collection"* was added by R1. Intensive roof is with evergreen vegetation; hence, it can act as a dust barrier.

There are no trees available in semi-intensive roof except few temple trees. Further, the combination of vegetation is limited in semi-intensive green roof. However, according to the respondents, the available vegetation is adequate enough to act as a dust barrier. Especially, Orchidaceae plants are roughly enough to retain dust. Moreover, most of the vegetation is evergreen. Therefore, the semi-intensive roof also can act as a dust barrier.

Table 4 summarises the benefits obtained by implementing each selected green roof type.

Table 4: Benefits of selected green roof types

	Literature		**Interviewees**	
Benefit	**Intensive**	**Semi-intensive**	**Intensive**	**Semi-intensive**
Economic benefits				
Energy consumption reduction	[1], [2]	[1]	R1, R3	R6
Enhancement of market value of the building	[3]	-	R2	x
Social benefits				
Improvement of physical and psychological health of occupants	-	-	R1	x
Enhancement of aesthetic appearance of the building	[4]	-	R2	x
Absorption of urbanized noise	-	-	R1, R2	x

	Literature		Interviewees	
Benefit	**Intensive**	**Semi-intensive**	**Intensive**	**Semi-intensive**
Environmental benefits				
UHI effect mitigation	[5]	-	-	-
Carbon emission control	[2]	-	R1	x
Air pollution mitigation	-	-	-	-
Stormwater runoff reduction	[6]	-	R2	R6
Expansion of eco-diversity and bio-diversity	-	-	R1, R3	R5*
Wind barrier	-	-	R2	x
Dust barrier	-	-	R1	R7

Sources: [1] Aboelata (2021); [2] Nadeeshani et al. (2021); [3] Ichihara and Cohen (2011); [4] Mowla (2010); [5] Razzaghmanesh, et al. (2016); [7] Nardini, Andri, and Crasso (2012)

*only eco-diversity (-) No sufficient literature (x) Not identified the benefit

As seen from Table 5, most of the benefits including all economic and social benefits of green roofs recognized in the global literature were identified by the respondents of intensive type. Further, the respondents have experienced some of the environmental benefits which were identified in the global context. However, only a limited social and environmental benefits could be experienced by the semi-intensive green roof type respondents. Therefore, it could be observed that more benefits are offered in intensive type than semi-intensive type.

5. CONCLUSIONS

The study aimed to explore the benefits of green roofs through two cases of intensive and semi-intensive green roofs implemented in Sri Lanka. Respondents of both cases evident that intensive green roof offer more benefits than semi-intensive green roof. Accordingly, enhancement of market value of the building, improvement of physical and psychological health of occupants, enhancement of aesthetic appearance of the building, absorption of urbanized noise, carbon emission control, expansion of bio-diversity and wind barrier are the benefits specifically identified for the intensive type by the respondents while energy consumption reduction, stormwater runoff reduction, expansion of eco-diversity and dust barrier had identified as the common benefits offered by both types. In addition, intensive type offers benefits under all economic, social and environmental categories while semi-intensive type offers benefits only under economic and environmental categories. Further, both roof types offer more environmental benefits than other categories. Given these benefits of green roof types, effective implementation depends on the cost of alternative types of green roofs. However, the current study has limited to benefits of green roofs. Thus, a further study is recommended to evaluate the costs and benefits of available types of green roofs. Further, in terms of benefits, the current study has compared the benefits of green roofs qualitatively based on a single case study of intensive and semi-intensive types. Therefore, it is expected the future study to extend with more case study of considered types of green roofs as intensive, semi-intensive and extensive.

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HOUSING QUALITY INDICATORS: A SYSTEMATIC REVIEW

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ABSTRACT

A wealth of studies has demonstrated the significance of adequate or quality housing on occupant's productivity, performance, comfort and health. However, insufficient data on the conditions of existing housing stocks and a lack of consensus measures of housing quality hinder housing developments from achieving residential needs. Due to the lack of quality indicators, the quality of housing is not often assessed. Therefore, this paper presents a systematic review using the PRISMA protocol to provide an overview of the housing quality indicators that can be employed to evaluate housing quality. The review consisted of 62 studies investigating 66 housing quality indicators. Each fall into one of eight categories, namely 1) dwelling unit architectural design characteristics and features; 2) user comfort; 3) housing site location and neighbourhood; 4) building services; 5) construction quality and stability; 6) economic aspect; 7) building maintenance; or 8) sustainability. The results show that investigating housing quality indicators is a growing research field where adequate ventilation was the most critical indicator of a quality home. Since the identified indicators are essential determinants of a quality house, architects and engineers can integrate these features at the design and construction stages in upgrading the conditions of dwellings while satisfying occupant's comfort and quality of life. Further, governments can develop housing quality standards or regulations using these indicators to improve the quality of new housing constructions.

Keywords: *Health; Housing; Quality Indicators; Satisfaction; Systematic Review.*

1. INTRODUCTION

Housing quality is a complex concept that is contextual without a static meaning and varies according to different user groups (Sengupta and Tipple, 2007). Quality housing does not confine itself to structurally stable but also depends on housing location and neighbourhood, indoor living environment, architectural design features, and housing maintenance (Chohan, et al., 2015). According to Lawrence (1995), quality housing should have a proper interrelation between architectural, economic, demographic, political and ecological factors. Moreover, housing and neighbourhood satisfaction are

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critical indicators of housing quality, which affect occupants' quality of life (Salleh, 2008). Stats NZ (2018) refers housing quality "to the degree to which housing provides a healthy, safe, secure, and resilient environment for individuals, families, and to live in and to participate within community activities" (pg.7). Furthermore, to produce a quality house, four elements interact with each other, including housing habitability, housing functionality, social and cultural sustainability, and environmental sustainability. Housing habitability and environmental sustainability are related to the physical structure of a house, which are also influenced by occupants' behaviour and activities. Housing functionality and social and cultural sustainability are related to inhabitant's interactions with families and their neighbourhood.

Maintaining quality and adequate houses are critical in improving inhabitants' health, comfort, satisfaction, safety and security. Poor quality dwellings can trigger multiple diseases to residents, including infections, injuries, chronic diseases and psychological problems (Evans, et al., 2000, Krieger and Higgins, 2002, Zock, et al., 2002). Establishing housing quality indicators is an effective way to measure housing quality (Goodman, 1978). Quality indicators are usually described with housing statistics, performance and quality standards. Housing quality indicators are "measurement and assessment tools designed to allow potential or existing housing schemes to be evaluated based on quality rather than simply of cost" (Housing Corporation England, 2008). However, indicators need to be evaluated according to some rational principles. The indicators can be used to assess the condition of housing, together with occupants' safety, health and comfort in an indoor living environment (Brkanić, 2017). However, it is vital to periodically review housing quality indicators to measure its effectiveness with changing technological, economic, climate, and social environments (Sinha, et al., 2017).

Evaluation of housing quality enables construction stakeholders, policymakers and research organizations to evaluate the conditions of existing and new houses and then provide some recommendations/ improvements (Sinha, et al., 2017). Secondly, it guides homeowners, tenants, and council agents to make an informed decision on housing management. However, there are no studies have involved in conducting systematic reviews on housing quality indicators. Therefore, it is vital to investigate all the housing quality indicators that lead to improved housing conditions and resident's comfort, satisfaction, and health. This paper analyses and evaluates research articles focused on housing quality indicators that have been developed to assess housing quality or inhabitant's health, comfort or satisfaction. The identified quality indicators can be used to assess the quality of detached houses, semi-detached houses or apartments. However, when assessing the quality, it is required to use indicators that are applicable only to the specific type of housing.

2. METHODOLOGY

According to Moher, et al. (2009), a systematic review is a "review of a clearly formulated question that uses systematic and explicit methods to identify, select, and critically appraise relevant research, and to collect and analyze data from the studies that are included in the review" (p. 264). In a systematic review, the relevant studies were systematically searched and evaluated based on inclusion and exclusion criteria with a peer review protocol and have a well-defined strategy of choosing research articles with a quality assessment process that is not included in the traditional reviews (Uman, 2011). Compared with a traditional literature review, a systematic review follows more reproducible, explicit, rigorous and auditable methodologies to provide an answer to a specific research question rather than providing a summary or overview of a topic (Oates and Capper, 2009).

Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) was followed to guide the current systematic review to facilitate the systemic review's reproducibility, comparability, and transparency. After establishing the research question, the review was conducted following four steps (refer Figure 1). These included: 1) the identification of articles, 2) the screening of relevant articles, 3) the application of eligibility criteria, and 4) the inclusion of articles identified and a synthesis of the findings.

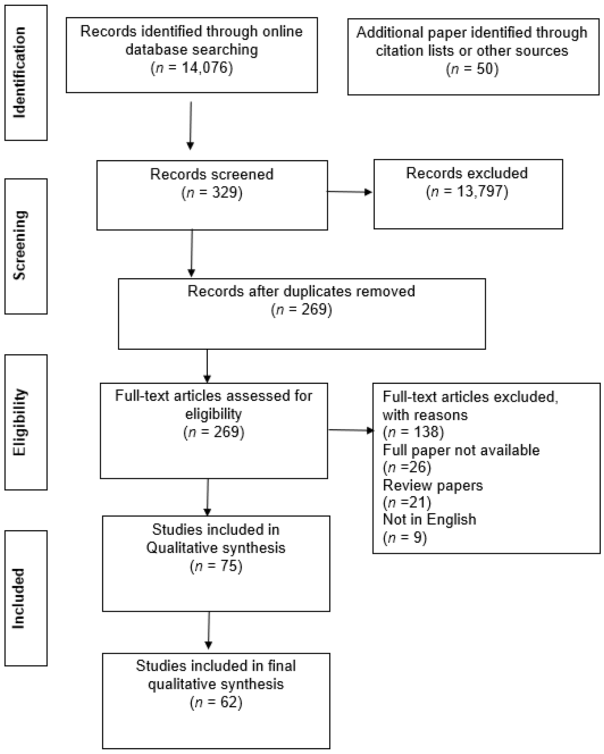

Figure 1: PRISMA flow-chart summary of search strategy and results

In the identification stage, a systematic search of scholarly electronic databases including Scopus, Web of Science, Google Scholar and Engineering Village was conducted from October 2019 and December 2019. The search terms were "(hous* OR indoor) AND (Quality) AND (indicators OR parameters)". The same search terms were used in each database. Scopus was selected because it is the world largest abstract and citation database of peer-reviewed literature, including journals, conference proceedings, and books in essential subject fields ranging from engineering, science, medicine, arts, and humanities. Web of Science is also one of the leading databases, with multidisciplinary articles. This fully covers over 12,000 highly acclaimed impact journal around the world including the subject arears of life sciences, health sciences, physical sciences and social sciences. Engineering Village is a comprehensive database that contains the most authoritative engineering studies available to provide answers to existing questions. This covers the subject areas of physical sciences and life sciences. Google Scholar is a search engine that offers an extensive search for scholarly literature.

The initial database search produced 14,076 records. A further 50 records were identified through citation lists and other sources. Therefore, finally, 14,126 records were included in the screening process. The focus of the screening state was on the relevance of the articles and the duplicate removal. In total, 13,797 records were excluded during the title and abstract screening process as they were not relevant to the housing quality indicators. After further removal of duplicates, a total of 269 records remained. The eligibility stage involved a further checking of the relevancy of articles by exercising four inclusion and exclusion criteria. Firstly, only peer-reviewed journal articles and conference proceedings that presented housing quality evaluation criteria to assess housing quality were selected without limiting to a year of publication. According to Stats NZ (2019), dwelling energy efficiency features along with occupants' health, well-being, comfort, satisfaction, and security represent the quality of dwellings. Therefore, the studies that focused on investigating the parameters that influence occupants' satisfaction, health, comfort, well-being, security, and housing energy efficiency are also included in the current review. Secondly, the publications on housing design and construction features that not associated with quality indicators were excluded as the research aims to ascertain the parameters of quality housing. Thirdly, book chapters and dissertations were not included because those were not peer-reviewed. Review or discussion papers were also excluded as those consisting of secondary data. The studies published in the English language were only included since researchers could not understand other languages. Any discrepancies between the authors were resolved through discussion until an agreement was reached. Finally, the eligibility assessment resulted in a total of 75 publications.

In the final stage, a methodological quality assessment of each article was undertaken. The methodological quality of all 75 articles were measured using the "Standard Quality Assessment Criteria for Evaluating Primary Research Papers" (Kmet, et al., 2004). This tool comprises ten criteria to measure the quality of research articles (Appendix A). A scorer assigns "yes" = 2, or "partial" = 1, or "no" = 0 for each criterion, depending on the degree to which each criterion was met. A criterion not applicable to specific research was marked as "n/a" and were excluded from the summary score calculation. A summary score was calculated by summing the total score attained across ten items and divided by the overall possible score (i.e., 20 – (number of "n/a" x 2)). The summary score range between 0 and 1, with higher scores indicating higher quality article.

The summary score of 75 studies was ranged between 0.2 and 0.85 (refer Table 1).

Table 1: Quality Assessment of the studies included in the review

Normalized score	Number of articles
0.1 – 0.2	0
0.2 – 0.3	3
0.3 – 0.4	4
0.4 – 0.5	6
0.5 – 0.6	9
0.6 – 0.7	28
0.7 – 0.8	20
0.8 – 0.9	5
0.9 - 1	0

The study used a normalized score of 0.5 as the threshold value because it is the average value between the highest (0.85) and the lowest (0.2) normalized values. A summary score of 82% of the papers is above 0.5. This indicates that the quality of the articles reviewed to ascertain housing quality indicators are relatively high. According to the quality assessment, 62 articles are within the quality range, which is included in the final analysis.

3. RESULTS

The authors designed a data extraction form to review housing quality indicators. The extracted information comprised of publication classification, publication year, the country where the research was conducted, publication source and dwelling type. The statistical analysis was performed using Microsoft Excel.

3.1 PUBLICATION PURPOSE OF THE REVIEWED ARTICLES

In the current systematic review, studies could be divided mainly into two categories; studies that developed housing quality evaluation criteria or studies that used existing quality indicators for different applications, including to assess housing quality directly or to evaluate occupants' comfort, satisfaction, security or health or to measure the energy efficiency of dwellings. Therefore, Figure 2 depicts the different categories of studies used to develop the housing quality indicators in the current review.

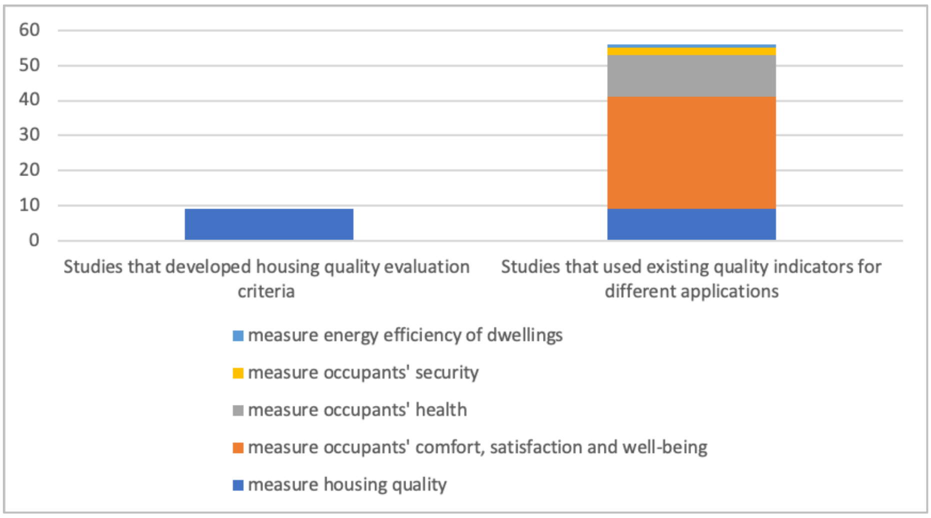

Figure 2: Classification of the studies in the review

As shown in Figure 2, around two-thirds of the studies in the current review used existing quality indicators for different applications (i.e. measure housing quality, housing energy efficiency, and occupants' comfort, satisfaction, well-being, security, and health). However, only a few studies have developed housing quality evaluation criteria to determine the quality of dwellings by attaining the inputs from housing experts.

3.2 CHRONOLOGICAL DISTRIBUTION OF THE REVIEWED ARTICLES

The systematic review revealed the extensive use of housing quality indicators in the last five years to measure dwelling quality or occupants' life quality (comfort, satisfaction, health and safety), as shown in Figure 3. While 26% of the studies (16 articles) were conducted in the five years between 2010 and 2014, around 40% (25 articles) were carried out in the five years between 2015 and 2019.

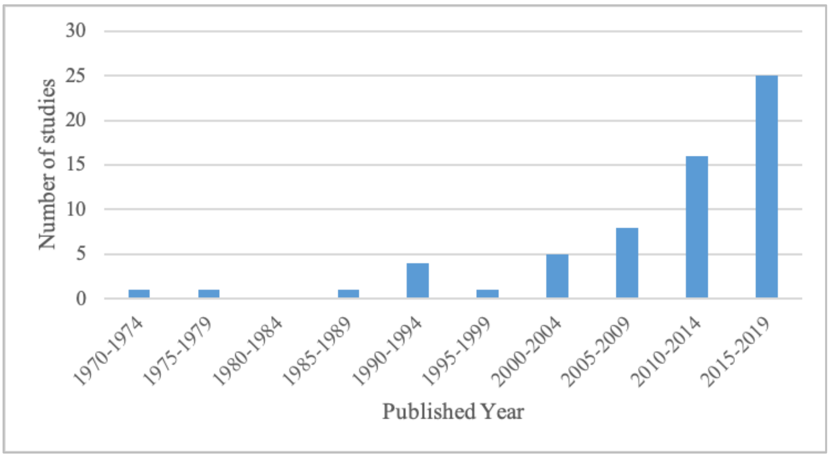

Figure 3: Chronological distribution of reviewed articles

3.3 Geographical Distribution of Identified Articles

The final 62 articles covered 33 different countries from four different income economies[5], as shown in Figure 4. Of these, 32 (52%) were conducted in high-income economies (HI) (52%). Nevertheless, only 2% of the studies were conducted in low-income economies. Since these low-income countries struggle with poor housing quality issues, it is essential to conduct research in ascertaining housing quality indicators to identify what constitutes a quality house in low-income countries.

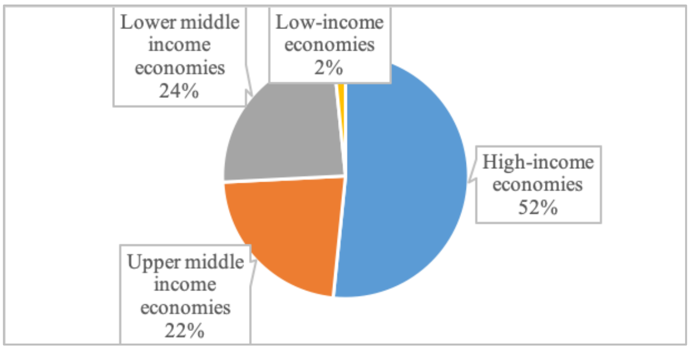

Figure 4: Review articles by different income economies

3.4 Housing Quality Indicators

Analysis of findings in the reviewed articles suggested that housing quality can be divided into eight categories namely;

1. **Dwelling unit architectural design characteristics and features (25%)** - Measure the quality of adopted architectural design features and standards
2. **User comfort (22%)** - Measure the indoor environment parameters that make occupants comfortable and healthy

[5] Use Gross National Income (GNI) per capita data in U.S. dollars to group the economies. High-income > $12,235, Upper-middle income $3,956-$12,235, Lower-middle income $1,005-$3,955, Low-income <1,005

3. **Housing site location and neighbourhood (20%)** - Measure the condition, as well as the security of housing neighbourhoods and proximity to main amenities
4. **Building services (15%)** – Measure the design, installation and operation of principal utilities in a dwelling
5. **Construction quality and stability (9%)** - Measure the quality and stability of structural work and non-structural related work
6. **Economic aspects (4%)** - Measure commercial aspects of dwellings that account for housing quality
7. **Building maintenance (3%)** - Measure the acceptable standard and technical performance of building elements
8. **Sustainability (2%)** - Measure the adaptation of sustainable measures in housing construction to reduce environmental impacts of dwellings

These eight sets of categories together contained 66 housing quality indicators, as shown in Table 2.

Table 2: Key housing quality categories with associated indicators

Housing quality category	Housing quality indicators	Number of reviewed articles	Country
Dwelling unit architectural design characteristics and features (C1)	Crowding (number of people per room)	23	HI, UMI, LMI
	Well-designed passive lighting	19	HI, UMI, LMI, LI
	Average household size	15	HI, UMI, LMI
	Space and quality of bath and toilets	14	HI, UMI, LMI
	Functional space design for kitchen performance	12	HI, UMI, LMI
	The content of dampness, moisture and fungi	10	HI, UMI, LMI
	Number of rooms in the dwelling	7	HI, LMI
	Space and quality of the bedrooms	6	HI, UMI, LMI
	Age of dwelling	3	HI, LMI
	Staircase size for smooth movement and emergency purpose	1	LMI
User comfort (C2)	Adequate Ventilation	29	HI, UMI, LMI, LI
	Acoustic comfort (Measures for sound insulation)	25	HI, UMI, LMI, LI
	Thermal comfort	24	HI, UMI, LMI
	Indoor Air Quality	18	HI, UMI, LMI
	Passive and total lighting comfort	11	HI, UMI, LMI, LI
	Odour in the dwelling	8	HI, UMI,
Housing site location and neighbourhood (C3)	Access to nearby hospital	18	HI, UMI, LMI, LI
	Availability and access to public transport	17	HI, UMI, LMI, LI
	Access to a nearby school	17	HI, UMI, LMI
	Access to grocery stores and restaurants	15	HI, UMI, LMI

Housing quality category	Housing quality indicators	Number of reviewed articles	Country
	Neighbourhood safety and privacy	14	HI, UMI, LMI
	Noise generated by neighbourhood or street	13	HI, UMI, LMI
	Sufficient car parking	13	HI, UMI, LMI
	Access to a nearby public park	11	HI, UMI, LMI, LI
	Neighbourhood plants and green areas	11	HI, UMI
	Cleanliness and pleasant of the surroundings	9	HI, UMI, LMI
	Distance to main roads & railways	8	HI, UMI, LMI, LI
	Well-designed spaces and roads around the housing	7	HI, UMI, LMI, LI
	Quality of landscaping	4	HI, UMI, LMI
	Quality of open spaces	4	HI, LMI
	Access to the place of worship	4	UMI, LMI
	Radon concentration	3	HI
	Space for exercise	3	HI
	Supply and security of pavements	3	HI, UMI
	Maintenance by the local authorities	3	UMI, LMI
	Access to bank	1	LMI
	Outdoor odour and air quality	1	LI
	Nearby pollen concentration	1	HI
Building services (C4)	Design of the gas supply system	3	HI, LMI
	Design of the water supply& storage system	17	HI, UMI, LMI
	Design of sewage drainage system	11	HI, UMI, LMI
	Design of the electrical wiring system	10	HI, UMI, LMI
	Availability of garbage disposal and recycling facilities	10	HI, UMI, LMI
	Availability of sanitation facilities	6	HI, UMI, LMI
	Design and availability of the heating system	4	HI
	Installation of fire alarm and sprinkler systems	2	HI
	Design of stormwater and wastewater disposal system	2	LMI
	Design and availability of the air-conditioning system	1	HI
	Use of quality and durable building materials	11	HI, UMI, LMI

Housing quality category	Housing quality indicators	Number of reviewed articles	Country
Construction quality and stability (C5)	Quality of construction workmanship - Structural (foundations, walls, roof)	11	HI, LMI
	Quality of construction workmanship - non-Structural (floor finishes, painting, pipe, doors & windows)	6	HI, UMI, LMI
	Use of quality fittings and fixtures	3	HI, LMI
	Use of advanced building and construction technology	2	LMI
	Consideration of seismic loads in structural design	2	HI, LMI
Economic aspects (C6)	Tenure (ownership) status	6	HI, UMI, LMI
	Affordability (housing expenses-to-household-income ratio)	3	HI, LMI
	Interest rates and mortgage availability	1	HI
Building maintenance (C7)	Provision for structural maintenance	4	LMI
	Provision for MEP service maintenance	4	LMI
	Provision for non-structural maintenance	3	LMI
	Provision for appliances maintenance	2	LMI
	Provision for pest control	1	LMI
Sustainability (C8)	Use of recyclable building material	3	HI, LMI
	Use of eco-friendly building material	2	LMI
	Use of energy-saving design features	1	LMI
	Adoption of onsite renewable source of energy (i.e., wind and solar)	1	LMI

Note: HI - High Income economies, UMI - Upper Middle-income economies, LMI - Lower Middle-income economies, LI - Low Income economies

Dwelling unit architectural design characteristics and features

The highest number of articles (51 articles) reported housing unit architectural design and features related quality indicators in the review. This criterion described housing design features that constitute a quality house. This category comprises ten housing quality indicators. Under this category, "the number of people per room" (23 studies) and "well-designed passive lighting" (19 studies) are found to be the most significant indicators to measure the quality of housing since the majority of the studies mentioned these two quality indicators. Household crowding is one of the key contributing factors for occupant's health, including respiratory diseases (Murray, et al., 2012, Taksande and Yeole, 2016), depression and sleep disorders (Suglia, et al., 2011). In addition, well-designed passive lighting affects occupant's visual comfort as it allows them to obtain the required natural daylighting to the indoor environment (Frontczak, et al., 2012). The concentration of dampness and moisture is another important indicator of housing quality, which directly affects resident's respiratory health, such as asthma and pneumonia (Karvonen, et al., 2015, Park, et al., 2018).

User comfort

In the current review, around 22% of publications described quality indicators related to resident's comfort. There are six housing quality indicators in this category, as shown in Table 3. The contribution of all these six indicators to housing quality is high since these directly affect housing occupant's comfortability. "Adequate ventilation" is the uppermost reported indicator under this category because an adequate ventilation system is essential for a house in maintaining good indoor air quality. Likewise, thermal comfort, acoustic comfort, visual comfort and indoor air quality are also imperative to improve indoor environmental quality. According to the WHO, the indoor temperature should be maintained between 18^0C and 21^0C to achieve a healthy indoor environment (Science Media Centre, 2008). Indoor air quality is another critical aspect of user comfort. Biomass fuel usage, tobacco smoking, lead base products, and exposure to volatile organic compounds are the leading causes of poor indoor air quality (Wimalasena, et al., 2021). These will increase indoor PM (Particulate Matter), CO (Carbon Monoxide), NO_x (Nitrogen Dioxide), SO_2 (Sulfur Dioxide) and VOC (Volatile Organic Compound) concentrations, which will negatively impact occupant's respiratory health. Acoustic and visual comfort are another two indicators of a quality house as this trigger both physical and psychological health problems, including injuries, visual loss, headache, sleep disturbance and annoyance (Arif, et al., 2016).

Housing site location and neighbourhood

Housing site location and neighbourhood is the third-highest reported housing quality category comprises 22 quality indicators. In the review, around 19% of the studies outlined location and neighbourhood associated housing quality indicators. Neighbourhood quality refers to the quality of the surrounding environment of a house where it is located (Aliu and Adebayo, 2010). Moreover, according to Erdogan, et al. (2007), occupant's satisfaction is positively influenced by various social and environmental living conditions in traditional and modern neighbourhoods. . People consider these factors when making their housing choices. Salleh (2008) reported that some private developers are highly profit-oriented and give less attention to housing neighbourhood facilities and the environment. But when a housing neighbourhood does not fulfil residential desires and aspirations, then inhabitants feel dissatisfied. Therefore, neighbourhood quality and safety are vital factors in evaluating the quality of a house.

Building services

Building services is the fourth highest reported housing quality category, and it contains ten quality indicators. This category mainly measures housing quality through the quality of main utilities, including water, gas, electricity, heating, air-conditioning and fire. If these systems are not functioning properly, occupants feel discomfort and result in spoilage microbes such as bacteria and mould with an unpleasant odour (Cox-Ganser, et al., 2009). Governments are responsible for providing reliable access to utilities to all housing occupants under a responsible regulatory framework (International Labour Organisation, 2021). Moreover, design features of housing sanitary facilities, garbage disposal, and waste and stormwater disposal systems also decide the quality of a house. However, in the world around 2 billion people still do to have basic sanitary facilities such as toilets or latrines (World Health Organization, 2019).

Construction quality and stability

Construction quality and stability is the fifth-highest reported quality category. According to Page and Gordon (2017), structural stability is essential for a house to reduce structural defects and damages caused by structural failures. The stability of a dwelling mainly depends on the structural quality with the use of advanced construction technologies and durable and quality building materials (Aliu and Adebayo, 2010). Zainal, et al. (2012) found that defective construction, inadequate waterproofing, and uneven floors caused serious housing quality problems, including injuries. However, only 9% of the studies reported construction quality and stability related quality indicators.

Economic aspects

The economic aspect is another category that needs to be evaluated when measuring dwelling quality as the nature of tenure, affordability, the value or price of a house generally considered as measures of dwelling quality (Sinha, et al., 2017). According to Windle, et al. (2006), psychological health problems are more common among tenants than owner-occupiers due to tenant's weaker tenure security. However, sometimes low-income house owners have also shown a slight but notable decline in mental health due to housing unaffordability issues (Bentley, et al., 2016).

Building maintenance

Baer (1988) has demonstrated the requirement of regular housing maintenance and its direct relationship with housing quality. Building maintenances include provision for structural, non-structural, mechanical, electrical and plumbing (MEP) and appliances maintenance. The natural environment like rain, extreme hot and cold weather, wind and salt spray cause the house to weather over a period of time (Baxta, 2021). Therefore, housing maintenance avoids deterioration and make the dwelling more durable. Similarly, effective maintenance in houses/ buildings can minimize the harmful effects of housing on the environment regarding waste production, energy consumption and carbon dioxide emission (Lee and Ahn, 2018).

Sustainability

Sustainability-related design features also need to be considered as quality indicators due to the scarcity of natural resources. This category includes four sustainable design features, which reduce environmental impacts caused by the housing sector. The concept of sustainability involves improving humans' quality of life, making them live in a healthy indoor living environment with improved social, environmental, and economic conditions (Akadiri, et al., 2012). Adaptation of quality materials, designs, and insulation methods lessens the environmental impact of a house and minimises the cost of living by reducing energy consumption (Howden-Chapman, et al., 2017).

4. CONCLUSION

The quality of housing has a significant impact on occupant's health, productivity, and comfort while substandard dwellings trigger many physical and psychological health issues to the inhabitants. Using a systematic review approach, this paper has provided a state-of-the-art analysis of housing quality indicators, with a total of 62 studies published between 1970 and 2019 included in the final analysis. Analysis of the content of these 62 studies revealed that measures for housing quality is an evolving research domain with the highest interest shown in journal articles in the last five years. The analysis identified

66 housing quality indicators across eight categories: dwelling unit architectural design characteristics, user comfort, housing site location and neighbourhood, building services, construction quality and stability, economic aspects, building maintenance, and sustainability.

As with housing supply shortage and deterioration of housing conditions due to ageing and lack of maintenance, the quality of houses has become a severe problem, especially among lower and upper-middle-income economies. However, very few studies have examined housing quality indicators in lower and upper-middle countries in the current review. In contrast, the highest number of studies were conducted in higher-income economies. Nevertheless, the existing housing quality indicators described in high-income countries can also be adapted to measure dwellings' quality in upper-middle- and lower-income countries. However, when assessing the housing quality base on the subjective factors like user comfort or housing site location and neighbourhood, the countries should define the thresholds according to their housing standards. The research analysis portrays that housing quality parameters are mainly described from the perspective of housing occupants when measuring their satisfaction, comfort, health, well-being and safety in the indoor living environment (67% in the current study). In contrast, only limited studies (33%) have developed quality indicators checklists by attaining the perspectives of experts. Further research can also look at developing or updating the housing quality indicators by obtaining insights from construction, housing and health professionals.

The paper provides a state-of-the-art systematic review of literature on housing quality indicators. The insights derived from this analysis provide a full picture of the categories and indicators for a quality house and the geographical distribution of categories. Such an understanding can be used as a knowledge base for researchers to assess residents' satisfaction, comfort, safety and health in the indoor living environment. Since these indicators are essential determinants of a quality house, architects and engineers can integrate these features at the design and construction stages in upgrading the conditions of dwellings while satisfying occupant's comfort and quality of life. The identified quality indicators can also assist homeowners and tenants in making informed decisions on buying or renting a property. Moreover, governments can develop housing quality standards using these indicators to evaluate dwelling conditions because housing rating systems allow countries to enhance the quality or standard of existing and new dwellings.

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6. APPENDIX A

No	Criteria
1	Question / objective sufficiently described?
2	Study design evident and appropriate?
3	Context for the study clear?
4	Connection to a theoretical framework / wider body of knowledge?
5	Sampling strategy described, relevant and justified?
6	Data collection methods clearly described and systematic?
7	Data analysis clearly described and systematic?
8	Use of verification procedure(s) to establish credibility?
9	Conclusions supported by the results?
10	Reflexivity of the account

Rasanjana, H.P. and Allis, C., 2022. Implementing Safe Working Cycle (SWC) concept amidst the COVID-19 crisis in Sri Lanka. In: Sandanayake, Y.G., Gunatilake, S. and Waidyasekara, K.G.A.S. (eds). *Proceedings of the 10th World Construction Symposium*, 24-26 June 2022, Sri Lanka. [Online]. pp. 545-557. DOI: https://doi.org/10.31705/WCS.2022.44. Available from: https://ciobwcs.com/2022-papers/

IMPLEMENTING SAFE WORKING CYCLE (SWC) CONCEPT AMIDST THE COVID-19 CRISIS IN SRI LANKA

H.P. Rasanjana[1] and Chamari Allis[2]

ABSTRACT

The phenomenon of COVID-19 has introduced critical challenges in the architecture, engineering, and the entire construction industry. A safe Working Cycle is a Japanese concept. It incorporates to enhances the effective implementation of safety management systems, thereby helping to prevent health and safety issues. This research mainly aims at identifying the strategies for overcoming barriers to implementing the Safe Working Cycle (SWC) concept during the COVID-19 pandemics in Sri Lanka. The research study focused more on reducing health-related illnesses caused by COVID-19 than on the other physical safety issues at the construction site. In such a critical health issue, the protection of human resources, an essential part of the construction industry, should be prioritized. The aim of the Study was reached through the sequential mixed method. The semi-structured expert interviews were initially conducted, and after that questionnaire survey was achieved among health and safety officers in construction projects in Sri Lanka. In the semi-structured interviews, data were analyzed using Nvivo thematic analysis software and questionnaire survey; M.S. Excel analyzed the collected data. Following the findings, several potential barriers were arisen to implementing the SWC concept in the Sri Lankan construction industry: including limited Budget allocation, poor safety attitude, limited land space, strict project schedules, and unawareness of workers. Further, this Study also indicated several potential practical strategies to overcome these barriers identified for SWC implementation. Such as; Implementing the COVID-19 bio bubble concept, Organizing regular toolbox meetings, demonstrating sign boards specific to this new concept, arranging separate systematic time slots, build-up a good communication network. The safe Working Cycle (SWC) is not currently practised in Sri Lankan construction culture. However, health and safety professionals are familiar with almost every aspect of the Safe Working Cycle (SWC); therefore, it is possible to put this into practice in the Sri Lankan construction industry.

Keywords: *Construction Safety; COVID-19; Safety Barriers; Safe Working Cycle; Strategies.*

1. INTRODUCTION

Global Pandemic situations are not a new phenomenon. Regional and global pandemic situations have occurred at various times throughout history. In the last century, the world faced various pandemics, such as SARS in 2002, Swine flu in 2009, and Ebola in 2014. The impact of large-scale pandemics is high and spreads rapidly, regionally and globally

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(Jordà, et al., 2020 and Stephany, et al., 2020). Today, the world is facing a critical pandemic situation. It is the COVID-19 virus that is rapidly spreading and is currently a major global issue. (WHO, 2021). These conditions have a massive effect on the social

and economic sector of Srilanka. It is a significantly uncertain situation. In Sri Lanka and the world industry culture, the health and safety hazards of the construction industry are high compared to other sectors (Rameezdeen, et al., 2006). According to Nawi, et al. (2016), there is a considerable requirement for health and safety in the construction industry. The main reason for this is that direct human resource involvement is relatively high. They recommended that the best solution establish a proper health and safety management system. It is crucial during this critical time if the construction industry is to survive a deadly virus such as COVID-19.

Chan and Choi (2015) further emphasized that an effective way to do this is to implement the concept of a Safe Working Cycle (SWC) in the construction industry. Chan and Hung (2013) indicated that the Safe Working Cycle concept (SWC) is a methodology introduced in Japan to regulate the daily working process related to health and safety. This research has based on current pandemic health issues in Sri Lanka. Although the Safe Working and safety in the Sri Lankan construction industry (Mendis, et al., 2017). Therefore, Darshana (2017) identified that the traditional safety management systems followed in the Sri Lankan context have not been very successful in satisfying the construction industry's fundamental health and safety requirements, modifying existing tools, and applying a new safety management tool. In this critical pandemic situation, SWC could be extraordinarily prudent in mitigating the prevailing unsafe working environment in the Sri Lankan construction industry. Therefore, this research investigates the practical strategies to overcome barriers to implementing the Safe Working Cycle (SWC) concept during the COVID-19 pandemic in Sri Lanka.

2. IMPACT OF A COVID-19 PANDEMIC ON HEALTH ASPECTS IN THE CONSTRUCTION INDUSTRY

Human activities related to the construction industry have been limited for a short time due to the incredible speed of the COVID-19 virus (Congressional Research Service, 2021). This COVID-19 health issue has affected the current economy of Sri Lanka. Sri Lanka's current economy is mainly dependent on exports, tourism, foreign employment, and the industrial sector. Annual Report (2020) in Sri Lanka further highlighted the GDP contribution of the industrial sector, which is a major sector, shows a decline in 2020 compared to 2019. In 2019-26.4% and 2020-25.5%.

The construction industry in Sri Lanka has to face many risks due to the COVID-19 pandemic situation. Further, Vithana, et al. (2020) illustrated that this pandemic situation had caused many health issues in the construction industry, posing huge economic barriers and risks. Such as damage to existing building raw materials, labour shortage, delays in payments by clients, rental cost for office buildings and hired equipment, plants, and machinery, risk of bankruptcy, and risk of termination of projects. Economic impacts and health-related impacts are also interconnected in the whole industry culture. According to the Congressional Research Service, 2021, due to the increase in human activities and the inevitable need for a workforce compared to other industries, the health problems caused by this COVID-19 pandemic have a significant impact on the overall construction project performance. Many countries, including Britain, are currently allocating extra money to control the COVID-19 pandemic in the construction industry. The labour force must be reduced in Sri Lanka and other parts of the world due to the health guidelines controlling COVID-19 (Wimalaweera, 2020).

Bloom et al. (2005) stated that as the construction industry deals mainly with foreign investment, the pandemic will severely impact construction projects' overall economy and future investment. For example, according to Harinarain and Haupt (2014), while the construction industry in South Africa was at risk of spreading AIDS and HIV, its employees were at a higher risk of Infecting the diseases. Further, they added that the ever-changing workforce was a significant factor in spreading the disease. In such a critical health or safety issue, the protection of human resources, an essential part of the construction industry, should be prioritized. Chan and Choi (2015) further emphasized that an effective way to do this is to implement the concept of a Safe Working Cycle (SWC) in the construction industry.

3. IMPLEMENTATION OF THE SAFE WORKING CYCLE (SWC) CONCEPT

The Real Estate Developers Association of Hong Kong and The Hong Kong Construction Association (2005) also identified that Safe Working Cycle (SWC) Concept is the most effective and convenient way to promote construction health and safety. Chan and Hung (2013) indicated that the main objective of the Safe Working Cycle concept is to improve construction safety and health culture. Further, create a conducive environment for working employees. The SWC concept was first introduced to Japan in 1982 by the Japan construction safety and health association for construction companies. This concept has been practically implemented in Japan for over 20 years (Environment Transport and Works Bureau, 2002). The Safe Working Cycle is a well-planned, scheduled event program with specific targets/goals set daily, weekly, or monthly (Occupational Safety and Health Council Hong Kong, China., 2002). They further emphasized that implementing this concept ensures that the construction site is safe and hygienic. The process is repeated daily with the awareness of the construction workers for both health and safety practices (Figure 1).

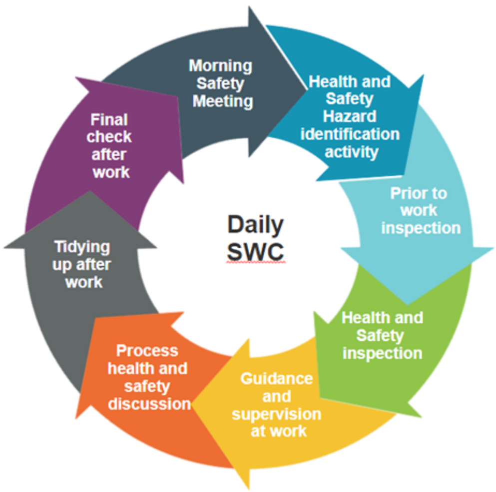

Figure 1: The daily SWC

Sources: Chan and Choi (2015); Occupational Safety and Health Council Hong Kong (2002); Lam, H. (2000)

Ozaka (2000) indicated that another goal of implementing the SWC concept is to increase cooperation in security activities between contractors and subcontractors, build mutual trust between supervisors and construction workers, and encourage proper communication skills. Further Occupational Safety and Health Council of Hong Kong, China (2002) stated that this concept trains construction workers to recognize, accept, and execute safety messages. In addition, it ultimately transforms the construction environment into a systematic proper safety culture.

The SWC concept is primarily a tool for ensuring the health and safety of the industry, which is mainly subject to systematic inspections, and oversight and supports the implementation of frequent safety committee meetings (Lam. H, 2000). According to Occupational Safety and Health Council Hong Kong, China (2002), implementing a management system with health and safety policies could change the management of traditional companies and minimize overall safety issues and other related issues. The SWC concept can be implemented in any problematic situation, and by putting it into practice, significant progress has been made in the safety and health aspects of construction projects. It also significantly reduces the number of accidents (Occupational Safety and Health Council Hong Kong, China, 2002). Further, they illustrated that in the current world, China, Hong Kong, Singapore, the United Kingdom, and Japan are increasingly adopting the Safe Working Cycle concept in their construction projects. The United Kingdom and Hong Kong governments make significant contributions to implementing the SWC concept. Thus, passing on this new knowledge to construction workers, even books also have been published.

Implementing the Safe Working Cycle concept in the construction industry benefits the client and the contractor (Choi, et al., 2011). In addition, they emphasized that the SWC concept is an effective tool to improve the safety of the entire construction industry by allowing contractors to carry out construction work safely and without any hindrance. Chan and Choi (2015) reported that implementing the SWC concept in construction projects will benefit the entire construction project and its employees. Such as having a better understanding of site conditions and daily activities, facilitating safety-related communication between site management staff members and construction workers, making every construction worker better aware of safety, improving the safety practices of construction workers, to minimize the cost of health and safety, introduce a better site safety system and take steps to prevent an accident before it occurs, promote the reputation and image of the construction company or organization involved in the project. In addition to the above, a few benefits have been identified and included in this literature. Reducing the accident rate on the construction site, improving safety communications (Occupational Safety and Health Council Hong Kong, China., 2002), and improving health and safety-related training (Chan, et al., 2005). Strengthen the safety awareness of the construction site and create a hygienic environment in any problematic situation quickly (Tse S.L, 2005).

Mendis, et al. (2017) indicated that one could create a safe working environment by incorporating the concept of the Safe Working Cycle in the construction culture of Sri Lanka. They also elaborated that implementing this Safe Working Cycle concept in all construction industries globally, including Sri Lanka, can bring many benefits in terms of health and safety. Thus, attention should be paid to the barriers to implementing this concept and related health and safety issues. It was, therefore, emphasized that the implementation of this concept would go a long way in reducing mortality and hazard rates. According to (Mendis, et al., 2016:2017), although the concept of the Safe Working Cycle is not very popular in Sri Lanka, it has been pointed out can gain many opportunities by implementing this concept in practice in the construction industry in Sri Lanka. Further, they also stated that many foreign investment projects are currently being implemented in Sri Lanka. This expert knowledge could also help to promote this concept in the construction culture of Sri Lanka.

3.1 BARRIERS TO IMPLEMENTING SWC

Chan and Hung (2013) indicated that the Hong Kong construction industry had faced various barriers and risks in implementing the concept of a Safe Working Cycle. The construction industry in Sri Lanka also faced various barriers and risks in establishing a new safety management system (Darshana, 2017). They further emphasized that various barriers and risks are involved in establishing a new health and safety management concept in Sri Lanka. Due to the traditional safety management techniques currently available in the construction industry in Sri Lanka, many people in the construction industry are reluctant to adopt a new concept.

Mendis, et al. (2016:2017) highlighted that the main barrier to implementing the safe working cycle concept in the construction industry is the tight work schedule on the site. In addition, they also indicated that there are significant barriers to the implementation of the safe working cycle concept in the construction industry in Sri Lanka. Such as low literacy level of site workers, poor health and safety attitude of site workers, Inadequate health and safety attitude of top managers, poor participation in SWC activities, less awareness of the SWC concept, and budget allocation issues. Mendis, et al. (2017) also emphasized that the need and suitability of implementing the Safe Working Cycle concept in the construction industry in Sri Lanka are very high. Further, they indicated that this safety management concept would significantly improve individual safety behaviour and would potentially gain Sri Lanka's safety construction culture to an adequate level. According to (Choi, et al., 2012), there are three main categories of common barriers to implementing a new safety management system on construction sites. Such as challenges related to workers, challenges related to contractors, and problems related to the practices of subcontractors.

Given the cited above, the concept of a Safe Working Cycle (SWC) is an essential tool that provides several benefits to the health and safety sectors of the construction industry. Due to the current pandemic of COVID-19 in the construction industry and around the world, the implementation of the SWC concept in the construction industry is a timely necessity. This research focused more on reducing health-related illnesses caused by COVID-19 than on the other physical safety issues at the construction site. As mentioned in section 1, statistics on accidents and health-related illnesses describe the construction industry in Sri Lanka as a vital sector that needs to be overhauled in the current health and safety management system. Furthermore, the need for this health and safety management system is well illustrated by the impact of the current COVID-19 pandemic on the construction industry, as described in section 2. The construction industry in Sri Lanka can move forward without any interruption if proper attention is paid to the new barriers and inherited barriers in implementing this concept during the current pandemic season. Therefore, this research aimed to Identify the practical strategies to overcome barriers to implementing this Safe Working Cycle concept during the COVID-19 pandemic in Sri Lanka. In literature review did not find significant new barriers and strategies based on this research aim.

4. RESEARCH METHODOLOGY

The aim of the Study was reached through the sequential mixed method. According to Creswell (2009), both qualitative and quantitative forms have been included in mixed-method to enhance the overall research strength. The literature survey has identified several common barriers to implementing the safe working cycle (SWC) concept in the construction industry in Sri Lanka. These are common barriers that occur in a construction environment with normal conditions. (Before the COVID-19 pandemic situation). This research was studied related to the COVID-19 pandemic. It investigated barriers to implementing this safe working cycle concept during the pandemic and identified practical strategies to overcome those barriers. In the sequential mixed method, the semi-structured interviews were initially conducted, and after that questionnaire survey was achieved. Semi-structured interviews were conducted to collect necessary data with the support of five subject matter experts from the construction industry, health, and safety management position (more than ten years of experience). Phenomenology was used to capture the people who participated in this interview's professional experience, behaviour, and opinions. The semi-structured interviews were transcribed, and code-based thematic analysis was performed. The data collection was analyzed using the NVivo (Thematic analysis software) and included encrypting all data before identifying and reviewing two major themes (barriers and strategies). The questionnaire survey aimed to identify the significant barriers and strategies (determine the priority) of the safe working cycle concept during the COVID-19 pandemic in Sri Lanka. The barriers and strategies identified in the semi-structured interview were classified according to a priority sequence. This survey aims to increase the accuracy of the data collected.

The questionnaire survey was conducted with thirty (30) numbers of health and safety officers. Participants in the questionnaire survey were selected subject to the following criteria: These thirty (30) numbers of safety officers should be engaged in projects carried out by contractors with a grade of C1 or higher for building construction. C1 is a classification of contractors in the Sri Lankan context by the construction industry development authority (CIDA) of Sri Lanka. All major contractors in Srilanka belong to categories C1 and above). Respondents filled the google form with great interest in understanding the Safe Working Cycle (SWC) and achieved a 77% response rate. The survey consisted mainly of 10 questions measured on a 5-points Likert scale. The Likert scale of 1 to 5 was used in the data collection. Where 5 indicates a very high level of priority and 1 indicates a very low level of priority.

Furthermore, four multiple-choice questions also consisted in this survey. In the questionnaire survey, collected data were analyzed using percentage statistics for each barrier and strategy. The collected data were systematically processed before analysis. Data analysis was done by using M.S. Excel.

5. FINDINGS OF SEMI-STRUCTURED INTERVIEWS

Semi-structured interviews were conducted to identify the barriers to implementing the Safe Working Cycle concept during the COVID-19 pandemics in Sri Lanka and the strategies to overcome these barriers. As shown in Table 1, five experts from the management positions were selected for expert interviews based on their knowledge and experience in the relevant field of construction health and safety.

All the respondents who participated in these semi-structured interviews had good knowledge and understanding of the SWC concept. Some respondents have gained knowledge and experience of the SWC concept through their specialized foreign projects (e.g., the Port city project). Some of the respondents were persons who had acquired knowledge and experience while employed abroad. (e.g., gulf countries Oman, Qatar, Japan, Singapore, China, etc.). Further, training workshops and CPD sessions have helped some respondents understand the SWC concept. It was revealed in this interview that many respondents have heard of this concept as a Site Safe Cycle. All respondents indicated that this SWC concept is not currently practised in the construction industry in Sri Lanka. However, they emphasized that some practices related to the SWC concept were still in use. All the respondents pointed out that the SWC concept is a timely necessity to minimize the impact of the construction industry in Sri Lanka during this COVID-19 period.

Table 1: Details of Respondents

Respondent	Designation	Years of experience in relevant field
A	Executive Health, Safety and Environment	16 years
B	Health, Safety, and Environment (HSE) Manager	12 years
C	Health, Safety, and Environment (HSE) Manager	20 years
D	Health and Safety Engineer	15 years
E	Health, Safety, and Environment (HSE) Assistant Manager	10 years

5.1 BARRIERS TO IMPLEMENTING SWC

This research is based on a new concept. General barriers also will be created when implementing a new concept in Sri Lanka. That is a typical situation in every country. These general barriers were identified through a literature survey and semi-structured interviews. In addition, based on expert interviews, several new barriers caused by COVID-19 were added to this Study. The identified barriers are listed in Table 2.

All respondents highlighted that lack of health and safety budget allocation is a major barrier to implementing the Safe working cycle concept (SWC). Proper budget allocation is a significant factor in the success of a construction project. All processes in the construction industry depend on the budget. So, all parties involved are concerned with cost reduction and profit maximization. Therefore, focus mainly on profit and not on health and safety practices. Respondent B further stated that the contractor would discontinue the health and safety activities due to the target profit at the initial stage. All respondents believed that important functions of SWC may not be functional to save time and money. They cited the current economic crisis caused by COVID-19 as the main reason for this. Respondents A and C mentioned that the strict project/work schedule is another major barrier to implementing the SWC concept. A tight work schedule in a construction project is caused by the need for the contractor to deliver the project to the client within the agreed time frame. Further, to avoid paying for additional costs due to unforeseen delays. Therefore, the respondents pointed out that regular toolbox meetings, health and safety workshops, and inspections are often not carried out due to these strict schedules.

Table 2: Reexplored barriers and strategies on SWC implementation

Barriers	Strategies
Limited Budget allocation	Implement the COVID-19 bio bubble concept
Lack of officers with good knowledge and experience	Organize regular toolbox meetings.
Limited land space.	Demonstrate sign boards specific to this new concept.
Strict project schedules	Organize workshop series on this new concept.
Increased contact with the external environment.	Manage manpower properly.
Poor safety attitude and low literacy level of workers	Monitor 100% on how this new concept will work.
Unawareness of workers	Assign appropriate responsibility to sub-contractors. Arrange separate systematic time slots.
Labour shortage.	Buildup a good communication network.
Lack of interest in the new concept from top managers.	
Poor subcontracting habits.	

Respondents A, C, D, and E stressed that the unawareness, low literacy level, and poor health and safety attitude of Sri Lankan workers are the main reasons for these barriers to implementing a new concept. They indicated that non-attendance at health and safety meetings also affected limited access to the opportunity to obtain health and safety knowledge. Respondent C highlighted that the limited land or site space could be a significant challenge to the practical implementation of the SWC concept. He also indicated that required a considerable area to do regular toolbox meetings, health and physical exercise before work in the morning, and all site staff accommodation purposes. All respondents emphasized that due to the COVID-19 pandemic situation, all site staff officers and workers should pay special attention to accommodation. Respondents A and E further stated that due to the limited construction land area. Working in urban areas, including Colombo, could be a significant challenge.

Moreover, respondent D indicated that different work schedules affect another barrier to implementing the SWC concept. Such as, many employees work without proper time management. This barrier also could disturb the smooth operation of the SWC concept. Further, respondents A and C believed that the lack of experienced officers in the construction industry in Sri Lanka was a barrier to implementing a new concept such as SWC. Respondent E further mentioned that poor subcontractors' habits and a labour shortage are significant barriers to implementing the SWC concept. He also pointed out that the lack of human resources due to the COVID-19 pandemic was a major barrier. Although the Sri Lankan construction community is not much aware of this SWC concept, all experts mentioned that. However, health and safety professionals are familiar with almost every aspect of SWC; therefore, it is possible to put this into practice in the Sri Lankan construction industry by providing basic training on the concept.

5.2 STRATEGIES FOR IMPLEMENTING SWC

This research study aimed to identify the practical strategies to overcome barriers for SWC during the COVID-19 pandemic in Sri Lanka. Based on an expert survey, all the strategies added to the above list are indicated in Table 4.2. All these strategies are based on the current COVID-19 pandemic-related strategies and general strategies (General strategies used to overcome the barriers when implementing a new concept in a normal situation.) All respondents stated that organizing regular toolbox meetings is an important strategy for maintaining a good health and safety culture. They point out that this regular toolbox meeting can raise health and safety awareness, which is also important for improving workers' and staff members' attitudes and literacy levels. Respondent B strongly believed that the bio-bubble concept was currently used in many industries; they indicated this strategy should also be suitable for implementation on the construction site. All respondents emphasized that this important strategic reason would help protect the human resource in this pandemic situation. They highlighted that this strategy is vital in implementing this new concept during this critical situation.

Interviewees C, D, and E indicated that demonstrating sign boards specific to this new concept is an essential strategy for the construction site at the initial stage. They believed that the display of these signboards on the construction site could raise the awareness of the workers to a very high level. Respondents A and C mentioned that Organize workshop series on this new concept for staff members such as; supervisors, technician officers, managers, etc. They indicated that this strategy is also important to better understand this new concept and easily pass that knowledge on to workers. Moreover, respondent D indicated that the manage manpower properly is another strategy to overcome those barriers. Further, as all experts mentioned, arranging separate systematic time slots is an important strategy for implementing new concepts. And respondent B emphasized that this new concept could be easily implemented by building a systematic communication network between everyone on the construction site. In addition, he also indicated that assigning appropriate responsibility for sub-contractors is one of the strategies to implement this new concept. However, all respondents mentioned that even in pandemic situations like COVID-19, the barriers to implementing a new concept (SWC) could be overcome using the strategies discussed above. The respondents agreed that the Safe Working Cycle (SWC) concept is functionally important and appropriate for the Sri Lankan context. All experts emphasized that as many foreign investment projects are being implemented in Srilanka today, all those involved in the construction industry will gain more knowledge and experience on the SWC concept. It has the potential reason to promote this concept in Srilanka. Furthermore, they emphasized that the SWC concept is a timely necessity factor due to the current COVID-19 pandemic.

6. FINDINGS OF QUESTIONNAIRE SURVEY

The questionnaire survey aimed to identify the significant barriers and strategies (determine the priority) of the Safe Working Cycle concept during the COVID-19 pandemic in Srilanka. The barriers and strategies identified in the semi-structured interview were classified according to a priority sequence (refer Tables 3 and 4). This survey aimed to increase the accuracy of the data collected.

The questionnaire survey was conducted by thirty (30) numbers of safety officers. These thirty (30) numbers of safety officers should be engaged in projects carried out by contractors with a grade of C1 or higher for building construction. Participants in the questionnaire survey were selected subject to the following unique criterion.

(C1 is a classification of contractors in the Sri Lankan context by the construction industry development authority (CIDA) of Sri Lanka. All major contractors in Sri Lanka belong to categories C1 and above)

Table 3. Priority sequence of particular barriers

	Percentage					
	Very low level priority	**Low level priority**	**Medium level priority**	**High level priority**	**Extremely high level priority**	**Total**
Limited Budget allocation	0%	0%	13%	30%	57%	100%
Lack of officers with good knowledge and experience	0%	3%	27%	53%	17%	100%
Limited land space.	7%	10%	17%	20%	43%	100%
Strict project schedules	0%	0%	7%	40%	53%	100%
Increased contact with the external environment.	60%	23%	17%	0%	0%	100%
Unawareness of workers	3%	10%	33%	23%	30%	100%
Labour shortage.	27%	30%	43%	3%	0%	100%
Lack of interest in the new concept from top managers.	13%	37%	50%	3%	0%	100%
Poor subcontracting habits.	20%	57%	23%	0%	0%	100%

The majority of those involved in the questionnaire survey identified limited budget allocation as the most priority barrier; 57% of participants have identified it as an extremely high-level priority. In addition, the respondents have identified two key priority barriers. 53% of participants identified strict project schedules as an extremely high-level priority, and participants also were identified limited land spaces as another major barrier. Participants identified that a lack of officers with good knowledge and experience was not an influential priority factor. They identified it as a high-level priority in the construction culture of Sri Lanka. All participants mentioned that unawareness of workers, the labour shortage, and lack of interest in the new concept from top managers was identified as related to the medium-level priority. In addition, increased contact with the external environment and poor subcontracting habits were identified under low-level priority.

The majority of those involved in the questionnaire survey identified organizing regular toolbox meetings as the most priority strategy; 60% of participants identified it as an extremely high-level priority. In addition, the respondents have identified two key priority strategies. Demonstrate sign boards specific to this new concept identified 43% of participants as an extremely high-level priority. Participants were identified to implement the COVID-19 bio bubble concept as another major strategy. This strategy also identified the timely necessity factors.

Table 4. Priority sequence of particular strategies

	Percentage					
	Very low -level priority	**Low-level priority**	**Medium-level priority**	**High-level priority**	**Extremely high-level priority**	**Total**
Implement the COVID-19 bio bubble concept	0%	10%	30%	43%	17%	100%
Organize regular toolbox meetings	0%	0%	17%	23%	60%	100%
Demonstrate sign boards specific to this new concept	0%	3%	23%	30%	43%	100%
Organize workshop series on this new concept	3%	13%	47%	30%	7%	100%
Manage manpower properly	0%	27%	57%	17%	0%	100%
Monitor 100% on how this new concept will work	7%	53%	17%	13%	10%	100%
Assign appropriate responsibility for sub-contractors	30%	50%	20%	0%	0%	100%
Arrange separate systematic time slots	0%	10%	63%	20%	7%	100%

All participants mentioned that organizing workshop series on this new concept, managing manpower properly, and arranging separate systematic time slot; these strategies were identified as related to the medium level priority. In addition, assign appropriate responsibility for sub-contractors and Monitor 100% how this new concept will work; these strategies were identified under low-level priority.

The majority of those who participated in the questionnaire survey also expressly responded that this SWC concept is important and needs to be implemented at this critical moment.

7. CONCLUSION

The research study mainly aimed at identifying the strategies to overcome barriers for implementing the Safe Working Cycle (SWC) concept during the COVID-19 pandemic in Sri Lanka. The Safe Working Cycle concept (SWC) is a construction site health and safety management tool. Today, the world is facing a terrible pandemic situation. It is the COVID-19 virus that is rapidly spreading and is currently a major global issue. The research focused more on reducing health-related illnesses caused by COVID-19 than on the physical safety issues at the construction site. The current situation in the world is that health needs are more important than the economy. In such a critical health issue, the protection of human resources, an essential part of the construction industry, should be prioritized. The research emphasized that the SWC is not currently practised in Sri Lankan construction culture. However, health and safety professionals are familiar with almost every aspect of SWC; therefore, it is possible to put this into practice in the Sri Lankan construction industry by providing basic training on the concept.

The literature survey finds that the construction community in Sri Lanka can gain many benefits from implementing the SWC concept. Such as reducing the accident rate on the construction site, improving safety communications, strengthening the safety awareness of the construction site, creating a hygienic environment in any problematic situation, etc. However, findings from the expert interviews reveal several potential barriers to implementing the SWC concept in the Sri Lankan context. In addition, several new barriers caused by COVID-19 were added to this study, such as; limited budget allocation, poor safety attitude, the low literacy level of workers, lack of officers with good knowledge and experience, limited land space, strict project schedules, unawareness of workers, lack of interest in the new concept from top managers, Poor subcontracting habits, labour shortage. Further, this research study included several potential practical strategies to overcome barriers to the SWC concept in the Sri Lankan context. These strategies are based on the current COVID-19 pandemic-related and general strategies. Such as; implementing the COVID-19 bio bubble concept, organizing regular toolbox meetings, demonstrating sign boards specific to this new concept, managing manpower properly, arranging a separate systematic time slot, building up a good communication network, and assigning appropriate responsibility for sub-contractors.

This research study reveals that effective implementation of the Safe Working Cycle (SWC) concept during the current pandemic period can enhance the health and safety behaviours of the people involved in construction projects, thereby building a better health and safety Culture. All expert interview respondents agreed that the Safe Working Cycle (SWC) concept is functionally essential and appropriate for the Sri Lankan context. Furthermore, they also emphasized that the SWC concept is a timely necessity factor due to the current COVID-19 pandemic.

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IMPORTANCE OF A VALUE ASSESSMENT TOOL IN REGENERATING A CIRCULAR BUILT ENVIRONMENT IN SRI LANKA

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ABSTRACT

Attribute to the rapid expansion of the built environment, excessive resource consumption and waste generation aligned with the corresponding linear economy practices have impacted the preservation of the ecosphere. In addressing the shortcomings of the linear economy, the circular economy concept was introduced by prioritising the circular value streams of the resources which minimises resource extraction and waste generation. However, environmental concerns are often disregarded in construction processes where the priority is given to the cost and economic return of construction applications. Simultaneously, the absence of a proper methodology in assessing the economic aspects of circular economy principles is apparent in the built environment sector. Therefore, this study aimed to assess the importance of a proper value assessment tool in shifting to a circular built environment in Sri Lanka. Instigating from a literature survey, the existing knowledge on the study area was synthesised. A qualitative approach was followed in the empirical study where semi-structured interviews were conducted with ten experts in the field of circular economy in Sri Lanka. The manual content analysis technique was followed in analysing the collected qualitative data. The findings revealed that the extremely low maturity of circular economy practices in the Sri Lankan construction sector is mainly caused by the absence of a proper value assessment tool. Therefore, the introduction of a proper value assessment tool is important for circular built environment experts to encourage the fellow construction community towards the transition to a circular built environment in Sri Lanka.

Keywords: *Built Environment; Circular Economy; Value Assessment Tool.*

1. INTRODUCTION

The contradictory relationship between the development of the built environment and the preservation of the ecosystems has resulted in numerous negative consequences which complicate the entire process of environmental conservation (Bao, et al., 2019). The existing linear economy practices of extracting, producing, using and disposing of natural resources are considered to be the key reason which stimulates the ecological degradation and therefore, the circular economy concept was introduced to encourage the practices of extracting, producing, using and reusing (Sariatli F., 2017). Simultaneously, the

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principles of the circular economy concept intend to reduce the excessive material consumption and waste generation resulting from the built environment creations by effectively delivering the resources in circular value streams (Hossain, et al., 2020). Thus, a circular economy directly contributes to several philosophies primarily including the concept of sustainable development and the twelfth goal of the 17 Sustainable Development Goals introduced in the United Nation's 2030 Agenda for Sustainable Development, i.e. "responsible consumption and production" (Rodriguez-Anton, et al., 2019).

In addition to environmental sustainability, a circular economy contributes to social and economic sustainability through its peculiar applications in the construction industry (Wijewansha, et al., 2020). However, the absence of a proper methodology in assessing the economic sustainability provided by the circular economy principles is evident all over the globe (Saidani, et al., 2017). Specifically, due to the financial uncertainties, circular economy applications are often disregarded since the cost and economic return are generally given priority when making decisions in construction projects (Adams, et al., 2017). Thus, Hossain, et al. (2020) affirm that a special concern is required in addressing the lack of robust criticisms on the establishment of proper methodologies in assessing the economic value of circular economy practices. Simultaneously, Gorecki, et al. (2019) highlight that the establishment of structured methodologies in assessing the value for money related to circular economy applications can ensure a successful transition to a circular built environment.

Followingly, the role of a value assessment tool in economically assessing the circular economy applications in the construction industry directed this study for further exploration. Accordingly, this study aims to investigate why a value assessment tool is important in regenerating a circular built environment in Sri Lanka.

2. LITERATURE REVIEW

2.1 CIRCULAR ECONOMY AND THE BUILT ENVIRONMENT

Rapid industrial development and the corresponding urbanisation have stimulated the advancement of the construction sector while negatively influencing the conservation of the ecosphere (Govindan and Hasanagic, 2018). Relatively, the construction industry is identified as a major contributor to resource exploitation, waste generation, and toxic emissions due to its linear economic patterns (Gorecki, et al., 2019). The construction sector is accountable for more than 30% of the natural resource extraction while accounting for 25% of the global waste generation (Benachio, et al., 2020). By the early 20th century, the construction sector was accentuated as the most unsustainable industry in the globe (Núñez-Cacho, et al., 2018). Consequently, by the 21st century, the need for new concepts and strategies to lessen the impact of the linear built environment on the eco-sphere became alarmingly apparent (Osobajo, et al., 2020).

Accordingly, the concept of circular economy was introduced as a measure to replace the linear economic pattern with the circular economic strategies of extracting, producing, consuming and reusing products (Lieder and Rashid, 2016). The open-loop linear model which results in a higher degree of waste production while releasing toxic emissions can be replaced by the closed-loop circular economy model (Sauve, et al., 2016). According to Ellen MacArthur Foundation (2022), the circular economy concept is developed on the basis of the three principles of eliminating waste and pollution, circulating products and materials and regenerating nature. Therefore, industry specialists recognised the circular economy concept as a driver to sustainable development. (Anastasiades, et al., 2020).

Simultaneously, Pomponi and Moncaster (2017) declare that a circular built environment can create a link between environmental and economic prosperity and Heshmati (2017) pinpoints that economic growth can be stimulated by the effective use of circular economy principles. According to Ellen MacArthur Foundation (2020), the circular economy concept can provide the economic benefits of cost reduction, revenue increments, and risk reduction. Thus, Finch, et al. (2021) identify the circular economy as a concept that eradicates the inverse relationship between economic development and ecological preservation. Importantly, Gorecki, et al. (2019) state that circular economic strategies are gaining popularity among construction industries of many nations due to their potential in ensuring sustainable development by preserving the environment for future generations.

2.2 CIRCULAR ECONOMY APPLICATIONS IN THE SRI LANKAN CONSTRUCTION INDUSTRY

The developing economies with a higher growth rate also have a higher rate of ecological degradation (Lee, et al., 2020). Siew (2019) reports that the construction material footprint of developing countries is rapidly increasing. Being one of the developing nations, Sri Lanka is also encountering critical environmental issues due to the continual development of the built environment sector (Abeydeera, et al., 2019; Kumanayake and Luo, 2018). More specifically, Bekchanov and Mirzabaev (2018) report that environmental pollution is high in urbanised areas e.g. Kandy and Colombo. Thus, ecological preservation concerning the built environment sector has become a key consideration in Sri Lanka (Wijewansha, et al., 2020).

According to Fort and Cerny (2020), most of the developed nations are successfully adhering to a circular economy, however, Yadav, et al. (2020) report that many developing nations e.g. Sri Lanka and India sustain a lower rate of success. Besides, Wijewansha, et al. (2020) assert that the acknowledgment of circularity principles in the Sri Lankan construction industry is currently at a primitive phase. It can be justified since many challenges e.g. lack of financial resources and public awareness hinder the successful implementation of a circular built environment in many developing and underdeveloped nations (Joshi, et al., 2018).

2.3 BARRIERS AND ENABLERS FOR CIRCULAR ECONOMY APPLICATIONS

Even though a circular built environment offers many benefits, shifting to a circular economy from a linear economy is still at a slower pace due to numerous challenges (Saidani, et al., 2017; Eberhardt, et al., 2020). Explicitly, the complexity of the processes in the construction industry has confronted adopting circularity principles for the built environment sector (Mhatre, et al., 2021). Besides, Hopkinson, et al. (2018) argue that moving towards a circular economy may cause conflicts within firms as the transition will affect the usual method of business operations. Thus, it is essential to comprehensively recognise the barriers related to legal, social, technological, and financial aspects concerning the transition to a circular economy (Gorecki, et al., 2019). Accordingly, Table 1 presents an assessment of the barriers that hinder the transition to a circular economy focusing on several contexts around the globe.

Table 1: Barriers to the transition to a circular economy

Barriers to a circular economy	**China**	**India**	**Sri Lanka**	**Taiwan**	**South Korea**	**Oman**	**Australia**	**New Zealand**	**UK**	**Spain**	**Netherlands**	**Italy**	**Ghana**	**Nigeria**	**Argentina**	**U.S.A**	**Canada**	**Mexico**
Lack of knowledge and awareness	[1]	[2]	[3]	[5]	[6]	[7]		[9]	[10]		[12]	[13]	[14]	[15]	[16]	[6]	[17]	[18]
Lack of industry communication and interest	[1]	[2]	[3]	[5]	[6]	[7]		[9]		[11]			[14]	[15]		[6]	[17]	[18]
Lack of support from the government	[1]	[2]		[5]		[7]	[8]			[11]	[12]	[13]		[15]			[17]	[18]
Lack of supportive legislation	[1]	[2]	[3]			[7]	[8]		[10]		[12]	[13]		[15]			[17]	[18]
Lack of financial incentives			[4]	[5]	[6]			[9]		[11]			[14]	[15]	[16]	[6]	[17]	[18]
Ambiguities regard to financial return and value assurance issues	[1]	[2]		[5]	[6]	[7]	[8]		[10]		[12]	[13]			[16]	[6]		
Higher implementation costs	[1]		[4]			[7]	[8]	[9]			[12]			[15]			[17]	[18]
Lack of an assessment tool to evaluate financial benefits		[2]					[8]		[10]		[12]			[15]				[18]
Technological boundaries	[1]	[2]	[4]			[7]	[8]		[10]	[11]	[12]			[15]	[16]			[18]
Quality assurance issues			[4]			[7]	[8]		[10]					[15]			[17]	

[1] (Zhang, et al., 2019) [2] (Gupta, 2019) [3] (Wijewansha, et al., 2020)
[4] (Bekchanov and Mirzabaev, 2018) [5] (Chang and Hsieh, 2019) [6] (El Asmar, et al., 2018)
[7] (Al Hosni, et al., 2020) [8] (Halog, et al., 2021) [9] (Low, et al., 2020)
[10] (Adams, et al., 2017) [11] (Ormazabal, et al., 2018) [12] (Springvloed, 2021)
[13] (Mura, et al., 2020) [14] (Virtanen and Kojo-Sakyi, 2018) [15] (Ogunmakinde, 2019)
[16] (Becerra, et al., 2020) [17] (Cantu, et al., 2021) [18] (Kellam, et al., 2020)

According to Table 1, it is evident that regardless of the context, the challenges are almost similar for a circular economy. Lack of community knowledge and awareness, lack of governmental support, technological boundaries, and ambiguities regard to financial return and value assurance issues are a few of the major barriers which need to be properly addressed to ensure a successful transition to a circular economy. On the other hand, the key enablers which influence a successful transition to a circular economy are presented in Table 2.

Table 2: Enablers for the transition to a circular economy

Enablers for a circular economy	Source (Reference Numbers are mentioned according to the list of authors in Table 1)
Strategies to increase community awareness and knowledge	[3], [4], [6], [8], [9], [10], [17]
Increased governmental support	[2], [4], [7], [13], [17]
Introduction of supportive legislation and industry standards	[2], [3], [8], [13], [15], [16], [17]
Increased industry collaboration	[4], [7], [17]
Introducing a tool for value assurance	[10], [12], [16]
Introducing financial incentives	[4], [5], [6], [9], [12], [17]
Innovations in technologies	[1], [8], [10], [16], [12]
Market development for secondary materials	[8], [9], [12], [15], [17]

Table 1 showed that the lack of knowledge and awareness of the circular economy principles is the most quoted barrier and Table 2 evidenced that the implementation of strategies to increase the community awareness and knowledge is one of the most quoted enablers of the transition to a circular built environment. Simultaneously, Agyemang, et al. (2019) state that community awareness and knowledge of the circular economy concept are negatively affected by the financial uncertainty of circular economy principles since it can be a cause that reduces the interest of the people in studying and experimenting with circular economy applications. Besides, due to the competitive nature of the construction sector, organisations are more inclined only toward the strategies which clearly offer a competitive advantage while ensuring a premeasured economic success and this negatively affects the rise of the circular economy concept (Gorecki, et al., 2019). El Asmar, et al. (2018) argue that the financial benefits are uncertain related to a circular built environment, and it drastically complicates the decision-making process of the project stakeholders. Thus, a tool for measuring the economic benefits of a circular economy is important in addressing the low community interest and awareness of circular economy principles which is a barrier that primarily hinders the rise of a circular built environment (Adams, et al., 2017; Benachio, et al., 2020). Therefore, in empowering an effective transition to the circular built environment, proper strategies and tools must be established to measure the value of the operations in terms of economic aspects (Gorecki, et al., 2019; Adams, et al., 2017).

2.4 THE NEED FOR A VALUE ASSESSMENT TOOL IN SHIFTING TOWARDS A CIRCULAR BUILT ENVIRONMENT

Economic value addition is a major project aim of many stakeholders and in adding economic value to a project, the aspects of time, cost, quality, project performance and project safety are considered (Witjaksana, et al., 2019). Among these aspects, Ibironke and Elamah (2011) pinpoint that the assessment of time, cost and quality is rather important during the design stage in increasing the total project value. At the same time, the introduction of a method for value assessment will be an incentive for the implementation of the circular economy concept as it will assist in identifying the economic gain in the dimensions of time, cost and quality from transferring to a circular economy (Heshmati, 2017). Accordingly, the absence of a tool complicates the process of measuring the overall economic benefit of shifting to a circular built environment (Núñez-Cacho, et al., 2018). Kirchherr, et al. (2018) argue that circular economy initiatives are comparatively expensive, and it further stresses the need for incentives.

However, according to Saidani, et al. (2017), various tools are introduced to evaluate the performance of circular models concerning environmental, organisational, and social performance. As reported by Sassanelli, et al. (2019), there are many tools and approaches e.g. Life Cycle Assessment (LCA), Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA), Multi-Criteria Decision Analysis (MCDA), Design for X, Input-Output (I-O) and Material Flow Analysis (MFA). Among these tools, LCA, I-O, and MFA can be considered the widely applied circularity assessment tools (Corona, et al., 2019). Nonetheless, most of the approaches are focused on environmental assessment, and the absence of a proper tool for the assessment of economic dimensions such as time, cost, and quality is a major barrier to the implementation of the concept (Saidani, et al., 2017).

Sanchez and Haas (2018) mention that linear applications will be continued by the industry community as the economic aspects are much clear in linear business models and it eases the overall project planning and decision-making process. Thus, Velte, et al. (2018) argue that value-focused approaches are essential concerning a rapid transition to a circular economy, and Saidani, et al. (2017) affirm that these approaches will positively inspire the community in moving from a linear economy to a more sustainable circular economy.

3. METHOD

This study addresses the following exploratory question “why a value assessment tool is important in regenerating a circular built environment in Sri Lanka”. The exploratory nature of this study directs a qualitative approach while centralising around the views, opinions, and experiences of the construction industry professionals related to the establishment of circular economic principles in the construction industry (Ward, et al., 2018). Besides, interviews were selected as the data collection tool since the interview approach assists in acquiring comprehensive findings for exploratory studies (Jain, 2021). Accordingly, an expert interview survey was conducted where 10 experts in the field of the circular built environment were selected using the non-probability purposive sampling method. The consideration was given to selecting the professionals in both construction consulting and contracting firms as well as academia experts in the field of the circular built environment. The profiles of the respondents are presented in Table 3.

Table 3: Profiles of the respondents

Respondent	Discipline	Years of Industry Experience	Field of Expertise
R1	Chartered professional engineer, chartered quantity surveyor	30 years	Consultancy
R2	Chartered civil engineer	10 years	Consultancy
R3	Quantity surveyor	7 years	Consultancy
R4	Chartered architect	6 years	Consultancy
R5	Chartered architect	5 years	Consultancy
R6	Project manager	30 years	Contracting
R7	Chartered quantity surveyor	15 years	Contracting
R8	Senior lecturer	20 years	Academia
R9	Senior lecturer	17 years	Academia
R10	Senior lecturer	18 years	Academia

To fulfil the requirement of the context-specific findings for this study, the data were collected limited to the Sri Lankan context. Besides, ten semi-structured expert interviews were conducted until the saturation of data since the point of data saturation indicates the optimum sample size of an interview survey (Tran, et al., 2017). Ultimately, the collected data was analysed through the content analysis method as content analysis provides a comprehensive perception of the findings of the study (Erlingsson and Brysiewicz, 2017).

4. RESULTS

4.1 SIGNIFICANCE OF THE CIRCULAR ECONOMY CONCEPT IN THE SRI LANKAN CONTEXT

As acknowledged by all the respondents, the circular economy concept is significant to the construction sector since it minimises the negative impacts caused by the existing linear economy practices. When rationalising the importance of the circular economy concept, several benefits were mentioned by the respondents which are mentioned in Table 4.

Table 4: Benefits of a circular economy according to the respondents

Benefits mentioned by the respondents	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
Minimising material consumption and waste generation		✓	✓	✓	✓	✓	✓	✓	✓	✓
Minimising energy waste		✓	✓	✓	✓					✓
Reducing Pollution					✓	✓				
Extending the life cycle of the products and buildings	✓						✓			✓
Regenerating Systems						✓				✓
Giving more attention to the physical limit of materials									✓	

In the respondents' opinion, the implementation of circular economy principles is fundamentally required in neutralising the impact of the construction industry mechanisms such as excessive resource utilisation and waste generation. As mentioned by R7, a circular economy has a "*significant impact on construction, especially future construction and sustainability of material and resources*".

4.2 ABSENCE OF A VALUE ASSESSMENT TOOL AS A BARRIER TO A CIRCULAR ECONOMY IN THE BUILT ENVIRONMENT

According to empirical findings, the shortage of a value assessment tool for circular economy applications was distinguished as a major barrier to the transition to a circular built environment. According to R1, *"return and financial value"* are dominant factors for the construction community in considering and experimenting with new concepts. Besides, R8 argued for the need for a well-developed circularity value assessment tool that aligns with the complexity of the construction industry. Supportively, R2 mentioned the need for incentives in shifting to the new concept of the circular economy whereas R6 finds the value assessment tool as a major incentive. As mentioned by R2, "*there is a return which we are currently unable to quantify. We need a tool to see that and convince someone else".* Thus, as suggested by the existing literature and empirical findings, the need for a value assessment tool is apparent for the transition to a circular built environment.

4.3 THE IMPORTANCE OF A VALUE ASSESSMENT TOOL IN REGENERATING A CIRCULAR BUILT ENVIRONMENT

During the semi-structured interviews, the respondents were questioned about the importance of a circularity value assessment tool focusing on the transition to a circular built environment in Sri Lanka. The results suggested that there are several benefits provided by a value assessment tool which are broadly discussed below.

- Increased interest of the clients towards circular economy applications

As mentioned by the respondents, clients are less encouraged to adhere to circular economy applications with uncertainties in the final return. R2 stated that "*almost all the clients are so conscious towards the project budget and the ultimate return of the project*". Consequently, R5 pinpointed that the corresponding financial ambiguity of the circular economy is a considerable issue in convincing the clients since *"any client would ask how much it will cost and how much is the return or the saving"*. Simultaneously, R3 affirmed that most of the construction clients lack the broader technical knowledge of construction mechanisms where their focus is mostly directed towards the apparent economic return of the construction applications. Therefore, due to the absence of a value assessment tool, the clients are less interested in applying circular economy principles to their construction projects. Simultaneously, the respondents suggested that the introduction of a value assessment tool can increase the interest of the clients in circular economy applications.

- Increased motivation among the professionals in recommending circular economy principles

Results suggested that, due to the absence of a proper value assessment tool, circular economy experts in the construction sector are encountering difficulties in distinguishing the economic return of the circular economy applications. As argued by R2, circular economy experts are generally questioned about the benefits of the circular economy concept in terms of the economic return which they are unable to manifest due to the unavailability of a value assessment tool. Simultaneously, R7 declared the complications encountered by the circular economy experts in convincing the designers and developers to adhere to the circular economy principles without a proper mechanism to distinguish the economic benefits of the concept. Besides, circular economy experts are more discouraged in recommending the circular economy concept and R2 pinpointed that the circular economy experts in the construction industry are *"trapped"* without a value assessment tool as they "*need a tool to quantitate the benefits and to show others*" the significance in adhering to circular economy principles. Thus, it is important to introduce a circularity value assessment tool as it will increase the motivation among professionals in promoting the circular economy principles in Sri Lanka.

- Ease in communicating the benefits of the concept

According to the respondents, the absence of a value assessment tool is a considerable issue in communicating the benefits of the circular economy concept in the construction industry. As mentioned by R3, "*it is difficult to promote the circular economy concept"* with the absence of a proper tool to distinguish the economic benefits. R6 mentioned that *"financial return or benefit of return or IRR"* are major factors that seize the attention of the construction community. Therefore, the need for a circularity value assessment tool is evident and R9 declared that a properly developed value assessment tool *"will clearly communicate the benefits of the circular economy concept".*

- Higher rate of success

It was revealed during the empirical study that benchmarking and validation issues reduce the rate of success for circular economy practices in the construction industry. As mentioned by R6, for benchmarking and validation, a value assessment tool is essential to distinguish the economic benefits of the concept. Simultaneously, R10 stated that "*the unavailability of realisable costs and time-related data"* reduces the success rate of a circular built environment which is directly caused due to the lack of a value assessment tool for circular economy applications. Specifically, R9 stated that the shortage of a value assessment tool complicates the successful transition to a circular built environment since there are no example projects that have clearly benefited from the circular economy applications from an economic perspective. Eventually, the respondents suggested that the introduction of a value assessment tool can increase the rate of success of circular economy applications in the Sri Lankan construction industry.

- High maturity of circular economy principles in Sri Lanka

Results suggested that one of the major reasons governing the extremely lower maturity of circular economy principles in the Sri Lankan construction sector is the unavailability of a value assessment tool to measure the economic benefits of the concept. R10 stated that due to the unavailability of a proper value assessment tool *"the benefit of true circularity is not completely realised at the industry"* which is the root cause behind the low maturity of circular economy principles in the Sri Lankan construction sector. More specifically, R2, R3 and R5 affirmed that unless there is a properly developed value assessment tool to distinguish the benefits of the concept, the maturity of circular economy principles will remain low among the Sri Lankan construction community. However, since the economic benefit of applying the circular economy concept cannot be properly identified, both clients and construction professionals have been reluctant to engage in the application of the circular economy principles in the construction sector. Ultimately, the introduction of a value assessment tool can address the extremely low maturity of circular economy principles by accelerating the transition to a circular built environment and increasing the maturity of circular economy applications in the Sri Lankan construction sector.

5. CONCLUSION

The disastrous linear economic patterns of the construction sector have immensely affected the well-being of mankind and ecosystems by overconsuming natural resources and exploiting non-renewable energy sources. Even if the concept of circular economy was introduced as the ultimate solution, numerous barriers have hindered the effective transition to a circular built environment. Among these barriers, the absence of a proper value assessment tool can be perceived as a key obstruction that complicates the process of distinguishing the economic benefits of the concept. According to the study, a value assessment tool is important in increasing the interest and the motivation of the developers and industry experts on the circular economy applications while communicating the benefits of the concept to address the extremely low maturity of the circular economy principles in Sri Lanka. Hence, it is essential to have a proper value assessment tool to assess the benefits of the circular economy applications to stimulate the transition to a circular built environment for the betterment of the construction industry in Sri Lanka.

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INDUSTRY 4.0 BASED SUSTAINABLE MANUFACTURING MODEL FOR APPAREL INDUSTRY IN SRI LANKA

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ABSTRACT

Global industrialisation creates many challenges in achieving the balance of sustainability pillars called social, economic and environmental. Manufacturing is the largest subsector of industrialisation. Hence the sustainability of manufacturing greatly affects the sustainability of industrialization. Thus, the research community and industry professionals give attention to the Sustainable Manufacturing (SM) concept. Further, they have realized the significance of technology when focusing on SM. Accordingly, they have aligned the path of achieving SM with the recent manufacturing technology called "Industry 4.0" (I4.0) for more innovative and efficient outcomes. The developed countries and some of the developing countries drive towards the I4.0 concept to achieve SM. However, in terms of the Sri Lankan context, there is no clear evidence to demonstrate the integration of the I4.0 and SM. But there are few studies based on implementing I4.0 for apparel manufacturing in Sri Lanka. Thus, this study aimed to investigate the present status of the application of the I4.0 concept towards achieving SM in apparel manufacturing in Sri Lanka by selecting three large scale apparel manufacturing case studies. This was tested using a model which links the I4.0 pillars and the key opportunities for three dimensions of SM from nine technology pillars observed through previous studies. The findings from the case studies proved that there is a huge gap in the application of I4.0 for SM in the Sri Lankan context.

Keywords: *Industry 4.0 (I4.0); Industry 5.0 (I5.0); Manufacturing Sector; Nine Technology Pillars; Sustainability; Sustainable Manufacturing (SM).*

1. INTRODUCTION

The present industrialization is experiencing significant challenges in ensuring the balance of social, economic, and environmental sustainability dimensions while aiming to attain the product demands in the competitive market (Jamwal, et al., 2021; Menon, Shah and Coutroubis, 2018). Manufacturing holds the largest portion of industrialisation that can highly impact sustainability (Stock and Seliger, 2016). According to Sartal et al. (2020), from the perspective of manufacturing, sustainability is adjoining with transforming resources into economically valuable final products while being socially and environmentally responsible. However, it is a great challenge and, hence, the research community and industrial sector pay great attention to Sustainable Manufacturing (SM) to overcome sustainability challenges in present industrialisation (Sartal, et al., 2020). Under this context, it is vital to use technology when focusing on SM (Gholami, et al.,

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2021). Based on the recent technological trends, it is observed that Industry 4.0 (I4.0), the current phase of the industrial revolution, which is developed on many technologies, offers excellent opportunities for SM (Jamwal, et al., 2021; Mehnen, et al., 2021; Sartal, et al., 2020; Sharma and Jain, 2020). The I4.0 technologies are implemented by different sensors that can physically monitor and create a virtual demonstration of the physical world using Cyber Physical Systems (CPS) (Menon, et al., 2018). The CPS can be defined as the concept of embedding software in a machine that can understand itself (Sharma and Jain, 2020). In Sri Lanka, the implementation of the I4.0 in the apparel manufacturing industry has been discussed in several studies (Lakmali, Vidanagamachchi and Nanayakkara, 2020; Jayatilake and Withanaarachchi, 2016).

Presently, many countries drive their industrial value creation towards I4.0 to strengthen SM (Jamwal, et al., 2021; Stock and Seliger, 2016). Further, due to continuous improvements and innovations in automation, Industry 5.0 (I5.0) has become the latest development which is not an entirely new paradigm; it is an upgradation of I4.0 (Pramanik, et al., 2020). Further to the authors, the organizations will be eligible to have more focused and customised manufacturing with effective collaboration between humans and machines as the benefits of I5.0. As observed, the manufacturing-related global studies still focus on I4.0 to grab the actual benefits of nine technology pillars called the foundation of I4.0 to enhance SM (Machado, Winroth and da Silva, 2020; Pramanik, et al., 2020; Sartal, et al., 2020; Sharma and Jain, 2020). Specifically, Pramanik, et al. (2020) stated that I4.0 will be replaced by I5.0 in near future, but to achieve that the absolute implementation of I4.0 is required. Accordingly, this study was limited to I4.0.

It has been ten years since the I4.0 concept was introduced and still, there is no clear evidence to prove the proper identification and application of the I4.0 for SM in apparel industry in Sri Lanka. Further, there are no studies based on demonstrating the integration of I4.0 and SM under the Sri Lankan context. Hence, this research aims to investigate the existence of I4.0 towards the enhancement of sustainable manufacturing in apparel industry in Sri Lanka. The objectives of the paper are (1) to develop an I4.0 based SM model that demonstrates the impact of I4.0 for SM; (2) to apply the proposed model in the apparel industry to assess the level of existence of I4.0 based SM.

2. LITERATURE REVIEW

2.1 THE CONCEPT OF INDUSTRY 4.0

Germany had introduced I4.0 which represent the recent era of the industrial revolution in 2011 at the Hannover Fair event (Tay, et al., 2018). The I4.0 will make the manufacturing process fully integrated and automated through the communication among single automated cells (Javaid, et al., 2022; Rüßmann, et al., 2015). According to Ghobakhloo (2018), the heart of I4.0 is based on the integration and fusion of the physical and the virtual world through the CPS. Numerous authors stated that the I4.0 is a collection of innovative foundational technological advances (Machado, Winroth and da Silva, 2020; Rüßmann, et al., 2015). The Boston Consulting Group (BCG) defined nine foundational technological pillars in I4.0, including Industrial Internet of Things (IIoT), big data analytics, augmented reality, additive manufacturing, autonomous robots, simulation, horizontal and vertical system integration, cloud computing and cybersecurity as the foundation of I4.0 (Rüßmann, et al., 2015). Additionally, those technological pillars have been used and adapted in several studies to conduct their studies covering the concept of I4.0 (Erboz, 2017; Hughes, et al., 2022; Luque, et al., 2017; Machado, Winroth and da Silva, 2020; Noor Hasnan and Yusoff, 2018; Rehman and Ejaz, 2020; Saturno, et al., 2018; Sharma and Jain, 2020). Therefore, the nine technology pillars introduced by BCG (Rüßmann, et al., 2015) have been selected to enrich the definition of the I4.0 concept in this study.

1st first pillar (IIoT): IIoT facilitates the machines with sensor systems, electronics, and embedded software which allows to capture and exchange data using internet connectivity (Luque, et al., 2017; Pramanik, et al., 2020).

2nd Pillar (Big data): Big data facilitates real-time decision making through the comprehensive evaluation of data collected from different sources (Rüßmann, et al., 2015).

3rd Pillar (Augmented Reality): Augmented reality consists of a real-time virtual model of a physical world environment that has been enriched by the several computer-based information components called displays, input devices and tracking (Craig, 2013).

4th Pillar (Additive Manufacturing): Additive manufacturing is called sequential layering-based 3D printing, widely used for producing small batches of customized products (Pramanik, et al., 2020).

5th Pillar (Autonomous Robots): Autonomous robots represent the recent robots that collaborate more closely with humans (Menon, et al., 2018).

6th Pillar (Simulation): The simulation creates a virtual model of the physical manufacturing system including machines, products, and humans (Rehman and Ejaz, 2020; Rüßmann, et al., 2015; Tay, et al., 2018).

7th Pillar - Part I (Vertical Integration): Vertical integration refers to the connection between systems inside of the factory with each other for achieving better performance (Erboz, 2017).

7th Pillar - Part II (Horizontal Integration): Horizontal integration includes the connection of partners within the supply chains (Erboz, 2017).

8th Pillar (Cloud Computing): Cloud computing permits real-time data sharing through the creation of a digital cooperated and integrated environment (Kumar and Nayyar, 2020).

9th Pillar (Cybersecurity): Cybersecurity is an innovative technology, which protects critical industrial systems and manufacturing lines from cybersecurity threats (Mehnen, et al., 2021; Rüßmann et al., 2015).

2.2 THE CONCEPT OF SUSTAINABLE MANUFACTURING

Sustainable Manufacturing (SM) involves the transformation of resources into economically valuable goods by operating socially and environmentally responsible processes (Sartal, et al., 2020). Thus, SM requires to consider the implications of social, economic, and environmental dimensions associated with the manufacturing stages (Sajadieh, et al., 2022). The base of the social dimension of sustainability is ensuring safety and equity to the employees, stakeholders and community (Sangwan and Bhatia, 2020). The focus on economic performance, market presence, indirect economic impacts and procurement practices is the base of sustainability's economic dimension (Sangwan and Bhatia, 2020). The focus on preserving supply, waste handling and direct usefulness is the basis of the environmental dimension of sustainability (Sangwan and Bhatia, 2020). Thus, SM can be defined as a process of creating socially responsible, economically viable and environmentally friendly products.

2.3 THE RELATIONSHIP BETWEEN INDUSTRY 4.0 AND SUSTAINABLE MANUFACTURING

The I4.0 is one of the recent applications to achieve SM (Gholami, et al., 2021; Sartal, et al., 2020). Further, Sartal, et al. (2020) proved that the ICT based infrastructure, technological advances, human-machine and machine-to-machine interaction of I4.0 enables SM. According to previous studies (Erboz, 2017; Ghobakhloo, 2018; Javaid, et al., 2022; Mehnen, et al., 2021; Menon, et al., 2018; Psarommatis, et al., 2022; Rehman and Ejaz, 2020; Rüßmann, et al., 2015; Sajadieh, et al., 2022; Stock and Seliger, 2016; Tay, et al., 2018), the technology pillars of I4.0 facilitates manufacturing process with numerous opportunities covering all three dimensions of SM; social, economic and environmental. Those opportunities derived from the above-mentioned studies were captured under each dimension of SM (refer Table 1).

Table 1: Opportunities from I4.0 for SM

Dimension of SM	Derived Key Opportunities from I4.0 Technology Pillars
Social dimension of SM	Ensure occupational safety, reduce human errors, ensure better communication and reduce workload and demands-based product designing.
Economic dimension of SM	Reduce maintenance costs by early predictions, ensure energy cost saving, decrease product failure rate, decrease time to market and save resource handling costs.
Environmental dimension of SM	Prevent waste generation by controlling defective manufacturing, ensuring energy saving, facilitating eco-friendly product development, raise efficient resource handling and space utilization.

The relationships among the derived key opportunities (Table 1) and the I4.0 pillars were used to develop a conceptual model (see Figure 1) to visualize the I4.0 based SM.

Colour code: Green - IIoT; Yellow - Big Data; Red - Augmented reality; Blue - Additive manufacturing; Pink - Autonomous robotics; Purple - Simulation; Orange - System Integration; Ash - Cloud computing; and White - Cybersecurity.

Accordingly, it can be logically concluded that the I4.0 can support meeting targets in manufacturing under three dimensions of SM and the concept of I4.0 is having a positive impact and unavoidable influence on the SM.

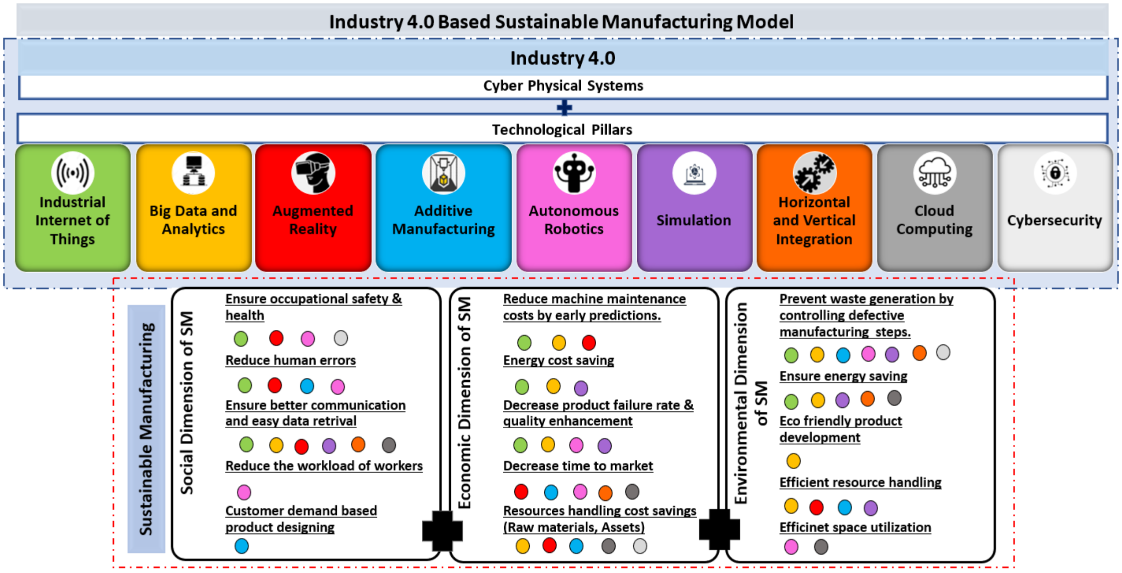

Figure 1: I4.0 based SM model

3. RESEARCH METHODOLOGY

The research was designed to investigate the application of I4.0 for SM in Sri Lanka. Since this study involves an in-depth investigation, the qualitative approach was preferred over the quantitative approach (Dawson, 2002). To investigate the application of I4.0 to enhance SM in the Sri Lankan apparel industry, the proposed conceptual model illustrated in Figure 1 was used in case studies after validation. The validation experts were selected based on their field and experience. The profiles of the experts are given in Table 2.

Table 2: Profile of the validators of the I4.0 based SM model

Name of the Validation Expert	Area of expertise
VE1	Director and consultant in business and industry development, production planning and industrial engineering with expert knowledge of the I4.0. The overall experience: 50 years
VE2	Senior technologist, productivity consultant for leading manufacturing organizations and Administrator in Industrial Engineering with knowledge of the I4.0 concept. The overall experience: 20 years

The unit of analysis was the application of I4.0 for SM. Perry (1998) stated, that when qualitative research comprises a wide study area, it is suitable to use only one or two cases and a maximum of four cases. Accordingly, the cases were limited to three leading wearing apparel manufacturing organizations (refer Table 3).

Semi-structured interviews were selected for collecting data. The validated "I4.0 based SM" model was introduced to the nine industry professionals (refer Table 4) and their views on the current level of applying I4.0 for the three dimensions of SM were obtained. The cross-case analysis was carried out to have better comparison and summarization.

Table 3: Details of the selected cases

Case	Description
Case 01	BOI approved apparel manufacturer and exporter, located in Pannala and employed over 1000 employees. The factory manufactures lingerie.
Case 02	BOI approved apparel manufacturer and exporter, located in Rathmalana and employed over 1000 employees. The factory manufactures lingerie, men’s and women's underwear.
Case 03	BOI approved apparel manufacturer and exporter, located in Balapokuna and employed over 1000 employees. The factory manufactures kids wear, men’s and women's underwear.

Table 4: Profile of the selected professionals

Case	Code	Profile	Experience
Case 01	C1R1	General Manager, Sustainable Business, Familiar with the I4.0 concept by participating in discussions and webinars.	15 Years
	C1R2	Manufacturing Plant Head, Familiar with the I4.0 concept by participating in discussions and webinars.	20 Years
	C1R3	Senior Executive, production, Familiar with the I4.0 concept by participating in discussions and webinars. Being a part of I4.0 based pilot projects in Case 01.	6 Years
Case 02	C2R1	Senior Executive, Engineering, Familiar with the I4.0 concept by participating in discussions and webinars.	6 Years
	C2R2	Deputy general manager, Engineering, Familiar with the I4.0 concept by participating in discussions and webinars.	12 Years
	C2R3	Senior executive, Compliance, Familiar with the I4.0 concept by participating in discussions and webinars.	8 Years
Case 03	C3R1	General Manager Engineering and sustainability, Familiar with the I4.0 concept by participating in discussions and webinars. Already experienced the availability of the I4.0 concept in foreign countries.	20 Years
	C3R2	Manager, Compliance, Familiar with the I4.0 concept by participating in discussions and webinars.	7 Years
	C3R3	Manager Operations, Familiar with the I4.0 concept by participating in discussions and webinars.	10 Years

4. FINDINGS

4.1 THE EXISTENCE OF INDUSTRY 4.0 MANUFACTURING IN SRI LANKAN APPAREL INDUSTRY

Findings revealed that all of the technology pillars are available to some extent with few initiatives, except simulation and additive manufacturing. It was further observed there were several technological applications are aligned with some of the technology pillars (refer Table 5).

Table 5: Current availability of I4.0 technology pillars in Sri Lankan apparel industry

Technology Pillar	Availability			Description
	C1	C2	C3	
IIoT	★	★	★	Case 01: Smart routing flexibility and looking for applying sensor-based product counting; Case 02: Sensor-based innovations are going on, use iAuditor called QR code-based human-machine communication, PLC-based innovations are going on; All three cases: use energy monitoring systems and solar energy systems
Big Data	★	★	✕	Case 01: ANDON boards (real-time alert generator), finished good management digital screens, data analysis on environmental footprint; Case 02: discussing on installing real-time data displaying screens, VOC level data calculations and analysis; Case 03: Higg product module.
Augmented Reality	★	★	★	The design teams of all three cases are applying augmented reality and computer vision for sample fitting. But still not applying this technology to communicate with machines.
Additive Manufacturing	●	●	✕	Case 01 and case 02: 3D printing is in the Research and Development (R&D) stage.
Autonomous robotics	★	★	★	Case 01: Automated Guided Vehicle (AGV); Case 02 and Case 03: Using Ring Robot
Simulation	✕	✕	✕	All three cases have not reached this level
Horizontal and vertical integration	★	★	★	All three cases: Apply SAP as the Enterprise Resource Planning (ERP) system to integrate all the internal systems; Case 01 and case 02: Discussing on spreading data connectivity along with the supply chain.
Cloud Computing	★	★	★	All three cases are covered with cloud computing
Cybersecurity	★	★	★	All three cases are covered with cyber security systems. But comparatively the strength of the cyber security system of the case 01 is higher than both case 02 and case 03.

(Guide: ★ Available to some extent, ● Discussion Level, ✕ Not Available)

4.2 THE LINK BETWEEN INDUSTRY 4.0 AND THE THREE DIMENSIONS OF SUSTAINABLE MANUFACTURING IN SRI LANKAN APPAREL INDUSTRY

4.2.1 Industrial Internet of Things

Social dimension of SM: Case 01 is focusing on applying RFID chips and sensor-based automated manufacturing steps that can reduce human-based errors. C1R2 revealed, *"The recently installed smart routing flexibility will enhance the communication among machines, materials and processes through sensors and internet connectivity"*. C2R3 stated, *"We are discussing machine-related smart sensor-based upgrading to enhance the easy data retrieval"*. However, none of the cases used internet connectivity-based safety sensors and real-time hazard warnings that can ensure occupational safety.

Economic dimension of SM: All three cases align with self-energy generation by installing solar applications. However, none of them has sensors and detectors to check the status of manufacturing machines to reduce operation and maintenance costs. C1R1 pointed out that *"We can familiar with the consumption patterns through our energy monitoring system and plan for cost savings".* All cases do not include sensor-based product quality checking and failure detections.

Environmental dimension of SM: C1R1 expressed that *"We are focusing on upgrading the existing system into a real-time smart energy monitoring system, then there will be a capability as well".* Similarly, case 02 disclosed their intention to use a smart energy motoring system. However, none of the cases used sensor-based applications for sensing the defects of machinery in real-time that can reduce defective product outputs.

4.2.2 Big Data

Social dimension of SM: C1R1 mentioned, *"ANDON system will display target levels and condition of machines in real-time".* Further their *"Finished good management digital screens"* ensure better data retrieval on finished products than traditional methods. Both case 02 and case 03 stay behind in applying big data initiatives for real-time data retrieval.

Economic dimension of SM: C1R1 revealed, *"The ANDON system notifies the condition of the machine as working or malfunctioning. If there is a malfunction then the maintenance team can attend before further loss".*

Environmental dimension of SM: The ANDON system applied in case 01, notifies the conditions of machines before occurring defective manufacturing from those machines. C1R1 mentioned, *"We evaluate the environmental footprint of the products in terms of carbon composition and we do material-based comparisons using a software application".* In case 02, both C2R1 and C2R2 raised their VOC level calculations for eco-friendly product development. In addition, C3R1 mentioned a method called *"Higg product module"* used to calculate the life cycle impact of a product before commencing the manufacturing *"We use Higg Product Module, for calculating the life cycle impact based on the raw material compositions".*

4.2.3 Augmented Reality

Social dimension of SM: All three cases are applying augmented reality for virtual sample fitting in some instances. C3R3 stated that *"Use of virtual samples can avoid the human-based errors occurred during sample making and redeveloping".* The current sample fitting application of all three cases increase the accuracy of the designs. C3R3 elaborated *"Augmented designs transfer more accurate data about the designs that can be easily customized with instructions".*

Economic dimension of SM: The virtual sample fitting control of design lead time. C3R2 mentioned, *"Virtual sampling will ensure resource handling cost savings, further, it will be more flexible in making changes without reusing resources".*

Environmental dimension of SM: C1R2 mentioned, *"Virtual sampling avoid consumption of fabrics and other related raw materials".*

4.2.4 Additive Manufacturing

Social dimension of SM: Case 01 and case 02 are at the discussion level of applying additive manufacturing for reducing human errors. In this regard, they are working on adapting 3D printing which facilitates avoiding human-based errors. C1R2 commented that *"we have identified that the 3D printing can easily be customized with the demand, it is flexible enough for smoothing the demand changes"*.

Economic dimension of SM: 3D printing will contribute to the economic aspect by speeding up manufacturing. C1R2 commented that *"we have identified that 3D printing can speed up our product manufacturing"*.

Environmental dimension of SM: 3D printing can be used for waste reduction of the manufacturing process by controlling defective manufacturing steps. For instance, as per C1R3 *"If we can successfully implement 3D printing, there will be a huge reduction in manufacturing defects"*. The precise amount of resource-based manufacturing is not currently focused.

4.2.5 Autonomous Robotics

Social dimension of SM: Case 01 replaces humans with robots that can mitigate musculoskeletal disorders of workers and hence has a social impact. C1R3 mentioned, *"Currently we are replacing travelers who involve in material handling with AGV robot, that can load up to 600 kg weight"*. Further Cases 02 and 03 experienced in reducing human errors by using ring robot. C3R2 affirmed, *"ring robot will attach elastic bands in more efficient, speed and accurate manner with less supervision and hence manual labour has been cut down"*. The "AGV" robot in case 01 already reduce the workload of material handlers positively. C1R1 expressed that *"An automated material handling process will motivate the workers by avoiding heavy load handling workload"*. Ring Robots in Case 02 and Case 03 could able to reduce the workload of workers by automating a whole process.

Economic dimension of SM: The application of Ring Robot has contributed to product quality enhancement and failure reduction. C1R3 stated that *"Our AGV robots will speed up manufacturing because there will be no waiting time as from travelers"*. It can be derived that the use of AGV robots creates a positive impact on decreasing time to market. C2R1 highlighted that *"Ring robot is more efficient in use when compare with human involvement because it can work at same speed for any number of hours"*.

Environmental dimension of SM: The application of the *Ring Robot* is a fully automated process, and hence it has less impact on the environment through accurate manufacturing that can avoid waste generate from defects.

4.2.6 Horizontal and Vertical Integration

Social dimension of SM: The SAP-based ERP systems of all three cases ensure better communication among the internal parties through efficient data sharing and data availability. But the majority of respondents highlighted that those integrations need to be smoother for ensuring better operations.

Economic dimension of SM: The SAP-based ERP of all three cases ensures efficient communication between all the nodes of the manufacturing process. C1R2 declared, *"We can have speed access for each manufacturing section-based data without delaying in decision making"*.

Environmental dimension of SM: C1R1 mentioned, *"Since the relevant process updates available in SAP, the possibility of occurring miss communication based defective manufacturing will be controlled".* C2R1 stated, *"Once we logged to the SAP all the relevant process data can be captured, no need to wait and consume more energy with systems".*

4.2.7 Cloud Computing

Social dimension of SM: C1R3 raised *"Cloud facilitates easy communication; we can access the system from any location".* In case 02, the C2R1 mentioned *"There is a web-based data collection platform called Control Room, we can check the condition of our plant centrally without visiting the plant".* Further, in case 03, C3R1 pointed out *"Our cloud is a good source of data and information".*

Economic dimension of SM: C1R1 stated that *"Since we can have access to the cloud system at any time from any destination, it ensures the real-time update on the process of the plant for making our decisions and comments without any delay".* In case 01 they have almost replaced servers and paper-based data storage via the cloud. C1R3 stated that *"Our cloud includes all the data related to our manufacturing process, so there will be no cost to manage servers and paper-based files".*

Environmental dimension of SM: The energy-saving that can be gained through avoiding physical servers available in all three cases. The use of online data storage, instead of space allocation for servers is appeared.

4.2.8 Cybersecurity

Social dimension of SM: All three cases have a cyber-attack free environment that can create a positive mental health-based working environment. C1R2 mentioned, *"Since we are having a strong cyber security system, we feel safe to update our systems with sensitive data".*

Economic dimension of SM: All three cases, are aligned with the safety of organizational systems but not specified with manufacturing machinery. Hence the cost savings through preventing the damages occurring for machines are not focused.

Environmental dimension of SM: Cybersecurity and control of defective products are developing in case 01, and both case 02 and case 03 are focusing on it. Case 01 is developing the machine program safety via cyber security, but sill the other two cases are just focusing on machines based cyber security systems.

5. DISCUSSION

The manufacturing process of the Sri Lankan apparel manufacturing industry required both human and technological assistance. Hence, at first, the availability of recent technological applications was assessed by overviewing the availability of I4.0 initiatives. The majority of technology pillars were available to some extent with few initiatives but all the I4.0 initiatives need to be improved. As a result of investigating the present status of the application of I4.0 for SM, it was observed that the majority of links among nine technology pillars and respective opportunities from them to enhance SM; which are displaying in the model (refer Figure 1) was not even focused on the Sri Lankan apparel manufacturing industry. Concerning the already appearing links on the social dimension of SM, the application of autonomous robotics for reducing workload and human errors, and the use of cloud computing for easy communication among people was highlighted. Regarding the already appearing links on the economic dimension of SM, the impact of autonomous robotics on decreased product failure rate and decreased time to market was highlighted. In the matter of already appearing links on the environmental dimension of SM, the impact of vertical integration on preventing waste generation by controlling defective manufacturing steps and energy-saving was highlighted. As a positive factor, there are a few developing level and focused level links also observed. As the outcome of this study, the "I4.0 based SM" model (Figure 1) will be a tool for encouraging the Sri Lankan manufacturing industry to identify the application of I4.0 to achieve more SM environment.

The current status of the application of I4.0 for SM is categorized into four categories with unique symbols (refer Table 6) to facilitate better-summarized visualization (refer Figure 2).

Table 6: Categories of the current status of the application of I4.0 for SM

Category	**Symbol**	**Definition**
Link already appears	✓	The link well appears within the current technological applications and initiatives of the I4.0 technology pillars.
Link is in the developing stage	↑	The link partially appears and still developing within the current technological applications and initiatives of I4.0 technology pillars.
Link is currently focusing on	▲	The link is currently focused on within the current technological applications and initiatives of the I4.0 technology pillars.
Link is not focused yet	✗	The link is currently not considered or focused yet within the current technological applications and initiatives of the I4.0 technology pillars.

The summarized visualization of the present status of the application of I4.0 for SM in apparel industry in Sri Lanka was presented (refer Figure 2) with the aid of these four categories (refer Table 6).

Accordingly, Figure 2 notifies that the apparel industry should concern with more advanced manufacturing applications to achieve SM technologically. Because the majority of links among the nine technology pillars and respective opportunities from them to enhance SM; which are displayed in the conceptual model (Figure 1) were not even focused on the Sri Lankan apparel manufacturing industry. Hence, as an extension of this study, it is better to overview the exact reasons and barriers behind this current backward position of the Sri Lankan manufacturing industry in achieving SM through I4.0 and give strategies to overcome those barriers.

Assessed key areas of SM	IIoT			Big data			Augmented Reality			Additive Manufacturing			Autonomous Robotics			Simulation			Horizontal and Vertical Integration			Cloud Computing			Cybersecurity		
	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3
Social Dimension of SM																											
• Ensure occupational safety and health	✗	✗	✗				✗	✗	✗				✓	✗	✗										✓	↑	↑
• Reduce human errors	▲	✗	✗				↑	↑	↑	✗	✗	✗	▲	✓	✓												
• Ensure better communication and easy data retrieval	↑	▲	✗	✓	✗	✗	↑	↑	↑							✗	✗	✗	↑	↑	↑	✓	✓	✓			
• Reduce the workload of workers													✓	✓	✓												
• Customer demand-based product designing										▲	▲	✗															
Economic Dimension of SM																											
• Reduce maintenance costs by early predictions	✗	✗	✗	✓	✗	✗	✗	✗	✗																		
• Energy cost saving	▲	▲	▲	✗	✗	✗										✗	✗	✗									
• Decrease product failure rate and quality enhancement	✗	✗	✗	✗	✗	✗							✗	✓	✓	✗	✗	✗									
• Decrease time to market							↑	↑	↑	▲	▲	✗	✓	✓	✓				✓	✓	✓	✓	↑	↑			
• Resources handling cost savings (raw materials, assets)				✗	✗	✗	↑	↑	↑	✗	✗	✗										✓	↑	↑	✗	✗	✗
Environmental Dimension of SM																											
• Prevent waste generation by controlling defective manufacturing steps.	✗	✗	✗	✓	✗	✗				▲	✗	✗	✗	✓	✓	✗	✗	✗	✓	✓	✓				↑	▲	▲
• Ensure energy saving	▲	▲	✗	✗	✗	✗										✗	✗	✗	✓	✓	✓	✓	↑	↑			
• Eco-friendly product development				↑	↑	↑																					
• Efficient resource handling				✗	✗	✗	↑	↑	↑	✗	✗	✗				✗	✗	✗									
• Efficient space utilization													✗	✗	✗							✓	↑	↑			

Figure 2: Summary of the present status of the application on I4.0 for SM

6. CONCLUSION

The concept of I4.0 is having a positive impact and unavoidable influence on the three dimensions of SM. Then the relationship between I4.0 and SM was graphically represented with the aid of a unique colour code and named it as the "I4.0 Based SM" model. Then the model was validated by industrial engineering experts and used as a tool for the data collection. As the initial step of identifying the present status of the application of I4.0 for SM, the availability of nine technology pillars was assessed. As observed, IIoT, Big data, Augmented reality, Autonomous robotics, Horizontal and vertical integration, Cloud computing and Cybersecurity are available to some extent with very few applications and initiatives. Additive manufacturing is at the discussion level while the simulation is not even focused yet. In terms of the present status of the application of I4.0 for SM, the availability of the relationships displayed in the "I4.0 based SM" model was assessed. Findings from the case studies proved that there is a huge gap in the Sri Lankan context. The majority of links are not focused yet. But there were a few focused level, developing level and appeared level links as well. Since there are several pre-studies available on I4.0 for the Sri Lankan apparel manufacturing sector, the current performance in gaining benefits from I4.0 technology pillars are very low. Accordingly, the "I4.0 based SM" model guides the Sri Lankan industry to conduct a self-assessment on the application of globally recognized links between I4.0 and SM to install I4.0 technology pillars to achieve SM environment.

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INDUSTRY 4.0 ENABLED PREDICTIVE MAINTENANCE OF FACILITIES: A STUDY ON APPLICABILITY, BENEFITS AND CHALLENGES

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ABSTRACT

Maintenance management is an important function under Facilities Management (FM). Industries moved to preventive maintenance models to counteract the inefficiencies of reactive maintenance and further evolved into predictive maintenance (PdM) models. The demand for Industry 4.0 enabled PdM for FM has risen as a result of the industrial revolution and the dynamic nature of the FM functions. Thus, the study aimed to investigate the applicability, benefits, and challenges of applying Industry 4.0 concept for effective PdM in FM. The qualitative research approach was undertaken to accomplish the aim. A comprehensive literature review followed by 15 semi-structured interviews was carried out with experts in the maintenance sector who have Industry 4.0 knowledge. The data was collected from experts in Australia, Qatar, Dubai, Singapore, and Sri Lanka, and analysed through code-based content analysis using NVivo 12. The results demonstrate that there is a huge potential for using Industry 4.0 smart technologies such as big data analytics, Cyber-Physical Systems (CPS), autonomous robots, Cloud Computing, Industrial Internet of Things (IIoT), cybersecurity, Machine Learning (ML), Augmented Reality (AR), Data Mining (DM), system integration, and simulation for PdM under FM. Applying Industry 4.0 concept for effective PdM under FM provides significant benefits such as the deployment of a zero-failure strategy, establishment of machine-to-machine communication and interaction, detection of early anomalies and extended equipment lifetime. Lack of technological knowledge, capital, data management, employees' interest, integration between systems, standardized procedures, and internet access are identified key challenges.

Keywords: *Applicability, Benefits and Challenges; Industry 4.0; Facilities Management (FM); Predictive Maintenance (PdM); Smart Technologies.*

1. INTRODUCTION

Facilities Management (FM) incorporates multiple disciplines to ensure the optimum performance of the built environment in terms of people, process, place and technology (International Facility Management Association, 2009). Due to rapid and large-scale urbanisation, the role of FM along with maintenance management is more effective in emerging countries (Myeda, et al., 2011). Poor, et al., (2019) highlight how maintenance has progressed from reactive to proactive maintenance over three generations. Reactive

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maintenance allows the equipment to run until the failure (Swanson, 2001). Moreover, identifying and correcting the causes of failures that result from the failure occurrence is known as corrective maintenance. (Wang, et al., 2014), where as a Computerized Maintenance Management System (CMMS) is a tool that utilizes an information system with a set of functions to process data and provide informative maintenance-related indicators (Lopes, et al., 2016). Preventive maintenance uses schedules of pre-described frequencies to minimize commonly occurring failures whereas, predictive maintenance (PdM) utilizes time-based information to predict forthcoming failures to avoid unwanted downtime (Matyas, et al., 2017). Compared with other maintenance methods, PdM has some substantial advantages such as, (a) equipment, which needs maintenance is shut down solely before impending failure, (b) minimizes the time spent on equipment maintenance, (c) reducing the cost of maintenance by avoiding disastrous damage, (d) maximizing the availableness of equipment, (e) extending the useful lifetime of equipment and (f) improve occupational and environmental safety and (g) increases the reliability (Bousdekis, et al., 2020). Hence, industries requires real-time monitoring and controlling for the proper execution of maintenance management, which is also beneficial to efficiently regulate and manage maintenance activities (Su, et al., 2011). The present scope of FM solely focuses on the core business activities of the organization to add value to its bottom line by increasing revenue, boosting the company's image, lowering expenses and increasing productivity, whereas, forthcoming advancement in the FM will have the significant impact of future novelty and revolution (Okoro and Musonda, 2019). The demand for Industry 4.0 enabled PdM for FM has risen as a result of the industrial revolution and the dynamic nature of the FM industry. However, there is a lack of a study on how Industry 4.0 can enable PdM in FM. Thus, the study aimed to investigate the applicability, benefits and challenges of applying Industry 4.0 concept for effective PdM in both product and process-based FM. This paper starts with a literature review on Industry 4.0 and its applications to PdM of facilities. 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 on Industry 4.0, its applications to both product and process-based FM and PdM and benefits and challenges in applying it to PdM of facilities.

2.1 FOURTH INDUSTRIAL REVOLUTION AND ITS APPLICATION TO FM

The Fourth Industrial Revolution (Industry 4.0) is initially raised in Germany to comply with the innovative requirements of the forthcoming industry (Lee, et al., 2014). Unlike the last three industrial revolutions, Industry 4.0 will not be triggered by a single technology (Meissner, et al., 2017). Additive Manufacturing (AM), Big Data Analytics, Autonomous Robots, Cloud Computing, Industrial Internet of Things (IIoT), Cyber Security, Augmented Reality (AR), System Integration and Simulation are considered as nine pillars of Industry 4.0 (Rubmann, et al., 2015). Further, Cyber Physical System (CPS) (Li, et al., 2016), Machine Learning (ML) (Su and Huang, 2018) and Data Mining (DM) (Li, et al., 2016; Su and Huang, 2018) technologies are considered as emerging technologies for the implementation of Industry 4.0.

Industry 4.0 is a fusion of technology, which continuously builds and extends the influence of digitalization in everyday applications, and ensures the function of FM remains sustainable (Okoro and Musonda, 2019). Industry adaptation vs. advancements in FM-related Industry 4.0 practices have created a demand for up-to-date digitized building assets (Stojanovic, et al., 2018). Maintenance management, which is a key area in the FM field, has recently begun to invest in smart technologies to enhance service supply in a novel way (Talamo, et al., 2019). FM is evolving in the Industry 4.0 scenario, as a result of the introduction of new technologies that can boost the capabilities of positions committed to structure management (Nota, et al., 2021). Moreover, the authors highlighted that the adoption of new technologies such as IoT, IIoT, CPS, and Cyber Physical Production System (CPPS) has led to recent advancements in the FM industry.

2.2 APPLICATION OF INDUSTRY 4.0 FOR PDM IN FM

PdM in its early stage utilized measuring, sensing and controlling aspects of machinery to identify whether there have been faced with any significant changes in the physical condition of machinery, whereas now, technological advancements may improve the effectiveness of PdM (Bengtsson and Lundstrom, 2018). The sophisticated sensor infrastructure of Industry 4.0 is enabling the employment of algorithms that evaluate data, predict impending scenarios, and prescribe mitigating steps for production and maintenance operations (Bousdekis, et al., 2021). Further, the authors highlighted that monitoring techniques have changed in recent years as a result of the introduction of Industry 4.0, from visual inspections and manual data processing to high-frequency sensors that generate real-time big data on a variety of techniques like vibration, temperature, and thermography.

2.3 BENEFITS OF APPLYING INDUSTRY 4.0 CONCEPT FOR PDM IN FM

Industry 4.0 boosts PdM capabilities and lays the path for more effective and optimal maintenance operations (Bousdekis, et al., 2020). Numerous benefits gained through the implementation of the Industry 4.0 concept for PdM are listed in Table 1.

Table 1: Benefits of applying Industry 4.0 concept for PdM in FM

Advantages	**References**						
	[1]	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**	**[7]**
Ability to determine appropriate intervals for PdM						X	
Enhance production and maintenance processes					X		
Ability to maintain high levels of quality	X			X	X		
Minimize failure and maintenance costs		X	X		X		
Ability to implement a zero-failure strategy		X	X	X	X		
Predictive analytics			X				X
Improve asset status forecasting prognosis		X	X				X
Machine-to-machine communication and interaction			X				
Generate and forecast maintenance-related information		X	X		X		
Facilitate large amounts of real-time and historical data to detect early anomalies		X					
To gain a competitive edge		X					
Extended operating equipment lifetime		X					

Advantages	References						
	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Enhanced safety (Occupants and equipment)		X	X				
Effective use of maintenance resources		X					
Upgraded plant reliability		X					

References: [1] Bengtsson and Lundstrom (2018), [2] Bousdekis, et al. (2020), [3] Li, et al. (2017), [4] Poor, et al. (2019), [5] Sezer, et al. (2018), [6] Spendla, et al.(2017), [7] Kumar and Galar (2018)

2.4 CHALLENGES IN APPLYING INDUSTRY 4.0 CONCEPT FOR PDM IN FM

PdM faces a variety of practical implementation challenges in the complex and dynamic Industry 4.0 environment (Bousdekis, et al., 2020). Table 2 presents various types of challenges of using Industry 4.0 for PdM.

Table 2: Challenges in using Industry 4.0 concept for PdM in FM

Challenges	References
Technological challenges	
• Lack of technological knowledge to handle sophisticated computer solutions	[9]
• Ignorance of Industry 4.0 technologies	[5]
• Implementation and adoption challenges	[7]
Investment challenges	
• Lack of capital for investment	[4]
• Uncertain returns from investments	[5]
Data challenges	
• Lack of adequate real-time and historical data	[1]
• Need to manage, store and process voluminous data	[5]
• Unstructured data format	[2]
• Insufficient data processing power	[2]
• Poor data quality	[3]
• Inability to derive information from data	[3], [5]
• Challenge in using production data as a catalyst for Industry 4.0 initiatives	[9]
Employees related challenges	
• Lack of employees towards knowledge upgrades	[1]
• Scarcity of industry 4.0 skilled experts or employees	[4], [11]
• Lack of organizational interest in change	[1], [10]
• Need to invest in data analytics roles	[1]
Integration Challenges	
• Create a synergy between organizational systems and their respective productive teams	[10]
• Lack of integration between systems	[3], [4], [11]
• Enable internal data sharing in the system	[13]

Challenges	References
Standardization Challenges	
• Absence of a well-established uniform standard solution	[5]
Communication Challenges	
• A lack of internet access	[5]
Security Challenges	
• Insecure connectivity protocols	[4]
• Lack of investment to invest in huge security and protection for databases	[6], [8]
• Need for data protection	[4]

References: [1] Bousdekis, et al. (2020), [2] Kiangala and Wang (2018), [3] Li, et al. (2017), [4] Moktadir, et al. (2018), [5] Singh, et al. (2019), [6] Dalenogare, et al. (2018), [7] Frank, et al. (2019), [8] Lezzi, et al. (2018), [9] Moeuf, et al. (2018), [10] Muller, et al. (2018), [11] Oztemel and Gursev (2020), [12] Sung (2018), [13] Xiang, et al., (2018).

3. METHODOLOGY

A comprehensive literature review was conducted to perceive a theory-based knowledge from the research area. Industry 4.0, PdM and FM concepts are reviewed from a broader perspective to elaborate the research problem. The literature review assisted in identifying feasible smart technologies to develop an integration between Industry 4.0 and PdM approach. Hence, in order to achieve the aim, the research necessitates an in-depth expert opinion to be evaluated in a descriptive way. Thus, this research applied semi-structured interviews through qualitative research approach. However, obtaining a large sample of respondents was difficult due to the lack of Industry 4.0 applicability. Hence, 15 experts who had proficiency in the maintenance sector with the knowledge of Industry 4.0 from manufacturing facilities were selected through convenient sampling and interviewed. NVivo software was used in this research to carry out the code-based content analysis.

4. RESEARCH FINDINGS

The semi-structured interviews were conducted with 15 maintenance field experts from Australia, Qatar, Dubai, Singapore and Sri Lankan manufacturing industries, who have Industry 4.0 awareness and knowledge. Experts' profile is given in Table 3.

Table 3: Experts' profile

Code	Designation	Nature of the organization	Experience	Country
R1	Facilities Coordinator	Food Manufacturing	10 Years	Australia
R2	Facilities Engineer	Food Manufacturing	10 Years	Qatar
R3	Head Industry 4.0 Initiative	Stationary Manufacturing	11 Years	Sri Lanka
R4	Plant Engineer	Cement Manufacturing	20 Years	Sri Lanka
R5	Facilities Engineer	Food Manufacturing	09 Years	Dubai
R6	FM Estimation Engineer	Food Manufacturing	08 Years	Qatar
R7	Facilities Engineer	Food Manufacturing	09 Years	Dubai
R8	Mill Manager	Food Manufacturing	20 Years	Sri Lanka

Code	Designation	Nature of the organization	Experience	Country
R9	Senior Reliability Engineer	Tyre Manufacturing	08 Years	Sri Lanka
R10	Facilities Engineer	Food Manufacturing	09 Years	Dubai
R11	Maintenance Manager	Food Manufacturing	12 Years	Singapore
R12	Maintenance Engineer	Food Manufacturing	10 Years	Sri Lanka
R13	Head of Autonomation	Garment Manufacturing	10 Years	Sri Lanka
R14	Engineering Maintenance Manager	Cement Manufacturing	15 Years	Singapore
R15	Senior Factory Engineer	Cement Manufacturing	16 Years	Sri Lanka

Among the respondents, R3 is from a manufacturing firm where Industry 4.0 strategy is developed and their system indicators are clearly defined (Intermediate stage in the Industry 4.0 Ladder). Research findings are discussed below.

4.1 CURRENT MAINTENANCE PRACTICES USED FOR FM

To identify the existing industry practices in the maintenance field, respondents were asked to mention the maintenance practices followed in their current organization. Respondents' responses are summarized in Figure 1.

Name	Files	References
Current Maintenance Approaches	15	102
Computerized Maintenance Management System	15	15
Condition Based Maintenance (CBM)	12	12
Corrective Maintenance	15	15
Lean Maintenance	2	2
Predictive Maintenance (PdM)	15	15
Preventive Maintenance	15	15
Reactive Maintenance	15	15
Reliability Centred Maintenance (RCM)	8	8
Total Productive Maintenance (TPM)	5	5

Figure 1: Currently utilized maintenance approaches in FM

According to the analysis, it was evident that reactive maintenance, corrective maintenance, preventive maintenance, PdM and Computerized Maintenance Management System (CMMS) are prominently used maintenance approaches. Respondents also mentioned that CBM and PdM terms and approaches are interchangeably used in the maintenance field. However, all respondents have highlighted that the PdM approach is not well-established in the industry at the moment. However, the applicability of PdM for FM is acknowledged through currently utilizing PdM techniques and by recognizing its intended benefits for each organization through respondents' responses. According to the analysis, the most commonly used PdM techniques are oil analysis, thermographic analysis and visual inspection. Moreover, vibration analysis is also cited by most of the respondents. Only a few respondents are utilizing ultra-sonic analysis. A proactive approach like PdM is beneficial for the operations of the industries in numerous ways. According to respondents' opinion, most industries are trying to implement the PdM approach to reduce their cost burdens. Next significance is given by the respondents to avoid or reduce downtimes. Further, respondents highlighted that there is a high opportunity for identifying the maintenance requirement accurately. Each and every organization and its maintenance managers are getting benefited from the PdM approach.

Asian maintenance experts are satisfied with current maintenance approaches. After COVID-19, Gulf industries are becoming more interested in smart maintenance solutions with less human interaction, whilst the majority of Australian (Oceania) companies are still using excel-aided preventive maintenance programs. On the other hand, maintenance management approaches evolve from time to time in a way to fulfil arising maintenance requirements. However, there are many issues in executing the current maintenance approaches. R1, R3 and R10 stated that the complex and unpredictable nature of maintenance is "*generic and inevitable in the maintenance field*". R5 and R8 highlighted that "*PdM will determine the future of the industries*". Still, they highlighted that a proper PdM is not possible without the foundation of correlation techniques or smart technologies. All experts answered in a similar way to "*computerize or digitalize the maintenance management process*" to carry out effective PdM in FM.

4.2 INDUSTRY 4.0 AND ITS SIGNIFICANCE TO CARRYOUT PDM IN FM

This section focuses on the expert's awareness and knowledge of Industry 4.0. All fifteen respondents were well aware of Industry 4.0. "Automation", "integration" and "smart machinery, people and resources" are the keywords used by the respondents for defining Industry 4.0. Other than these words, respondents gave prominent focus to the word "real-time data". Considering the feedback received from respondents, Industry 4.0 can be defined as:

> "*An industrial transformation or a digital transformation, which can be considered as an expensive solution to overcome existing gaps in the industries by enabling automation through advanced technology, simulating, scheduling, integrating smart machinery, people and process, monitoring, controlling machines and equipment by real-time data collected through wireless connectivity and sensors".*

4.2.1 Need for a Novel Maintenance Approach in Facilities Maintenance

Industries are gradually recognizing the value of the facilities maintenance. However, the current level of maintenance is not adequate to address all the maintenance requirements of the industries. Respondents' responses to identify whether there is an actual need for a novel maintenance approach in the facilities maintenance are summarized in Figure 2.

Name	Files	References
Need for a novel maintenance approach in Facilities	13	13
To achieve greater added values	2	2
Requirement for a change or proactive approach	5	5
Increasing criticality in managing assets	6	6

Figure 2: Need for a novel maintenance approach in facilities maintenance

Thirteen respondents mentioned that there is an actual need for a novel maintenance approach. On other hand, two respondents argued that there is no need for a novel maintenance approach. Supporting this, R1 stated, "*There is no term is validated as a novel maintenance approach. New maintenance concepts and practices are using the same existing approaches to optimize available maintenance practices. Concepts are same, approaches are getting smarter and trying to define more combination, optimization and monitoring ways.*". Further, R4 presented his reason as, "*There is no need for a new maintenance approach for facilities maintenance. Anyhow, modification* *in the traditional maintenance approaches along with smart technologies is appreciated.*".

4.2.2 Importance to Switch toward the New Industrial Paradigm

The opinion of all respondents about the significance or importance to switch toward a new industrial paradigm is summarized in Figure 3.

Name	Files	References
Importance to Switch Towards New Industrial Paradigm	15	17
Achieving sustainability	1	1
Competitive advantage	7	7
Enhancing collaborative smart work environment	2	2
Globalization	1	1
Inevitable or mandatory requirement	2	2
Reduced costs	1	1
Supply the demand for real-time insights	3	3

Figure 3: Importance to switch toward a new industrial paradigm

R3 and R4 highlighted their answer with a real-life example of "KODAK". KODAK failed to retain its market as it fails to give importance to digital technology. Likewise, R10 mentioned that "*Failing to adopt Industry 4.0 smart technologies will force firms to lag, as their activities will not be sufficiently smart to compete with other industries*".

4.3 APPLICABILITY OF SMART TECHNOLOGIES TO IMPLEMENT INDUSTRY 4.0 ENABLED PDM IN FM

Possible applications of smart technologies to enable effective PdM in FM were collected from industry experts and presented in Table 4.

Table 4: Possible application of smart technologies to enable effective PdM in FM

Smart Technologies	Possible Applications
AM	Printing 3D spare parts
Big Data Analytics	Assessing the health of machines and predicting breakdowns
CPS	Inducing self-aware and self-adaptive abilities of machines
Autonomous robots	Performing critical maintenance activities in human restricted areas
Cloud computing	Processing, analysing, and storing maintenance data
IIoT	Predicting future failure events
Cyber security	Providing data protection against cyber-attacks
ML	Facilitating both supervised and unsupervised ML to predict failures
AR	Visualizing machine's physical conditions
DM	Extracting hidden patterns, trends and relationships from data
System integration	Automating communication cooperation and standardized procedures regarding PdM
Simulation	Developing a virtual model using real-time data

R11 highlighted that "Industries which are now practicing Industry 3.0 are more curious about Industry 4.0 implementation". Further, above-identified all possible applications of smart technologies can be successfully utilized to enable effective PdM in FM.

4.4 BENEFITS OF APPLYING INDUSTRY 4.0 TO PDM

Respondents identified the advantages of applying Industry 4.0 to PdM in FM and the identified benefits are presented in Figure 4.

Name	Files	References
Derivable Advantages	15	224
Ability to determine appropriate intervals for PdM	15	15
Ability to implement a zero-failure strategy	14	14
Ability to provide high quality of maintenance	15	15
Detecting early anomalies (Real-time and historical data)	15	15
Effective use of maintenance resources	15	15
Enhance maintenance processes	15	15
Enhanced safety (Occupants and equipment)	15	15
Extended operating equipment lifetime	15	15
Generate and forecast maintenance related information	15	15
Improve asset status forecasting prognosis	15	15
Machine-to-machine communication and interaction	15	15
Minimize failure and maintenance costs	15	15
Predictive analytics	15	15
To gain a competitive edge	15	15
Upgraded plant reliability	15	15

Figure 4: Advantages of applying Industry 4.0 to PdM

All experts agreed that determining appropriate intervals for PdM, enhancing maintenance, predictive analysis and high levels of quality, asset forecasting prognosis, machine-to-machine communication and interaction, detection of early anomalies, extended operating lifetime, safety, effective use of maintenance resources, upgraded plant reliability, gaining competitive advantage and minimizing failure and maintenance cost as some of the benefits that can be gained from Industry 4.0 application for PdM in FM. Except R1, all experts agreed on the benefit of the "ability to deploy a zero-failure strategy". R1 stated that a "*zero-failure strategy cannot be achieved*". However, "*implementing a zero-failure strategy is possible with appropriate strategic planning and implementation of maintenance activities*" stated R9.

4.5 CHALLENGES IN APPLYING INDUSTRY 4.0 TO PDM

All respondents identified challenges for the application of Industry 4.0 to PdM in FM. Respondents' opinions towards each type of challenge are discussed below.

Technology-related challenges

Industry 4.0 is a digital transformation, which requires the support of smart technologies. R1 stated that "*switching into new technology-based systems is always a challenge in its earlier phases of implementation*". Industries must overcome these technological challenges to achieve intended Industry 4.0 benefits.

Investment related challenges

Investment challenges are very common in the industries. Industrial transformation requires a high initial cost. R11 highlighted that "*large manufacturing firms are hesitant to invest due to unknown risks in investments, where medium scale manufacturing firms face limited capital concerns when investing.*"

Data related challenges

Data plays a significant role in the fourth industrial revolution. Initially, it is difficult to collect, manage, process and analyse data. Industries must overcome these data challenges to derive the actual benefits of the implementation. However, all respondents mentioned that "*smart technologies have solutions for all identified data challenges. These data-related challenges just an initial implementation challenge"*.

Employees related challenges

Employees are always resistant to change. Industrial changes are growing concerns for employees. R1, R3, R4, R5, R9 and R13 highlighted the fact that, inducing employees' willingness toward new changes or implementations is always challenging.

Integration related challenges

Industries might face integration challenges while transforming the current industry into smart. Industries have to change the existing system to smart systems gradually. However, there is a need to maintain both old and new systems parallelly. R7 stated that *"upgrading an automated system into a smart system is not a complex one. But there is a challenge in identifying the integration requirements of the systems"*.

Standardization related challenges

Standardizing the application of smart technologies will ensure their interoperability, compatibility and security along with the industrial processes. R4 mentioned that "*Standardization challenges are common in industries. Still, there is less to be concerned about standardization because conformance requirements for all industries are revised continuously*".

Communication related challenges

The Industry 4.0 concept relies on data communication by which all real-time decisions are taken. Communication challenges affects the Industry 4.0 implementation.

Security related challenges

Currently, industries are relying on computerized systems to carry out their business processes. R4 mentioned that "*Cyber-attacks are inevitable in technological advancements*". Further, R8 stated that "*Cyber security is constantly developing as cybercriminals are finding new ways to exploit loopholes*". Before investing in smart technology-based industrial platforms, industries must assure the security of their data.

5. CONCLUSIONS AND RECOMMENDATIONS

FM input appears to be essential in the forthcoming industry. With the introduction of the Industry 4.0 idea, the use of complicated machines and equipment in the contemporary industry has rapidly increased. Maintenance practitioners in the FM industry are currently facing difficulties in managing assets due to their increasing critical nature. Thus, the FM industry foresees a proactive maintenance approach rather than a reactive maintenance approach. Therefore, maintenance practitioners in the FM industry are now realizing the significance of Industry 4.0 to carry out effective PdM under FM. Feasible applications of each smart technology such as AM, Big Data Analytics, cloud computing, CPS, IIoT, cyber security, autonomous robots, ML, AR, DM, system integration and simulation are gathered. Nowadays, every spare part comes with an embedded system that allows the spare part manufacturer to gather and evaluate real-time data on behalf of the client in exchange for a fee. Rather than investing money on external monitoring systems, maintenance professionals can avail the potentials of Industry 4.0 concept and smart technologies. Application of Industry 4.0 smart technologies can facilitate machine-to-machine communication and interaction to improve the self-aware, self-predictable, self-maintainable, self-diagnosis, and self-adaptive abilities of machines and equipment. Utilizing smart technologies for PdM upgrades plant reliability, extends operating equipment lifetime, enhances safety for occupants and equipment and facilitates FMs with effective use of maintenance resources. Still, there are technology, investment, data, employees, integration, standardization, communication and security-related challenges in applying the Industry 4.0 concept for carrying out effective PdM under FM, which needs proper solutions. Maintenance practitioners involved in FM can apply the findings of this study on Industry 4.0 smart technologies for PdM to enhance the overall effectiveness of the maintenance process.

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INVESTIGATING THE SUSTAINABLE USE OF ENERGY ON CONSTRUCTION SITES IN SRI LANKA

S.A.U.M. Athukorala[1] and K.G.A.S. Waidyasekara[2]

ABSTRACT

The construction sector can be identified as one of the highest energy-consuming industries in the world. The energy usage of the construction, operation, and maintenance stages is significant due to the complex nature of the industry. However, energy is one of the most undervalued resources in terms of efficiency and conservation in the construction stage. Higher energy usage and energy wastage in construction sites can be identified as significant matters, and various energy efficiency measures have massive potential for saving energy during the construction stage. Accordingly, this paper aims to investigate the sustainable use of energy practices on construction sites in Sri Lanka. A comprehensive literature review was conducted to identify principles and practices of sustainable use of energy, energy-using activities, processes, and the most applicable energy efficiency measures. The research aim was achieved through a qualitative research approach, and four case studies on building construction projects were conducted within the Colombo district. The case boundary of the study is defined as high-rise building sites. Semi-structured interviews, site observation, and document reviews were carried out as data collection techniques within each case. The collected data were analysed using manual content analysis. Key findings revealed how to use energy sustainably, what are the current energy sources and alternative sources available, construction activities and equipment used in the construction process, and reduce energy wastage by using energy efficiency measures. Rework, and workers' behaviour highly affects the energy wastage on the site. Lack of planning, lack of information, limited space, and poor responses from the construction organisation were identified as the most relevant barriers that influence sustainable energy use on construction sites. The proposed recommendations for improving the sustainable use of energy should be adopted at the project level. Measures exceeding the scope of site management, industry-level support, and policy intervention are required.

Keywords: *Construction Sites; Energy Efficiency; Energy Management; Sustainable Energy Use.*

1. INTRODUCTION

Energy is one of the most expensive inputs into the construction industry and the source of the majority of its polluting effects (Der-Petrossian and Johansson, 2000). The built environment accounts for about 40% of the energy consumed worldwide (Devi and Palaniappan, 2017). The world's economic development rapidly increases, consuming a high amount of degraded resources in the environment. Energy and energy-related

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problems are global (Zhang, Nizam and Tian, 2018), and energy consumption and greenhouse gas emissions are critical concerns across the world. A reduction target for greenhouse gas emissions and energy consumption has been recommended in the construction sector, which consumes the most energy (Hong, et al., 2014). Energy consumption in construction projects is not well recognised because of the fragmented nature of the construction industry (Shrivastava and Chini, 2011). The construction industry has several stages, such as construction, operation, and building maintenance (Gottsche, Kelly and Taggart, 2016). According to Devi and Palaniappan (2017), the energy usage during the construction phase presents a significant component of energy usage during the building life cycle. Most studies on the buildings' life cycle were incomplete because they only focused on the energy usage of the building operation and maintenance stages (Gottsche, Kelly and Taggart, 2016). Bilec, Ries and Matthews (2010) mentioned that this was largely due to the highest energy usage and significant impact on the environment during the operation and maintenance stages. Obviously, the time duration of the construction stage is less compared to the maintenance and operation stages. However, the possible environmental impact during the construction stage was significant. Hong, et al. (2014) stated that a detailed analysis is necessary for a more reliable assessment for investigating the energy usage and environmental impact during the construction stage. Buildings generate greenhouse gases due to the energy used in building operation and maintenance stages and also due to energy consumption of onsite construction works and the usage of significant construction materials (Dong, et al., 2015). Korol and Korol (2018) stated that high-rise buildings require more construction energy than low-rise buildings due to the complexity and vertical travelling.

Nowadays, most national estimates referred operational energy and embedded energy studies, which focus on energy consumption in the pre-construction stage (Gottsche, Kelly and Taggart, 2016). Few research works have investigated energy consumption in the construction stage of buildings worldwide. Some researchers have focused on energy usage only for a specific activity in the construction phase. For example, Devi and Palaniappan (2017) studied energy use for excavation and soil transport in construction. Some researchers have focused on the energy usage of specific construction materials in the construction phase; e.g. Heravi, Nafisi and Mousavi (2016) investigated energy consumption during the production and construction of concrete and steel frames in their research.

As depicted in the literature, energy is a crucial and mandatory need for the total life cycle of buildings. In the Sri Lankan context, many researchers have studied embodied energy and operational energy in buildings during the design stage (Tennakoon, et al., 2019) and operational and maintenance stages (Pathirana and Yarime, 2018). However, limited studies are available in Sri Lanka on energy consumption during the construction phase. Hence, this paper focuses on the sustainable use of energy consumption in Sri Lanka during the construction stage of building projects. The next section provides concepts of sustainable development, energy consumption, and energy efficiency measures related to the construction industry.

2. LITERATURE REVIEW

2.1 SUSTAINABLE DEVELOPMENT IN CONSTRUCTION

According to the WCED (1987, p. 43), sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The construction sector is making a significant contribution to unsustainable development and its environmental and economic effects. The construction sector consumes 40% of the total output of energy, 40% of all raw materials, and 25% of all timber globally while also accounting for 16% of the total consumption of water and 35% of CO_2 emission (Son, et al., 2011). The construction sector will incorporate the improvement of sustainable design procedures, efficient and sustainable construction equipment in the industry, changes in material sustainability practices, the use of high-performance materials, and public and government policy actions for sustainable design and construction practices (Majdalani, Ajam and Mezher, 2006). Moreover, appropriate buildings may accomplish sustainable development by utilising fewer materials with minimal environmental consequences, energy-efficient construction techniques, and employing renewable energies to minimise environmental burdens and energy and water consumption (Ortiz, Castells and Sonnemann, 2009).

2.2 ENERGY CONSUMPTION IN THE CONSTRUCTION SECTOR

The construction industry utilises a large amount of energy and resources because of the current population growth. Building construction only requires approximately 40% of the energy consumed globally (United Nations Environment Programme, 2020). Furthermore, the primary energy resources used in construction include fossil fuels, coal, gas, and secondary sources such as electricity. Supplies of some of these resources might last only a few more decades. Figure 1 illustrates the contribution of energy use activities in the construction sector based on the study of Panagiotakopoulos (2005).

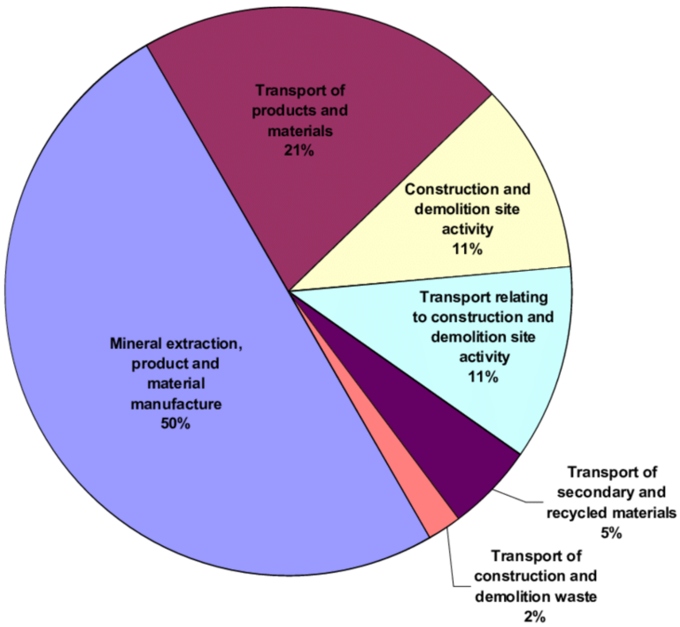

Figure 1: Energy use in the construction sector (%)

(Source: Panagiotakopoulos, 2005)

The industry's energy consumption is not well recognised during construction because of its fragmented structure and involvement of various parties throughout the building phase (Gottsche, Kelly and Taggart, 2016). Therefore, contractors have to estimate energy consumption during the construction phase of a project. Identifying high energy-intensive construction activities during construction and seeking energy-efficient alternatives are more important before investigating the sustainable practices of energy in construction (Shrivastava and Chini, 2011). Energy efficiency is moving near the top of many national agendas for many compelling reasons that are economic, environmental, and intergovernmental in character (Peck and Chipman, 2007). Hence, sustainable use of energy does not harm the environment and protects the resources for future demand.

2.3 ENERGY EFFICIENCY MEASURES RELATED TO CONSTRUCTION

The discovery of energy efficiency methods to minimise energy usage in the building industry can be useful. Relatively few studies have identified energy efficiency techniques used in the construction phase. Having an idea about energy efficiency before beginning the construction process may assist contractors in focusing on energy management means and procedures, such as energy-efficient lighting systems and purchasing renewable energy for managerial set-up to minimise the carbon emission of the building (Shrivastava and Chini, 2011).

2.3.1 Energy Management Policies

The government promotes investments related to energy-efficient construction equipment or increases the purchase of energy costs via tax and fiscal policies (Peck and Chipman, 2007). Dimitriev (2013) introduced two principles of energy consumption in construction: (1) only renewable energy sources should be used, and (2) the amount of consumed energy should not exceed the amount of energy received by the Earth.

2.3.2 Energy Audit

An *Energy audit* is a visual inspection, survey, and analysis of energy flow to reduce the amount of energy input while maintaining the system's output. Therefore, it is considered a systematic and reliable strategy in the construction industry (Moya, Torres and Stegen, 2016). An energy audit assists an institution in analysing its energy consumption and identifying areas where energy waste can occur, planning and implementing feasible energy efficiency methods that will improve their energy efficiency, identifying all energy flows in a facility, and quantifying energy consumption in an attempt to mitigate the overall energy inputs with its consumption (Abdelaziz, Saidur and Mekhilef, 2011). Figure 2 presents the energy audit process.

The energy audit report includes a detailed analysis of energy usage in each activity, which helps investigate larger energy-demanding activities and equipment in the construction process.

As stated by Shrivastava and Chini (2011), the project manager can use the energy audit report to identify site energy-related issues, find solutions, prepare energy reduction plans, and investigate alternative energy-efficient methods and techniques for identified energy-intensive activities.

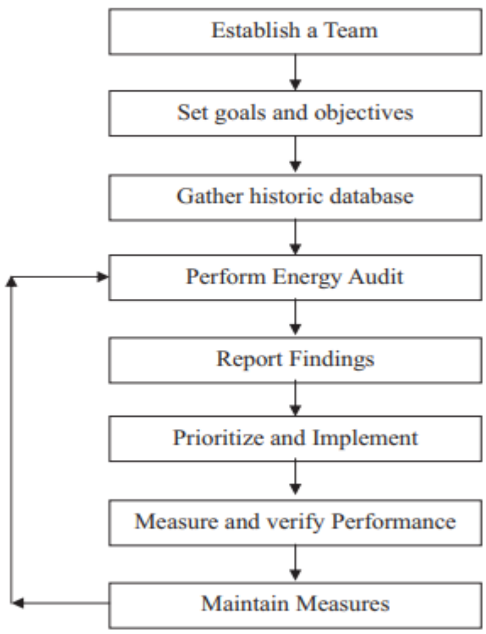

Figure 2: Energy audit process

Source: Abdelaziz, Saidur and Mekhilef (2011)

2.3.3 Site Management

Site management is the most important energy-efficient tactic on a construction site. Site planning helps minimise double handling materials and equipment and avoids reworks in building construction supplies (Sharrard, Matthews and Roth, 2007). Further, site delivery and onsite processing of supplies account for a significant portion of the energy used on construction sites. Selecting resources that are easily accessible may reduce transportation to the site, and effective site layout planning may reduce transportation on site. Inefficiency is caused by inefficient deliveries, such as materials being late or having too many items on the construction site. Therefore, scheduling material orders are a must (Der-Petrossian and Johansson, 2000).

As mentioned above, the contractor may minimise the transportation distances for materials. When the distance of transport is raised by three times, energy demand for facilitating the transport of workers, construction inputs, and transporting equipment grow by 26%, 22%, and 9%, respectively (Der-Petrossian and Johansson, 2000). This indicates that the increased transportation distance significantly influences the energy usage by employees and materials than construction equipment (Shrivastava and Chini, 2011). Moreover, project managers who want to save energy should focus on reducing labour and material transportation distances but may acquire equipment from a faraway location if it is more energy efficient.

2.3.4 Efficient Use of Machinery and Labour

The efficient use of machines and manpower has the potential to save a significant amount of energy. The contractor might insist that energy-saving lighting systems be used and energy-efficient electrical items and equipment be purchased and properly maintained to avoid energy losses (Majdalani, Ajam and Mezher, 2006). According to the financial cost perspective, machines with new technologies are the best (Repin and Evtjukov, 2015) because of their energy efficiency and less maintenance. According to Der-Petrossian and Johansson (2000), when manpower is inexpensive, the replacement of machinery with employees can save energy while boosting employment. Nonetheless, some activities must be performed by machinery.

A comprehensive training programme without excluding any specific group of experts (with varied backgrounds and qualifications) involved during the inception is necessary for the construction stages and afterwards in monitoring and maintenance (Gottsche, Kelly and Taggart, 2016).

Enhanced education and training will ensure the development of energy-efficient design and practices as the standard. Permanent ties and exchanges may be formed with all professional partners by including them in the process of establishing the energy efficiency targets, setting the funding and assessing the related actions for their advantages (ESCAP, 2004). Some research identifies training initiatives and their mediums. The contractor can sustainably use energy by implementing these energy-efficient practices effectively. Table 1 provides some onsite training initiatives as highlighted by Gottsche, Kelly and Taggart (2016).

Table 1: Training initiatives used onsite

Medium	Topic
Pocket meetings	Energy efficiency onsite, Eco-driving techniques, Fuel efficiency, Lighting onsite
Posters	Idling machinery onsite, Night-time lighting, Lighting onsite, Fuel efficiency/usage, Energy-saving tips at the accommodation, Energy savings at the site office
E-mails	Office equipment, Transport

(Source: Gottsche, Kelly and Taggart, 2016)

3. RESEARCH METHODOLOGY

A qualitative research approach was conducted to achieve the study aim. Yin (2011) described that a qualitative approach is suitable if the researcher investigates existing phenomena, current situations, opinions, aspects, and in-depth study on topics. First, a comprehensive literature review is carried out to identify and understand the research gap and practices of sustainable use of energy, construction activities and equipment that have higher energy consumption during the construction stage, and current energy sources used for the activities discussed in the above alternative sources. Data were collected through qualitative data collection techniques. A case study research strategy was chosen as a research strategy. This research required an in-depth study of the sustainable use of energy rather than a sweeping statistical survey. Yin (2011) introduced fundamental types of case study designs, such as single and multiple case studies. Four high-rise building construction projects were reviewed under the case study. The underlying principle of a case study is to get a clear idea of a problem, and thus, several data collection methods should evaluate the real-life situation from many aspects and perspectives (Yin, 2009). The interviews, document reviews, and observations were selected as data collection methods. They identified variables specific to the Sri Lankan context and investigated the most applicable energy efficiency measures and strategies for enhancing the sustainable use of energy practices in construction projects. Each of the four cases conducted individual, semi-structured interviews with construction professionals. The interview questions were prepared based on the literature. Table 2 provides a profile of selected cases and interviewees.

Table 2: Profiles of interviewees in case studies

Interviewer	Case 1	Case 2	Case 3	Case 4
Project Manager (PM)	PM-C1	PM-C2	PM-C3	PM-C4
Site Engineer (SE)	-	SE-C2	SE-C3	-
Project Quantity Surveyor (QS)	QS-C1	QS-C2	QS-C3	QS-C4
Planning Engineer (PE)	PE-C1	-	-	PE-C4
Site Supervisor (SS)	SS-C1	SS-C2	SS-C3	SS-C4
Storekeeper (SK)	SK-C1	-	SK-C3	-

Multiple sources of evidence such as project documents (Bill of Quantities, specifications, labour records, Environmental Management System, energy bills, and Building Schedule of Rates-BSR) and site observations contributed to gathering extra data for the case analysis. Both individual case analysis and cross-case analysis were employed to analyse data.

4. RESEARCH FINDINGS

A detailed description of the cross-case analysis of Cases A, B, C, and D are presented in the following subsections: Section 4.1 describes the "onsite energy efficiency measures", Section 4.2 describes "barriers that affect the efficient use of energy during the construction stage", and Section 4.3 describes "recommendations for the sustainable use of energy during construction".

4.1 ONSITE ENERGY EFFICIENCY MEASURES

This section presents the most applicable energy-efficient measures based on case study findings. The objective of energy efficiency measures in construction is to reduce energy consumption while maintaining or enhancing the quality of works provided on the construction site. Nine energy efficiency measures were identified based on case study findings.

4.1.1 Energy-Efficient Lights and Equipment

The interviewees highlighted that there are many onsite energy-efficient lights and equipment. According to QS-C1, the site operated on mercury bulbs and filament lamps before the use of Light-Emitting Diode (LED) lighting, and it consumed much energy. The use of LED lights has now reduced electricity usage up to 20%. Besides, it has increased the lifetime, instant lighting ability and lumen per square meter, voltage operation, cost, heat, and UV emissions.

PM-C4 mentioned that LED lights with motion sensors and the switch are activated when the sensor detects movement. Due to safety purposes, unnecessary locations were lit up frequently and LED lights with motion sensors helped reduce the mass quantity of electricity. Case 2 used solar-powered motion sensor wireless light as security lighting, with no connection to any electricity line. In addition to lights, high-efficiency grinders, sanders, putty mixtures, and breakers are used in most cases. This was also emphasised by many other respondents.

According to PE-C1 and SE-C2, there is a dusk-to-dawn feature in some LED lamps. These bulbs have built-in sensors that turn them *on* when dark and turn them *off* at dawn. This eliminates the need to turn the light on and off manually. The study revealed that most energy-efficient and cost-effective machines had been purchased for construction activities as a site policy. PE-C4 stated, *"we can minimise the energy usage, and it can be reduced up to 80% to 60% by using energy efficiency machines"*.

4.1.2 Site Planning

Site planning is the best way to manage energy. It is noted that energy consumption is calculated approximately before beginning the project. The site arrangement, selection of heavy equipment such as tower cranes, hoists, concrete pumps, placing booms, generators, project programme, and project duration significantly impact energy consumption. Several interviewees highlighted that storage facilities, loading bays, hoists, concrete pumps, and tower cranes were allocated in a planned manner in the site layout to reduce unnecessary movements. SE-C3 mentions, *"the storage, hoist, loading bay, and tower cranes are better placed in the same location"*. This facilitates unloading materials and lifting reinforcements and concretes using tower cranes without wasting energy.

It is also important to choose heavy equipment with a suitable capacity. Selecting a low capacity hoist may save energy, but it may require more cycles to fulfil site requirements. This will consume more energy than the high-capacity hoist.

The same will happen when choosing a suitable tower crane. As highlighted by many respondents, it is essential to plan how many heavy machineries are needed to optimise the construction works. In Case 3, the management has planned early procurement for the passenger lift contract during the planning stage, and the lift was placed after finishing the structure. It resulted in significant energy savings.

4.1.3 Energy Management Plans

Construction management plans and method statements include energy management plans. Those documents include how to use equipment efficiently without wasting energy. It also includes suitable equipment for a particular work since using appropriate tools and equipment help to reduce energy usage. PE-C4 mentioned that their site has an energy plan for the construction period, and the Mechanical, Electrical, and Plumbing (MEP) section checked whether the actual energy consumption tallied with the plan. If there is a discrepancy between plans and actual consumption, the MEP division makes appropriate adjustments. Construction management plans help maintain the required project performance quality standards, as highlighted by several respondents.

4.1.4 Monitoring and Supervision

PM-C2 pointed out the uselessness of having energy plans or method statements without monitoring workers. Even without an energy management plan, energy can be optimised by monitoring. The site management has assigned staff to monitor and supervise construction activities, including preventing energy waste by site workers while performing all direct and indirect site activities.

SS-C2 mentioned that supervisors behaving like responsible persons are sufficient to reduce energy waste. However, it was noted that some supervisors are not performing their job roles suitably. In Case 2, senior engineers monitored the supervisor's actions at the site. The study revealed that site meetings should be held to discuss the work progress and problems at the site. During the meetings, energy-related matters such as energy usage, energy wastage, and energy management actions can be discussed. PE-C1 stated, *"We never do night work without proper planning and supervision. Because in night works, a large amount of energy is used for lighting and there may be an energy waste if productivity is low"*.

4.1.5 Increasing Employee Awareness

Many respondents highlighted that energy usage is often based on employees' behaviour, and employees are one category of the main influencers in a construction site. Proper site meetings are required to discuss daily work plans, safety aspects, instructions about machines, equipment, and awareness of electricity and water consumption. Workers, as well as staff members, should be instructed about energy management. Signboards are an effective method to increase the workers' awareness because the instructions given in the meetings can be forgotten due to various reasons. Signboards and posters can display in areas with a high chance of energy waste. The site office, canteen, washrooms, and electrical distribution panels in a site are identified as the best places to display posters. The SS-C2 stated, *"According to my experience, this method is more effective than other methods because workers may recall what the supervisor said during the meeting"*.

4.1.6 Assign Responsibilities for Works

The majority of respondents believed that a particular person should monitor temporary electricity at the site. His job role is to supply and maintain electricity connections, monitor and effectively control the energy use, and always be responsible for temporary lighting. As revealed, a separate person has been assigned in each case. SE-C3 mentioned that the MEP section is responsible for the supply and control of temporary electricity on the site, and each floor has a particular technical officer as the in-charge of the floor. The electrical crew should have a separate red colour uniform for easy identification, and they are always responsible for temporary lighting.

In addition, the construction manager, project engineer, quality assurance and quality control engineer, mechanical, electrical, and plumbing engineers, site supervisor, and every worker have equal responsibility for energy usage on construction sites. The site supervisor of Case 2 (SS-C2) stated that signboards and monitoring systems are more effective but maintaining notices throughout the construction period is difficult.

4.1.7 Energy Audit

The energy audit is an inspection survey and analysis of energy flows for energy conservation in the site. It could involve a technique or system that reduces the amount of energy input while maintaining the work output.

Energy audit has major steps, which include several sub-activities. The Mechanical, Electrical, and Plumbing (MEP) section publish energy audit reports to the project manager and contractor's head office. The project manager should review the report and take necessary actions to enhance energy efficiency. Case 2 and Case 3 have proper energy audit processes.

The main steps in the energy audit used in Case 2 were as follows:

- Step 1: Investigation of energy inlets and outlets
- Step 2: Data collection and measurements
- Step 3: Economic evaluation of energy consumption in the site
- Step 4: Examine energy-consuming sub-processes
- Step 5: Propose energy conservation methods and alternatives
- Step 6: Propose strategies for reducing energy consumption without losing productivity

4.1.8 Submetering

Installing power meters that can detect energy usage after it reaches the primary utility meter is known as *electrical submetering*. It can be used on the site, floor-wise, or based on organisations that involve construction works. For example, PM-C2 and PM C4 mentioned that the sub-contractor office has a separate meter connection for electricity, and it can help to manage electricity consumption efficiently. Case 2 and Case 4 had 4 and 15 submeters, respectively. PM-C4 stated, *"We get energy usage reports from submeter connections, and those are analysed every month"*.

However, sub-contractors did not pay separately for meter readings, and those costs were claimed under the attendance fee. The case study findings revealed that the sub-metering concept easily identifies which section consumes more energy and which section has sudden deviation within the meter section.

4.1.9 Fuel Monitoring System

Fuel is used for most site activities. Hence, a proper fuel monitoring system is necessary to manage fuel purchases, fuel storage, and fuel issuing. Typically, the storekeeper is the responsible person for fuel purchasing, issuing, and maintaining proper records. The responsibility of the assistant quantity surveyor is to collect the fuel usage details and check machine hours or meter readings. Then machine report is prepared, and fuel usage per unit is calculated. Most sites have pre-calculated fuel rates in the site. QS-C2 stated, *"Every month, actual unit rates should be compared with pre-calculated rates, and if there is a major deviation, the particular supervisor should find the reasons for the deviation"*.

Several reasons were identified for deviations: serviceability issues, economic lifetime expired, not being properly maintained, and fraudulent labour acts. All four cases reported fuel use, but fuel analysis was subjective.

4.2 BARRIERS THAT AFFECT SUSTAINABLE AND EFFICIENT USE OF ENERGY DURING CONSTRUCTION

Based on cross-case analysis findings, this section examines key barriers that affect the sustainable and efficient use of energy during the construction stage.

4.2.1 Lack of Knowledge

Information is the main input of any kind of analysis. Lack of knowledge is the main barrier to implementing energy efficiency practices. PM-C1 stated, *"Without proper information, we cannot make correct decisions"*. Sometimes, site supervisors attempt to reduce energy consumption in a particular activity, but that work may have a minor impact on total energy. Thus, using resources to reduce energy in such activities is useless.

The management should be aware of energy management and energy efficiency. Several professionals with proper knowledge of energy should be at the site. SE-C2 stated, *"Before thinking about energy-reducing, it is necessary to identify energy usage trends on the site".* Most professionals were not aware of the stage which used more and which stage used less energy.

4.2.2 Lack of Planning

Many respondents emphasised that if the information is available, there should be an appropriate planning procedure to make energy management decisions. Lack of planning affects onsite energy wastage. Planning is the first step of energy management, and it is a set of activities that includes site planning, plant and machinery selection, energy sources selection, selection of construction methods and technologies, and preparation of a detailed working schedule. The study revealed that the project manager should plan the site to minimise unnecessary transportation, get maximum daylight for the site office, store, canteen, and other common areas, and minimise the tower crane movement. Energy management becomes difficult if management fails to make proper planning decisions in the early stage. PM- C3 and Pm-C4 mentioned that sometimes the site office and labour facilities are improperly ventilated and receive inadequate daylight due to poor site planning; hence, reducing lighting and air conditioning becomes an issue.

4.2.3 Lack of Responsibility

The study revealed that lack of responsibility is a serious problem in Sri Lanka. Although the management level collects information and makes decisions to improve energy efficiency practices, people are reluctant to take responsibility for implementing such practices. As many respondents highlighted, everyone on the site is responsible for minimising energy consumption and reducing waste, but frequently, the administrative division is responsible for any major deviations of the site's monthly energy bills. It is noted that one person or one department cannot control it, and burdening one party with the whole responsibility is not a good practice - all parties should share the responsibility.

4.2.4 Poor Responses from the Construction Organisation

The construction organisation may respond poorly to energy management and may not focus on introducing any energy management during the project's design stage. In the tendering stage, proposals should come up to reduce energy in the site with the involvement of the consultant. Also, the contractor can implement policies to increase energy management, which are strong policies to fulfil energy-efficient practices.

4.3 RECOMMENDATIONS FOR THE SUSTAINABLE USE OF ENERGY DURING CONSTRUCTION

Sustainable energy is defined as 'a type of energy that may be used repeatedly without placing a source at risk of becoming depleted, expired, or disappearing'.

As suggested by respondents of each case, the proposed recommendations for improving the sustainable use of energy should be adopted at the project level, and some recommendations exceed the scope of site management. Table 3 summarises the findings.

Table 3: Recommendations for the sustainable use of energy in construction site

The action made within the site	The action made beyond the site level
• Establish a code of conduct for managers and other employees, including labourers. • Explore alternative energy sources for facilities like the site office, labour hut, and security lights. • Implement a supervision and monitoring system for energy management. • Display established targets and energy usage plans for energy usage activities at sites for site workers and staff to reference. • Develop an energy action plan for the site. • Establish detailed guidelines for the construction activities. • Encourage innovations in the site. • Submetering the connection as much as possible. • Establish a computerised fuel monitoring system. • Set goals with equipment operators. • Identify the right equipment for each activity.	• Set up energy management components from the initial stages of the project. • Raising public awareness about the future energy crisis. • Add credit points for using renewable energy sources on a construction site in the green building rating system. • Ensure that appropriate environmental protection legislation is enforced. • Include energy-efficient measures in contract documents. • Establish energy limits for construction projects by CEB. • Encourage the renewable energy offset concept within the industry. • Laws should be enacted by the government and appropriate authorities to increase the sustainable use of energy.

5. CONCLUSIONS

The construction sector consumes more energy than other industries. Construction sites have become one of the largest energy consumers with the highest energy waste. In the Sri Lankan context, there is a lack of research evidence on the sustainable use of energy on construction sites. This study provided a comprehensive overview of sustainable principles of the construction industry, energy consumption during the construction stage, energy-efficient measures related to the construction industry, barriers, and finally, recommendations. The measures related to site staff and workers can influence energy efficiency more than the measures related to machinery and equipment. The strategies were identified in sub-section 4.3. The suggested recommendations for improving the sustainable use of energy should be implemented at the project level, and some suggestions go beyond the scope of site management. The project level strategies established in the pre-contract stage and post-contract stage can directly impact the energy efficiency at the site. Some actions exceed the project level guides to facilitate and govern the development of energy-efficient requirements and measures. The study was limited to examining ongoing high-rise building projects in building construction. It guides construction industry stakeholders to use energy in a sustainable way. Further research can quantify the energy requirement and develop a suitable framework for enhancing the sustainable use of energy practices on construction sites in Sri Lanka.

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KNOWLEDGE MANAGEMENT PRACTICES TO MINIMIZE THE IMPACT OF STAFF TURNOVER

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ABSTRACT

Skilled staff turnover plays a wide role in continuous knowledge loss in manufacturing organizations. The result of staff turnover impacts organizational performance, productivity, effectiveness, employee performance and knowledge. The importance of managing an organization's knowledge is a need in organizations. This research identified the importance of knowledge management in the trailer manufacturing sector with high staff turnover. This enables project managers to take project knowledge management into practice within the organization. This study uses a qualitative research approach. The aim of the study was achieved by a case study research strategy along with 16 semi-structured interviews, which were performed as a data collection technique. Data were collected from the case study organisation, focusing on knowledge management methodologies used during the project phases and identifying the impact of staff turnover on organizational knowledge. The knowledge management techniques vary from one project phase to another project phase. Based on the outcome of this research, project managers can identify the most effective knowledge management techniques to be used at each phase. According to the study, the most frequently used KM techniques in the planning stage were "Learning & Idea Capturing" and "Refer Knowledge Base". The most prominently used KM techniques in the designing stage were "Brainstorming" and "Learning & Idea Capturing". While the most frequently used KM technique in the building, testing, and launching stages was found to be "Refer Knowledge Base". From this research study, project managers can identify the critical areas affected by skilled staff turnover, how to prepare in advance and minimize knowledge loss.

Keywords: *Knowledge Management; Staff Turnover; Techniques; Trailer Manufacturing.*

1. INTRODUCTION

Knowledge management needs to be understood as a process of systematically and actively identifying, activating, replicating, storing, and transferring knowledge (Sadq, et al., 2020). In recent years several ideas and concepts of knowledge management (KM) have been developed. Knowledge management is not a purely managerial activity

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because it may be performed by all project team members and the management team (Jayasuriya and Medis, 2019). The knowledge is passed from the project level to the organization level to distribute to other projects that are implemented by the organization or used in line with other processes. Furthermore, knowledge is passed from the organization level to the global level to use in global sources of knowledge.

Nowadays, staff turnover is one of the challenging issues in the business sector (Irabor and Okolie, 2019). Considerable attention has been given to the impact of staff turnover by senior management, human resources professionals and industrial psychologists. Staff turnover is proven one of the costliest and seemingly intractable human resource challenges confronted by several organizations globally. According to Meier and Hicklin, (2008), and Al Mamun and Hasan (2017), employee turnover harms organizations.

According to Mathis and Jackson (2007), employee turnover is the process where employees leave an organization and have to be replaced. Kreitner (2003) views employee turnover as the rate that which an organization's workforce terminates employment and requires replacement. Employee turnover is related to organizational commitment and job satisfaction. In any organization, staff turnover can occur either voluntarily or involuntarily.

Employee turnover is considered to be one of the persisting problems in organizations (Armstrong, 2009); especially if it involved quality employees that have worked for the organization for many years, and who are highly experienced, high performing and loyal individuals (Branham, 2005; Katcher and Snyder, 2007; Somaya, et al., 2007). On the other hand, employee turnover means that another organization may gain a new knowledgeable employee who can become its competitive advantage. Thus, knowledge loss is a threat to the former organization, which increases the significance of knowledge continuity. Management of the organization has to consider in advance, the ways to cope when a potential employee leaves for its competitor or on retirement. Staff turnover is one of the essential factors influencing organizational knowledge continuity; it is necessary to minimize its consequences by utilizing knowledge management. Further, high employee turnover reflects the instability of organizations (Brahmannanda and Dewi, 2020). Organizations will be greatly affected due to high skilled employee turnover. This will reflect badly on its product quality, targets, and performance; and ultimately increase the product cost. Hence, retaining organizational knowledge is more important in the manufacturing industry (Hickey and Kozlovski, 2020). Several studies were conducted concerning the assessment of staff turnover in the manufacturing industry (Ng, et al., 2019; Hristova, 2021; Barlow, 2003).

However, a research gap was identified in terms of a review of the impact of staff turnover in the trailer manufacturing industry. In this regard, a better understanding of knowledge management techniques and organizational knowledge management is essential to minimize the knowledge losses of the case study organisation. Accordingly, this study aims to identify the knowledge management techniques and minimize the knowledge loss in a high staff turnover environment in the manufacturing industry in Sri Lanka.

The paper is structured as follows; first, the literature review contains secondary information regarding the project knowledge management techniques. Thereafter, the research methodology is demonstrated with the justification of the selection of research approach, data collection and analysis techniques. Finally, the conclusion summarises the findings of the research concerning knowledge management and its application for the reduction of the impact on organisations with staff turnover.

2. LITERATURE REVIEW

2.1 PROJECT KNOWLEDGE MANAGEMENT

Project Knowledge Management (PKM) is knowledge management practised in different situations of the project. It creates the link between the ideas and principles of knowledge management and project management. PKM involves two basic perspectives: the inter-project and intra-project perspectives. Depending on the size and structure of a project, subprojects, or inter-project constellation could exist within a project. Because of this, a clear differentiation between the two perspectives is not always possible. Nisar et al. (2019) made a valuable contribution by setting the base for understanding knowledge management in project environments.

Schindler and Eppler (2003) builds a framework of Project Knowledge Management (PKM) and identifies three major types of knowledge in project environments as knowledge about projects, knowledge within projects and knowledge from/between projects. The knowledge transfer from and between projects can be categorised into four main parts: such as expert knowledge, methodological knowledge, procedural knowledge, and experience knowledge. Knowledge from projects contributes to the organizational knowledge base. "*Despite recent advances in our understanding of how to manage knowledge, its capture and transfer remain acute problems for project-based firms and organizations*" (Hall and Irani, 2005). PKM contributes to the reduction of project risks through awareness of mistakes and pitfalls of former projects (Schindler and Eppler, 2003).

After completing the project, the team member attains a new level of knowledge. This forms the basis for the process of knowledge management planning, which produces the project knowledge management plan (PKM Plan). The PKM Plan addresses all the topics related to project knowledge management and covers both the personalized and codifying techniques of knowledge management (meetings, knowledge exchanging teams, and using knowledge repositories) in alignment with project type and needs (Stanislow, 2014).

2.2 KNOWLEDGE MANAGEMENT TECHNIQUES

In terms of understanding KM techniques, Raymund (2006) identified some KM techniques, which are IT-based and non-IT-based. As per his identification, these KM techniques were Brainstorming, Learning & Idea Capturing and After-Action Reviews were categorized as non-IT-based KM techniques. Blogs and Refer Knowledge Bases are categorized as IT-based KM techniques.

2.2.1 "Brainstorming" KM Technique

According to Raymund (2006), brainstorming is a simple way of helping a group of people to generate new and unusual ideas.

It is further defined as a process that involves a group of people who meet to focus on a problem and then intentionally propose as many deliberately unusual solutions as possible through pushing ideas as far as possible (Boamah, et al., 2021). The participants shout

out ideas as they occur to them and then build on the ideas raised by others. All the ideas are noted down and are not criticized.

2.2.2 "Refer Knowledge Base" KM Technique

It has the objective to collect knowledge, store it in databases and provide the available knowledge in an explicit and codified form. Then reuse of explicit knowledge and solutions can save time and money. Thus, the design of databases, document management and workflow management can be considered part of this strategy. The codification strategy is assumed successful for companies whose business strategy requires re-using existing knowledge (Hansen, et al., 1999; Snehvrat and Dutta, 2018).

2.2.3 "Learning and Idea Capturing" KM Technique

The learning and idea capturing technique takes place at a personal and team level to capture the learning and ideas collectively and systematically (Raymund, 2006). The objective of the personalization strategy is to transfer, communicate and exchange knowledge via knowledge networks such as discussion forums. If the business strategy focuses on generating new or customer-specific solutions or product innovations, the personalization strategy should be chosen rather than the above-discussed codification strategy (Hansen, et al., 1999).

2.2.4 "After Action Review" KM Technique

After the action, review (AAR) is a KM technique focused on learning from a specific event. During the process of after-action reviews, participants in an activity, event or project conduct a structured discussion of what happened and why to learn from the experience (Russell, 2017). Furthermore, AAR is a technique to evaluate and capture lessons learned upon completion of a project. It allows project team members to discover for themselves what happened, why it happened and how to sustain strengths and improve on weaknesses (Raymund, 2006).

2.2.5 "Blogs" KM Technique

A Blog is a very simple 'journal style' website that contains a list of entries, usually in reverse chronological order. The entries are typically short articles or stories, often relating to current events (Raymund, 2006). A person's weblog is much like an open diary. It chronicles what a person wants to share with the world on an almost daily basis (Blood, 2002). According to Ntsoereng (2021), a blog is a frequently updated, publicly accessible journal.

3. METHODOLOGY

3.1 RESEARCH APPROACH

From the researchers' perspective, the ability of qualitative data to describe a phenomenon more fully is an important consideration. Also, from the reader's perspective, it is applied the same. Lincoln and Guba (1985) mentioned, "*If you want people to understand better than they otherwise might, provide the information in the form in which they usually experience it*" (p. 120).

Referring to qualitative research reports, it is typically rich with detail and insights into participants, maybe epistemologically in harmony with the reader's experience (Stake, 1978) and thus it is more meaningful. Based on the above discussion, this research study is following the qualitative methodology, as the research requires gathering in-depth investigation on the KM techniques that can be used to minimise the knowledge loss due to staff turnover in organisations.

3.2 RESEARCH STRATEGY

Yin (2009) stated that a case study strategy should be used when questions such as "*how*" and "*why*" are being asked and that it is preferable to use this approach to answer questions about a contemporary set of events over which the researcher has no control.

For this study, a case study research strategy has been selected as it involves investigating a contemporary phenomenon. A single case study has been carried out with a trailer manufacturing company that reports high staff turnover in Sri Lanka. Since trailer manufacturing is a unique industry in the Sri Lankan context only one case study was considered with the participation of 16 interviewees representing the case study organisation. The case study boundary was defined as the employees who are involved in the managerial and executive levels of the selected case study organisation. Berg (2007) identified that the value of interviewing is because not only does it build a holistic picture, analyse views, and report details of informants, but also it enables interviewees to speak in their voice and express their feelings and thoughts. Moreover, interviewing, as well as other qualitative approaches, differs from quantitative methods in the sense of its ability to analyse the resulting data making an allowance for participants' social life. The researchers have identified the usefulness of interviews. That it tends to provide detailed descriptions of individuals and events in their natural settings. Furthermore, interviewing is 'usually' thought of as a key factor in research design (Weiss, 1994).

In this study, the data were collected through semi-structured, in-depth interviews. Accordingly, 16 personnel ranging from managers to executives within the case study organisation were interviewed. Participants were approached via phone and email. They were informed of the nature and purpose of the study and were invited for a face-to-face interview with the researcher at their place of work or a meeting room during the lunch break/hour or normal working hours. As participants are at a managerial to the executive level, the interviews were conducted in both Sinhala and English. All interviews were audio-recorded with prior consent from the participants and were transcribed verbatim. A structured interview protocol with predetermined questions was developed based on the existing literature to guide the flow and direction of the interview. Table 1 provides the interviewees' profile.

Table 1: Profile of the Interviewees

ID NO	Designation	Department	Experience (Years)
IN_01	Engineering Manager	Engineering	5
IN_02	Senior Design Engineer	Engineering	6
IN_03	Supply Chain Manager	Supply chain	5
IN_04	Operations Manager	Independent	3
IN_05	Director In Charge	Independent	24
IN_06	Manager Shipping & Logistics	Shipping & Logistics	9
IN_07	GM- Marketing	Marketing	9
IN_08	Assistant Manager Engineering	Engineering	5 ½

ID NO	Designation	Department	Experience (Years)
IN_09	Assistant Manager HR	HR	13
IN_10	Manager IT	IT	9 ½
IN_11	Manager QC	QC	4
IN_12	Assistant Production Manager	Production	3
IN_13	Consultant HR	HR	2
IN_14	Internal Auditor	Finance	1 ½
IN_15	Assistant Manager, QA	QC	2
IN_16	Assistant Production Manager	Production	2 ½

3.3 DATA ANALYSIS

The data analysis procedure consists of examining, testing, tabulating, categorizing or otherwise recombining both qualitative and quantitative evidence to address the initial proposition of a study (Yin, 2009). Yin (2009) highlighted that to reduce potential analytical difficulties, a general strategy for data analysis should be developed. In addition, to the experience of various methods of data analysis, no specific data analysis has been found to accommodate case studies (Petty, et al., 2012). In addition, Easterby-Smith (2022) noted that it is important that the researcher follow analysis procedures that are consistent with the philosophical choices of the study. This research adopted a qualitative analysis procedure. The data collected from the semi-structured interviews were analysed using the manual content analysis method.

4. DATA ANALYSIS AND FINDINGS

The case study organisation is one of the leading global manufacturers of Port & Road trailers in Sri Lanka. They cater for the growing demand for trailers and related products in South Asia, the Middle East and Africa. Since its inception, the company has designed and manufactured a variety of trailers for both export and domestic markets. The case study organisation's specialization is in Port Trailer requirements as well as Road Trailer requirements including special needs for the logistic and mining industry.

4.1 CAUSES FOR HIGHER STAFF TURNOVER IN MANUFACTURING ORGANISATIONS

The interviewees mentioned that the skilled staff leaving organisations would have a direct impact on the organizational knowledge. As a project-based manufacturing company, because of these reasons, the impact is very high. The company need to address this issue very carefully and take precautions to retain the organizational knowledge within the company. According to the findings from the interview, several reasons have been identified that are causing to leave the organisation. They include lack of job satisfaction, low salary, future carrier development, environment, leadership, knowledge, skills, new opportunity, location, other personal issues, and internal issues. Low salary is the major issue causing to leave organisations. Additionally, future carrier development is affected to leave the organisation. However, location and other personal issues are the least concerns affecting the organisational leaves. Additionally, environment, knowledge, leadership, and skills are minor causes for leaving the organisation. This is concerning the interview question introduced to get ground information about the person who left the organization for the past few years and to investigate any possibility of capturing his/her knowledge on the time he or she left.

4.2 KM TECHNIQUES IN THE DIFFERENT STAGES OF THE TRAILER MANUFACTURING PROCESS

The interviewees identified the impact on the project timeline, cost, scope, and quality caused by skilled staff leaving the organization.

The project timeline was identified as the most affected stage due to skilled staff turnover; furthermore, the quality of the product is affected and gives a direct impact on the organizational manufacturing process standards. When identifying the consequences of skilled staff turnover on the project timeline, cost, quality and scope, the company needs to follow proper knowledge management practices to overcome this issue.

The effectiveness of these techniques in each project stage was identified and the interviewees highlighted their importance. Considering the project stages, the plan, design, build, tests and launch stages were analysed according to the views of the interviewees.

4.2.1 Planning Stage

The KM techniques that have currently been practised within the organization for the planning stage were identified. IN_01 emphasised "*in this stage most effective KM methodologies will be Learning and Idea Capturing and Refer Knowledge Base. Sometimes we may use a little of the Brainstorming Methodology"*. However, IN_ 02 mentioned, "*In the planning stage I think most of the time it is Knowledge Base. We can use our experience to tackle this stage. Mainly it is helpful to identify the lead-time, and delivery period estimations based on the past data. Brainstorming will not be important in this stage"*. In summary six interviewees identified brainstorming as one of the KM methodologies used in the planning stage. At the same time, 11 participants stated that Learning and Idea Capturing are used in this stage. Six participants commented that After-Action Review is being used in this stage. Eleven interviewees stated that Referring Knowledge Base is being used as a KM technique in the planning stage. Two participants commented that Blogs Techniques were also used in this stage. Accordingly, IN_04 highlighted, "*In the planning stage we use Brainstorming, Learning, and Idea Capturing, After Action Review as well as Refer Knowledge Base. As you know, planning is a mix of codification and personalization. So, I think we are using all the above techniques other than Blogs"*. Only one interviewee agreed that all the above five techniques will be useful in the planning stage.

4.2.2 Designing Stage

IN_02 commented, "*Brainstorming is the most important KM technique. We can develop a new design through brainstorming"*. Therefore, affirming these statements 15 interviewees identified Brainstorming as one of the KM methodologies used in the design stage. Nevertheless, IN_15 elaborated, "*Brainstorming is more important, but we are using it at a very low level. Learning and Idea Capturing are used too, which is how we improve our product design. After Action Review can also be used, but I see no use of it for our current practice"*. Accordingly, 15 participants commented that Learning and Idea Capturing would be used in this stage too. Therefore, IN_12 stated, "*Learning and Idea Capturing is used in the design stage too; we need to share the experience and share* *the knowledge among others to overcome practical problems and issues so that others can also share their knowledge to give a better output"*. Only five participants commented that After-Action Review is being used in this stage. Eleven interviewees identified that Referring Knowledge Base is being used as a KM technique in the design stage. Two participants commented that Blogs Technique was also used in the design stage. Only one interviewee stated that all the above five techniques will be useful in the design stage.

4.2.3 Building Stage

Interviewees identified Brainstorming as one of the KM methodologies used in the building stage. IN_12 commented, "*In the building stage when the product comes to this stage, all the other parameters are already finalized. Therefore, we do brainstorm to streamline our process and see the possibility of improving the lead time, process quality and efficiency"*. However, IN_02 stated, "*Brainstorming is not much relevant to this stage. For this case most of the time it is experience-based, not much written in this stage"*. At the same time, 10 participants stated that Learning and Idea Capturing would be used in this stage. Accordingly, IN_05 elaborated, "*We are having pre-production meetings, actually that is also to discuss the project, what are the difficult corners, and share past experiences, which means that Learning and Idea Capturing is touched at this stage"*. Eight participants commented that After-Action Review is used. Thirteen interviewees identified that Referring Knowledge Base is being used as a KM technique in the building stage. One participant commented that Blogs Technique is used in this stage. At the same time, one interviewee stated that all the above five techniques will be useful in the building stage.

4.2.4 Testing Stage

IN_13 mentioned, "*There is no Brainstorming in this stage. Learning and Idea Capturing is not much important."* However, only two interviewees identified "*Brainstorming*" as one of the KM methodologies used in the testing stage. Nevertheless, IN 16 manifested "*When the product comes to this stage, most of the time delivery is very critical, so we do brainstorm with our team and see how fast we can do it, what are the points which help us to improve the productivity and efficiency"*. At the same time, seven participants stated that "*Learning and Idea Capturing*" would be used in this stage. Six participants commented that "*After Action Review"* is used. Twelve interviewees stated that *"Refer Knowledge Base*" is used as a KM technique in the testing stage. Only two participants commented that "*Blogs Techniques*" were used in this stage.

Considering all the responses received from the interviewees "*Referring Knowledge Base"* was used during the building stage for the KM methodology. Moreover, "Learning *and Idea Capturing*" is applied as another KM technique applicable in the manufacturing process. Furthermore, "*Blogs Technique*" and "*Brainstorming*" are utilised during the testing stage.

4.2.5 Launching Stage

Interviewees identified "*Brainstorming*" as one of the KM methodologies being used in the launching stage. IN_07 mentioned, "*When you launch your product you need to position your product in the correct market, correct time frame and correct price positioning. Those are the most important criteria"*. At the same time, five participants stated that "*Learning & Idea Capturing*" would be used in this stage. IN_12 elaborated, "*I think we are not focusing much on this stage. You need to use Brainstorming and Learning & Idea Capturing to position our product in the market*". Four participants commented that "*After Action Review*" is used. Eleven interviewees mentioned that "*Referring Knowledge Base*" is being used as a KM technique in the launching stage. Two participants stated that the "*Blogs Technique*" was used in this stage. Apart from that one interviewee agreed that all the above five techniques will be useful in the launching stage.

According to Figure 1, brainstorming technology is a common technology used in the planning, designing and building phases. However, in these phases brainstorming technology is less used compared to other phases. Blog technique is a common technique for testing and launching phases, where it is less used. However, in the building phase blog techniques are used effectively for knowledge management. In the building and launching phase, experience is used to tackle problems. Learning and idea capturing are used in the launching phase to position the product in the market. Furthermore, learning and idea capturing are in the building phase for knowledge management. During the testing phase, brainstorming is used as a critical KM technology. However, some emphasised that there is no use for brainstorming in the particular phase. Hence, it signifies that the use of brainstorming technology is varying based on the type of product. During the design phase, both experience and knowledge are shared to overcome practical problems in the manufacturing process.

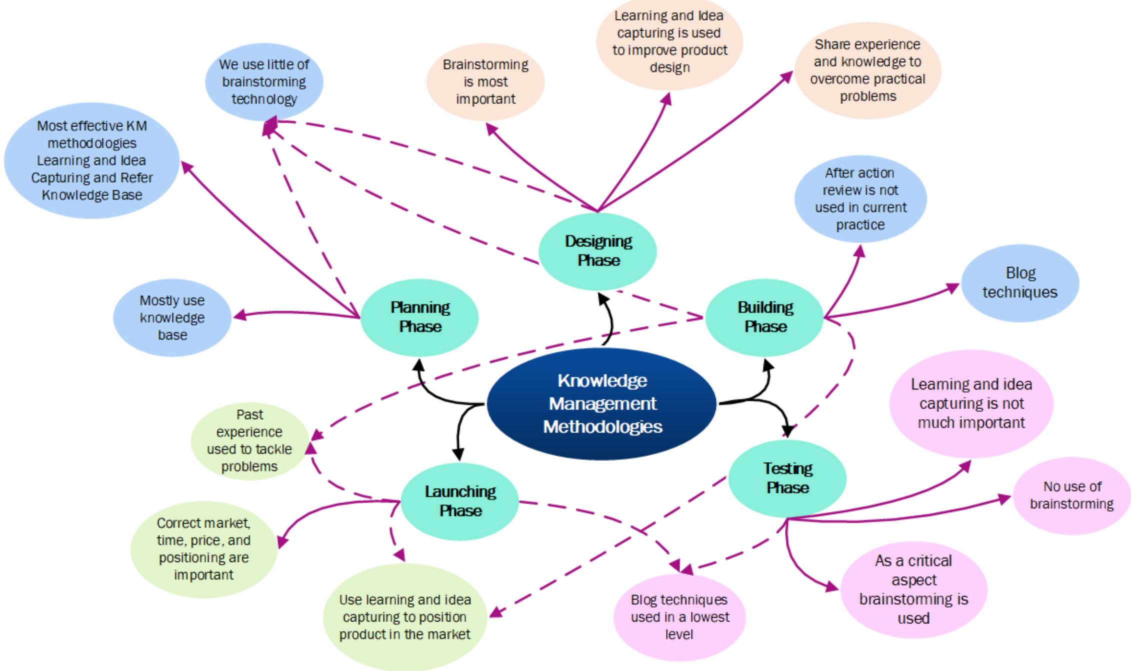

Figure 1: Summary of KM technologies

Summarizing all the views received from the interviewers, introducing a computer-based system to store knowledge is important. In addition, the preparation of a database to store past data and analysing will be helpful for continuity of the organizational knowledge as the other KM methodologies are used in different stages.

5. DISCUSSION

As demonstrated by the expert interviewees knowledge management techniques are applicable in all the five phases of the project, starting from planning to the launching stage. All the different phases of the manufacturing process are connected with a standard set of knowledge management techniques illustrated by (Blood, 2002; Raymund, 2006; Russell, 2017; Hansen, et al.,1999) and it was confirmed by the expert interviewees. The combination of different KM techniques is required throughout the process of manufacturing to ensure the reduction of staff turnover. Furthermore, as Raymund (2006) illustrated combination of both IT-based and non-IT based applications is required for KM techniques. A similar idea was presented by the research study findings.

Different KM technologies are demonstrating the connectivity among the practices to provide a basis for the minimisation of staff turnover. Accordingly, as the research findings demonstrated the use of diversified KM techniques is supporting the company to retain the information that is possible to leave the organisation with the staff turnover. The use of brainstorming is a session to share the knowledge among the staff members and ensure that the knowledge is retained within the organisation while shared with the employees.

Furthermore, the blog technique is an IT-based KM technique proposed for the manufacturing organisation to record and preserve the data which is required for the business aspects. The blog technique is providing accessibility to the staff for knowledge and knowledge sharing is a comparatively easy process. Use of learning and idea chaptering is possible to apply in different phases of manufacturing as a method of acquiring knowledge for other members to ensure the availability and the reliability of the information. Daghfous, et al. (2013) emphasised that the use of combined methods while transgressing the ordinary procedures effectively retains knowledge and mitigates knowledge loss in manufacturing companies. Additionally, coordination of knowledge and maintaining information systems are effective approaches for knowledge retention.

Furthermore, as Mohajan (2009) elaborated, this research confirmed that KM is a process of retaining organisation knowledge with the use of the KM techniques and ensuring that the available knowledge is shared among the organisation's staff. Therefore, brainstorming, learning and idea capturing, referring knowledge base, actions reviews, and blogs are available techniques for a better KM process.

Hence the key intention of KM techniques is to retain knowledge within the organisation while sharing the available knowledge among the staff and to avoid staff turnover and its impact on organisational development and success.

6. CONCLUSIONS

There is an impact on ongoing projects and continuity of organizational knowledge when skilled staff leaves the project. Concerning the impact of leaving skilled staff, the highest impact is reflected in the project timeline. This is mainly due to the commitment to product delivery time and lead time is already fixed and agreed upon by the manufacturer. In terms of the deviation of project duration, the staff turnover is directly impacted because of the knowledge loss. Then due to the scarcity of skilled labour within the industry will take time to recover. In terms of the outcome of the study, project timeline, quality, cost, and scope respectively affected due to skilled labour turnover in manufacturing organizations. According to the study, it was identified design and building stages as the most impacted phases due to high turnover rates.

The KM method varies from one project phase to another. The KM methodologies used in manufacturing projects such as “Brainstorming,” “AAR,” Learning and Idea Capturing”, “Refer Knowledge Base” and “Blogs” were identified. All above five methods are used in each project phase of the trailer manufacturing process. The most used methods for planning stage are “refer Knowledge Base” and for design, the stage is “Brainstorming” and “Learning & Idea Capturing.” Considering building, testing, and launching stages, the most used technique is “Refer Knowledge Base.” The effectiveness of KM methodologies is varying from one project phase to another. When considering the planning stage most effective techniques are “Learning & Idea Capturing” and “Refer Knowledge Base.” In the designing stage, “Brainstorming” and “Learning & Idea Capturing” are the most effective KM methodologies used. Considering the building stage, the most effective technique is “Refer Knowledge Base.” The most effective KM technique identified for the testing stage as well as for the launching stage is “Refer Knowledge base.”

KM is highly in need within the organization, and the documentation and sharing of the knowledge have to be encouraged. In terms of capturing the knowledge, need to develop a bottom layer to transfer that knowledge. Team building and developing confidence between team players and offering ownership and responsibility are also identified as the best methods to retain organizational knowledge within the organization.

7. RECOMMENDATIONS

Considering the KM role identification of the trailer manufacturing organizations, the need for a role of project manager was identified. To improve the KM within the organization, recommended educating the managers regarding the KM practices and use of retaining organizational knowledge. The organization should take immediate actions to fill the gap of a knowledge manager as all the projects are implemented are does not have a knowledge manager. In addition, the organization should take immediate actions to maintain law turnover rates as it is directly affected on continuity of the organizational knowledge. In addition, the documentation of the project knowledge should encourage after closing each project.

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LEAN ICEBERG MODEL FOR POST DISASTER RECONSTRUCTION PROJECTS

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ABSTRACT

Post Disaster Reconstruction (PDR) projects are currently facing many issues. The highly demanding construction process of PDR projects that involves a number of different and well-coordinated courses of action can be simplified through integrating lean construction. Hence, Lean Iceberg Model (LIM) implementation for PDR projects will eventually minimise the issues in PDR projects. However, there is lack of research on implementation of lean construction to PDR projects. Therefore, this study aims to develop a framework to minimise PDR issues through LIM. This research adopted interpretivism stance and uses the qualitative survey strategy. Semi-structured interviews were conducted with ten experts, selected based on purposive sampling. The code-based content analysis was used to data analysis, which was supported by NVivo12. The findings of the study revealed that lack of quality, lack of budget and delays as the main issues in PDR projects. The essential part, therefore, was to identify invisible elements which were most of the times neglected rather than the visible elements of LIM. Finally, a framework was developed by systematically mapping the identified PDR issues for both visible and invisible elements of the LIM. In addition, the "LIM for PDR" mobile application has been developed as part of the framework which deals with educating and guiding users on a successful implementation of lean in a PDR project through LIM. The results of this research contribute to overcome the PDR issues which can be derived from the LIM. Hence, industry practitioners can use the outcomes to successfully implement lean in PDR projects.

Keywords: *Lean Construction; Lean Iceberg Model; Post Disaster Reconstruction; Sri Lanka.*

1. INTRODUCTION

The world is increasingly vulnerable by the influences of disasters, which are followed by a susceptible combination of both climatic and non-climatic associated risks (Wamsler and Johannssen, 2019). During 2001-2015, 341 climate-related disasters have been recorded worldwide, which is a 50% increment comparing to the previous 15 years. Ahmad and Ma (2019) stated that, during 1994 to 2013, floods alone have accounted for 43% of global natural disasters, causing 2.5 billion people affected at a 160,000-death toll and economic losses amounted to US $ 115 billion. Furthermore, Ahmad and Ma (2019) stated that 95% of people affected by foods each year in Asia and Africa, accounted for 73% of total direct economic losses. In Sri Lanka, the total number of people affected by

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floods, landslides, strong winds, fires, and lightning in 2017 was approximately 946,176, while the number of partially damaged and destroyed houses have increased significantly compared to 2016 (Disaster Management Center, 2017). Therefore, Ismail, et al. (2014) stated that, PDR projects are complex and highly demanding process that involves a number of different and well-coordinated courses of action. In addition, PDR Projects encountered difficulties in provisioning, scheduled transportation, aviation clearances, custom clearances, and delivery of materials to target communities without any delay while ensuring the expected quality, allocated budget limit and timely completion of the projects (Enshassi, et al., 2019; Matsumaru, et al., 2012; Barakat, 2003). Therefore, it is vital that these complex activities are well planned, subject to thorough consultation with process improvement methodologies (Ismail, et al., 2014).

Lean construction is well acknowledged in the construction industry for achieving value of the project through proper planning and continuous improvement (Tezel, Koskela and Aziz, 2018). Therefore, implementation of lean construction will improve the value of PDR project. Hines (2008) developed the "Lean iceberg model (LIM)" to provide an accurate definition by grouping technology, tools, techniques, process management, strategy, alignment, leadership, behaviour, and engagement into five organizational components in terms of cultural and technical elements for successful lean implementation. Many researchers in United Kingdom (Tezel, et al., 2018), Sweden (Eriksson, 2010), Malaysia (Marhani, et al., 2013), Sri Lanka (Hettiaarachchige, et al., 2022: Ranadewa, et al., 2021) and Turkey (Polat and Ballard, 2004) had successfully applied the lean construction in projects and achieved the benefits. However, there is a lack of research in incorporating lean to PDR projects. Therefore, the aim of this study is to develop a framework to minimise the issues in PDR projects through LIM. This paper begins with a review on issues in PDR projects and the significance of lean construction for PDR projects. The next section discusses the methodology used in this study. The findings of the research are presented by mapping the suitable elements of LIM to the issues of PDR projects. Finally, a framework for LIM along with the mobile application is presented in this paper.

2. LITERATURE REVIEW

2.1 ISSUES IN POST DISASTER RECONSTRUCTION PROJECTS

PDR projects are known to be dynamic, complex, and chaotic in nature, which in turn represents many failures as they are different from traditional construction. Hidayat and Egbu (2010) mentioned that management of the construction procedure of PDR is similar to traditional construction, only with more emphasis on inadequate resource, quality, and coordination. Some of the issues are controllable although some of the issues are uncontrollable. Following Table 1 presents the most common issues identified with regard to PDR projects.

Table 1: Issues in post disaster reconstruction projects

PDR Issue	References
1. Budget	[2] [3] [4] [5] [8] [10] [11]
2. Policies	[3] [4] [10] [13]
3. Limited Time	[5 [6] [7] [8] [13] [16] [18]

PDR Issue	References
4. Lack of Resources	[1] [2] [4] [8] [11] [13] [18]
5. Political Pressure	[2] [3] [4] [8] [13] [15]
6. Procuring Resources	[3] [4] [8]
7. Community Participation	[8] [10] [13] [15]
8. Communication and Coordination	[1] [2] [10] [15] [20]
9. Inappropriate Assessment	[6] [13] [19]
10. Unproductive Design	[6] [14] [19]
11. Government Support	[10] [13] [15]
12. Transportation	[9] [14]
13. Social Pressure	[7] [8] [13] [15]
14. Poor Quality	[2] [5] [8] [11]
15. Delays	[3] [4] [5] [7] [8] [10] [16] [17]

1.Chang, et al. (2011), 2. Hidayat and Egbu (2010), 3. Nissanka, et al. (2008), 4. Kulatunga (2011), 5. Norling (2013), 6. Alexander (2014), 7. Ismail, et al. (2014), 8. Barakat (2003), 9. Matsumaru, et al. (2012), 10. Enshassi, et al. (2019) 11. Ye and Okada (2002), 12. Freeman (2004), 13. Sadiqi, et al. (2015), 14. Ika, et al. (2012), 15. Dikmen (2005), 16. Steinberg (2007), 17. Moloney (2014) 18. Arain (2015), 19. Kennedy, et al. 2008), 20. Chang, et al. (2010)

Many authors have identified funding and resourcing as the most common PDR issues which will ultimately result in cost and time overruns. Therefore, the efficiency of PDR projects depends mainly on the accessibility and availability of resources such as, labour, materials, plant, and equipment as the lack of resources might lead to a delay in reconstruction works and increased costs (Kulatunga, 2011). According to Kulatunga (2011), although the background may be different from one project to another, if a PDR project is to be completed effectively, these identified challenges need to be overcome through a successful process improvement methodology. Consequently, Mojtahedi and Oo (2012) indicated the possibility of improving the construction process and labour productivity of PDR projects through lean implementation.

2.2 LEAN CONSTRUCTION

Koskela (2020) identified lean construction as a continuous waste eliminating process that meets the needs of customers, focuses on the entire value stream, and pursues excellence in the execution of a construction project. Value creation in design and building projects has an especially strong position in the lean construction (Koskela, et al. 2002). Lean construction has been used with significant benefits in countries such as United Kingdom (Koskela, 2020; Mossman, 2009), Singapore (Dulaimi and Tanamas, 2001), Brazil (Silva and Cardoso, 1999), Chile (Alarcon and Diethelm 2001), The Netherlands (Johansen, et al., 2002), South Africa (Emuze and Smallwood, 2012), Turkey (Polat and Ballard, 2004), USA (Nahmens and Ikuma, 2009), Sri Lanka (Ranadewa, et al., 2019; Ranadewa, et al., 2021) and in many other countries.

Organizational culture has been identified as a crucial element in the implementation of lean construction (Ranadewa, et al., 2021; Hettiarachchige et al., 2022). '*Lean Culture*' allows all workers to contribute ideas, responds rapidly to new ideas for change, offers a collaborative learning atmosphere, aims for excellence in its goods, services and processes and enjoys the clear support of all employees and leaders (Koskela, 2020; Hines, et al., 2008). Findings of Waduwawala, et al. (2019) showed that companies believe that lean improvements are very short-lived and complained that lean does not help them to achieve their long-term objectives. This is due to the use of lean only as a toolkit where there is no change in the culture of employees, the management of the development process and the development of leaders (Ahmed, 2013). Therefore, cultural barriers (Ranadewa, et al., 2021) and change (Singh, 2019) of an organization are the most critical obstacles for lean implementation. Unfortunately, the over-focus on tools, resources and fast solutions are unlikely to work if the fundamental concepts of lean have been overlooked (Womack, 2007). Therefore, there needs to be a strategic vision and a culture (Hines, 2010). As a result of that, LIM was developed by Hines in 2008. There are several models such as Liker model, Toyota Production System (TPS) and Shingo model. However, out of these models, many researchers have highlighted the applicability of LIM for construction industry.

2.3 LEAN ICEBERG MODEL

Hines, et al. (2008) likened the lean transition process to the iceberg, the visible part includes technology, tools, and techniques as well as process management; the invisible part includes internal features that endorse lean and should be applied to all levels of the organization, including strategy and alignment; leadership; behaviour and engagement as present in the following Figure 1.

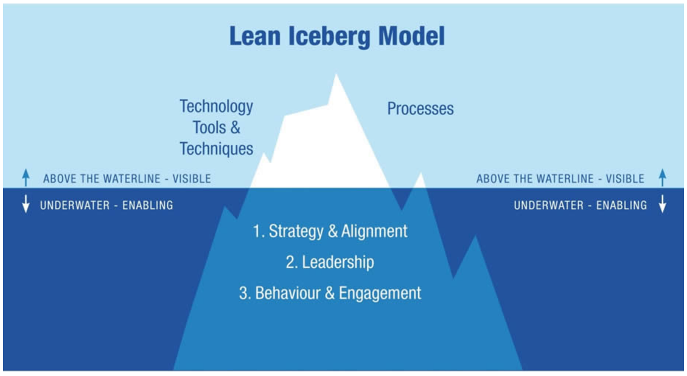

Figure 1: Lean iceberg model

Source: Hines, et al. (2008))

LIM is the graphical representation of the underlying causality of successful implementation (Pearce and Pons, 2017). Similarly, the LIM is an analogy for the two elements of a lean organization, the visible and the invisible (Hines, et al., 2008). The visible elements are those above the waterline and the invisible ones below the waterline. It is easy to identify the Lean process as an iceberg. However, the bulk of the iceberg is below the surface and invisible, and this allows the anchoring mass to render the iceberg a strong force (Hines and Lethbridge, 2008). At the top of the iceberg model are the visible elements which are easily identifiable namely technology, tools and techniques and processes, deposited and substantially described in literature, yet the most essential elements, namely strategy and alignment, leadership and behaviour and engagement are located below the waterline and need to be considered prior to the application of lean tools and techniques (Damrath, 2012). However, there is lack of studies to investigate the applicability of LIM for PDR projects. Therefore, there is a need to empirically investigate the possibility of mapping the LIM elements to the issues of PDR projects.

3. METHODOLOGY

A literature review was carried out to explore the theoretical understanding. There is a need to ascertain different views of the experts with regards to PDR issues and LIM in Sri Lankan context. Therefore, the research adopted the interpretivism stance. The research strategy followed by the study is 'qualitative survey strategy'. The empirical data collection technique adopted is semi-structured interviews with experts in Sri Lanka selected through purposive sampling. Employing semi-structured interview method is preferred in qualitative approach since the respondents have a structured flow to ask questions from interviewees. The identified 15 number of issues from the literature were further questioned during the expert interviews. The number of experts was limited to 10 as there is a lack of experts, who are having experiences both in PDR projects and lean implementation. Table 2 gives the profile of the experts of the study.

Table 2: Profile of the experts

Respondent	Discipline	Industry Experience	Experience in		Awareness in	
			PDR	LC	PDR	LC
R1	Quantity Surveyor	12	High	High	Well Aware	Well Aware
R2	Quantity Surveyor	12	High	High	Well Aware	Well Aware
R3	Professor	20	Medium	Medium	Well Aware	Aware
R4	Project Manager	16	Low	High	Well Aware	Well Aware
R5	Contracts Manager	16	High	High	Well Aware	Well Aware
R6	Researcher	18	High	Medium	Well Aware	Aware
R7	Town and Country Planner	12	High	Medium	Well Aware	Aware
R8	Architect	34	High	Medium	Well Aware	Aware
R9	Civil Engineer	11	High	High	Well Aware	Well Aware
R10	Quantity Surveyor	13	High	Medium	Well Aware	Well Aware

The interviews had to be conducted through 'Zoom' platform due to the implications caused by global pandemic. The content analysis method was used to analyse the qualitative data and NVivo 12 computer software tool was used for the analysis.

4. ANALYSIS

The interviewees were asked about the PDR issues, lean construction, and LIM. The interviewees were asked to explain how the issues in PDR can be overcome using the five elements of LIM. Ultimately, the PDR issues identified from the literature were further verified during the expert interviews. The findings lead to map the relationships between the issues of PDR to the elements of LIM as described in detail below.

4.1 BUDGET

During the interview, R5 stated that "*mainly it was the frequent change of the scopes. Works which were not included at the award of the tender were inserted at the latter part* *of the project. Hence, time overruns and cost overruns had occurred. So, the contractor had to compromise the quality of the works*." Therefore, budget links with all five elements of the LIM namely, technology, tools and techniques, process management, leadership, strategy and alignment and behaviour and engagement. Hence, all respondents suggested that the budgetary issues can be resolved addressing both the visible and invisible elements of LIM.

4.2 POLICIES

R6 mentioned that "*the customary tender procedure was time consuming. The designs that were made at the initial stages, had become outdated when the construction had been started after a lengthy tender procedure. By the time a second wave might have hit the affected region as well. New requirements will be generated by the time of getting approvals. And it caused budgetary constraints*." Policies enacted by the government, statutory, legal body or any other institution / organization deals with process management, leadership, and behaviour and engagement only. It only associates with the invisible elements of the LIM. Hence, the policy issues can only be overcome addressing the above-mentioned invisible elements.

4.3 LIMITED TIME

The improper planning leads to limited amount of time for the completion of a project. Limited time issue relates to all five elements of the LIM. Consequently, it suggests that the limited time issues can be resolved addressing both the visible and invisible elements of LIM.

4.4 LACK OF RESOURCES

This is the most common issue that any PDR projects face nowadays. This issue relates with entire five elements of the LIM. Thus, both the visible and invisible elements of LIM need to be addressed to minimise the lack of resources issue.

4.5 POLITICAL PRESSURE

R2 stated that "*Employees are not personally affected from these issues or challenges. But they might end up in a dilemma due to political interventions. The professionals were thinking that their expertise was neglected and overridden by political authority. So, they lost the motivation towards the project. Other than thinking of the profession itself, most of the professionals had a genuine interest towards the construction and it seemed to be damaged by the political authorities*". Political pressure issues are widely generated in government aided or funded projects. Due to the intervention of local politicians in areas, most of the projects have been suspended or cancelled. Hence, this issue can only be overcome addressing the invisible elements in LIM.

4.6 PROCURING RESOURCES

R6 highlighted that since number of parties are involved and interested of PDR, especially the public, government, and funding agencies, they seek the transparency of the work. Therefore, transparency in procuring resources was vital for the success of the project. In addition, it was further mentioned that the proper documentation and granting approval of the relevant authorities and bodies consumed more time and needed to be avoided as it was an emergency. In order to overcome an issue relating to procuring of resources, significant consideration must be given to all of the elements.

4.7 Community Participation

R5 said that "*Community participation should not always be by supplying labour, but also providing and sharing their ideas, views, interests, knowledge, and requirements. This is called "Participatory Reconstruction". When participatory reconstruction is not used and the community's authority of making decisions is withdrawn, there would be deficiencies of the constructions and make an avenue for issues*". Community participation issue deals with all elements of LIM except, technology. The invisible elements hold a substantial role in overcoming and facing the issue/s.

4.8 Communication and Coordination

R7 said "*the disaster victims did like to move to new places due to changes in cultural aspects and difficulties*." Therefore, effective communication is a must to ensure that the victims' trust is gained, and the risks and impacts need to be communicated properly to the victims. Hence, this issue is directly relating to all elements in LIM.

4.9 Inappropriate Assessment

Inappropriate assessments issues are related to process management, leadership and behaviour and engagement elements. R6 added that *'during 2004 post-tsunami reconstructions, few politicians were influencing the officials as to repair roads which were not damaged from the disaster. Politicians tried to favour their political bases making influences. As a result of that, there was a conflict of interests as what should be constructed and what really is needed to be constructed*'. Hence, two third of linked elements are invisible elements of the LIM.

4.10 Unproductive Design

R9 noted that '*project team suffered from the time constraints as they had to prepare project charters within a short period of time. The rush caused errors when defining the scope, coming up with productive designs and not waiting for final designs*.' Unproductive design issue relates to all five elements of the LIM. Consequently, it defines the need of addressing both the visible and invisible elements of LIM.

4.11 Government Support

R1 stated that the corruption in governance was an added issue which could be identified unlike in domestic conventional constructions initiated by individuals. As a result, the stakeholders did not get the support they needed. Government support is related to technology, tools and techniques, strategy and alignment and behaviour and engagement. Out of three, two linked elements are invisible elements of the LIM.

4.12 Transportation

Transportation issue relates to all five elements of the LIM. Therefore, it defines that the issue can be resolved addressing both the visible and invisible elements of LIM.

4.13 SOCIAL PRESSURE

R3 highlighted that "*the convincing of the victims to move to newer locations was critical as they tend to move back to the disaster-prone areas as they were not satisfied with the new dwellings and settled locations*". Further, R3 added that "*managing the expectations of victims and donors was much more difficult*". In order to overcome this issue, significant consideration must be given to all of the elements.

4.14 POOR QUALITY

R3 mentioned that, due to lack of finance, quality has been. Poor quality issue relates to all five elements of the LIM and hence need to address both visible and invisible elements of LIM.

4.15 DELAYS

R5 stated that "*Variations affected the critical paths of the activities and caused time overruns. It also affected the other projects as the resources were being used by the PDR projects. The delay affected the cash flows and resource allocation*." Delay issue links to all five elements of the LIM.

4.16 LEAN ICEBERG MODEL FOR PDR PROJECTS

By incorporating the emperical findings of the study, a model has been developed as illustrated below in Figure 2.

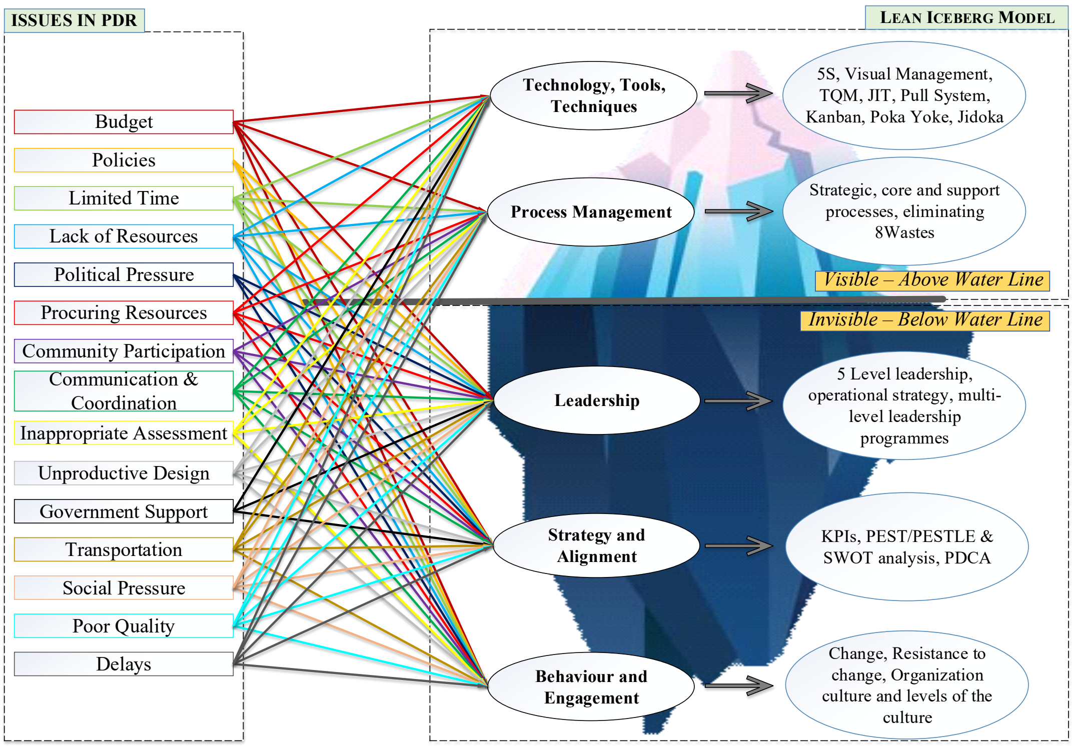

Figure 2: LIM for PDR framework

The relationships of the issues in PDR and elements of LIM had been formulated with the findings from the expert interviews. Number of authors identified budget (Hidayat and Egbu, 2010; Nissanka, et al., 2008; Kulatunga, 2011; Barakat, 2003; Sadiqi, et al., 2015; Dikmen, 2005), limited time and delays (Norling, 2013; Alexander, 2014; Ismail, et al., 2014; Sadiqi, et al., 2015; Steinberg, 2007; Arain, 2015 and lack of quality (Hidayat and Egbu, 2010; Norling, 2013; Ye and Okada, 2002) as the main PDR issues. These issues linked with all the invisible elements namely, leadership, strategy and alignment and behaviour and engagement. It depicted that these PDR issues could be overcome through successful implementation of the above-mentioned LIM elements. It was also found during the analysis that the PDR issues linked with the elements of LIM placed above the waterline which were considered as visible elements and to invisible elements placed below the waterline. 22 connections were made to the visible elements while 52 connections were made to the invisible elements. It clearly suggested the significance of the invisible elements was much larger than the invisible elements. It proved that in order to achieve success, addressing only the invisible elements or visible elements were not enough. Therefore, both needed to be addressed simultaneously while more consideration should be given for invisible elements.

4.17 "LIM FOR PDR" MOBILE APPLICATION

Based on the findings, a mobile application was developed to address the issues of PDR through LIM. This has been designed to run on android operating systems using the Android Studio version 3.5. The very first interface is a splashing activity along with an animation. Next window displays an interface showing the issues in PDR. A modern User Interface has been designed with a grid view in which the images act as buttons and navigate to the corresponding page/window. Java with sdk was used for programme coding as illustrated in Figure 3.

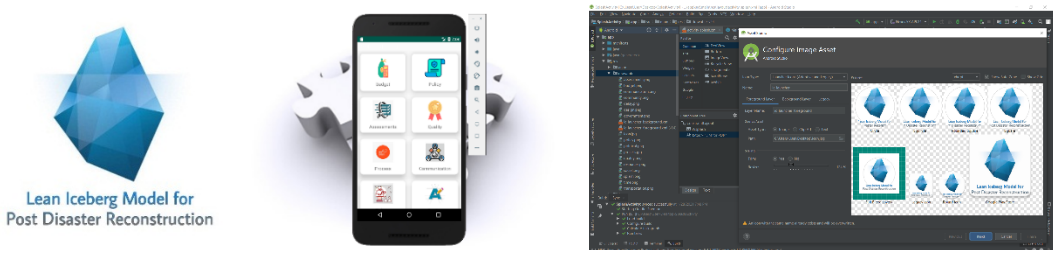

Figure 3: Developed mobile application for PDR

Files such as manifest gradle were modified to make the application more efficient and attractive. The app can be used by any personnel who are interested and enthusiastic in LIM for PDR projects. In addition, it can aid any professional or any student to identify and analyse the existing or the possible related issues of a PDR project and the best methods to overcome those issues. Major advantages of the app are the ability to access the content without having an active internet connection (Offline) and the consumption of a small volume of storage and RAM. The concise nature of the app also encourages anyone with a smartphone or a smart device to install it and use it as it frisks the use of paperwork. Most importantly, the App can be updated with newer versions carrying latest news, acts, and amendments etc. imposed by the state or relevant authorities and bodies. Therefore, the App itself would be continuously improving with time to time. 'LIM for PDR' would be cloud storage or a library of e-books/ e-documents. External links can be easily inserted into the App saving the user time spent on finding strategies for specific PDR issue.

5. CONCLUSION

The literature review of the research confirmed fifteen issues of PDR projects and the outcome was incorporated to expert interviews for further verification. The empirical findings revealed that, each PDR issue can be overcome through appropriate identification of suitable elements of LIM, even though the PDR projects are subjective in nature. The relationship of the PDR issues and elements of LIM namely, technology, tools and techniques, process management, leadership, strategy and alignment, behaviour and engagement were identified. In addition, a mobile application which runs on android OS was also developed to present the findings and at the same time to be used as a guideline for any member involved in the PDR project for successful LIM implementation. Since the rigid policies and regulations act as barriers to the construction industry and proper leadership is needed to manage and tackle the changes in legislation, the mobile App "LIM for PDR" can also be used as reference for enthusiasts and policy makers in the PDR as well as the conventional construction. The existing and upcoming laws, acts, guidelines, and protocols enacted by the state regarding the use of Lean Construction in PDR can also be updated and uploaded to the mobile App. The users can easily access the related documentation without further delay or cost. It will aid to improve the speed, flexibility of the successful practices in the construction industry.

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LEVEL OF RISK MANAGEMENT KNOWLEDGE AMONG CONSTRUCTION PROJECT MANAGERS IN SRI LANKA

D.H.N. Welikala[1], H.S. Jayasena[2] and B.K.C. Perera[3]

ABSTRACT

Risk management often becomes a significant concern among the construction professionals especially due to the complex nature of the industry. Though it is a popular subject in project management discipline, it was observed that authentic application of the principles of risk management at times is arguable in practice. As a Project Manager who is a key role player in a project, it is vital to have a solid knowledge on risk management and its related arena. Evidence was found of limited risk management knowledge among construction professionals. Therefore, a study was conducted to find the status of risk management knowledge among the construction Project Managers in Sri Lanka. A mixed method approach was followed by a comprehensive literature review on elements of body of knowledge of risk management and later a questionnaire survey to contextualise the status of the knowledge gap of Project Managers in real. According to the findings of the study, it could be concluded that Sri Lankan Project Managers are not fully confident on their risk management knowledge. It was primarily likely to be due to the limited learning in the subject area when pursuing higher studies. The study also identifies the options to device appropriate strategies to improve risk management knowledge among the Construction Project Managers in Sri Lanka.

Keywords: *Construction Industry; Project Management; Risk Management; Sri Lanka.*

1. INTRODUCTION

The construction industry in nature itself is complex and it is exposed to various risks. Managing such risks play a vital role in the sector which has direct impact on project performances. While it is clear that risks are inevitable, managing risks using effective methods has already been identified as a crucial concern. The major objectives of risk management were stated as identifying and reducing the risk for the success of the project and achieving its goals. Even though construction projects of different scales incorporate different levels of risks, their effect should not be disregarded (Maytorena, et al., 2004; Ray, 2017).

Risk management is one of the foremost disciples brought out in project management practices. Apparently, Bosse in 2020, showed that the responsibility of risk management has to be taken by the Project Manager in each construction project. Iacob (2013) has also

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mentioned that multidisciplinary training, varied experience and education of risk management were important as a Project Manager to be competent in mitigating and managing the risks. Therefore, it can be stated that, construction professionals have already acknowledged the essentiality of knowing the risk management techniques and applications properly, by the Project Managers. Meanwhile, Madushanka and Tilakasiri (2020), have found that, there was a lack of awareness of risk management among the construction industry professionals in Sri Lanka. However, it was observed that, the level of knowledge gap was not established either by them or by any scientific source so far.

There are key elements of risk management body of the knowledge that Project Managers are required to know and be skillful, in order to properly manage the risks. Lack of such knowledge shall become a key source for aggravated exposure to risks (Ghale, et al., 2021; Sankar, et al., 2022). Thus, this brings the need for strategies to equip Sri Lankan Project Managers with necessary risk management knowledge. To device effective strategies, it is imperative to identify the gaps in current risk management knowledge among them.

Hence the aim was set as finding the status of risk management knowledge among construction Project Managers in Sri Lanka. The knowledge status was contextualized from several perspectives: viz (a) confidence on risk management knowledge, (b) subject learning, and (c) preference for learning. The set objectives of the study were 1) identify the key elements of risk management body of knowledge, 2) identify the knowledge acquisition process of those key elements and 3) find the level of acquisition of those elements by the Project Managers in Sri Lankan construction projects.

2. ELEMENTS OF RISK MANAGEMENT BODY OF KNOWLEDGE

From the past, construction industry has associated with risk management theories and techniques. This has become a vantage to avoid sudden emergencies and to pursue a stable construction process for clients (Dionne, 2013). Howbeit, the construction industry has made relatively slow progress in realizing the advantage of risk management, wherein which, stakeholders mainly focused on other aspects of project performances. Even, in Sri Lanka risk management was not satisfactorily established due on various grounds (Perera and Rameezdeen, 2014).

Management of risks is a salient feature and quite a challenging task in practical implementations. Since risk management is a frequentative process, responsible department, personnel or the Project Manager required the skills on realizing and recognizing the main causes of risk and monitoring them throughout the project duration. Banaitiene and Banaitis (2012) have presented the importance of this process while accommodating it in a systematic manner from the inception to the end of the project life cycle. As mentioned by them, Project Management Institute has stated that, management of risks was one of main competencies out of the other nine competencies of knowledge that Project Managers require to be promoted. After conducting thorough literature survey, following steps were found as the body of knowledge in risk management for Project Managers.

2.1 RISK MANAGEMENT PLANNING

Good risk management plan has helped to Project Manager to handle the risk in the construction project. Also, this helped to identify ways of assessing the risk and how often it requires to plan (Parker and Mobey,2004). According to Watt (2020), there were four ways to act upon a risk. Those were accepting, avoiding, mitigating, and transferring. Avoiding the risk was the best action that could carry out. If it's possible to prevent risk or its impact that won't create any damages for the construction project. Unless, avoiding the risk wouldn't be the best option rather mitigating would be the best way to deal within. Thus, it is mandatory to predict and plan the risk well as to mitigate with the least disturbance for the project.

2.2 RISK IDENTIFICATION

The next stage of management of risk was the identification of risks. This was another important part for Project Managers to be concerned about. They should have proper knowledge on identifying risks in the projects. This step identified the potential risks that are very common and other uncommon risks events. According to the given literature, risks were investigated by studying the activities of organizations in all directions and trying to present new risks that would arise in the future as a result of changes in the external and internal environment. (Ranong and Phuennggam,2009). Normally, in the identification period, previous similar project's risks were observed and analysed. Moreover, it was not limited the previous project's risks but also incorporate many other risks that could have happened in the new project. Hence, it is indeed to be thorough in this knowledge area and having good experiences may aid well in advance to ascertain all upcoming risks.

2.3 QUALITATIVE RISK ANALYSIS

The qualitative analysis made it possible to identify the significant risk factors. The aim was to compile a list of the key roots of risk and a description of their possible outcomes, including an initial estimate of their potential impact on time and cost calculations (Perry and Thompson, 1992). Many managers have accepted that, this initial qualitative analysis was important and brought significant benefits in terms of understanding the project and its possible problems as mentioned by Perry and Thompson (1992). Also, this analysis included assessing the probability, the impact of various risks, and identifying risks to improve project performance while identifying high priority risks (Nadaf, et al., 2018). This was also an important factor in improving Project Managers' knowledge and skills when managing risks.

2.4 QUANTITATIVE RISK ANALYSIS

Another identified body of knowledge on risk management was quantitative risk analysis. This was a process that explored the cumulative impact of identified individual project risks and other sources of unpredictability on the overall objectives of the project mathematically. It contained more advanced techniques and methods to investigate and analyse the risks of construction projects. Usually, it involved more complex analytical methods that often require computer programs. The use of quantitative risk analysis made it possible to model the showing of a construction project and quantified the probability of the appearance of identified risk factors and their possible impact (Banaitiene and

Banaitis, 2012). The purpose of quantitative analysis of risk was to determine the impact of the recognized risks on the overall objectives of the project. (Bansal, 2019).

2.5 RISK RESPONSE PLANNING

According to Chou and Wang (2003), the risk response planning was the choice of an appropriate reduction strategy which used to reduce the negative impact of the risk. Further, they have mentioned, the way that risks have to be managed or handed over the same into another party or retained itself. Similarly, this method was also used to reduce the threats of the project. To adopt this technique, Project Managers have to be aware of the content and the repercussions of such risks (Miller and Lessard, 2001). The goal of this method was to achieve project objectives at planned cost without unnecessary overruns and take action to minimize its threats beforehand (Fang et al., 2013).

2.6 RISK MONITORING AND CONTROLLING

Risk identification, planning, and tracking new risks involve risk monitoring and planning. According to Schieg (2010), there were four strategies of risk control. They were avoidance, decrease, passing on risk and bearing the risk by oneself. This included tracing existing risks, recognizing new risks, monitoring the effects of previous risk management activities and evaluating the effectiveness of present risk management processes. Same as mentioned above, this step also a necessary body of knowledge that Project Managers are required intentionally.

The above-discussed body of knowledge on risk management is on-demand essentiality of the industry. Hence, the Project Managers as key role players of a construction project are mandated to be qualified and should be competent in the above knowledge areas. There are variety of sources available to improve their knowledge as well as their awareness. To acquire these bodies of knowledge, Project Managers need to update their knowledge and improve the skills via training, and other mechanisms which can be provided by their companies to them such as coaching programs, mentorship programs, seminars and status meetings. Despite that, Jen (2012) has stated, self-training can increase the knowledge about the risk management substantially.

3. RESEARCH METHODOLOGY

From the literature review conducted in previous section, the key elements in the body of knowledge of risk management were identified. As to achieve the aim of the study, the research was designed according to the mixed method approach where both qualitative and quantitative data have been analysed. The selected strategy of inquiry was a survey. Hence, the deductive theory was adopted and the believed research philosophy was pragmatism where questions were asked from a number of people and some of the observed data were measured in the data analysis.

The adopted research methodology was as follows. Initially a literature review was conducted to identify the required knowledge on the risk management as Project Managers. Accordingly, an extensive set of data on important body of knowledge in risk management was found exploring various sources regarding risk management discipline in construction projects. The used sources were journal articles, online reports, books and relevant other available resources. Based on the findings of conducted literature review, a questionnaire was developed to establish the existing body of the knowledge. While questionnaire survey carried many quantitative questions as in multiple options, few explorative questions were inserted to gather qualitative data. The questionnaire has consisted of eleven questions and each question was designed to collect data in order to furnish the status of existing knowledge of Project Managers in risk management. The prepared questionnaire was on an online form and it was sent for twenty-five participants who were working in the construction field as Project Managers in Sri Lanka and collected the necessary data for the research. The collected data were analysed based on their own percentages in the collection of overall data. Other numerical data were analysed as at average value. For example, the learning hours of risk management topics were analysed as average values. The data representation was done via graphical methods for further clarification. The last question was an open question that was analysed through a descriptive method. From the collected data, knowledge acquisition process of the key elements of body of knowledge in risk management and the level of acquisition of those elements by the Project Managers in Sri Lankan construction projects were analysed and compounded. Finally, the conclusions of the study and the recommendations of novel enunciator were given for future implementations.

4. DATA ANALYSIS AND DISCUSSION

Based on literature review in this study, the key elements of body of knowledge in risk management were identified. The survey was done to find out the knowledge and confidence about risk management in construction industry among the industry professionals. The obtained raw data were analysed with the aid of pie charts for clear graphical representation. The analysis output paved the path to reach a conclusion by discussing the findings of the questionnaire survey. This section is based on the findings that were obtained in the data collection.

4.1 DEMOGRAPHIC DATA

In this research, demographic data gives an idea about the professional qualifications of the personals that provided the data for the survey. Thus, Figures 1 and 2 presents the educational qualifications and the number of years of gained experience in the field.

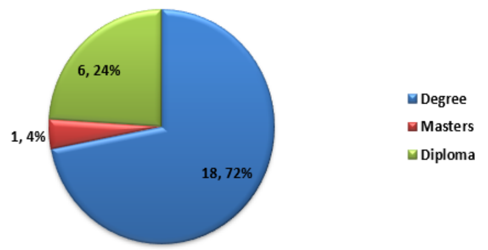

Figure 1: Educational qualifications

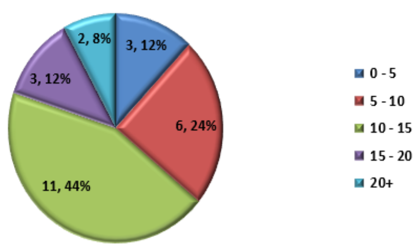

Figure 2: Years of experience

Since the survey was limited to Project Managers, out of twenty-five respondents eighteen Project Managers were Bachelor's degree holders while one person had a masters' degree and six respondents were diploma holders. When considering the years of experience in the field, Figure 2 shows that, only three people had experience below 5 years. More than 60% of the respondents had either 10 years or more years of experience in the industry. Considering all these factors, it can be considered that all the respondents were responsible personnel in field who were having a sound knowledge about the subject.

4.2 CONTEXTUAL DATA

In order to achieve the set research aim, the contextual data which includes the subject matter in which deployed for analysis were given below.

4.2.1 Confidence on Knowledge about Risk Management

The responses for the question about the level of confidence were limited to intermediate levels. 56% of personals were quite confident about the knowledge while rest of all the Project Managers were somewhat confident. Interestingly, none had recorded their responses as in either fully confident or not confident at all. In complying with the above demographic finding, all the participants in the sample were taken as sound knowledgeable professionals and it was a comparatively good sign to have no response as "not confident". On the other hand, nobody was assured enough to state out that they were "full confident" though the majority was been the industry more than ten years. Figure 3 represents graphical view on confidence level of total sample set.

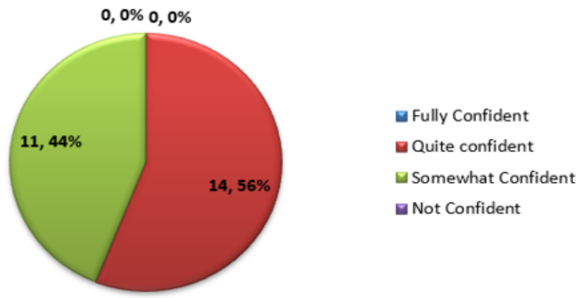

Figure 3: Confidence level

4.2.2 Risk Management Studying

The respondents answered a question by stating that, if they learned nothing on risk management, risk management as a part of a subject module, or as a separate subject module of a full. Although they had come from different diplomas, Bachelor's degrees and Master's degrees, no program had taught them risk management as a separate subject module. This was a considerable observation that was found in the educational system which would cause the way to exist "not fully confident" Project Managers in the field of risk management.

4.2.3 Qualification which taught Risk Management

The level of qualification in which the risk management was taught is shown in Figure 4.

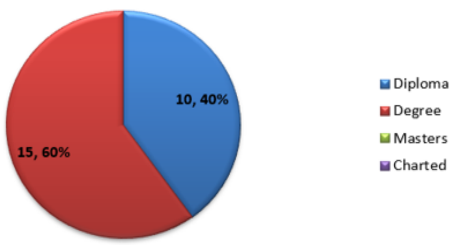

Figure 4: Qualification which taught risk management

Out of the twenty-five respondents, fifteen experts have studied the risk management in Bachelor's degree programme while other ten experts have studied risk management in their diploma programme. This indicated that in Sri Lanka, the risk management was only taught in initial levels of higher study programs. The relevant area of the subject was touched neither Master's degree programs nor chartered programs.

4.2.4 Total Number of Hours Spent on Learning and Studied Areas on Risk Management

By taking the average of the collected responses, the average learning hours that were being allocated for learning risk management could be identified as 10 hours. The key areas that have been taught were found as risk management planning and mitigatory measures. Although a diploma or a degree runs for two to four years' time, only 10 hours were allocated for risk management learning which indicates that a less attention and priority has been given by the programme itself. This could imprint a less consideration towards risk management discipline among diplomats and graduands who were going to be occupants in the industry. The total number of hours spent on learning risk management is given in the Figure 5.

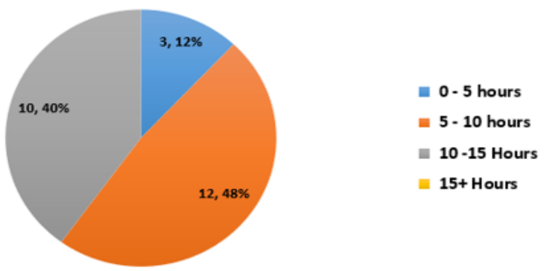

Figure 5: Total number of hours spent on learning

4.2.5 Studied Topics in Risk Management

Among the study topics of risk management, the mostly studied topic was risk management planning which followed by risk monitoring and controlling (refer Figure 6). Only seven Project Managers had studied on risk identification. From the survey, it was clear that no much attention was given to quantitative risk analysis, risk response and qualitative analysis planning in the subject modules as per the conducted construction educational study programmes. But all these topics were recognised as essential learnings that all Project Managers should be thorough as key role players in the construction industry. The lack of knowledge in these two areas clearly indicates a problem in the practical field.

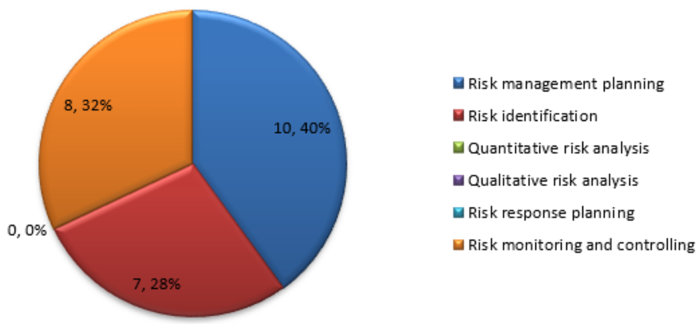

Figure 6: Studied topics in risk management

4.2.6 Number of Hours Spent on Studying the above Topics

In average, the mostly studied topic has been taught for 6 hours which is 60% of the total studied period on risk management. From the survey, it was clear that, mostly the risk management was only taught via a single case study regarding a single construction site. This clearly projects the poor educational background that has being provided for risk management by many study programmes. Figure 7 shows the number of hours spent on the mostly studied topic key knowledge elements by the Project Managers.

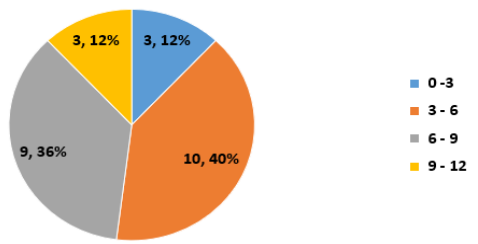

Figure 7: Number of hours spent on studying the key knowledge elements

4.2.7 Other Risk Management Topics Learnt

Other than the given options, risk management was mentioned as the other mostly studied topic area among the respondents. Whereas in section 4.2.5, none of the respondents chose either qualitative risk analysis or quantitative risk analysis out of given options. Hence, it can be seen that, respondents were familiar with the term 'risk assessment' but not the 'quantitative and qualitative risk analysis' where the similar content has been covered in both the instances. Having said that, this showed that taught programs adopt 'risk assessment' term than the two other analysis terms in Sri Lanka. Most of the respondents revealed that the study of risk management was completed by preparing a risk assessment for a case study. Also, the risk mitigations were discussed within those programs. These two topics have occupied about 5 hours in lecturing. But four respondents have mentioned that although the subject module limited its time duration, they have self-studied about the topic for more than 12 hours in order to prepare the risk assessment. Some few other participants have answered that, they have been taught on risk management and improvements to risk management. Further they recorded their duration of learning as 2-4 hours for the above topics. Two respondents have studied about risk identification for 2 hours session while a single person has mentioned that, unforeseen risk management was learned for three hours. Apart from all these, one person has mentioned that he/she could not remember what else he/she studied. Therefore, it shadowed, how professionals in the construction industry hindering the risk management discipline even still being engaged in live projects.

4.2.8 Other Topics Respondents liked to Study

Other than the deductive questions, the questionnaire was included an explorative question also to find other topics that respondents were willing to learn on risk management. Accordingly, these answers were the ones that the respondents considered as the most important topics to learn other than the taught course or subject module. After analysing the responses, it was clear that many respondents considered the ways of addressing the risks are the most crucial thing that need to learn. Having said that, it could be considered as important factor because, sometimes the most damage would not cause by the risk, but from the deficiencies of the way that the responsible personal react.

Moreover, it is important to prevent the risk from happening. Therefore, avoidance of risks is also important to learn. As well as, it is important to know how to maintain a risk management portfolio and to do the risk evaluation quantitatively. This would help in identifying the most crucial risk out of many at a time. With the development of the world, there are many software's that eases the work of people. Henceforth it is advantageous to study the relevant software to handle the work in an easier manner. Also, learning the causes of accidents and injuries that could occur within the site would be assist in preventing them and the injuries. Figure 8 shows the recorded other topics that respondents like to study.

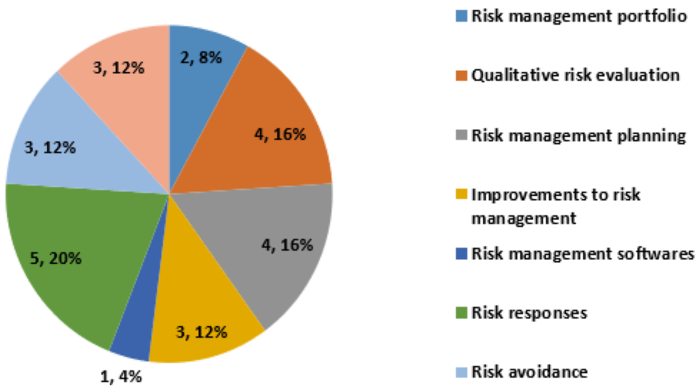

Figure 8: Other topics respondents like to study

4.2.9 The Best Ways to Increase Risk Management Knowledge

Most of the professionals identified, the best way to gain knowledge about the risk management as to face the situation and acquire it within experience. Although the required knowledge cannot be gained without experience, the best solution can be identified as increasing the learning hours by providing a separate course module. Moreover, it is important to have practical sessions or workshops to gain clear idea as in differentiating what to do and what to avoid in a risky situation. Also, it is best if risk assessments could be done in every activity regarding every separate construction work in the industry as in having case studies in road construction, piling sites, retaining wall construction and water projects etc. Every project differs from one to one and henceforth it is worthwhile to know about the risks that could occur in every situation. The proposed ways of improving the knowledge on risk management is given in the Figure 9.

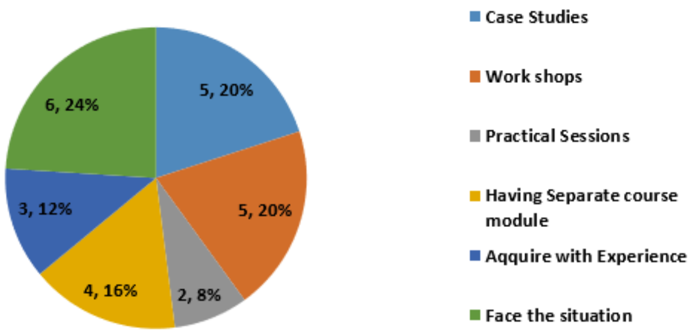

Figure 9: Ways of improving knowledge on risk management

5. CONCLUSION AND RECOMMENDATIONS

Because of complexity of the construction industry, abundance of risks can be occurred. Thus, proper management of risk process is pompous for the success of the project. With indication of limited risk management knowledge among Project Managers in Sri Lanka, a research study was conducted to finding the status of risk management knowledge among them.

The study finds that Sri Lankan Project Managers are not fully confident on their risk management knowledge. They already are aware that their knowledge is limited, likely to be due to limited learning they had on the subject. They currently learn the subject as subsection of one of main subject modules either in the undergraduate degree or diploma. The key areas that, they covered in those programmes are (a) Risk management planning, (b) risk identification and (c) risk monitoring and controlling. Less attention was there for (d) quantitative risk analysis, (e) qualitative risk analysis and (f) risk response planning. However, these topics could have been covered using an alternative topic named as 'risk assessment'. The large majority of Project Managers have spent less than ten hours on learning risk management. Accordingly, their lack of confidence on their own knowledge on risk management can be rationalized. Further to those topics, Project Managers found the use of risk management software also to be important. By not limiting the subjects to taught modules, Project Managers expressed the interest on learning, through alternative means such as case studies, workshops, and real-life experiences. The findings of the study are consistent with previous findings, and these provide a more elaborated explanation than the previous findings.

The findings indicate that the risk management of projects by Sri Lankan Project Managers is not at the optimal level. Appropriate strategies should be devices to bridge their knowledge gap for them to be able to perform well. If the full scope of knowledge elements cannot be included in taught programmes, above-identified modes can be utilized to impart such knowledge among them.

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OFFSITE CONSTRUCTION SKILLS PREDICTION: A CONCEPTUAL MODEL

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ABSTRACT

Industry 4.0 driven technological advancements have accelerated the uptake of Offsite Construction (OSC), causing the need for re-skilling, up-skilling, and multi-skilling traditional onsite construction skills and competencies. The purpose of this paper is to develop a conceptual model that predicts OSC skills as a response to the OSC demand. The paper is a theoretical presentation of a skill profile prediction model which introduces the key concepts, OSC typology, OSC skill classification and their relationships. Components, panels, pods, modules, and complete buildings represent the OSC typology. Managers, professionals, technicians, and trade workers, clerical and administration workers, machine operators and drivers, and labourers constitute the OSC skill classification. The conceptual model takes the OSC project parameters: gross floor area, OSC value percentage and skill quantities as input and provides predicted skill variations as the output. The skills are quantified in "manhours/m2" under six skill categories, for five distinct OSC types. As such, the research presents a comprehensive conceptual model for the development of an OSC skills predictor to capture the skill variations and demand in a construction market moving towards rapid industrialisation. The research contributes to the existing body of knowledge by identifying the key concepts, parameters, and mutual relationships of those parameters that are needed to develop a realistic prediction of future trends of OSC skills.

Keywords: *Conceptual Model; Offsite Construction; Prediction; Skills.*

1. INTRODUCTION

Offsite construction (OSC) has attracted growing research interest in the recent past (Goulding and Pour Rahimian, 2020; Smith and Quale, 2017). OSC is the manufacturing of buildings or functional elements of buildings in a factory to be transported and assembled onsite (Blismas, et al., 2009; Goh and Loosemore, 2016). OSC has always been a part of traditional construction as some building elements such as doors, windows and light fittings are not constructed onsite by any means (Arif and Egbu, 2010; Gibb, 2001). However, Industry 4.0 and its technological advancements have influenced OSC to the extent that the entire building may be manufactured in a factory to be simply

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transported and fixed onsite (Ginigaddara, et al., 2019; MADI, 2021). On the other hand, OSC offers a pathway to rapid industrialisation of the sector improving its production capabilities and efficiency (Goulding and Pour Rahimian, 2020).

OSC is a fusion of manufacturing and construction know-how, eliminating long-known efficiency shortcomings of the construction sector (Goulding and Pour Rahimian, 2020; Pan, et al., 2012). Traditionally, built construction is inherently less productive due to its heavy reliance on skilled labour (Karimi, et al., 2018). Moreover, it is prone to health and safety risks, less sustainable, and creates uncertainties in time and cost management (Goh and Loosemore, 2016; Smith and Quale, 2017). These factors have led to the popularity of OSC with key research aspects such as productivity improvement (Eastman and Sacks, 2008; Wuni, et al., 2021), production process optimisation (Zhang, et al., 2020), economic value addition (Taylor, 2010), and multi-skills development (Arashpour, et al., 2018; Nasirian, et al., 2019). Industrialisation-driven technological advancements improve OSC processes (Ginigaddara, et al., 2022; Goulding and Pour Rahimian, 2020) and its impact on OSC skills are yet to be found. OSC skills are different from traditional construction skills, and hence there is a critical need to identify and develop such OSC skills (Brennan and Vokes, 2017). However, the limited research on OSC-specific skills has created a knowledge gap in OSC research.

It is believed that the identification of OSC skills facilitates skills prediction, providing a platform for skill creators; industry practitioners, education providers, professional institutes, and the government to understand, be aware of, and support the development of necessary OSC skills to match the job market's demand. The paper presents the rationale for OSC skills prediction, key concepts and parameters behind OSC skills prediction, the proposed conceptual model, its innovation, and the current research conducted on OSC skills.

2. RATIONALE FOR OSC SKILLS PREDICTION

The term "skills" in this research refers to job roles or occupations under both professional and vocational work categories. Researchers suggest that OSC results in the emergence of new skills while some skills become redundant, and some skills can be easily substituted from the manufacturing sector (Gann, 1996; Goh and Loosemore, 2016; Smith and Quale, 2017). Industry 4.0 based technological advancements become a driver for such variations in OSC skills due to the involvement of robots, co-bots, exoskeletons, and similar human-machine integration (Adepoju, et al., 2022). These technologies are introduced to the market with a fascinating level of modernisation, to improve productivity and efficiency in skills utilisation (Farmer, 2016). As the construction industry is renowned for its poor labour productivity (Eastman and Sacks, 2008), the term "skills" in OSC can also be misinterpreted as a measurement for labour productivity. Labour productivity is a factor used to measure the relationship between labour inputs and production outputs (Eastman and Sacks, 2008; Parchami, et al., 2019). Previously, Tatum, et al. (1987) introduced a productivity measure for OSC labour usage considering the labour costs at each stage of production, transportation and onsite assembly. However, this research focuses on a rather broader concept to understand how the skills utilisation may vary for different types of OSC.

Depending on the features, level of OSC adoption and the degree of industrialisation involved in different OSC types, the skill requirements may vary. Such skill variations or patterns can be visible in two ways: usage of different kinds of skills, and the usage of different quantities of skills. Once the OSC skills are manifested, the next step can be productivity evaluation of OSC skills and multi-skilling, and they are beyond the scope of the current research. As such, this research proposes a conceptual model for OSC skills prediction, where the skills variations in unique OSC types are evaluated based on the quantity of different skills involved in each OSC type.

3. KEY CONCEPTS AND PARAMETERS

3.1 OSC TYPOLOGY AND OSC TYPES

OSC types have unique features and distinctive outcomes (Smith and Quale, 2017). Gibb (2001) classified different OSC types into component manufacture and sub-assembly (door, furniture), non-volumetric pre-assembly (panels, pipework), volumetric pre-assembly (toilet pods, plant rooms), and modular buildings. This classification was then exploited by various researchers but was modified to accommodate industry practices and different terminologies. This paper uses the OSC typology consisting of non-volumetric (components, panels) and volumetric (pods, modules, complete buildings) categories (Ginigaddara, et al., 2019). Components (light fittings, trusses) are non-volumetric elements of any shape or size excluding flat panels, while panels (floor, wall, ceiling panels) are flat elements that do not create usable space (Gibb, 2001; Pasquire and Gibb, 2002). Pods (bathrooms, prisons) are repetitive items with a high level of finishing (Goh and Loosemore, 2016), and modules (apartments, school buildings) are a part of a whole building (Bertram, et al., 2019). Several modules create a single unit or a complete building (site sheds, disaster recovery buildings) (Ginigaddara, et al., 2019).

3.2 OSC SKILL CLASSIFICATION AND SKILL CATEGORIES

Vokes, et al. (2013) categorised OSC skills under primary (design and project delivery), secondary (contribute to project delivery - assembly of components) and tertiary (supportive functions – office administration) roles. Later, six functions were introduced to classify OSC skills: digital design, estimating/ commercial, logistics, offsite manufacture, onsite assembly and placement, and site management and integration (Brennan and Vokes, 2017). Recently, the Construction Industry Institute (2021) classified OSC skills under three categories: design and engineering, construction and fabrication, and administrative.

Detailed skill classifications are available in country-based labour statistics databases (Australian Bureau of Statistics, 2019; Office for National Statistics UK, 2020; US Bureau of Labor Statistics, 2021). Yet none of them specify OSC skill classifications which can be due to the difficulties in differentiating OSC among construction and manufacturing sectors. These literature findings highlighted the need to develop a skill profile classification to recognise the OSC skills that are different from traditional construction skills. Based on the Australian Bureau of Statistics (2019) data, Ginigaddara, et al. (2021) classified OSC skills under managers, professionals, technicians, and trade workers, clerical and administration workers, machine operators and drivers, and labourers. This classification of six skill categories comprising of 67 potential OSC skills is incorporated into the conceptual model for OSC skill profile prediction. Apart from the key concepts discussed, three additional parameters; skill quantity variations, gross internal floor area of the building, and OSC value percentage of the OSC type are used to quantify skills used in OSC projects. They were selected to derive at a predictive measure for OSC skills.

3.3 SKILL QUANTITY VARIATIONS

OSC is a promising solution for the expanding onsite skills shortage (Blismas, et al., 2009) and high labour costs (Jaillon and Poon, 2008) as Industry 4.0 driven technological advancements facilitate up-skilling, re-skilling, and multi-skilling of traditional construction workforce (Goh and Loosemore, 2016; Hairstans and Smith, 2018). It is anticipated that skills usage varies depending on the OSC type, and their unique manufacturing techniques (Bertram, et al., 2019). Skill resource requirements refer to the total number of manhours required to complete an OSC project. They are recognised as onsite (construction site) and offsite (factory, office, and transportation) skills under the six skill categories.

3.4 GROSS INTERNAL FLOOR AREA (GIFA)

GIFA is an alternative measure for building cost that exempts the area of non-volumetric and vertical building elements such as wall panels and components (Jaillon and Poon, 2008). Besides, previous studies have also used GIFA as a suitable building parameter opposed to project duration and cost (Love, et al., 2005; Monahan and Powell, 2011). Therefore, GIFA (measured in m2) is considered to derive a "per unit measurement" for skill quantification. It is anticipated that GIFA provides a comparable measurement for skill profile prediction that can be repeated for any number of scenarios. For example, once the skill quantities of an OSC project are quantified in manhours, the GFA measured in square meter facilitates a measure (manhours/m2) that can be applicable to a similar OSC project.

3.5 OSC VALUE PERCENTAGE

Lawson, et al. (2014) specify the OSC value in components, panels, modules, and complete buildings of a construction project to be 10-15%, 15-25%, 30-50% and 60-70% respectively. However, Prefab Logic (2019) reports that the OSC percentage of many building projects adds up to 90-95% within the factory. Similarly, several other companies achieve high OSC percentages by adopting innovative methods (MADI, 2021; Ten Fold Technology, 2018). A case study review of OSC project costs in Western Australia reveals the offsite cost portion to be between 71-73 percent (Sutrisna, et al., 2019). As such, it is expected that diverse OSC types possess varying OSC percentages in a given OSC project, and hence it is considered one of the key attributes in the conceptual model. The value percentage of a particular OSC type can be calculated by dividing the total cost incurred for design, manufacture, and assembly of that OSC type by the total cost of building construction.

4. CONCEPTUAL MODEL FOR OSC SKILLS PREDICTION

A conceptual model combines key concepts and inter-concept relationships as a graphical illustration (Leedy and Ormrod, 2019). The conceptual model (Figure) incorporates skill quantity variations under different skill categories.

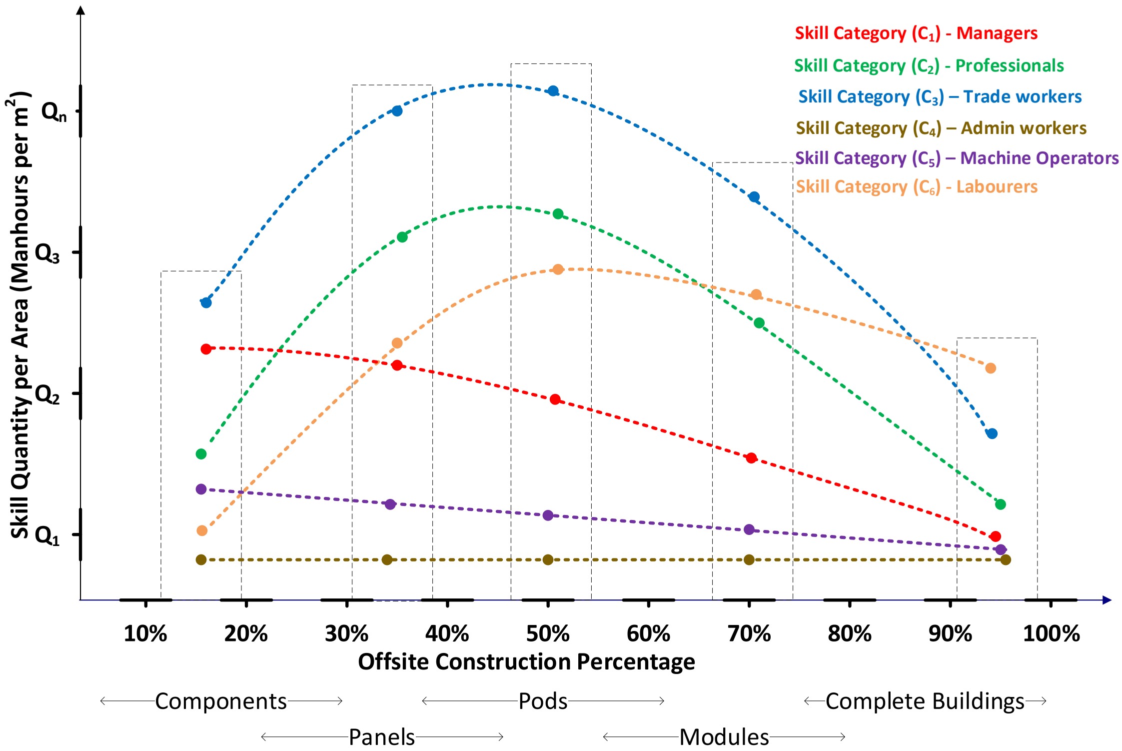

Figure 1: Conceptual model for offsite construction skills prediction

The variable, skill quantity per area (measured in manhours/m^2) recognises the different skill quantities of six skill categories under five distinct OSC types. Quantities of each skill category are expected to vary depending on the relevant OSC type, and their relationships are yet to be found using empirical data. A series of case studies of OSC projects will provide the basis to calibrate the skill profile prediction model. As such, skills quantities utilised in OSC projects, along with their GIFA and OSC value percentage need to be collected and analysed via regression analysis to adjust the curve representing each skill category. Once this process is completed, it will be apparent whether the relationships are linear (straight lines) or non-linear (curved lines). It is possible that some skill categories will be directly proportionate to the complexity of the OSC type, and thus linear relationships can appear.

Moreover, there can be complex skill variations depending on the level of automation involved in OSC types. For example, the number of trade workers and machine operators needed for a particular OSC type may vary depending on the prefabrication method adopted. The use of robotic arms with assembly line-based manufacturing processes may result in some skills being in high demand whilst the demand for other skills is substantially reduced. As such, the lines in Figure 1 resemble the possible skill variations for the six skill categories under five distinct OSC types.

The empirical data-based skill prediction model (OSC skills predictor) will forecast the potential skill quantity required to complete an OSC project. The expected OSC type, its value percentage and the GIFA of the building are the data inputs. Skills predictions will be generated for the six skill categories under onsite and offsite locations. For example, a modular OSC project of 1000 GIFA, with 70% OSC value percentage may require the following skill quantities: managers - 500 manhours, professionals - 1000 manhours, trade workers - 1500 manhours, admin workers - 125 manhours, machine operators - 250 manhours, and labourers - 1100 manhours. The onsite and offsite usage of each skill category may also vary. Furthermore, longevity of the OSC skills predictor will be assured by inserting the actual OSC project data, so that it can evolve with the market conditions of various skills usage. Once developed, the OSC skills predictor can be used as a mobile or a computer application.

5. INNOVATIONS OF THE CONCEPTUAL MODEL

Among the well-documented aspects of OSC research, several publications focus on OSC-specific skills development (Vokes, et al., 2013; Brennan and Vokes, 2017; Hairstans and Smith, 2018; Ginigaddara, et al., 2022). Despite the numerous models developed on skills optimisation (Arashpour, et al., 2018; Nasirian, et al., 2019), research on skills prediction for a mix of both traditional and OSC approaches are limited. The proposed conceptual model captures OSC-specific skills under six skill categories from managerial positions to labourers. Moreover, skills prediction accounts for the various types of OSC prevalent in the industry. Identification of both these aspects; OSC types and the skill categories was achieved by following systematic research processes which involved a rigorous literature review. Furthermore, the skills prediction model provides a unique skill quantifier, "manhours/m^2" which can be used to predict the magnitude of skill shortage and supply for any OSC type, under any skill category, for both onsite (construction site) and offsite (factory, office, and transportation) aspects separately. Recognising the different skills usage assists in pre-planning, and accurate budgeting of OSC project labour costs. Moreover, the skills prediction model proposes a forecasting tool to be used by regulators and tertiary education providers, industry training and professional bodies to decide on the labour market demand and requirements. Also, OSC skills prediction will be useful for new entrants to OSC businesses, to get an overview of the OSC skills under a specific OSC type, for a given OSC value percentage and GIFA.

6. FURTHER RESEARCH IN MODELLING OSC SKILL REQUIREMENTS

The conceptual model introduces an original framework to predict OSC skills in a quantitative stance. In related research, a state-of-the-art typology for OSC has been developed (Ginigaddara, et al., 2019). Other work also has evaluated skill profile classifications relevant to both traditional and OSC skills, evidenced in Australia (Ginigaddara, et al., 2021). Other research has applied digital procurement technologies such as Blockchain to supply chain management that can be adopted in OSC (Perera, et al., 2020). Current work is also exploring development of process protocols for integration of DfMA and blockchain for the OSC sector. Another outcome of the ongoing research work is to propose a validated prototype for OSC skills prediction highlighting the research findings and the methodology of developing the OSC skills predictor.

7. CONCLUSION

OSC is the production of construction elements in a factory fundamentally moving construction of buildings from an onsite process to offsite. The advent of Industry 4.0 has exacerbated the offsite construction methodologies breaking the established typologies for OSC to novel approaches. Although construction is far behind other industries in terms of industrialisation and digitalisation, OSC facilitates the industrialisation of the construction industry to improve the delivery of factory-made buildings and building elements/components. Evidently, the adoption of new technologies changes the traditional construction skills to embrace advanced technologies. Therefore, the future of construction skills in an OSC setting is not known, and thus creates a knowledge gap to be filled through research. This paper introduces a conceptual model that incorporates key concepts of OSC typologies and building areas to predict construction skills requirements. The identified concepts are the OSC typology and the OSC skill classification representing all possible skills. Further, GIFA of the completed OSC projects, value percentage of the OSC type, and the skill quantity variations are considered to develop the conceptual model. As such, OSC skills prediction incorporates the unit of measurement, "manhours/m^2" to quantify skills under six skill categories for five distinct OSC types.

The conceptual model for OSC skills prediction is the first of its kind. Also, the work presented contributes to the body of knowledge by introducing a methodology for OSC skills prediction. The research identified and integrated the key concepts, parameters, and their interactions in a prediction model to anticipate the emergence and expansion of OSC skills. Once developed, the OSC skills predictor will be presented in the form of a mobile or a computer application. It can be used by regulators, policymakers, education providers, and industry practitioners to understand the demand for various OSC skills based on the market conditions for distinct OSC types. It is anticipated that the actual data collection and analysis will lead to recognising the skills based on their location of work - onsite and offsite as well. The paper has inherent limitations of being a theoretical study, as it aims to present a conceptual model for OSC skills prediction. However, other research publications associated with this conceptual model will present empirical studies to develop an OSC skills prediction model using case study-based skills data.

8. DATA AVAILABILITY STATEMENT

No data were generated or analysed during the study.

9. ACKNOWLEDGEMENTS

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OPPORTUNITIES AND CHALLENGES IN CONDUCTING VIRTUAL ALTERNATIVE DISPUTE RESOLUTION (ADR) METHODS IN THE SRI LANKAN CONSTRUCTION INDUSTRY

Vithusha Lingasabesan[1] and Mahesh Abenayake[2]

ABSTRACT

The Covid-19 pandemic has created a new norm in which technology is at the forefront of keeping the globe running and rebuilding better after the crisis. Several countries practiced virtual ADR during the pandemic than in the pre-pandemic situation, and the virtual shift has gained traction. The research aims to explore the potentiality of the ADR methods in the virtual platform for the settlement of the dispute and make recommendations for effective legal implementation of those methods in the Construction Industry in Sri Lanka. The research aim was achieved through a qualitative approach; collected data through two stages: a preliminary interview and a semi-structured interview with experts and finally analysed with manual content analysis. Key research findings are the opportunities and challenges to implement and conduct ADR in the virtual platform in the Sri Lankan construction industry. In addition, the strategies were collected to identify the potentiality of virtual ADR. The research concludes that the blended approach is suitable for Sri Lanka and the entire virtual ADR is not suitable. The entire virtual ADR shall be potential for Sri Lanka if all the opportunities are utilized and all the strategies are followed. As the virtual ADR is a game-changer for the SL construction industry, regulatory bodies and arbitration institutions must take initiatives to implement and conduct virtual ADR successfully in the future.

Keywords: *Alternative Dispute Resolution (ADR); Opportunities and Challenges; Pandemic; Virtual.*

1. INTRODUCTION

Construction projects are typically complicated and uncertain with challenges (Changaroth, 2015). One of the most significant aspects that prevent any construction project from being completed successfully is a dispute (Soni, Pandey, and Agrawal, 2017). Alternative Dispute Resolution (ADR) methods are recognized as a legal instrument designed to help parties reach solutions in any form of dispute (Niriella, 2016). The overall aim of the construction sector in using ADR methods is to resolve disputes quickly while preserving the reputation of all parties involved (Abenayake, 2014).

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The SARS-CoV-2 virus that caused the COVID-19 disease was discovered in China in December 2019 and declared a global pandemic by the World Health Organization (WHO) in March (Beck, Shin, Choi, Park, and Kang, 2020). Outbreaks of the Coronavirus (COVID-19) have affected the economy negatively. It heavily depends on global trade and impacts households, businesses, financial institutions, industrial facilities, and infrastructural corporations simultaneously (Biswas, 2021). The construction industry is not escaped from the list (Zin, et al., 2021).

It appears that the pandemic has had a more substantial impact on ADR procedures (Rooney, 2020). The covid-19 pandemic requires ADR practitioners to convey results immediately and empower economic restoration despite an extended dramatic expansion in disputes (Sourdin and Zeleznikow, 2020). Given the fact that dispute in the construction industry is a consistent issue, it is fundamental to start a conversation among industry specialists by the ADR practitioners concerning ways to address the issue (Saseendran, et al., 2020).

Technology-mediated ADR, also known as Online Dispute Resolution (ODR), has grown into a global movement (Ojiako, Chipulu, Marshall, and Williams, 2017). Growing momentum for change occurred with the increased use of the virtual platform. Rabinovich-Einy and Katsh (2014) illustrated that virtual ADR began as an online version of ADR, initially focusing on applying technology. The Covid-19 pandemic has created a new norm in which technology is at the forefront of keeping the globe running and rebuilding better after the crisis (Osadua, et al., 2020). The virtual hearing has thrived with the pandemic (Osadua, et al., 2020).

In other jurisdictions, the virtual shift has gained traction. Similarly, the need for a long-time change for a new normal is already gaining traction in Sri Lanka. This study focused on virtual ADR. The potentiality of virtual ADR by comparing the opportunities and challenges experienced by developed countries would differ from the Sri Lankan context. This matter should be carefully addressed by studying the opportunities and challenges of ADR on the virtual platform in Sri Lanka. In addition, there are queries on whether the virtual ADR is a substitution for typical ADR in the long run, why beneficial to continue, and how to improve the effective implementation and conduct successfully in the Sri Lankan construction industry. Given the lack of studies that have shed light on the situation, this work closes the research gap.

2. METHODOLOGY

The primary goal of this section is to present the methodological structure of the study. The research question is “What is the potentiality of virtual ADR in Sri Lanka and how to improve the widespread use of virtual ADR in the Sri Lankan construction industry?”. The research question of this research falls under the type “why what and how”. A large volume of data needs to be collected in words, and the approach used to handle the data with “words” is the qualitative approach. A qualitative research approach was conducted to achieve the research aim. It is significant in terms of focusing on a specific group of people, representing the views and perspectives of the people, and in-depth studies on topics.

To achieve the objective through the question of “what are the strategies to overcome the challenges for implementation and conduct of virtual ADR in the Sri Lankan construction industry?”, a survey strategy was used. A comprehensive literature survey was carried out to identify the general concept of ADR, implementation of ADR for settlement of Dispute, and the general concept of virtual ADR. The literature survey was achieved by referring to journals, books, conference proceedings, dissertations/ thesis, and other related sources. A semi-structured expert interview was used as a data collection technique and the findings presented in the paper were analyzed using manual content analysis.

3. VIRTUAL ALTERNATIVE DISPUTE RESOLUTION

Parties should anticipate "how the disputes would be handled and resolved" (Bates and Torres- Fowler, 2020). For this purpose, Cheung (as cited in Raji, Mohammed and Oseni, 2015) opinioned that given the construction industry's nature, there has been a definite tendency toward exploring alternate methods of resolving disputes to come at cost-effective, adaptable, and time-efficient solutions. The overall aim of the construction sector in using ADR methods is to resolve disputes quickly while preserving the reputation of all parties involved (Abenayake, 2014).

The impact of the COVID-19 pandemic on projects under construction at the time of governmental actions, as well as projects that were deferred or canceled due to the pandemic's economic impact, has increased the number of new disputes (Bates and Torres-Fowler, 2020). According to Rooney (2020), it appears that the pandemic has had a more substantial impact on ADR procedures. Innovative technology like Blockchain technology and artificial intelligence (AI) has not been used in dispute resolution. To prevent delays, numerous arbitrators have conducted ongoing proceedings virtually, and advisors and parties have expressed satisfaction with the procedure (Bates and Torres-Fowler, 2020).

3.1 OVERVIEW OF ONLINE DISPUTE RESOLUTION (ODR)

ODR is defined as "the complete range of possibilities for resolving disputes through the use of communications and other forms of technology, particularly the Internet." (Lavi, 2016, p.897). Technology creates ODR particularly appealing for global projects where face-to-face meetings are difficult, cultural and institutional differences are significant, and incentives to create long-term stakeholder trust are low because relationships between disputants are transient (Ojiako, et al., 2017). More crucially, because of its purpose as a portal or medium for constructing interaction and decision architectures via which disputes are channeled towards settlement, ODR is always considered to involve more than the usage of communications technology.

3.2 VIRTUAL ADR MODEL

While the whole world transferred to continue their activities in a virtual platform, the dispute resolution Institution has permitted to proceed in the virtual platform. Even though the virtual platform is not new, its utilization has been revealed and expedited during the crisis.

Virtual hearings have undoubtedly dominated discussions concerning virtual dispute resolution. There will be no obstacle to, and failure of dispute resolution mechanisms caused by the inability of disputing parties to meet physically because of this (Osadua, et al., 2020). Technology has aided in the erosion of barriers, making it a speedier and more cost-effective option with the added benefit of avoiding human trust difficulties that may hamper alternative ADR methods (Ojiako, et al., 2017).

The model of a virtual ADR is shown in Figure 1.

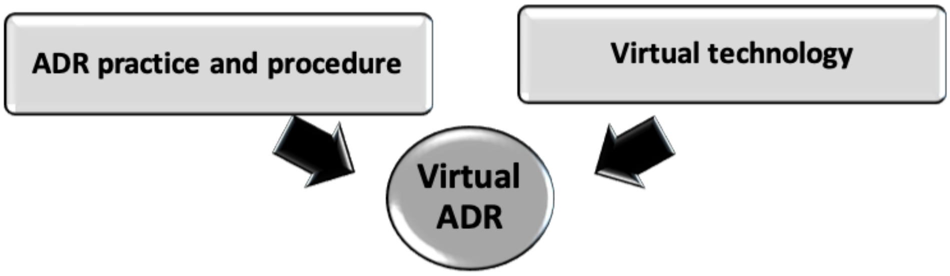

Figure 1: Virtual ADR model

4. IMPLEMENTATION AND CONDUCT OF VIRTUAL ADR IN SRILANKA

4.1 VIRTUAL ADR BEFORE THE PANDEMIC PERIOD

According to the survey carried out in the Sri Lankan construction industry through expert interviews, there were records of ADR conducted virtually during the pre-pandemic period. It showed, there were negotiations, mediations, adjudications, and arbitrations were conducted virtually before the pandemic period. However, it was sparingly used in case of either impossibility of the witness coming to Sri Lanka or the impossibility of parties and arbitrators traveling abroad where the seat of arbitration is fixed.

4.2 IMPACT ON PRACTICE AND PROCEDURE OF ADR DUE TO PANDEMIC

The pandemic has made changes to most of the procedures in the world, and ADR is not an exception. Technology has paved the way to practice ADR procedures virtually. Sri Lanka has thrived to practice it without any alternative options. A simple graphical representation obtained from the data collected is shown in Figure 2. It elaborates that initially the ADR proceedings have been stopped. To navigate from the postponement, used the technology to conduct the virtual hearings through zoom and Microsoft teams. It required the written consent of the parties. Then with the further steps as per the figure, virtual ADR was conducted. There are no protocols, guidelines, or regulations for virtual ADR in Sri Lanka. In addition, there are no laws or specific provisions addressing virtual ADR procedures in Sri Lanka.

According to the information obtained from the Institute of Commercial Law and Practice (ICLP), there was construction arbitration conducted in a hybrid manner. Nevertheless, specifically for construction disputes, there were two adjudications conducted virtually. According to Sri Lankan National Arbitration Centre (SLNAC), more than ten arbitrations were conducted virtually in Sri Lanka. In addition, a preliminary adjudication meeting which happened in person was then conducted virtually. In addition to SLNAC and ICLP, virtual ADR was practiced in individual chambers of arbitrators and adjudicators.

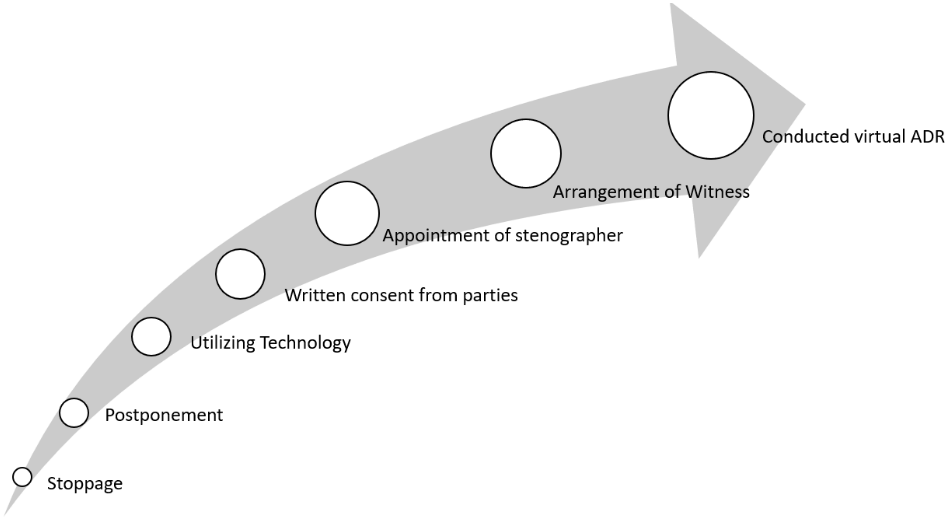

Figure 2: Impact of ADR due to pandemic

4.3 VIRTUAL PLATFORMS USED IN SRI LANKA

The virtual platforms used to conduct ADR in the Sri Lankan construction industry are Zoom, Web-Ex, Microsoft Teams, Google meets, and Skype. In addition, WhatsApp and Facebook messenger was used as messaging platforms, and Iconix was used as a file handling platform. Furthermore, computer tablets, laptop computers, desktop computers, and smartphones are the devices used in virtual conduct.

5. OPPORTUNITIES AND CHALLENGES TOWARDS VIRTUAL ADR

The factors that encouraged the change and resisted the change from in-person to virtual ADR are referred to as opportunities and challenges respectively. The encouraging factors and resistance factors are shown in a figure under respective subtitles.

5.1 FACTORS THAT ENCOURAGED THE CHANGE

The use of digital technologies to generate new revenue and value-producing opportunities is known as digitalization. As the world moves towards digitalization, conducting ADR in a virtual platform is an opportunity.

Table 1 provides the factors that encouraged the implementation of virtual ADR obtained from the survey carried out in the SL construction industry.

Table 1: Factors that encouraged the change toward virtual ADR

Category	Factors that encouraged the change towards virtual ADR
Laws in Sri Lanka	Electronic transactions (amendment) Act No 25 of 2017
	Data protection Bill of 2021
	Computer Evidence Act 1995
	Litigation Act no: 17 of 2021- Part III specifically addresses virtual hearings by courts
Party Autonomy	Agreed by parties

Category	Factors that encouraged the change towards virtual ADR
	Agreed to conduct on an Ad- hoc basis from individual chambers of arbitrators and adjudicators
Technology Advancements	Digitalization of globe
Convenience	Parties and witnesses consider virtual ADR as convenient
	Ability to participate from different locations
Cost savings	Less costly
	Cost for travel is eliminated
	Cost for accommodation
Time Savings	Less time-consuming procedure

Table 2 provides the factors that encouraged the conduct of virtual ADR obtained from the survey carried out in the SL construction industry.

Table 2: Factors that assisted in conducting virtual ADR

Category	Factors that assisted in conducting virtual ADR
Convenience	More flexible
	Tired of traveling is eliminated
	Quickly scan and share the documents
	Witnesses are very cooperative
	Conducted more smoothly than a physical hearing
	No translators required
Cost Savings	Fewer time restrictions and the submission
	Reduce administrative fees paid to the institutions
Time Savings	No delay in transportation

5.2 FACTORS THAT RESISTED THE CHANGE

There were two adjudication and three arbitrations of construction disputes that happened via zoom. Table 3 provides the factors causing reluctance to the implementation of virtual ADR obtained from the survey carried out in the SL construction industry.

Table 3: Factors causing reluctance to the change toward virtual ADR

Category	Factors that reluctant the change toward virtual ADR
Management of Human Psychology is Difficult	Reluctant to changing human nature
	Difficult to refuse by anyone if another party, resolutioner, and the witness agreed to proceed virtually
Poor Infrastructure of Sri Lanka	Technological limitations
Technological Limitations	Costly to set up gadgets, strong internet, and software licenses
	Virtual platform has their own characterized limitations
	Lack of technical knowledge
	Lack of familiarity with technology of senior professionals

	The file system is not digitalized
	Struggled to find stenographers
Lack of Encouragement from the Regulatory Body	No professional institutions encouraging

Table 4 provides factors that resisted the conduct of virtual ADR obtained from the survey carried out in the SL construction industry.

Table 4: Factors that resisted conducting virtual ADR

Category	Factors that resisted conducting virtual ADR
Lack of human touch	The art of meeting physically is lost in a virtual platform
	The negative impact on the decisions
	Difficult to express the contentions
	Difficult to express the arguments
	Difficult to establish the explanations for the fact
Management of human psychology is difficult	The moods of participants would be different
	Difficult to bring everyone to one focus
	Parties were not comfortable having virtual hearings
Poor Infrastructure of Sri Lanka	Connection Issues
	Unexpected power failures in Sri Lanka
Outcome of VADR	Lack of quality decisions
	Reduce the effectiveness of ADR
Technological Limitations	Deficiencies in the integrity of cross-examination of expert witness
Data Security	Porous of data transactions
	Screenshots by the third party

In addition, the research findings depict that SLNAC has taken a step to develop highly sophisticated software for the sole purpose of ADR procedure in SL. Similarly, ICLP has taken steps toward developing a protocol. Apart from that, ICLP is still struggling to develop a protocol that satisfies the needs of everyone.

5.3 STRATEGIES TO OVERCOME THE RESISTANCE TO IMPLEMENTATION AND CONDUCT OF VIRTUAL ADR IN THE SRI LANKAN CONSTRUCTION INDUSTRY

The strategies for the factors causing reluctance to implement and conduct virtual ADR in Sri Lanka are given in Table 5.

Table 5: Factors that resisted conducting virtual ADR

Factors that are reluctant the change or resisted conducting virtual ADR	Strategies to overcome the reluctancy
Lack of human touch	
The art of meeting physically is lost in a virtual platform	Identify what areas we can go virtual and manage and what is essential for the physical meeting
Difficult to establish the explanations of the fact	Conduct pre-ADR meeting
Management of human psychology is difficult	
Difficult to refuse by any one if other party, resolutioner, and witness agreed to procced virtually	Amendments to the conditions of the contract
	Changing the policies in the contract
	Revise the documents that describe the location of the hearings
Poor Infrastructure of Sri Lanka	
Connection issues in Sri Lanka	Make sure that all can connect to the meeting
	Have two laptops, one to connect virtually and the other for documents
Lack of encouragement from the regulatory body	
No professional institutions encouraging	Should implement a provision
Technological limitations	
Virtual platform has their own characterized limitations	Develop a highly sophisticated platform for Sri Lankan Construction Industry
Lack of technical knowledge	Appoint at least one person in the tribunal having technical expertise
Lack of familiarity with technology of senior professionals	Get well prepared for the meeting virtually
The file system is not digitalized	Records shall be digitalized, which supports people scanning and filing
	Fix another camera and give a picture of the entire room environment
	Arbitrators especially must have the right to be fully aware that the integrity of the hearing is not compromised
	Flexibility must be given to have a physical hearing when the witness must refer to several documents
Data Security	
Porous of data transactions	Develop each own data security
Screenshots by the third party	Impose duty on parties not to do unauthorized act

There will be a high potential to implement and conduct the virtual ADR by utilizing the opportunities and strategies to overcome the challenges (refer Figure 3).

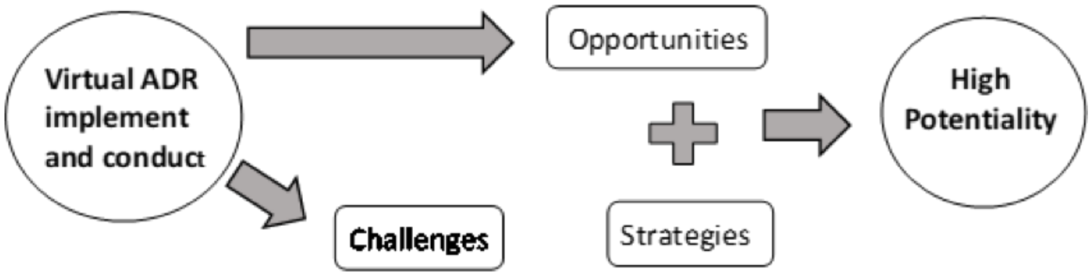

Figure 3: Potential for virtual ADR in the Sri Lankan construction industry

6. PRACTICE OF VIRTUAL ADR IN FUTURE

6.1 TYPE OF APPROACH

The research found that the virtual ADR will be practiced in the Sri Lankan construction industry in the future. Even though there are advantages such as timesaving and cost-saving, the construction dispute resolution specifically needs the physical meeting to a certain extent. The ADR procedure in the construction industry involves submissions, clarifications, more technical nature explanations, discussion, and understanding of the technology behind the dispute. Therefore, a considerable percentage of the matters can be discussed and finalized virtually; virtual ADR is not entirely feasible for construction disputes. However, it will be a norm in the future to solve construction-related disputes in an entirely virtual manner.

The friendliest approach by most parties is a blended approach, rather than going fully-in-person or entirely virtual manner. Even in the blended approach, most notice procedures, agreements, and document sharing would happen virtually. However, the site visit and final evaluation and decision-making would happen virtually.

6.2 CHARACTERISTICS OF DISPUTE INFLUENCE THE SELECTION

The characteristics of the dispute that influence the applicability of virtual ADR in the SL construction industry are the nature of the dispute, the complexity of the dispute, the financial value of the claim, and the parties involved.

6.3 ADDITIONAL SKILLS NEEDED TO CONDUCT VIRTUAL ADR IN FUTURE

The additional skills that must be developed by the parties of construction projects and dispute resolution practitioners are shown in Figure 4.

7. CONCLUSIONS

The most critical opportunity in Sri Lanka for virtual ADR, which is identified and verified by most experts is time-saving and cost savings. The time savings related to travel time and cost savings related to travel, accommodation, and administrative costs. On the other hand, most experts identified and verified the major challenge is the lack of human interaction and credibility of witness examination. Human interaction is an art in an ADR procedure. It got lost in virtual ADR.

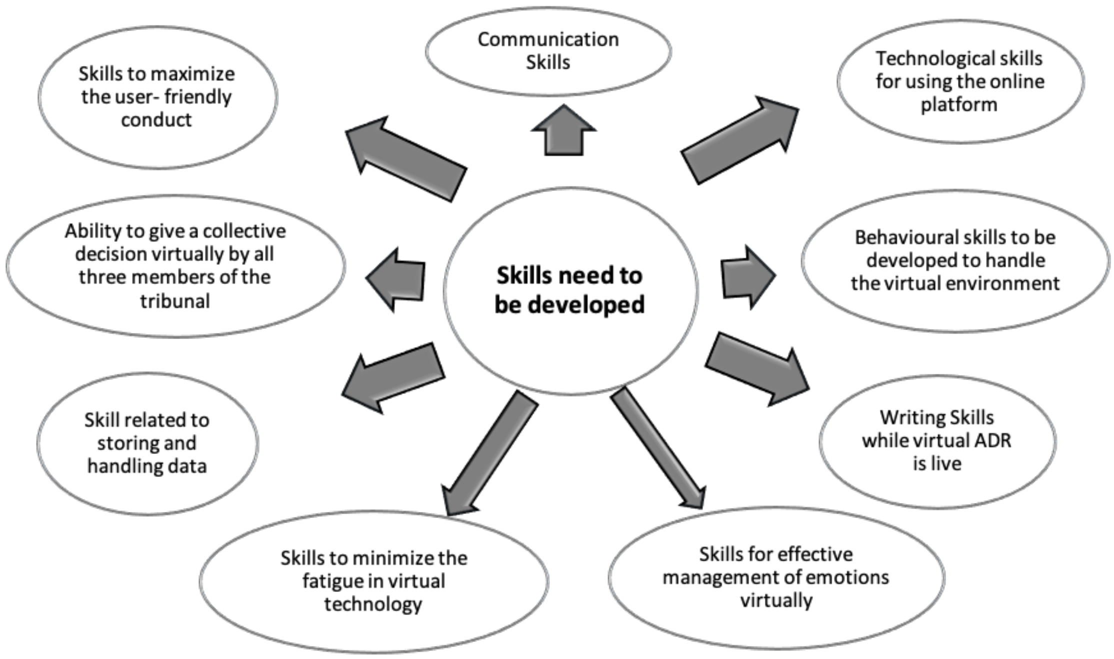

Figure 4: Additional skills needed to conduct virtual ADR

SLNAC and ICLP have not published their initiatives yet toward virtual ADR. Moreover, CIDA has not taken any steps yet. No legal steps have been taken toward virtual ADR. In contrast, all virtual ADR was conducted purely with the parties' consent, and they believe that is sufficient for the time being in Sri Lanka. Nevertheless, it will not be applicable in the long-run virtual ADR.

The most significant argument of construction industry professionals is that the site visits, evaluation of documents, witness cross-examination, and final decision making shall be done physically in a process of ADR. Construction industry professionals provide significant interest in in-person ADR compared to virtual ADR. Apart from that, the world is moving towards digitalization, and all the procedures are digitalized. Entirely-virtual ADR will be a norm in the future, which will be very valuable to the construction industry. Therefore, the necessity of identifying the potentiality in Sri Lanka to implement and conduct virtual ADR for construction disputes is validated. There is a high potentiality to implement and conduct virtual ADR in the Sri Lankan construction industry in the future if the opportunities are experienced and the strategies to overcome the challenges are utilized as a benefit.

This study is an eye-opener and game-changer for the stakeholders to induce the widespread use of virtual ADR. If the parties, dispute resolution practitioners, arbitration institutions, professional institutions, regulatory bodies, and statutory bodies, then entirely- virtual ADR can be effectively implemented and conducted in the Sri Lankan construction industry.

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POLICY-LEVEL CONSIDERATION ON MARGINALISED COMMUNITIES IN THE POST-DISASTER CONTEXT: A DESK STUDY

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ABSTRACT

Natural disasters have a disproportionate influence on the lives of those impacted, with the most marginalised often bearing the brunt of the repercussions. As a result, marginalised communities should be expressly considered in post-disaster policy development. While the international community has adopted the concepts of resilience and inclusion, marginalised communities are frequently disregarded in post-disaster management. There is a dearth of literature on the engagement of marginalised communities in Sri Lanka's post-disaster context. Moreover, the policies to support the marginalised communities need to be reviewed to explore the extent to which such policies are implemented to benefit the disadvantaged groups in a disaster situation. Therefore, this paper aims to review the existing policies to improve the engagement of marginalised communities during the post-disaster context in Sri Lanka. To achieve the aim, a comprehensive desk study on significant global and national policies was carried out. Through the desk study, the policies and frameworks related to disaster management were explored in order to identify the inclusion of marginalised communities in the post-disaster context. The policies related to marginalised communities were further explored in order to identify the inclusion of them in post-disaster situations. Finally, the study confirmed that a refinement of the policies in the Sri Lankan context is crucial. Furthermore, as a way forward, the study suggested assessing the current level of implementation of existing policies as well as barriers to implementation in order to increase the inclusion of marginalised communities in Sri Lanka's post-disaster context.

Keywords: *Marginalised Communities; Policy Studies; Post-Disaster Context; Sri Lanka.*

1. INTRODUCTION

Over the years, community participation in disaster management programmes and activities has grown in importance in the development area, gaining the attention of researchers, academics, policymakers, and national and international organisations

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(Chandrasekhar, et al., 2014). There is increasing recognition that the community is the first responder in any kind of disaster, so the management of emergencies and disasters would not be effective without the engagement of impacted communities (Burnside-Lawry and Carvalho, 2016). Community-oriented decentralisation programmes ensure greater participation from marginalised communities (Agrawal and Gupta, 2005), as highly decentralised recovery programmes consider the voices of marginalised community members concerning empowerment, equity, and sustainability (Mannakkara and Wilkinson, 2015). However, in the post-disaster context, much is unknown about the participation of communities that are marginalised (Cretney, 2018; Mannakkara and Wilkinson, 2015). The experiences of marginalised communities are crucial in understanding participation in post-disaster management programmes, as these communities are the most impacted (Islam, et al., 2020).

While risk governance is regarded as critical to achieving long-term and equitable recovery after a disaster and mitigating future risk (United Nations Office for Disaster Risk Reduction, 2005), societal dynamics that contribute to inequality and marginalisation might hinder this goal (Scott and Marshall, 2009). Marginalisation is a process in which a group or individual is denied access to major positions and symbols of economic, religious, or political authority in any community (Scott and Marshall, 2009). In broader terms, each society has identified some groups of people as vulnerable in mainstream society. Such groups could be the poor, children, women, people with disabilities, ethnic minorities, low caste groups, etc (Ferretti and Khamis, 2014). However, it has been claimed that most of these people are not always marginalised while women, the elderly, people with disabilities, and children are often and mostly marginalised due to multiple discrimination and vulnerabilities (Cordaid, 2020; Steele, et al., 2007). Marginalised communities are seen to be exposed to higher levels of risk, and subsequently face the brunt of disasters harder than others (Sharma, 2014). The concern is made worse by the fact that a large number of such groups are invisible (Mannakkara, et al., 2014). Moreover, the marginalised communities are denied their human rights because of their place within a system of unequal social relations of power. Besides, they are especially vulnerable to natural disasters due to the combination of their financial, socio-economic, cultural, health, age, and gender status; geographical location; lack of access to resources; decision-making; and justice (Global Facility for Disaster Reduction and Recovery, 2019). In the post-disaster context, these communities face potential challenges to access entitlements, such as government relief or recovery aid (Sledge and Thomas, 2019).

Policy frameworks at the international level addressing the issue of heightened risks to disasters have been developing since the declaration of the International Decade of Natural Disaster Reduction in 1989 through the United Nations General Assembly Resolution 44/236. Moreover, the need for inclusion of marginalised communities, perspectives on what constitutes disaster risks, and how these are best addressed is evidently changing towards accommodating more active involvement and participation from local communities and social groups (Zayas, et al., 2017). However, the engagement of marginalised communities during the post-disaster context in Sri Lanka has not been evidently reported, thus this research focuses on this gap to explore. Further, there is a dearth of research investigating the policy frameworks related to disaster management that can support the marginalised communities in Sri Lanka. Hence, this study intends to gather a deep understanding of the national and international policy framework that is required to engage marginalised communities in the post-disaster context to respond to their needs with the available resources.

2. METHODOLOGY

The desk study research method was selected to achieve the aim of this research. A desk study focuses on acquiring and analysing information or data that is already available in print or electronic form (Khombe, 2014). According to Crisp (1981), a desk study is defined as the process of gathering information from existing resources such as published papers, analytical reports, policy reports, and other publications. Furthermore, a desk study is a secondary data research method that is used to review previous research findings in order to get a full grasp of a relevant research field (Bingham, et al., 2012). As such this paper reviewed the policies to get insights into the policies that are related to marginalised communities in terms of their level of significance in improving inclusivity during the post-disaster context in Sri Lanka. Accordingly, the desk study on policies mainly covered the policies related to marginalised communities, policies related to post-disaster management, covering relief, rehabilitation, and recovery phases, and policies related to both the concepts and general policies. The term “policy” refers to a standard set of principles that guide a course of action (Porter, et al., 2018; Vernick, 2006; Kingdon, 2003). Public policies are established by the government, whereas private or institutional policies are created by organisations for institutional use. Many public policies are legally binding, meaning that individuals and institutions in the public and private sectors must comply with them. In contrast, policies created by private institutions do not carry the force of law; however, within an institution, compliance with such policies may be required. Legally binding public policies fall into 3 primary categories: legislation, regulation, and litigation. It is worth noting that some public policies do not have the force of law. Most often, these policies are guidelines produced by administrative agencies. Although guidance cannot be enforced, the expectation is that it will be followed or will provide answers when the law is unclear et al., 2018). As a result, policies, acts, guidelines, and frameworks are regarded and referred to as policies in the desk study.

The policies that are identified through the desk-study are listed in Table 1. To determine the relevant policies, the leading local and international organisations involved in disaster management efforts, as well as marginalised communities, were considered. Furthermore, key terms such as ‘marginalised communities, inclusivity, inclusion, and post-disaster phases, and post-disaster management’ were utilised in Google searches to find relevant policies.

3. POLICIES/FRAMEWORKS RELATED TO POST-DISASTER MANAGEMENT AND MARGINALISED COMMUNITIES

Without actively engaging marginalised communities through deliberate policies, physical displacement and a history of distrust can significantly limit the voices of the marginalised (Hamideh, 2020). Therefore, it is important to have an overview of the existing global and national policies/frameworks that govern post-disaster processes, how these takes into consideration challenges of marginalised communities, and how these may be leveraged to promote inclusiveness during the post-disaster phase. Accordingly, a desk study on the significant global/national policies was conducted. The policies reviewed under the desk study largely fall under 4 main categories such as:

- Category 01: policies related to both the marginalised and disaster management concepts,
- Category 02: policies related to marginalised communities,
- Category 03: policies related to disaster management, and
- Category 04: general policies.

The desk study mainly focused on analysing the explicit links between disaster management and marginalisation. As such the policies that are related to marginalisation were reviewed to see the explicit mentioning of disaster whereas the policies that are related to disaster management were reviewed to see the explicit mentioning of marginalisation. In addition, a few well-known policies were also reviewed to explore the explicit mentioning of either disaster or marginalisation. Accordingly, 35 policies were reviewed, of which 3 (P1 - P3) are related to both disaster and marginalised concepts, 15 (P4 - P18) are related to marginalised communities, 12 (P19 - P30) are related to disaster management, and 5 (P31 - P35) are general policies. Table 1 depicts the analysis of the desk study conducted.

Among the 15 policies on marginalised communities (category 02), 12 policies have explicit mentioning about disaster management whereas among the 12 policies on disaster management (category 03), 9 policies have explicit mentioning about marginalisation. As per Table 1, it can be identified that there are a lot of policies related to disaster management and marginalised communities in the global and local context. However, it is evident that in global policies related to disaster management, special consideration has been paid to the inclusion of marginalised communities compared to local policies and vice versa.

3.1 POLICIES RELATED TO DISASTER MANAGEMENT IN THE GLOBAL CONTEXT

Since the declaration of the International Decade of Natural Disaster Reduction in 1989 through UNGA Resolution 44/236, policy frameworks at the international level addressing the issue of heightened risks to disasters have been evolving. From a virtual non-recognition of differential conditions of socially 'vulnerable' groups to the latest pronouncements for the need for inclusion of marginalised communities, perspectives on what constitutes disaster risks and how these are best addressed are evidently changing towards accommodating more active involvement and participation from local communities and social groups (Zayas, et al., 2017).

The Hyogo Framework for Action 2005-2015, which had become the international blueprint for disaster reduction following the Indian Ocean Tsunami in 2004 (Priestley and Hemingway, 2007). Its successor, the Sendai Framework for Disaster Risk Reduction 2015-2030 developed during the Third World Conference on Disaster Risk Reduction is more explicit regarding the inclusion of marginalised communities, specifically the persons with disabilities, women and girls, children, and older people (UN, 2015). Besides, some other globally recognised frameworks with the inclusion of marginalised communities in disaster situations are Paris Agreement and Sustainable Development Goals.

Table 1: Analysis of the policies - desk study

Category		Policy Concern	Name of the policy	Global (G)/ National (N)		Consideration on Disaster Management (DM)/ Marginalisation (M)		Key highlights considering post-disaster management/marginalised communities
				G	N	DM	M	
01	Disaster Management & Marginalisation	Women	P1: Guidelines for Gender Sensitive Disaster Management	✓		✓	✓	Identify basic and specific needs of women, disabled, and elderly in relief, rehabilitation, and recovery aids, aid distribution for women should be handled by women, protect women from violence and abuse, ensure women's access to psycho-social counselling, eliminate the head of the household concept, ensure women's participation in decision-making processes, raising women's empowerment and awareness of their rights
			P2: GFDRR Gender Action Plan 2016-2021	✓		✓	✓	Provide adequate access to sexual and reproductive health services after disasters, ensure women's access to psycho-social counselling, break down gender stereotypes, increase access to information and income-earning opportunities, capture gender-disaggregated and losses in post-disaster assessments, protection of safety and human rights for women and children, including sensitivity and attention to multiple forms of social marginalisation, ensure women's participation in decision-making processes
		Older Adults	P3: Older people in disasters and humanitarian crises: Guidelines for best practice	✓		✓	✓	Check records in service facilities to find out if the expected numbers of older people have attended and, if not, the reason, build an 'outreach' approach to assessments, use the mutual support networks of older people to gather information, organise group meetings to allow older people to identify, address their problems and explore their capacities, ensure that they are represented on decision-making, provide training to the representatives to identify the most vulnerable members
02	Marginalised communities	Women	P4: Guidelines for Integrating Gender-Based Violence Interventions in Humanitarian Action	✓		✓		Provide assistance to coordinate, plan, implement, monitor and evaluate essential actions for the prevention and mitigation of Sexual Gender-based Violence (SGBV)
			P5: Guidelines for District and Divisional Level Referral System SGBV		✓	✓		Offer standardised treatment for SGBV victims and support the survivor's recovery and inclusion into the community, formalise district and divisional referral channels to allow efficient coordination of service providers in delivering SGBV multi-sectoral response
			P6: World Bank Group Gender Strategy 2016-2023	✓		✓		Bringing a gender lens to resilience and developing gender-smart solutions to climate change
			P7: Gender Equality Strategy 2019-2023 UNDP Sri Lanka		✓	✓		Strengthen gender-responsive strategies in disaster recovery
			P8: 3rd Global Gender Equality Strategy of UNDP 2018-2021		✓	✓		Strengthen gender-responsive strategies in disaster recovery, Increase women's participation and leadership in decision-making, Ensure that post-disaster needs assessments and recovery planning are gender-responsive

Category	Policy Concern	Name of the policy	Global (G)/ National (N)		Consideration on Disaster Management (DM)/ Marginalisation (M)		Key highlights considering post-disaster management/marginalised communities
			G	N	DM	M	
	Children	P9: National Policy on Child Protection		✓	✓		Strengthen activities and mechanisms to address protection threats to and recovery of children affected by disasters
	Children	P10: National Policy on Youth		✓	✓		Facilitate and recognise the participation of youth in national disaster situations
	Children	P11: UNICEF Child Protection Strategy 2021 -2030	✓		✓		Oversee child protection coordination in all disaster contexts to mobilise and implement a complete response that prioritises community-led action
	People with Disabilities	P12: Disability Inclusion Action Plan 2018–2023	✓		✓		Meaningful engagement of people with disabilities at all levels of disaster risk governance; building people's resilience; recovering and rebuilding in a way that truly translates into people's full inclusion and participation.
	People with Disabilities	P13: The Convention on the Rights of Persons with Disabilities	✓		✓		To protect and assist people with disabilities in disaster situations
	People with Disabilities	P14: Disability Policy Brief for Law Makers, Administrators and other Decision Makers		✓	✓		Inclusion of people with disabilities in the disaster management cycle, with consideration for their increased vulnerability during disasters
	People with Disabilities	P15: 1999 Special Educational Society (Incorporation) Act No. 3		✓	✓		Address disabled person's rehabilitation by offering educational services and involving them in social services, giving grants, providing relief aid and assistance, defending disabled people's rights, and providing nutritious food, medical facilities, vocational training, and employment
	People with Disabilities	P16: National Policy on Disability for Sri Lanka		✓	×		- [Considered only about armed conflicts]
	Older Adults	P17: National Elderly Health Policy Sri Lanka		✓	×		-
	Older Adults	P18: WHO Guidelines on Integrated Care for Older People	✓		×		- [Considered only about home hazards]
03	Disaster Management	P19: Sendai Framework for Disaster Risk Reduction 2015-2030	✓			✓	Require integration of gender, age, disability and cultural perspective in policies, practices, and programmes, promote inclusive risk-informed decision-making, empower children, youth, women and disabled people through adequate capacity-building measures, promote gender-equitable and universally accessible response, recovery, rehabilitation and reconstruction approaches, including older people in the policy design process, plans and mechanisms
	Disaster Management	P20: Hyogo Framework for Action 2005-2015	✓			✓	Ensure equal access to training and educational opportunities for women and vulnerable communities, strengthen the implementation of social safety-net mechanisms to assist

Category	Policy Concern	Name of the policy	Global (G)/ National (N) G	N	Consideration on Disaster Management (DM)/ Marginalisation (M) DM	M	Key highlights considering post-disaster management/marginalised communities
							the elderly and disabled, improve recovery plans, including psychosocial training programmes for vulnerable communities, particularly children, in the post-disaster context, include gender perspective to DRM policies, plans, and decision-making
		P21: National Policy on Disaster Management Sri Lanka		✓		✓	Provide special consideration to marginalised groups including persons with disabilities, senior citizens, pregnant women, and children, ensure the children can continuous education where necessary
		P22: Paris Agreement	✓			✓	Promote the respective obligations on human rights, right to health, right to development of children, disabled people, and women, empower women and intergenerational equity
		P23: Sri Lanka Disaster Management Act, No. 13 of 2005		✓		×	-
		P24: GFDRR Strategy 2021-2025	✓			✓	Prioritise the generation of data relevant and accessible to marginalised communities, support inclusive and gender-responsive post-disaster assessments, scale-up inclusive disaster risk management by consolidating and connecting existing initiatives for community resilience, gender, citizen engagement, and disability-sensitive disaster risk management with broader policy and institutional actions at all levels, ensure all projects financing public facilities in post-disaster reconstruction efforts are disability-inclusive, ensure that people with disabilities are considered in disaster-response
		P25: National Emergency Operation Plan		✓		✓	Pay special attention to the safety of women, children, the elderly, and disabled persons in the relief camps, the Ministry of Women and Child Affairs is responsible to collect information on children and women affected by the disaster to prepare programmes to assist them, the Ministry of Education is responsible to provide access to children to continuous education where necessary
		P26: National Adaptation Plan for Climate Change Impacts in Sri Lanka 2016-2025		✓		×	-
		P27: National Disaster Management Plan 2013-2017		✓		✓	Give special consideration to elderly people, children, disabled people, and gender/ women
		P28: Sri Lanka Comprehensive Disaster Management Programme 2014-2018		✓		✓	GN level plans need to be disability-inclusive and gender-sensitive, provide a foundation for organisations to collaborate on a single platform to mainstream gender concerns and the needs of disabled people, develop child and women-centred guidelines, collect disaster-affected gender and age-segregated data at all levels and share with relevant stakeholders, conduct awareness programmes for children, disabled, women, elders

Category	Policy Concern	Name of the policy	Global (G)/ National (N)		Consideration on Disaster Management (DM)/ Marginalisation (M)		Key highlights considering post-disaster management/marginalised communities
			G	N	DM	M	
04	General	P29: Road Map for Disaster Risk Management in Sri Lanka		✓		×	-
		P30: SPHERE Minimum Standards	✓			✓	Assess gender-related and power dynamics, and social marginalisation, set out policies including marginalised communities, ensure that marginalised and disadvantaged groups are appropriately represented in local leadership, pay attention to the needs of older people, women and girls, persons with disabilities and others who might be marginalised
		P31: The 2030 Agenda for Sustainable Development	✓		✓	✓	Build the disaster resilience of the poor and vulnerable people by 2030, promote disability-inclusive DRM, strengthen resilience adaptive capacity to natural disasters
		P32: UNDP Strategic Plan (2018-2021)	✓		✓	✓	Strengthen resilience to better respond to disasters, ensure gender equality, empowerment of women and girls and meet the needs of vulnerable groups, as well as that no one is left behind
		P33: UNDP Strategic Plan 2022-2025	✓		✓	✓	Strengthen countries and institutions to respond to natural disasters, leave no one left behind
		P34: National Family Policy Sri Lanka		✓	✓	✓	Address the special needs of women, elderly, disabled and children, give priority to the restoration of livelihoods in the recovery programmes, provide professional psycho-social support to children and the elderly, integrate mechanisms into the disaster management support systems to protect children and women from violations of their right to personal security, freedom from abuse, neglect and exploitation
		P35: The Policy Framework and National Plan of Action to address Sexual and Gender-based Violence Sri Lanka 2016-2020		✓	✓	✓	Prevent SGBV in disasters, encourage timely response to victims via policy reforms and capacity building, provide gender-equitable relief aids, ensure availability and continuity of reproductive health services in disaster situations, facilitate psycho-social support, improve legislation and legal processes to address children’s special needs in disasters

Sources: (Special Educational Society (Incorporation) Act, 1999; Sri Lanka Disaster Management Act, 2005; HelpAge International, 2000; Ministry of Social Welfare, 2003; Disaster Management Centre, 2005; 2014; United Nations Office for Disaster Risk Reduction, 2005; Disaster Management Centre, 2015; Asia Pacific Forum on Women Law and Development, 2006; National Council for Disaster Management, 2010; Institute for Health Policy for the Ministry of Social Services, 2010; Ministry of Disaster Management, 2014; United Nations, 2014; 2015b; 2015a; 2016; Inter-Agency Standing Committee, 2015; World Bank Group, 2016; Global Facility for Disaster Reduction and Recovery, 2016; 2018; 2021; Ministry of Health, 2017; National Child Protection Authority, 2017; World Health Organisation, 2017; Sphere Association, 2018; United Nations Development Programme, 2018; 2019; 2021; Mendis and Perera, 2019; Ministry of Women and Child Affairs, 2020; United Nations Children’s Fund, 2021)

Most of the global policies (e.g., Hyogo Framework, Sendai Framework) have considered gender equality, social inclusion, fragility, conflict and violence, as well as potential to leverage additional financing as cross cutting themes.

3.2 POLICIES RELATED TO DISASTER MANAGEMENT IN THE SRI LANKAN CONTEXT

Sri Lankan disaster management strategies are mainly governed by several policies and frameworks. All of the policies are based on the principle of creating a disaster risk-free environment for communities. Several policies are based on international standards and they are also localised according to the disaster contexts. The National Policy on Disaster Management is a core component of Sri Lanka's national regime for disaster management and the legal basis for the Policy, and all other core elements of Sri Lanka's disaster management regime is the Act. Under the "Equality, diversity, and inclusion" section of the policy, special consideration is given to the marginalised communities including people with disabilities, older people, pregnant women, and children. Besides, attention has been given to gender equality, in particular the empowerment of girls and women under a special subsection of the policy (National Council for Disaster Management, 2010). However, no specific concern for marginalised communities can be found in the Disaster Management Act. The Disaster Management Act has given only a general guideline for the disaster management mechanism in Sri Lanka and it has not specifically mentioned the roles and responsibilities of the stakeholder organisations (Sri Lanka Disaster Management Act, 2005). Besides, Steele, et al. (2007) revealed that the Act has not mentioned the provincial, district, divisional, local, and village level government agencies and their roles and responsibilities in managing disasters. Supporting, Amaratunga, et al. (2020) claimed that the role of these stakeholders is not defined clearly by any of the governing policies/frameworks. The DMC was endowed with the task of preparing the National Emergency Operational Plan (NEOP) as required by the Act and for easy reference, the NEOP was prepared as Volume I and Volume II. Nevertheless, NEOP does not address the Post Disaster recovery needs and "Build Back Better" approach in the implementation of early recovery plans yet initiating Post Disaster Need Assessment and restoration of essential services are addressed by NEOP.

3.3 POLICIES RELATED TO MARGINALISED COMMUNITIES IN THE GLOBAL CONTEXT

When reviewing the policies on marginalised communities in a global context, the majority of them are aligned with international disaster management policies. The GFDRR Gender Action Plan 2016-2021 retains a strong alignment with the Sendai Framework for Disaster Risk Reduction 2015–2030, the Paris Agreement, the 2030 Agenda for Sustainable Development, as well as the World Bank's Gender Strategy. Besides, the Disability Inclusion Action Plan 2018–2023 contributed to the World Bank's Ten Commitments on Disability Inclusive Development. Besides, this NEOP of Sri Lanka has made its best efforts to adhere to the SPHERE Minimum Standards in Disaster Relief & Response. The NEOP adheres to the SAARC agreement on emergency response, which was signed by all SAARC countries to support each other during major emergency situations through lateral agreements entered into by the government with countries in the Asian Region.

3.4 POLICIES RELATED TO MARGINALISED COMMUNITIES IN THE SRI LANKAN CONTEXT

Table 1 illustrates the policies targeting women outnumber those affecting other marginalised communities. The only guidelines discovered that are particularly concerned with post-disaster situations are Older People in Disasters and Humanitarian Crises: Guidelines for Best Practice and Guidelines for Gender Sensitive Disaster Management. The requirements of women are underlined throughout the post-disaster setting in the Guidelines for Gender Sensitive Disaster Management. However, the National Policy on Disability for Sri Lanka and the National Elderly Health Policy Sri Lanka have not paid special attention to natural disaster situations.

3.5 DISCUSSION

Table 2 summarises the explicit linkage between post-disaster management and marginalisation based on all policies discovered during the desk study.

Table 2: The explicit linkages between disaster and marginalisation based on policy review

Category	Policy Concern		Global	National	Link to Post-disaster Management	Link to Marginalisation
01	Disaster Management & Marginalisation	Women	P1, P2		✓	✓
		Older Adults	P3		✓	✓
02	Marginalised communities	Women	P4, P6	P5, P7, P8	✓	
		Children	P11	P9, P10	✓	
		People with disabilities	P12, P13	P14, P15	✓	
				P16	✗	
		Older Adults		P17	✗	
			P18		✗	
03	Disaster Management		P19, P20, P22, P24, P30	P21, P25, P27, P28		✓
				P23, P26, P29		✗
04	General		P31, P32, P33	P34, P35	✓	✓

In the above-summarised interpretation of the desk study (Table 2), it can be realised that some of the marginalised community-related internationally established (P18) and nationally established (P16 and P17) policies have not been considered in managing disaster situations. Besides, some national policies related to disaster management (P23, P26, and P29) have not considered the inclusion of marginalised communities in their policies. It is further revealed through the desk study that both global and local policies have not paid much attention to the intersectionalities in the post-disaster context.

It was revealed through the desk study that the policies related to disaster management and marginalised communities in Sri Lanka need updating, with a special concern for post-disaster circumstances. According to Amaratunga, et al. (2020), the National Policy on Disaster Management, the National Disaster Management Plan, the NEOP, and the Sri Lanka Comprehensive Disaster Management Programme are mainly based on the Hyogo Framework for Action, which was developed with targeting only for 2005 to 2015. Therefore, these documents need to adopt the vision of the Sendai Framework, the Paris Agreement, and the Sustainable Development Goals. Besides, the effective policies utilised in the global context can be referred to as a good practice transfer in the Sri Lankan context in order to improve the inclusivity of marginalised communities in the post-disaster context.

4. CONCLUSIONS AND WAY FORWARD

The study has gathered a deep understanding of the explicit connections between the policies related to post-disaster management and marginalised communities. It has become abundantly evident that disasters have a disproportionate impact on affected communities, with the most marginalised often suffering the brunt of the consequences. As a result, it is vital to explicitly consider these marginalised communities in policy formulation in order to manage post-disaster situations effectively. Given the foregoing realities, policy refinement in order to improve the inclusivity of marginalised communities in the post-disaster context in Sri Lanka is crucial. Furthermore, while there are policies that address marginalised communities to some extent in the disaster management context in Sri Lanka, it is clear that there are gaps in policy implementation since there is an exclusion of marginalised people in post-disaster situations currently in Sri Lanka. As a result, it is critical to investigate the degree of execution of those policies. As a way forward, the level of implementation and barriers to implementing the policies and frameworks related to disaster management and marginalised communities will be thoroughly assessed using primary data collection.

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QUANTITY SURVEYORS WORKING FROM HOME DURING COVID-19 PANDEMIC: DOES PLACE MATTER?

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ABSTRACT

COVID-19 pandemic affected people in many ways. To prevent the spread of the virus, governments-imposed travel restrictions. This became the main reason for many sectors to adopt work from home (WFH) concept. Although WFH grew prominently with the COVID-19 pandemic, it was already practiced in several sectors even before the pandemic. However, there was lack of evidence regarding the quantity surveyor's practice in WFH. This research therefore attempts to investigate how the quantity surveyors WFH during COVID-19 pandemic and factors that affected the successful functioning of their job. To achieve the aim, a mixed method research approach was undertaken. Initially, a comprehensive literature review was carried out and an interview guideline was developed as the data collection instrument. Subsequently, 30 semi-structured interviews were conducted to collect data. Collected qualitative data was analysed through code-based content analysis using NVivo 10 and quantitative data was analysed by using descriptive statistical analysis. Results shows that nature of job role, personal qualities, technology, organization related factors, gender, home-work interface, and economic condition of the country affects the QS's function during WFH. Further, age, location of home, weather condition, job experience and performance of other employees were identified as factors that have a potential to affect QSs during WFH. This research findings can be used to implement WFH concept effectively to optimise quantity surveyor performance in the construction industry by controlling each factor that affects when QSs WFH.

Keywords: *COVID-19; Quantity Surveyors; Sri Lanka; Work from Home (WFH).*

1. INTRODUCTION

If work can be done properly, does place matter? Louis and Kumar (2020, p.2944) stated that *"it's no longer necessary to be in an office full-time to be a productive member of the team"*. During the COVID-19 pandemic, Work from Home (WFH) became one of the most widely used phrases in the word due to the self-isolation policy, which was adhered by many countries to restrict the spread of the virus (Cetrulo, et al., 2020). Although this concept is widely known as WFH in the present, several terms have been used in the past literature interchangeably to identify the WFH concept such as home-based work, remote work, telework and off-site work, ultimately making it difficult to state a generally

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accepted definition for WFH concept (Baker, et al., 2007; Baruch, 2001). This level of contrast in terminology arises due to the breadth and complexity of the concept (Sullivan, 2003). According to Savić, (2020), WFH concept consists of four characteristics; (a) a direct employee of an organization, (b) undertaking a task related to aforementioned organization, (c) work being executed away from the company premises, and (d) employer and employee connected via a telecommunication network.

Kale (2020) believes that office-based roles in construction industry can be performed from home, and it was evident during the COVID-19 pandemic period. However, in certain situations, it is essential for construction professionals to be physically present at site (de Wet, 2009). Adding to that, Bsisu (2020) concluded that design civil engineers are able WFH, whereas site civil engineers will not be able to WFH highlighting that not every professional in construction industry is able to WFH.

Quantity Surveying Profession is one of the key disciplines in the construction industry. Ashworth et al., (2013) briefly described the traditional role of Quantity Surveying (QS) as formulation of the measure and value system. They further emphasized that estimation of initial cost of the project, preparation of bills of quantities, taking measurements for progress reports and final reports, tender documentation, and cost planning as few other key roles of the QS. Moreover, quantity surveyors are required to adopt to the changing nature of their profession, especially as a result of the changes in Information Technology (IT) to improve the efficiency of their work (Kulasekara, et al, 2013). It cannot be stated with a considerable certainty the applicability of WFH concept to the QS profession as well as what factors affect the QS during WFH. Hence, there is a lack of studies on how the QSs perform their duties through WFH during the pandemic period. Therefore, this paper intends to investigate how QSs WFH during COVID-19 pandemic. This paper further focusses on the factors affecting QS's WFH practice during the COVID-19 pandemic. This paper starts with a literature review on WFH concept and Section 3 presents the research methodology. Section 4 presents the research findings and discussion followed by conclusions and recommendations.

2. LITERATURE REVIEW

This section reviews the WFH concept during COVID pandemic period, factors affecting WFH, WFH in construction industry and factors affecting WFH.

2.1 WFH CONCEPT DURING COVID PANDEMIC

WFH concept is first promoted in 1980's by IT companies such as Yahoo, and after three decades, employees were facilitated to maintain connection with their colleagues through the introduction of affordable devices (such as smart phones and tablet devices), Internet and World Wide Web (Messenger and Gschwind, 2016). With the COVID-19 pandemic, some industries only had two options: either stop production or take health risk and continue production. However, other industries use WFH as their third option (Bartik, et al., 2020). Various technical platforms were developed to enhance the efficiency and effectiveness of homeworkers (Jain, 2021). COVID-19 replace the traditional work practice due to the digital transformation (Savić, 2020). Mobile applications such as "Zoom" and "Video conferencing cloud" enable functions such as online meetings, training, webinars, and conference rooms (Bhavya, 2020). Now people WFH on a full-time basis whereas before the pandemic WFH on a full-time basis was considerably low (Alipour, et al., 2020).

2.2 WFH IN CONSTRUCTION INDUSTRY

WFH is relatively new phenomenon to the global construction industry and specially to the Sri Lankan construction industry which became prominent after the COVID-19 outbreak. Ogunnusi, et al. (2020) emphasized that the construction industry must adopt more technological tools to integrate virtual environment which will increase the flexibility of work. Kale (2020) and de Wet (2009) believes that some office-based roles in construction industry can be done from home but some professionals such as site engineers are necessary to be physically present at site. According to construction industry online survey study conducted using data from 143 respondent who were either pre-construction managers or project managers, suggested that pre-construction functions could be allowed to be continued through WFH after pandemic (Overturf, 2021).

2.3 FACTORS AFFECTING WFH

A number of studies have addressed the issue on 'who can WFH?' considering several factors, since it became a major concern with the implementation of WFH policy during COVID-19 (Delaporte and Peña, 2020). Factors affecting WFH can be identified as nature of job, personal qualities, technology, organisation, gender, economic condition of the country and home/work interface as discussed further.

2.3.1 Nature of Job

All jobs cannot be performed from home. According to Steinle (1988 as cited in Baruch, 2000), two third of jobs can be done from home. Occupations which require specialised field knowledge, managerial and executive jobs have a higher ability to WFH (Cetrulo et al., 2020).

Moreover, studies show that there are links between occupation level, wage and ability to WFH (Bailey and Kurland, 2002; Delaporte and Peña, 2020; Dingel and Neiman, 2020; Saltiel, 2020). Adding to that, Alipour et al. (2020) found that jobs which use computers frequently and are associated with "developing, researching, constructing" are more suitable to WFH by a study done through a survey sample of 17,160 employees.

Although the role of a QS is originally defined as the role of building quantification and preparation of bills of quantities, it evolved into a profession which undertakes various other roles such as facilities management, cost advising (Owusu-Manu et al., 2014). Willis and Ashworth (1987) discuss two types of QS roles, namely traditional and non-traditional (as cited in Yogeshwaran et al., 2018). QSs major job roles include preparation of bills of quantities, cost planning/estimating, cost controlling, contract administration, subcontract administration, preparation of final accounts, prepare financial feasibility studies, life cycle costing, value engineering, claims management, risk management, alternative dispute resolution (adjudication, mediation, arbitration) and providing expert witness services to name a few (Smith, 2004; Kulasekara et al., 2013; Jaafar et al., 2016; Chandramohan et al., 2020; Ilmi et al., 2021; Ashworth et al., 2013).

2.3.2 Personal Qualities

Person himself is a factor which determine the suitability of adopting WFH concept. This depends on the personality, skill level and similar qualities of a person (Baruch, 2000). Nicholas Bloom answered a question raised by Harvard Business Review regarding whether there is anyone who should not WFH by saying "Absolutely, not everybody wants to or is disciplined enough to WFH" (Berinato, 2014, para 11) emphasizing that not every person is suitable for WFH.

2.3.3 Technology

Homeworkers depend on personal IT tools to execute their respective work (Savić, 2020). Siha and Monroe (2006) described IT as the backbone of WFH concept while Louis and Kumar (2020) identified technology as a strong factor which allows more WFH benefits to the organizations and employees. Moreover, they emphasize that many workers are able WFH due to technological tools such as email, video conferencing, screen sharing, file sharing and Virtual Private Network (VPN). Wide use of technology is seen during COVID-19 pandemic when people WFH (Chadee et al., 2021).

2.3.4 Organization

In theory, workers prioritise their work responsibilities, if they are loyal and value the organization (van der Lippe and Lippényi, 2020). Karanikas and Cauchi (2020) argued that outcome of WFH depends on the working arrangement between the employee and the organization. Characteristics such as supportiveness of organization towards the WFH concept, trust towards the teleworkers, and the management styles have impacts on WFH concept (Baruch, 2001). Savić (2020) states that, managers might need to implement different management styles to ensure the productivity of employees when WFH. Moreover, Ozcelik (2010) identified the size and the structure of the company as another vital factors. According to the author, an organization that is flexible, non-hierarchical, and technologically savvy is more likely to adopt a teleworking program successfully than one that is highly organized, and command driven.

2.3.5 Gender

WFH arrangements will differ according to the gender (Huws et al., 1997). When WFH, gender affects the job satisfaction and work-family conflicts differently (Crosbie and Moore, 2004). Although WFH gives opportunity for women to take care of family (Bailey and Kurland, 2002), van der Lippe and Lippényi (2020) state that women are subjected to more work family conflicts than men when WFH. Moreover, Collins et al. (2021) argue that women are not suitable for WFH, since household work reduce the working hours.

2.3.6 Economic Condition of the Country

Dingel and Neiman (2020), argued that economic condition of a country has a positive relationship with the share of jobs that can be done from home. Adding to that, Delaporte and Peña, (2020) stated that the level of development of the country has an impact on the ability to WFH.

2.3.7 Home-Work Interface

Kreiner et al. (2009) defines home/work interface as a "socially constructed boundary between the life domains: work and home" (p.705). Factors ranging from quality of family to the availability of physical space are covered under home/work interface (Baruch, 2001). Some considered that the availability of dedicated workspace as essential (Louis and Kumar, 2020), while some considered that it is not essential but a choice (Crosbie and Moore, 2004). However, availability of suitable working environment and having access to the infrastructures to WFH will highly affect when making the decision to WFH (Laumer and Maier, 2021).

Having identified the above factors from literature, this research investigates how those factors will affect when QSs WFH.

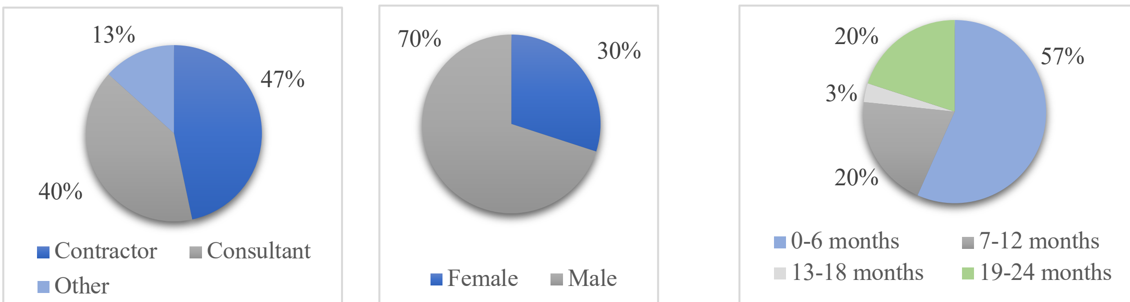
3. RESEARCH METHODOLOGY

The nature of this research problem, which is to investigate the factors affecting when quantity surveyor's WFH during COVID-19 pandemic, requires an in-depth investigation. Further, opinions of respondents concerning each factor needed to be collected. This research followed a mixed method approach, since it provides informative, complete, balanced, and useful research results (Johnson et al., 2007).

The research was initiated with a comprehensive literature review on WFH concept during COVID pandemic period, WFH in construction industry and factors affecting WFH. The literature review findings were used to develop a semi-structured interview guideline that consists with both qualitative and quantitative questions. Likert scale was added into the interview guideline to rank and compare certain data. Developed interview guideline was used to conduced semi-structured interviews with 30 QSs to investigate how the aforementioned factors affected the QS practice when they WFH. The collected qualitative data were analysed through code-based content analysis using NVivo 10, whereas quantitative data were analysed by using descriptive statistical analysis.

4. RESEARCH FINDINGS AND DISCUSSION

The semi-structured interviews were conducted with 30 quantity surveyors working in Sri Lankan construction industry and the sample profile is shown in Figure 1.



(a) Organisation Type *(b) Gender* *(c) WFH Experience during COVID*

Figure 1: Profile of the respondents

The research findings under the 7 factors are discussed below.

4.1 FACTORS AFFECTED QSS PRACTICE WHEN THEY WFH

Both quantitative and qualitative data derived after the data collection are analysed and the research findings under 7 factors are discussed below. The 7 factors are nature of job, personal qualities, technology, organisation, gender, economic condition of the country and home/work interface. Finally, a discussion on findings is presented.

4.1.1 Nature of QSs Job

The first question to the respondents were 'what QS job functions can be executed by a quantity surveyor through WFH?'. The respondents were requested to rate the extent to which they can perform the identified roles using a Likert scale from 0 to 4 (0 - Cannot perform; 4 - Can very easily perform) and provide reason for their rating. The results are presented in Table 1.

Table 1: Job functions that can be played by quantity surveyors through WFH

Job role	Mean	Frequently given reason for respondent's rate
QS job functions that can be performed very easily		
Cost-benefit analysis	3.33	Depends on availability and accessibility of information
Cost modelling	3.33	Depends on availability and accessibility of information
Cost planning/Estimating	3.28	Depends on availability and accessibility of information
BIM coordination	3.26	Use virtual platform
Preparation of BOQs	3.23	Can perform using documents
QS job functions that can be performed easily		
Life cycle costing	3.03	Depends on availability and accessibility of information
Financial feasibility studies	2.82	Depends on availability and accessibility of information
Value Engineering	2.79	Depends on availability and accessibility of information
Expert witness	2.72	Can use virtual platforms
Contract Administration	2.60	Require site visits and in-person meetings
Cost controlling	2.52	Require site visits
Claims management	2.43	Depends on availability and accessibility of information
Risk management	2.41	Require site visits
QS job functions that can be performed, but somewhat difficult		
ADR - Adjudication	2.38	Can use virtual platforms
ADR - Mediation	2.34	Can use virtual platforms
ADR - Arbitration	2.34	Can use virtual platforms
Preparation of final accounts	1.90	Require site visits
Subcontract administration	1.66	Depends on sub-contractor's knowledge

According to the findings, ability to perform most QS's functions depend on factors such as the availability and accessibility to information and site visit requirements. Further, respondents emphasized that some job roles can be performed through virtual platforms.

4.1.2 Personal Qualities Required for a QS to WFH

A 1 to 5 Likert scale was given to the respondents to mark their opinion on up to what extent the personal qualities identified through the review are needed for QSs to perform WFH successfully. Response for the personal qualities were prioritised using RII analysis and presented in Table 2.

Table 2: Personal qualities required for a QS to WFH

Personal qualities	RII value	Rank
Self-discipline	0.967	1
Loyal and honest	0.933	2
Self-motivation	0.907	3
Communication skills	0.887	4
Flexibility	0.876	5
Self-confident	0.873	6
Ability to work on own (with little supervision)	0.873	7
Time-management skills	0.873	8
Organized Person	0.869	9
Tenacity	0.867	10
Initiative	0.787	11

According to the above findings, 'self-discipline' is identified as the most significant personal quality, which is required to perform WFH, whereas 'initiative' is identified as the least significant personal quality to WFH. One respondent further stated that the "lack of above-mentioned personal qualities will affect the deliverables because we are doing task-based work". Another respondent added that "the lack of above-mentioned qualities cause inefficiencies, delays, and productivity losses". Several respondents emphasised the importance of effective communication to minimise communication gap when WFH.

4.1.3 Information and Communication Technologies Required to Perform QSs Functions during WFH

Under the information and communication technologies (ICT) used by QSs during the pandemic, a comparison is done to identify whether there is a significant difference in the use of communication software when work from office and WFH and the findings are shown in Figure 2.

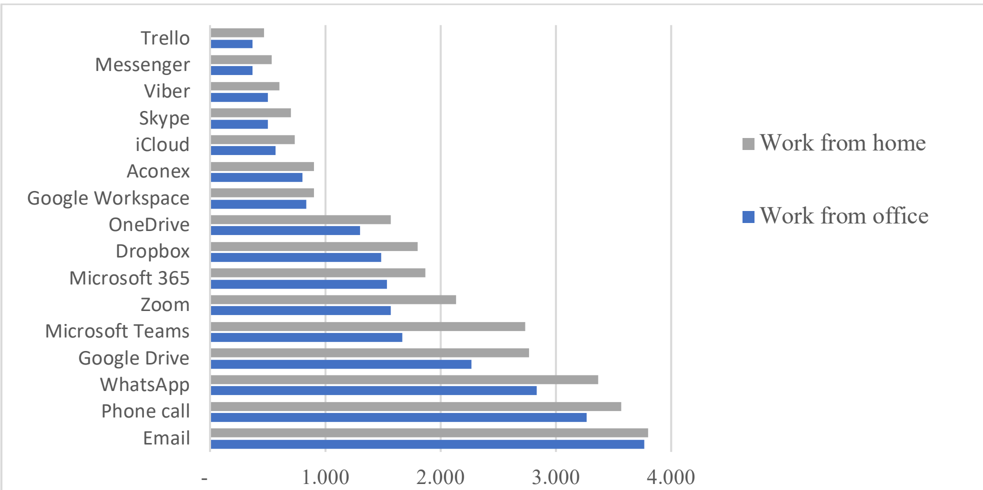


Figure 2: Comparison of technology usage in WFH and work from office

According to the comparison, it is evident that there is an increase of software usage for communication when WFH. Most significant growth can be seen in the usage of

WhatsApp, Google Drive, Zoom and Microsoft Teams software. However, still the most common method of communication for QS is Emails.

The study further extended to identify to what extent the QSs use software to deliver their work during WFH. Research findings are given in Table 3.

Table 3: Usage of QS function related software during WFH

Software	RII value	Rank
MS Excel	0.93	1
MS Word	0.86	2
AutoCAD	0.78	3
PowerPoint	0.44	4
MS Project	0.42	5
CostX	0.26	6
PlansSwift	0.26	7
Bluebeam	0.26	8
Revit Architecture	0.22	9
Primavera	0.21	10
Cubicost	0.15	11

According to the table 3, the mostly used software to deliver QS based work is MS excel, and secondly MS word. Least used software is Cubicost. According to Fanous (2012), QSs rely on simple software such as MS excel, MS word and AutoCAD, and the same is confirmed by these findings.

4.1.4 Organizational Support and Related Factors

Respondents were then requested to provide their opinion on the organization related factors and their impact on QSs WFH. For the question about their opinion on the organizational support for WFH, stated that *"company provided guidance and resources heavily affect the WFH performance"* highlighting that guidance and resources should be provided to employees when they WFH. R14 emphasized that not only physical resources and facilities but organizations should also support employees by giving *"moral and psychological support towards the mental wellbeing of the employees when WFH"*. On the contrary, PR2 highlighted that attitude of the person will affects to the performance despite the level of support by the organization. PR2 elaborated this by stating, "*Sometimes people think it is granted and does not try to perform if organization is unable to provide certain facilities*".

Interviewees were further questioned about their opinion on the organizations' trust toward the employees as a factor that influence WFH. All respondents agree that organizations' trust toward employee is essential to WFH. *"If the employer does not trust employees, then employees are not motivated"* stated R18. Further, R11 highlighted that organizational trust has an impact on the performance and stated that, "*company will not let employees to bring office laptops to home if they do not trust employees"*. Additionally, R15 shared his experience stating, "*since there was no trust, the employer implemented a heavy monitoring system"*. However, R8 argued that *"if the organisation received the expected output, they do not need to monitor"*. Moreover, respondents highlighted that distrust leads to increment of the workload. *"If organization does not trust employees, they will be given more work",* stated R4. However, R6 stated that "*most of the time organization does not trust us. That's why many organizations are trying to bring workers back to the office"*, emphasizing that most organizations do not trust employees who WFH. Moreover, most of the respondents agreed that competent management is required for better performance when WFH. R13 stated, *"You cannot manage WFH in the same way that you manage physically in the office. You have to follow different strategies to get the work done"*.

4.1.5 Gender and Marital Status

Respondents stated that gender itself has no impact on the WFH performance except in several extreme conditions. On the contrary, marital status and having children have an effect on QSs WFH. "*If married, there could be traditional house chores, negatively affect female QS performance*" stated R15. R4 shared her experience stating, *"When there is a need for my baby, it is me who take care. Not my husband. So, gender affects specially in Sri Lankan culture"*. Further, "*In my office, female employees with children complains that it is hard to WFH. In COVID situation, servants have stopped coming to work and they had to do both office and housework"* said R6. However, R2 emphasized that this issue is not limited to the female employees, "*It may affect to married men with children as well. Because children may disturb the work or meetings*". In contrast, R12 stated that the aforementioned issues depend on the personal qualities and self-discipline.

4.1.6 Economic Condition of the Country

It is evident that economic condition of the county affects the availability of facilities to WFH. "*Our electricity system is not well developed. In that case there are frequent power failures. Moreover, a developed country has unlimited internet but here we don't have that facility. Available internet packages are very expensive"* stated R4 emphasizing frequent power failures and expensive internet connection as factors that impact negatively to QSs WFH performance in Sri Lanka. Further, respondents stated that due to economic downturn, there are less construction projects. *"Sometimes, due to this pandemic situation, projects are less. There is salary reduction. Sometimes we may not get our bonus, allowances, etc. This affects more when WFH*" commented R9. Both R4 and R9 accept that the economic condition of the country as a factor that affects to QSs WFH practice. On the contrary, *"If there is no salary deduction, then I don't think there is an impact"*, R8 highlighted emphasizing economic condition of the country is not a factor that affects QSs WFH.

4.1.7 Home-Work Interface

Interviewees were questioned on how the identified home-work interface related factors will affect to the quantity surveyors' practice when they WFH. They were specifically questioned regarding the impact of quality of family on WFH. According to the respondents, understanding of the family is very important in WFH. *"Family needs to understand that we are not on a holiday, we are working. So, they should not interfere with work"* remarked R3. Further, respondents emphasized a peaceful family is required for the success of WFH concept. Moreover, respondents emphasized not only understanding but also support from the family is required for the success of WFH concept. Further, few respondents highlighted that increased performance due to the job satisfaction as an added advantage because they can spend quality time with their family. Subsequently, the respondents were questioned whether the availability of dedicated workspace has an impact on the QS's performance. Most respondents believed that availability of a dedicated workspace is required. They emphasized that it would help to reduce interruptions, help to create an office environment at home as well as it helps to organized documents. However, some respondents stated that it is not mandatory as some may find it hard to arrange workspace in home environment. Further, according to respondents, having access to infrastructure such as electricity and internet connection is of utmost importance for the performance of a QSs WFH. However, according to PR2, *"In Sri Lanka, WFH is difficult because some locations does not have the necessary infrastructure*". However, R12 stated that not only the access to infrastructure is required but also should have self-discipline.

4.1.8 Other Factors when QSs WFH

Respondents were asked for their opinion on any other factors that affect the WFH performance. According to the respondents, location of the home affects the WFH concept. Respondents stated that if they are living in a congested area or in a noisy neighbourhood, it will be hard to WFH. Further, respondents stated that age as a factor that affects WFH and highlighted *"Less technological familiarity and resistance towards change when getting older (R15)*". However, respondents like R12 emphasized that the benefit of WFH is to the elderly employees saying "*when you are old it is better to WFH. Because you don't have to travel*". Moreover, respondents (R1 and R22) highlighted that performance of other professionals will affect the WFH performance of a QS since it is a teamwork. Moreover, respondents identified weather condition, job experience, the attitude of the society toward the WFH employee, size or complexity of the construction project, economic condition of the employee, health condition and culture as some other factors that affect the WFH performance.

4.2 DISCUSSION

According to the results, nature of QSs job, personal qualities required for a QS to WFH, ICT requirements to perform QSs functions in WFH, organisational support, gender and marital status, economic condition of the country and home/work interface factors had major impacts on QS performance when WFH. Results shows that all the factors that were identified from the literature affected QSs when WFH. Further, the research has identified QS job roles that can be performed from home. Cost-benefit analysis, cost modelling, cost planning and estimating, BIM coordination and preparation of BOQs are identified as functions that can be done easily. However, ability to perform most of the QSs functions depend on factors such as the availability and accessibility to information and site visits requirements. Self-discipline is identified as the most essential personal quality for QS's to WFH. Being loyal and honest ranked second and being self-motivated ranked third. According to the respondents, lack of above-mentioned qualities cause inefficiencies, delays, and productivity losses.

According to the research findings, increase in technology usage in QS practice can be seen with WFH. Though, technologies used in WFH has not much difference from the general QS practice. Hence, it can be said that existing technology is sufficient for QS's to WFH. However, frequent power failures, signal issues caused inefficiencies when QS WFH. According to the respondents, this is due to the economic condition of the country.

Further respondents believe that organizations must play a key role when QSs WFH. Accordingly, organization support is required for QS in WFH. "*Every employee might* *not have the required facilities to WFH. Organization should provide those*" stated R23. Moreover, respondents highlighted that organization's trust toward the employees is required to WFH. "*Need trust as you are let to work alone"* said by respondent. Further, respondents emphasized requirement of competent management stating "*several problems emerged when we shift to the WFH. Organization should be able to manage that. If they are unable to manage, staff will suffer"*.

Respondents highlighted that gender has no impact on QSs WFH. However, due to the marital status, presence of children and culture can be considered as factors that affect to the WFH. "*If married, there could be traditional house chores effecting negatively on female QSs*" stated R15. Respondents agreed on that home-work interface related factors such as quality of family, availability of dedicated workspace and having access to the infrastructure affects QS's WFH. "*If there is lot of problems at home, employee might not prefer to WFH*" commented by R11. Other than the aforementioned factors respondents commented location of the home, age and performance of other professionals affects QS's function when they WFH.

5. CONCLUSIONS AND RECOMMENDATIONS

WFH became a well-known phrase in the world with the lockdowns implemented by governments to restrict the spread of COVID-19 virus. With the lockdowns, various industries adopted WFH concept and construction industry has no exception. Quantity surveying is one such profession that adopt WFH concept during pandemic period. Hence, this research aimed to investigate the factors affecting quantity surveyors WFH performance during COVID-19 pandemic.

The research identified nature of QS job, personal qualities of a QS, ICT facilities available, organisational support, gender and marital status, economic condition of the country and home/work interface as the factors mainly affect quantity surveyors WFH performance. Moreover, there was an increase in usage of ICT such as Zoom and MS Teams to communicate during WFH. The findings further revealed that QSs mostly conduct their work using MS Excel, MS Word, AutoCAD. These were used prior to COVID-19 as well. Hence, there are no significant difference in the software used to conduct QS functions. Respondents stated that gender itself has no impact on the WFH performance, but under various extreme conditions, gender may affect the performance of a QS. The research reveals that home-work interface related factors such as quality of family, availability of dedicated workspace, accessibility to infrastructure, organization support, organization's trust toward employees and competent management, have an impact on the QSs WFH. The study further identified few factors that affect WFH concept due to the social and cultural aspect of Sri Lanka. The construction industry practitioners can use this research findings to develop strategies to optimise the QS performance when WFH.

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REUSING AND REPURPOSING OF GLASS WASTE: A LITERATURE REVIEW

Tushar Sood[1] and Argaw Gurmu[2]

ABSTRACT

An increase in demolition activities has led to the generation of large amounts of glass waste. Due to its non-biodegradable nature, glass can stay in landfills for longer periods without decomposition; thus, it occupies a large volume of landfills. This study aimed to analyze the potential reuses and repurposing of glass waste in the construction industry. A systematic review of the literature was conducted, and secondary data were extracted. The data were analyzed qualitatively to achieve the objective of the study. The generation of glass waste in four different parts of the world, namely: Hong Kong, Australia, Europe and the USA has been studied to get an estimate for the increase in glass waste trends. The generation of glass waste saw a downfall from 2006 to 2010, was then steady from 2011 to 2016 and then slightly rose. A high volume of glass waste in landfills and its non-biodegradable nature has made it essential for the discovery of new methods of reuse and recycling of glass waste. Some of the potential reuse and repurposing options include Aggregate for Concrete, Filtration Media, Glass Fibres, Blast Abrasive, Roof Coating, Ceramic Based Products, Burnt Bricks, Low-Temperature Stoneware Tiles, Insulation, and Decorative Materials. The paper provides useful information to various stakeholders in the construction industry to understand how and where glass waste can be reused.

Keywords: *Construction Industry; Glass Waste; Repurposing; Reusing.*

1. INTRODUCTION

According to Ofori (2000), sustainable construction can be defined as the creation of construction items via efficient resources and best practices with clean techniques from the extraction of raw materials to the demolition and disposal of its components. Sustainable construction also aims at producing competitive as well as profitable industry-built assets, enhancing the quality of life, offering customer satisfaction, achieving higher growth, maximizing the efficient use of resources, reducing pollution, and providing support to both social and natural environments. According to Lu and Lai (2020), global carbon emissions saw a rise from 24.69 billion tons in 2000 to 36.14 billion tons in 2014. International Energy Agency (2020) stated that the building and building construction sectors are responsible for over one-third of global energy consumption and nearly 40% of the total direct and indirect CO_2 emissions.

As with so many materials in the construction industry, a series of technological breakthroughs in the glass industry has led to its extensive use in construction. Furthermore, its translucent ability made it a more versatile and popular material in the

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building industry. The uses of the material extended from doors, windows, skylights, and display shelves to glazing panels, greenhouses as well as crystal palaces making it an integral part of the architecture of the building industry. A wide variety of users suggests a large-scale use of the material and hence the problem of managing the waste generated due to its huge consumption. Kazmi (2017) highlighted that recycling the old waste products shall reduce the demand for new raw materials by reducing the costs of energy and transportation. Due to the non-biodegradable nature of glass, it occupies a larger share of landfill spaces. Recycling glass further helps in reducing these stresses on the land as well as reducing carbon footprint.

According to the national waste report published in 2018 (Pickin, et al., 2021), about 1.1 million tonnes of glass waste was generated in 2016-17 in Australia. The report further confirms the recycling rate of glass waste remains between 54% to 61%. And yet the alternative glass recycling markets such as using glass as aggregate in concrete, foam panels and others are still underdeveloped. A few studies have been conducted to comprehensively explore the potential areas for reusing and recycling glass waste. This research is thus conducted to fill that gap and find out how recycling glass waste can benefit such markets. Therefore, the objective of the study is to identify potential reusing and repurposing options for glass waste in the construction industry. In this research, repurposing can be defined as the use of a material for a use other than for its initial requirement (Rose, 2019).

2. RESEARCH METHODOLOGY

This research was conducted by adopting the qualitative analysis of data through a Systematic Literature Review (SLR). The steps followed in collecting and analysing data are shown in Figure 1.

2.1 DATA COLLECTION

With researchers collecting and storing data all over the world, the present age makes it more viable to analyze secondary data to draw more accurate results with limited resources and time (Andrews et al., 2012). Moreover, due to academic limitations, the process of collection of primary data becomes quite complex and time-consuming. The main advantage of using secondary data lies in the convenience and cost-effectiveness it provides since it allows access to high-quality data (Smith et al., 2011). To gather relevant data, an online search was conducted and relevant journal articles, government reports and conference proceedings were collected using databases such as the library of Deakin University and Google Scholar. The databases also provided access to esteemed databases such as the American Society of Civil Engineering, Emerald Insight, Science Direct, Semantic Scholar, Academia, Taylor and Francis and Elsevier. The first searches for the research included keywords such as “glass waste analysis”, “generation of glass waste”, “recycling glass waste”, “reusing glass waste”, and “repurposing glass waste”.

This was then followed by more comprehensive research in the same areas to gather specific knowledge. The timeframe selected for this research was 20 years (i.e. 2001-2021). The first step to comprehensive research involved the generation of a selection criterion which helped in the selection of the most relevant articles for the research study. The criteria consisted of comparability of the title, keywords and abstracts. After conducting SLR, data pertaining to glass waste generation, reusing options, repurposing the glass waste and the amount of waste generated by different industries were collected. The data also included information regarding study type and title, journal, author as well as methodology.

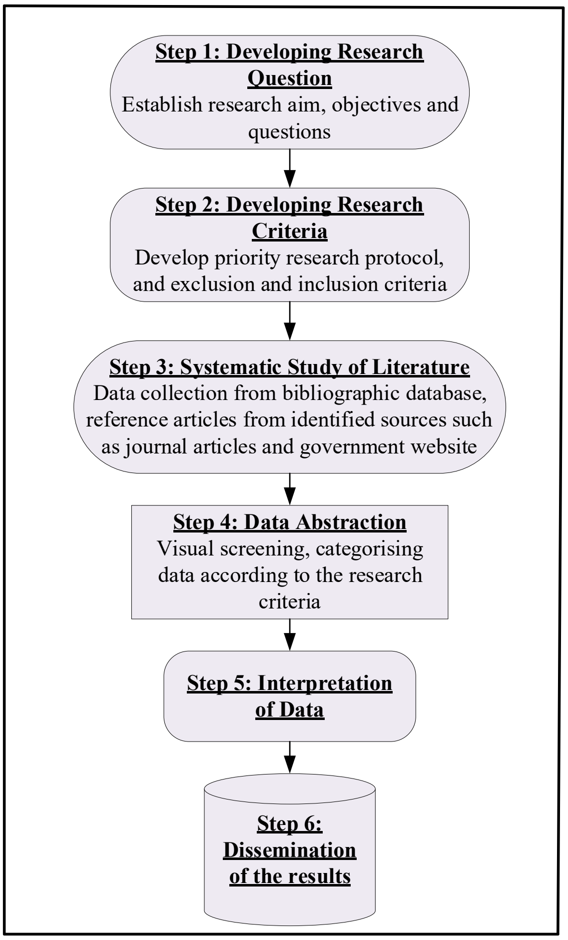

Figure 1: Overview of research methodology adapted from Schweizer and Nair (2017)

2.2 DATA ANALYSIS

Due to the methodological rigor of SLR, it is found to be one of the famous methods for synthesizing data. The two common ways in SLR to synthesize data involve narrative synthesis and meta-analysis (Seidler, 2020). Meta-analysis can be described as the use of statistical techniques to summarize and combine the results of various studies which may be contained within a systematic review. The method aims at providing more precise estimates than those derived from individual studies (Moher, et al., 2015). On the other hand, since the research does not study the statistics of the previous research, narrative synthesis was chosen as the best method for analyzing the data. Narrative synthesis is a form of storytelling, where we are a part of a storytelling culture describing in a convincing manner what needs to be done or stopped and why it is so. It also helps in understanding the impacts of various long-established policies or practices by researching the gaps so that the policies and practices can be bridged. The method involves the synthesis of findings from multiple studies to explain and summarize the findings via text and words. Furthermore, the method allows for focusing on a wide variety of questions and not only those relating to the effectiveness of a particular intervention (Van, et al., 2019).

3. FINDINGS

After applying visual scanning and applying selection criteria, 31 articles were selected for a comprehensive review to achieve the study's objective. Figure 2 presents the information regarding the various papers selected for SLR and the year in which they were published. As shown in the figure, most of the papers chosen for the study were published in the year 2020 followed by 2019. However, two of the sources have been published in the years 1974 and 1998 have also been taken into consideration due to the usefulness of the information they contain.

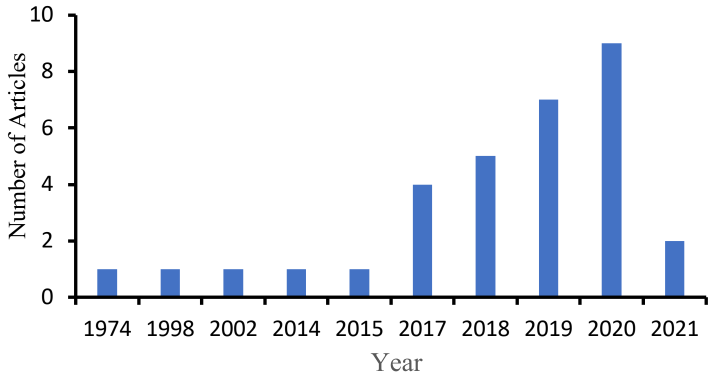

Figure 2: Breakdown of papers according to year

Table 1 depicts the information regarding the number of articles selected and the name of the journal from which they were selected to achieve the objective of the study. The highest number of articles were selected from the Journal of Cleaner Production followed by the Journal of Building Engineering.

Table 1: Sources of Secondary Data for Systematic Literature Review

Item	Name of Journal	No. of Articles
1	Journal of Materials in Civil Engineering	3
2	Journal of Cleaner Production	6
3	Journal of Building Engineering	4
4	Construction and Building Materials	2
5	Reference Module in Materials Science and Materials Engineering	1
6	Journal of environmental chemical engineering	1
7	Materials	1
8	Case Studies in Construction Materials	1
9	Environmental Science and Pollution Research	1
10	Materialia	1
11	SN Applied Sciences	1
12	Cement and Concrete Research	1
13	Journal of environmental management	2
14	Journal of Industrial Textiles	1
15	Composites	1
16	Composites Part A: Applied Science and Manufacturing	1

Item	Name of Journal	No. of Articles
17	Biomaterials	1
18	Ceramics International	1
19	Civil and Environmental Engineering	1
20	Journal of Non-Crystalline Solids	1
	Total	31

3.1 POTENTIAL REUSING AND REPURPOSING OPTIONS FOR GLASS WASTE IN CONSTRUCTION INDUSTRY

Glass waste has a lot of reusing potential which can be utilized as Aggregate for Concrete, Filtration Media, Glass Fibres, Blast Abrasive, Roof Coating, Ceramic Based Products, Burnt Bricks, Low-Temperature Stoneware Tiles, Insulation and Decorative Materials (Polley, et al., 1998; Jani and Hogland, 2014; Silva, et al., 2017; Gualtieri, et al., 2018; Al-Fakih, et al., 2019). This section shall present findings on how effective and practical these uses are and their potential for reusing in the construction industry.

The following functions will form the criteria against which different options for glass waste shall be analysed for the sake of this study. These criteria have been looked up in the various secondary sources to find evidence of the reusing potential.

1. Cost-Efficient - Allows for a reasonable cost for production (i.e. provides optimum results for least possible expenditure). The criteria have been chosen to make it more practical for the construction industry to become more sustainable.
2. Mass Production - It can be defined as the production of large quantities of standardized products using automation technology or assembly lines and facilitates the efficient production of a large number of similar products (Banton, 2021). This criterion has been chosen as it would lead to the reuse of large volumes of glass waste thereby moving it faster from the landfills.
3. Feasible Production - The criteria can be defined as the analysis of the production process to determine if it is technically feasible to manufacture to meet the customer requirements. It is not limited to necessary resources, estimated costs, required software, capacity, and skills including support functions (Mangla, 2021). The criterion is chosen to ensure that the production process is not overly complicated and can be easily adopted.
4. High-Quality Product - The criteria ensure that the glass waste has been reused to produce a product that is fit for the desired use or purpose, provides value for money as well as free from defects (Akrani, 2021).

The above functions have been chosen since they not only encourage utilizing large amounts of waste but also help the process become more practical. Table 2 presents information collected from papers regarding the presence of primary functions required for the reuse of glass waste. After going through 17 research papers, is quite evident that reusing options show great potential in terms of cost-efficiency, mass production, feasible production, and high-quality products.

The reusing option of glass as waste aggregates requires high energy and a long period of time to crush the glass waste. The glass waste may not be suitable for use as fine aggregate or part of the binder. The main reasons include the unsuitability of glass to participate in pozzolanic reaction, wide ranges of shapes and sizes, presence of high amounts of impurities and sharp edges (Khan, et al., 2020). Though using glass waste as aggregates can be a bit expensive but it offers a great resolution to move large volumes of glass waste from the landfills and thus helps in preserving the virgin material for future use. Due to the increase in durability compressive strength, freezing and thawing strength and permeability resistance (Kim, et al., 2018), the glass waste offers a high-quality product and thus makes it a popular choice of reuse in the cement industry thereby allowing for mass production. The process of production is not overly complicated and can be easily adapted and thus qualifies for feasible production.

Table 2: Functional requirements finding checklist

Reusing Option	Function 1 Cost efficient	Function 2 Mass production	Function 3 Feasible production	Function 4 High quality product	References
Aggregate for concrete	x	✔	✔	✔	(Kim, et al., 2018)
Filtration Media	✔	✔	✔	✔	(Jeong, et al., 2019
Glass Fibres	✔	✔	✔	✔	(Pegoretti, et al., 2002)
Ceramic Based Products	✔	x	✔	✔	(Gol, et al., 2021)
Burnt Bricks	✔	✔	✔	✔	(Saraswathy, et al., 2019)
Insulation	✔	✔	✔	✔	(Shafi et al., 2019)

The other reusing option which failed to satisfy one of the primary functions was ceramic-based products. This is mainly due to the poor shock resistance, weak in tension and may crack when hit with heavy items (TheKacasSite, 2021). This makes mass production of the reusing option a bit difficult as there is not much demand for the same. On the other hand, it offers a cost-efficient, high-quality product with a feasible production, giving it a very good potential in the construction industry. In Section 4, four alternatives (Filtration Media, Glass Fibres, Burnt Bricks and Insulation) and their reusing potential is discussed.

3.2 GLASS WASTE GENERATION TRENDS

The disposal of glass waste has become one of the major environmental concerns due to the increasing demand for natural resources and landfill space. In the early years of glass production, its uses were limited to beads, bowls and jars (Glass, 2021) but now it has found a plethora of uses. The increase in consumption has further led to an increase in the waste generation of the material. Upon studying the trends for glass waste generation, it was found the USA and Europe were producing a higher amount of glass waste than other countries (refer Figure 3).

According to Environmental Protection Agency (EPA) (2015), 10.37 million tonnes of glass waste was generated in the USA which consisted mainly of food and drinks containers. It was also understood that only about 27% of the glass was recovered for recycling and the rest was discarded in landfills. On the other hand, 1.5 million tonnes of glass waste was produced in Europe due to construction activities and about 15.9 million tonnes from glass packaging industries (Hestin, et al., 2016; Eurostat, 2021).

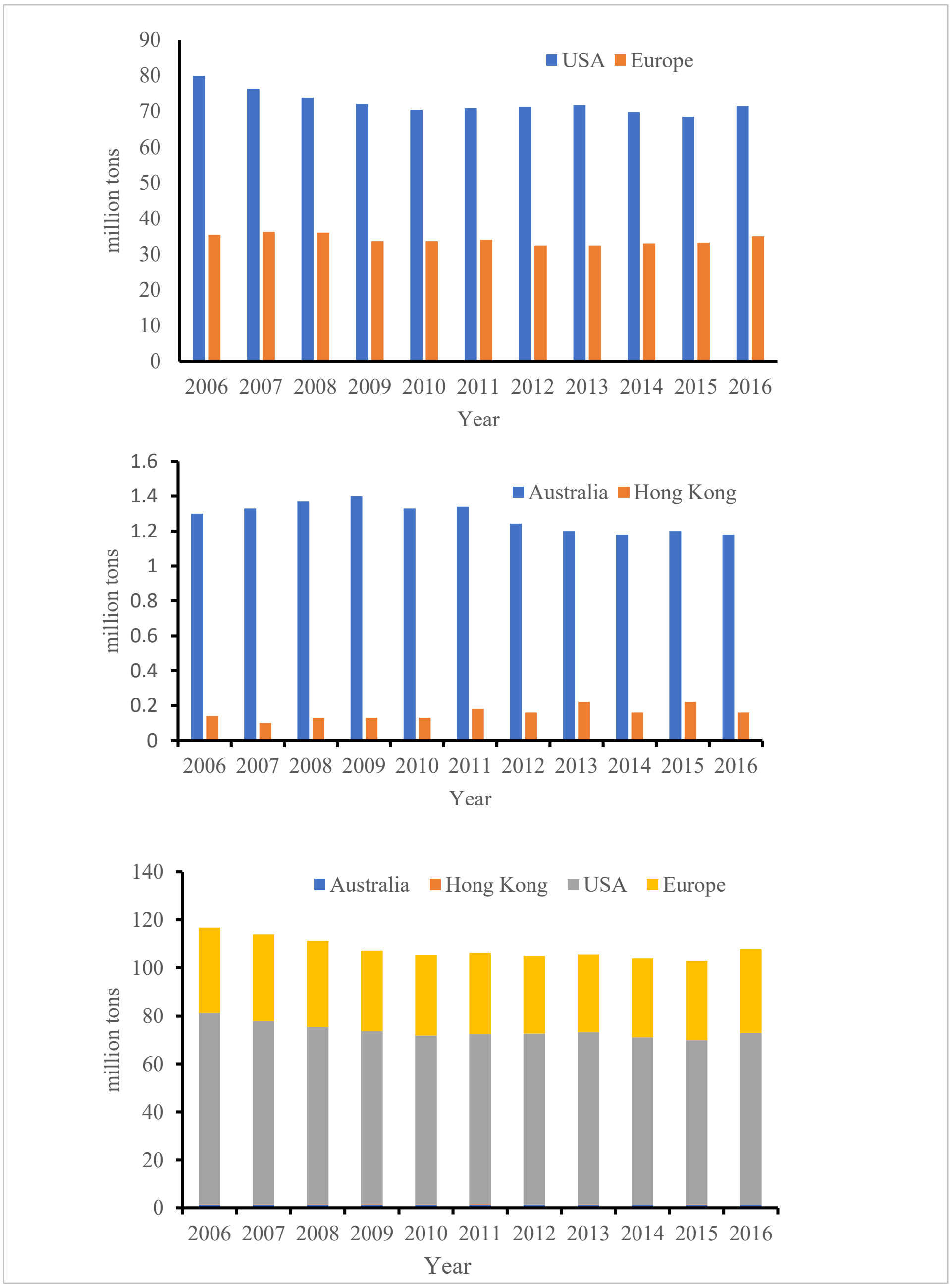

Figure 3: Glass waste generation trends

Though in Australia, an average of 1.25 million tonnes of glass waste have been produced every year it was able to stabilise the glass waste production and eventually reduce it due to its high recycling percentage which is about 57% (Pickin et al., 2021). On the other hand, Hong Kong seems to be volatile. This can also be the result of production over many years as it is one of the countries delivering the highest dollar value glass and glassware (Workman, 2021). It can also be related to its recycling rates which too were volatile ranging between 35% to 45% of the total waste generated. The combined waste generation trends for the USA, Australia Hongkong and Europe showed that the generation of glass waste indicated a downfall from 2006 up till 2010, was then steady for a couple of years until 2016 and then slightly rose (refer Figure 3).

4. DISCUSSION

4.1 UTILIZATION OF GLASS WASTE THROUGH REPURPOSING

To achieve more sustainability in the construction industry, it is crucial to preserve new or virgin natural materials and at the same time use materials which have low embodied energy. It is also essential that the work carried out produces high-quality work and with the least possible cost. When the materials are repurposed or reused, the total cost of the material is highly affected thereby affecting the lifecycle cost of the building. Since the materials have already been manufactured the cost of manufacturing is reduced to nil when the materials are repurposed and may form a small portion of its initial manufacturing cost when they are reused. These costs generally include cleaning, repainting, or repairing the material to be reused. This certainly makes reusing and repurposing more popular since they not only help in improving sustainability in the construction industry but also allow for financial incentives to the consumers by helping them save on the initial cost of materials.

If the material is highly durable and has a life of more than the life cycle of the current building, the quality of the material shouldn't cost as much. But if an extended life is expected of the material, the quality cost may be quite variable. Where some of the materials may require more cost for maintenance, others might just need a bit of repair work to be working as brand new. Quality costs can be significantly reduced provided proper planning is done regarding the implementation of the material and may thus help in saving the total cost for the material. The maintenance cost is an integral part of the total cost for any material as it is crucial to keep them working in the best possible condition. Though the cost of maintenance cannot be reduced; however, if the materials used are naturally maintenance-free due to certain properties it helps in reducing the overall cost. Repurposing materials helps in opening several possibilities in this regard. Though a material may not be naturally maintenance-free for a certain use, its repurposed use opens it to a limitless possibility due to its various characteristics.

Through repurposing new ways can be found to use glass and thus move tons of the glass waste accumulated in the landfills thereby saving space. This shall further reduce the pressure on land which can be used for other uses. The concept of repurposing can be seen in effect by using glass waste as aggregates for concrete. This not only helps in saving virgin materials but also saves costs on the whole project.

4.2 ADVANTAGES AND DISADVANTAGES OF THE REUSING OPTIONS

In this section, a brief overview of the advantages and disadvantages of the various reusing options for glass waste is presented (refer Table 3). This has been done to gain more insight into the options and help make a more efficient decision. The following table entails the information gathered through various journal articles for better understanding of reusing options and their potential.

5. CONCLUSION

This research delves deeper into glass waste generation to find out practical and achievable methods of reusing and repurposing glass waste. Through literature review, many uses of glass waste were found namely aggregate for concrete, filtration media, glass fibres, blast abrasives, roof coating, ceramic-based products, burnt bricks, low-temperature stoneware tiles, insulation as well as decorative materials. Of all the potential options, insulation, filtration media, burnt bricks and glass fibres satisfied all the four primary functions. Though all the options have great potential and bring sustainability to the construction industry, based on the findings of this study, insulation material was found to be the best material among all four due to its superior insulation quality as well as cost-efficiency. The product also offers to move large amounts of glass waste into a good quality product and like other potential options preserve virgin material for future use. The research not only provides many options for reusing and repurposing glass waste but also increases awareness regarding the amounts of glass waste generated in different parts of the world and its impact on our environment. Consequently, more and more glass waste shall be moved from the landfills, not only freeing up space but at the same time helping in reduction of carbon footprint in our environment making the construction industry more sustainable.

Table 3: Advantages and disadvantages of potential reusing option of glass waste

Material	Advantages	Disadvantages	References
Filtration Media	High porosity; Simple technology for production; Sustainable material and Method of production; Higher compressive strength at higher sintering temperatures; Improved efficiency; Cost-efficient	Requires high Firing temperatures; Low glass milling efficiency and thus Low sorption ability	(Shishkin, et al., 2021, Silva, et al., 2017)
Insulation	Production does not require High temperature; Absence of toxic gasses and chemical pollutants; Low carbon footprint; Recyclable product; Available in different sizes and colours; Both thermal and Acoustic insulation properties; Sustainable; Low conductivity; High mechanical strength		Assefi, et al., 2021)
Glass fibres	Resistance to chemical attack; Hardness; Flexibility; Strength; Low thermal conductivity; Low Density; Ability to float on water; Ultra-Light Weight	Long term performance still needs to be tested	(Silva, et al., 2017, Mohajerani, et al., 2017)
Burnt Bricks	Increased porosity and good water absorption rate of less than 20%; Increased flexural and compressive strength; High structural efficiency; Lighter in weight offering reduction in labour and transportation costs; Severe weather resistance; Sustainable and eco-friendly	Large amount of energy is required for production	(Akinyele, et al., 2020, Kazmi, et al., 2017, Hasan, et al., 2021, Al-Fakih, et al., 2019)

This research shall help the stakeholders in the construction industry to decide which reuse of glass is the best value for them according to the scope of their project and at the same time encourage them to use waste glass in their construction projects. The government can also use the research to find the best reuse of glass waste sitting in the landfills and thus control the problem of waste management as well as free up space accumulated with glass waste. Though much insightful information has been gathered, some limitations were faced while conducting this research. The research only analyses secondary data to come up with potential reusing and repurposing options. The concept of repurposing would have drawn more alternative potential options had there been a chance of collecting primary data through interviews and questionnaires. Further research can be carried out on different primary functions for use of glass waste in order to determine the best use of glass waste for different scopes for different projects thereby making it easier for the stakeholder to make a decision on how they can incorporate the use of glass waste for saving resources and at the same time providing a high-quality product. Research regarding the comparison of glass waste to other waste generated in the construction such as concrete, roof tiles, packaging, mortar, sand-lime bricks and elements, piles and stone tablets could also benefit the future study.

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SAFETY IN THE MARITIME CONSTRUCTION SITE: CAPTURING LESSONS LEARNED

Jose Rocha[1] and Anoop Sattineni[2]

ABSTRACT

The aim of this research is to examine the safety culture of the United States Army Corps of Engineers staff and contractors working on marine construction projects including dredging, beach nourishment, breakwaters, and jetties. A literature review was performed to understand existing issues and to develop a research methodology for the study. Qualitative data research was used to uncover significant themes and help gain a deeper understanding of safety related issues. Twelve construction professions were interviewed using semi-structured interview format. The data was analysed using thematic analysis techniques with an inductive approach to draw conclusions. The results were used to conclude that issues causing safety accidents in the maritime construction sector can be broadly attributed to unforeseen conditions, training, complacency, lack of support of safety and crew unpreparedness. Data from the interviews also indicates ways to improve maritime construction can be broadly categorised under training, improved communication, improved preparation and organisational support for safety.

Keywords: *Maritime Construction; Safety Culture; Semi-Structured Interviews.*

1. INTRODUCTION

This research is a look at the safety culture of the contractors and the United States Army Corps of Engineers (USACE) personnel performing and overseeing construction on various maritime projects for the USACE. Emphasis is on marine construction, including dredging, beach nourishment, and jetty and breakwater construction projects. Finding accident statistics for maritime construction projects has proved a difficult task. However, the Health and Safety Executive (HSE) does categorise between general construction and offshore construction projects. The general construction sectors cover all construction operation on land while the offshore covers offshore installations only. According to the HSE, there is a higher chance of an injury from being struck by a moving or falling object during offshore construction (Cruickshank and Cork, 2005). The aim of this research is to identify causes of maritime construction related safety accidents and make recommendations to minimize them.

The International Maritime Organization (IMO) stresses safety culture on vessels as a top priority, in shipping companies and in the shipping industry as such. The IMO states that "An organization with a 'safety culture' is one that gives priority to safety and realizes

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that safety has to be managed like other areas of the business" (Ek, et al., 2014). A safety culture ensures that employees can perform their job comfortably knowing that they will be able to go to work and come home safe at the end of the day. A safety culture helps drive a proper response when an accident or emergency does occur (Experts, 2022). Maritime work is particularly hazardous due to the hostile environment and uncertainty caused by the combination of weather, waves, currents, and tides. At present, there is little health and safety related guidance available to assist coastal/maritime contractors and to ensure this work is undertaken in a safe manner (Cruickshank and Cork, 2005). Understanding the most common violations can help prevent accidents and improve compliance in laws and regulations. Understanding the top injury occurrences in marine construction helps prevent injuries, keeps the workforce safe and reduces workers compensation costs. Literature suggests that common injuries during marine construction include overexertion, slips, trips, and falls, contact with objects or equipment, transportation incidents, exposure to harmful substances or environments, workplace violence and repetitive motion related injuries (Hofmann, n.d.).

USACE is the federal agency in the United States that maintains almost all of the nation's infrastructure, as it relates to waterways. The agency also oversees all federally funded maritime construction projects. This research is a review of the USACE construction personnel and contractors' safety culture during heavy civil construction projects. It will evaluate the safety mentality and establish reasons for recent issues and discuss possible solutions for improvement. The goal is to gather information that may be utilized to improve safety during construction of the various projects, utilizing semi-structured interviews gathered from USACE experts in safety and construction as well as from USACE contractors involved in marine construction.

2. LITERATURE REVIEW

2.1 GAPS IN ACCIDENT DATA IN MARITIME CONSTRUCTION

The construction industry has had many advances in construction safety equipment, technology, and training, despite these advancements it continues to face high rates of fatal and non-fatal injuries and accidents among its workers (Mehata, et al., 2019). Determining the most dangerous industry depends on the measure used to compare danger. The Bureau of Labor Statistics (BLS) produces data through the 'Injuries, Illnesses, and Fatalities' (IIF) program. This program produces a wide range of information about workplace injuries and illnesses and are reported annually through the Survey of Occupational Injuries and Illnesses (SOII) and the Census of Fatal Occupational Injuries (CFOI). The IIF program presents data for the industry on the number of workplace fatalities and the rates of workplace injuries and illnesses per 100 full-time workers in heavy and civil engineering construction. However, it is difficult isolate maritime construction related safety incidents from the data presented, as evidenced by the data shown in Table 1. The data only describes 'Other heavy and civil engineering construction' as a category and is not further broken down to show incidents related to 'Marine Construction'. This represents a significant gap in the recording of accidents in maritime accidents. Additionally, a literature search on the topic produced significantly less results as compared to safety issues for construction on land. The authors posit that inadequate data and research is a clear justification for conducting this research.

2.2 SAFETY IN USACE

Developing a strong safety program can help prevent workplace injuries, improve compliance of regulations, and reduce costs of insurance and reductions in workers' compensation premiums. Over the past four decades the rate of worker deaths and reported injuries has decreased by more than 60%. However, every working day nearly 5 construction workers are killed in the United States (Marefat et al., 2018). Prior to the start of construction, the USACE requires an Accident Prevention Plan (APP) approved by the USACE construction management and safety team. The APP includes contents such as a statement of safety, training, safety and health inspections, accident reporting, various plans (e.g., Emergency response, health hazard communication, traffic control, fire prevention) and Site Safety and Health Officer (SSHO) qualifications. The contractor is required to provide a minimum of one competent person serving exclusively as the SSHO. The SSHO is required to be onsite during all construction activity and is required to perform safety and occupational health management, surveillance, inspection, and safety enforcement. The SSHO is also required to prepare activity hazard analyses (AHA) prior to the start of new activities. The AHA's also need to be reviewed for compliance and used by the SSHO during the daily inspections to ensure implementation and effectiveness of the required safety and health controls for the work activity.

Table 1: Construction subsector incidence rates (per 100 workers) of nonfatal occupational injuries and illnesses by industry and case types, 2019 (BLS, Injuries, Illnesses, and Fatalities,2020)

Industry	Total recordable cases	Total	Cases with days away from work	Cases with days of job transfer or restriction	Other recordable cases
Heavy and civil engineering construction	2.4	1.5	1	0.6	0.9
• Utility system construction	2.1	1.3	0.9	0.4	0.7
• Water and sewer line and related structures construction	3.5	2.3	1.6	0.6	1.2
• Oil and gas pipeline and related structures construction	0.5	0.3	0.2	0.1	0.2
• Power and communication line and related structures construction	2.5	1.6	1.1	0.5	0.9
• Land subdivision	1.7	1.3	0.3	1	0.3
• Highway, street, and bridge construction	3.4	2	1.2	0.9	1.3
• Other heavy and civil engineering construction	1.8	1.4	0.9	0.4	0.4

2.3 SAFETY CULTURE

The term safety culture was first used by the International Atomic Energy Agency in its 1986 Chernobyl accident summary report (Roberts, 2021). It was a term used to describe how the thinking and behaviours of people in the nuclear plant contributed to the accident. The accident summary concluded that a low safety culture of the entire system was the root cause of the Chernobyl accident (Ukrainian Nuclear Society, 2019). Today the term safety culture is widely used and has gained more attention in the construction industry as companies realize the influence that workers attitudes towards safety has on the causes and effects of workplace incidents.

Having a positive safety culture is being proactive towards safety. It means that nothing takes precedence over safety under any circumstances, so the workforce does not feel that safety is an obstacle to getting work completed correctly and on time. A positive safety culture means that all personnel from senior leadership to the front line workers share the same responsibility for safety at work (Ransley, 2020). A negative safety culture contributes to the reactive vs. proactive safety culture. It means that most of the time one ends up having to react to a workplace incident because they are unable to prevent an incident from occurring. Often this can be result of feeling pressured to forego safety rules to meet deadlines.

In March of 2021, the Occupational Safety and Health Administration (OSHA) released a list of top 10 most frequently cited violations. The leading causes of death and injuries in the maritime industry (including maritime construction) are falling and drowning accidents, vehicular accidents and material handling accidents. According to OSHA statistics, slipping and falling into the water is one of the three leading causes of deaths in maritime industry. Some of the ways this accident can occur is by falling without a life vest, falling into the water, and being crushed due to lack of safe access to the barge or a worker falling when a corroded catwalk collapsed (Hofmann, n.d.). Leading indicators of safety culture may be a way to continue to reduce the accident rate by assisting safety professionals and management staff in identifying deficient areas in their safety programs before accidents occur. It is key that the safety programs that incorporate leading indicators can identify and measure which factors have a measurable impact on safety outcomes. These programs will also require buy-in from all involved and will take time before results can be measured, if measured at all (Hinze, et al., 2013).

3. RESEARCH METHODOLOGY

This research used qualitative methods to understand the safety mind-set and level of commitment of USACE contractors and staff working in the construction of maritime projects. One of the purposes of qualitative research is to provide insights into the setting of a problem, and to uncover common trends. It is a way of gaining a deeper understanding of a topic (Saunders, et al., 2009). The research focuses on a small group of participants mostly with several years of experience constructing heavy civil engineering construction projects including maritime construction projects. The data will focus on their experiences, observations, and perceptions on safety. These interviews provide greater depth than a standard survey, allowing insight into the vast knowledge of the interviewee. Interviews were recorded on audio and transcribed. A survey was also considered for this research; however, the data collection would have been incomplete and difficult to obtain as the contractors and personnel involved in marine construction available to the research team were limited.

Semi-structured interviews were chosen as the qualitative method for this research. This type of interview allows for it to flow like a natural conversation, the researcher was able to modify the questions to suit the interviewees specific experiences and insights into problems or issues that the questionnaire may not have revealed (Saunders, et al., 2009).

The candidates for this research were construction management professionals working in maritime construction and USACE staff with experience in maritime projects in their careers. The research will attempt to understand the safety culture of the workforce involved in these types of projects. The goal of the researcher is to learn of the experiences of the various interviewees and discuss how safety has changed throughout their careers. What have been some of the reasons for any safety issues that may have occurred and what have been some of the changes that have influenced safety in either a positive or negative way. The goal is to interview different candidates with extensive experience of maritime construction from both the contractor's side and the USACE side. Semi-structured interviews were conducted with twelve interviewees. Research shows that a full range of thematic discovery occurs almost completely within the first twelve interviews (Guest et al., 2006). Candidates were selected by the researcher based on availability and first-hand knowledge of maritime projects. Candidates had between 6 and 42 years of experience. A brief description of the interview candidates experience is provided below:

- Candidate 1: Chief of Safety for USACE, 6 years' experience
- Candidate 2: Project Manager, Mega Projects, USACE, 40 years' experience
- Candidate 3: Senior Construction Executive, USACE, 26 years' experience
- Candidate 4: Area Engineer, USACE, 22 years' experience
- Candidate 5: Area Engineer, USACE, 11 years' experience
- Candidate 6: Quality Assurance Executive, USACE, 30 years' experience
- Candidate 7: Chief of Operations, Private Industry, 15 years' experience
- Candidate 8: Senior Project Engineer, Private Industry, 35 years' experience
- Candidate 9: Project Manager, Private Industry, 6 years' experience
- Candidate 10: Lead Designer, USACE, 14 years' experience
- Candidate 11: Deputy Chief of Construction, USACE, 16 years' experience
- Candidate 12: Vice President, Private Industry, 35 years' experience

4. RESULTS AND DISCUSSION

12 participants with varying levels of knowledge and experience of maritime construction were interviewed for this research. Interviewee experience ranged from 6 years to 42 years in the construction industry. The results of the thematic analysis are presented in this section.

4.1 THEMATIC ANALYSIS OF SEMI-STRUCTURED INTERVIEW DATA

The semi-structured interview data was coded using open coding techniques. The responses for each interviewee were further analysed. This analysis indicated five major safety themes play significant roles in safety during construction of marine projects, these are issues that need to be paid close attention to, and shown in Figure 1, as well as described in sub-sections below.

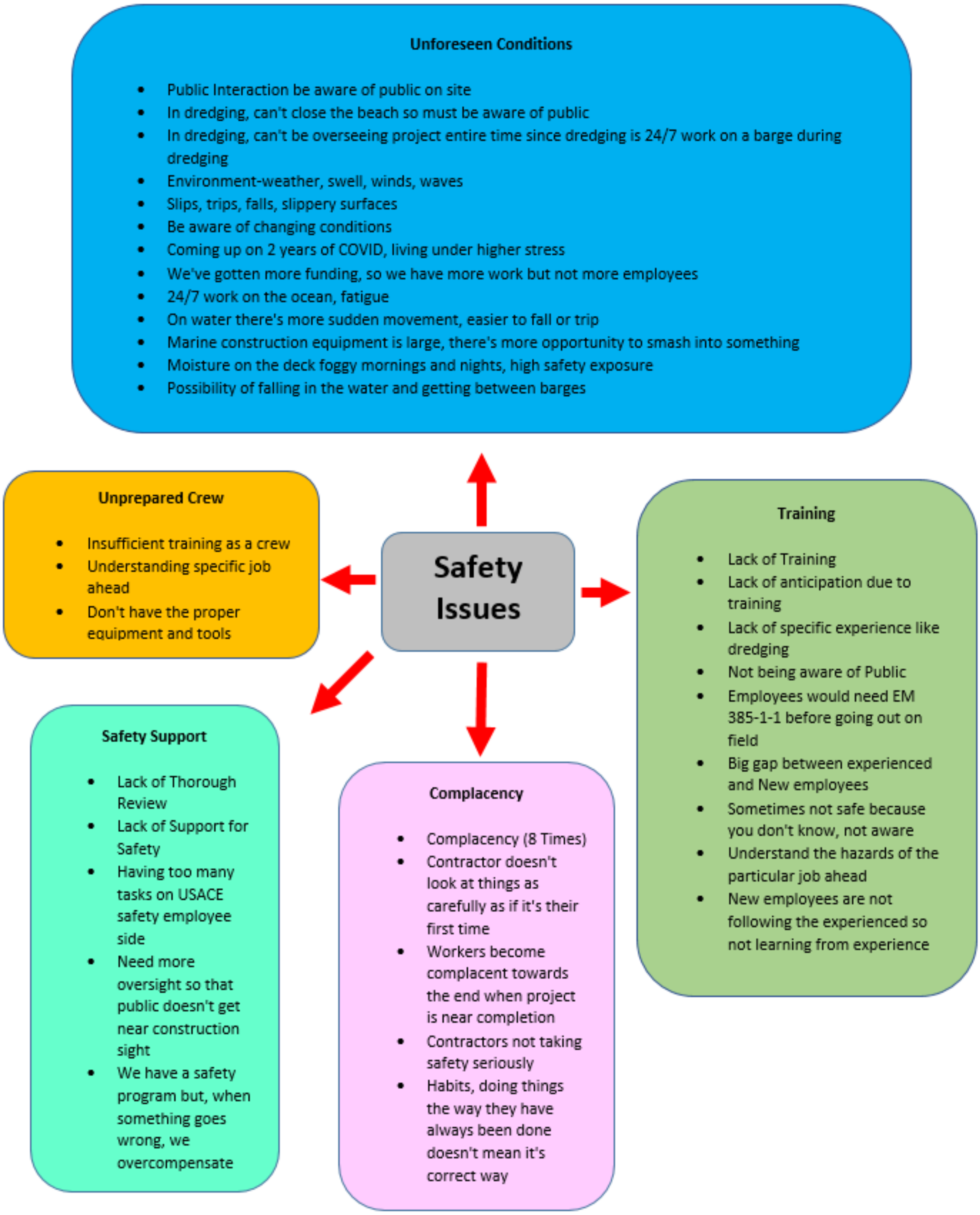

Figure 1: Causes of accidents in maritime construction projects

4.1.1 Unforeseen Conditions

Interviewee responses of safety issues that address unforeseen conditions were mentioned by 6 of 12 interviewees. Of note is that these unforeseen conditions were brought up mostly by the five interviewees with the most experience in marine construction. Most of the issues mentioned are also major issues in land construction but these dangers are elevated in marine construction. Some of the unforeseen conditions are shown below and in Figure 1.

- In dredging, can't close the beach so must be aware of public
- In dredging, can't be overseeing project entire time since dredging can be 24/7 work
- On a barge during dredging, oil spills occur and it is easier to fall or trip
- Environment issues such as weather, swell, winds, waves must be considered
- On water there's more sudden movement

4.1.2 Complacency

Interviewee responses of safety issues that address complacency were mentioned by 10 of 12 interviewees. Below are some reasons mentioned, and expanded further in the themes presented in Figure 1.

- Knowing the work involved and becoming comfortable
- Towards the end of a project when the project is near completion
- Difficult to maintain the same level of awareness throughout the entire construction project

4.1.3 Training

Training or the lack of was mentioned by all 12 in some capacity by the. When asked about marine construction safety, seven of the interviewees mentioned specific training in the marine construction projects is necessary, as well as specific training for other specialized work for example crane work and electrical.

4.1.4 Support for Safety

Support for safety was mentioned by five of the interviewees. Some of the issues mentioned were that there is a lack of time and funding for a thorough review of the safety specifications and other documents like the accident prevention plan and the various activity hazard analysis submittals. Another one is having the funding to be able to properly man the different construction projects with qualified personnel for proper oversight when construction is happening. Another reason that falls under support for safety is that throughout the years, personnel have been assigned with more tasks that don't necessarily pertain to safety during construction.

4.1.5 Unprepared Crew

Not being prepared was brought up by three of the interviewees. This is an issue for both the USACE and the USACE contractors. Accidents happen when employees don't have the proper training but also when they do not have the proper equipment for the job. It was also mentioned that employees do not prepare by discussing the specific work being performed on that day and addressing the issues that may arise.

4.2 SUGGESTIONS FOR IMPROVING MARINE CONSTRUCTION PROJECTS

In this section thematic analysis was performed on the interviews to identify the different ways discussed by the interviewees that may help improve the safety during construction. The different methods mentioned were grouped into four main themes including 'Develop/Tech/Train', 'Support for Safety', 'Communication' and 'Preparation'. Figure 2 shows codes developed during the analysis and categorised under these major themes.

4.2.1 Develop/Teach/Train

Developing, teaching, and training was a major theme amongst the interviewees. It was mentioned in some form by all 12 interviewees to improve maritime construction safety. It was mentioned that more site-specific training would be of great benefit, especially in the marine construction projects, other site-specific training mentioned was trenching, electrical, cranes, and vertical construction. Different stages of the construction project were mentioned as opportunities to develop and train employees, including in the development of specifications by training new employees how to read and understand the specifications, training to understand the plans to know the sequence of work and during construction, development of new employees by experienced personnel through mentoring out in the field during construction. Figure 2 displays all unique responses by interviewees that were grouped into this theme. Most of the interviewees recommended that all construction personnel should focus on safety as the top priority. At a minimum have had a safety course for example the OSHA 30 course. The interviewees stressed continued training. A recommendation was also that with so many experienced personnel onsite both from the USACE and contractors, to recommend that different workers discuss a safety topic that they are familiar with and to include workers in the conversation and encourage safety discussions.

4.2.2 Preparation

Preparation was the second most discussed issue for improvement and was discussed by all 12 interviewees. Knowing the safety requirements for the work ahead was a major topic of conversation. Knowing the work ahead leads to being proactive in anticipating possibilities for safety hazards. Inspecting equipment and maintaining it in good condition as well as preparing with the correct tools were all topics in preparation for a safe construction project.

4.2.3 Communication

Communication is a major topic for safety in all construction sites. This includes the marine industry and can be a much more significant factor in maintaining safety. In marine construction projects, communication with the public and the public entities for assistance was mentioned by all USACE contractors interviewed. Also mentioned was communicating with radios or being with someone that has a radio and always having a direct line of sight due to the large equipment used. Figure 2 includes the different ways the interviewees addressed communication for improving safety.

4.2.4 Support for Safety

Support for safety was mentioned as a major reason for having safety issues and it's also a major way that safety may be improved. Ten percent of the responses included supporting safety from supporting the safety program for the company to funding for safety oversight. This includes having the safety office being involved in all phases of the project from development to completion.

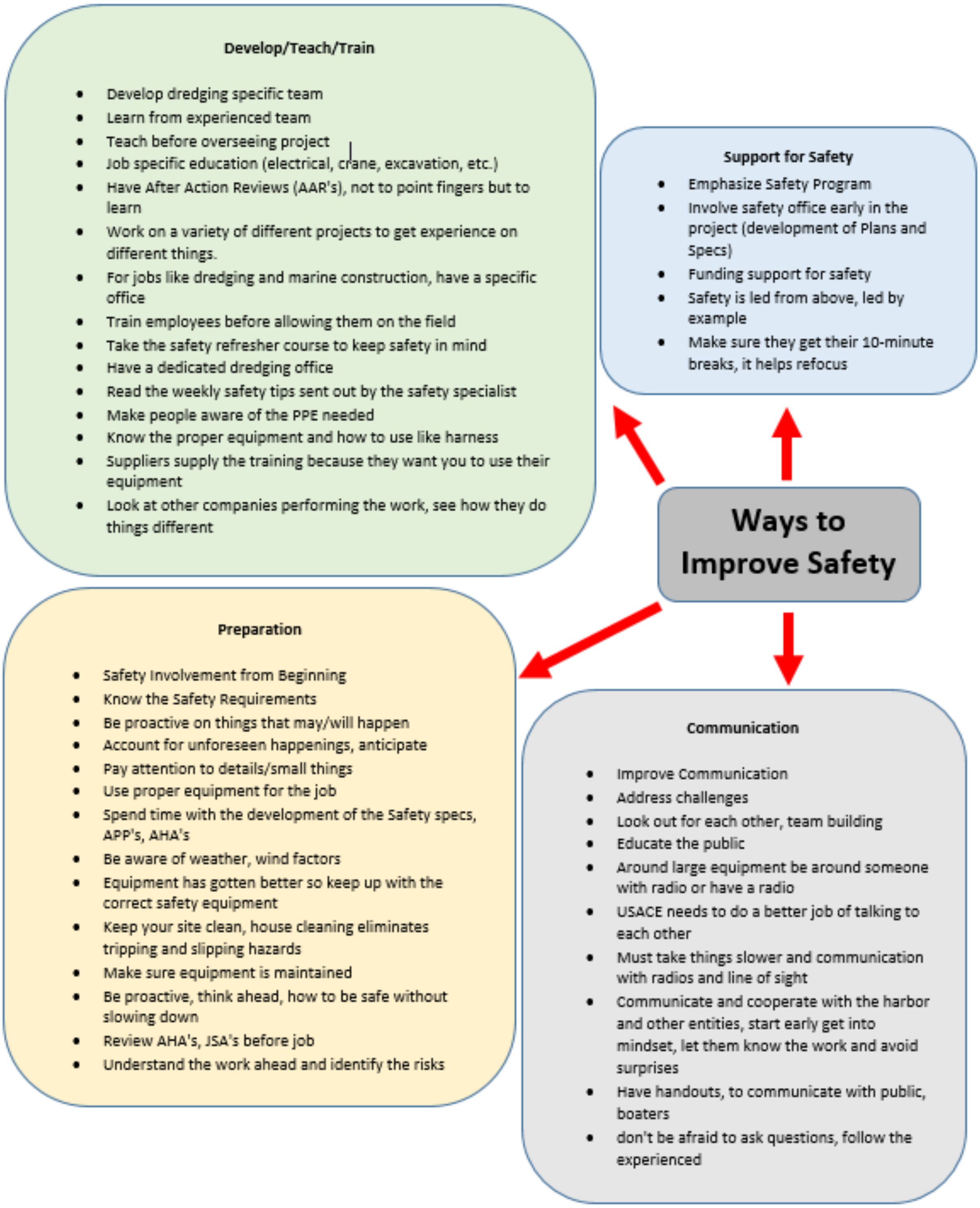

Figure 2: Four basic elements of reading ease

4.2.5 Best Practices

A best practices safety guide for marine construction may prove beneficial for both USACE and contractor staff. The guide may help explain some of the hazards to anticipate on such projects. Table 2 is a list of combined comments and recommendations for a safe project, beginning to end. This table was developed based on some of the most critical and repeated comments from the interviews. Further research is needed to validate this table and develop a framework or a guide to make improvements. Lack of sufficient data related to maritime construction projects is an impediment to drawing meaningful conclusions relating their frequency. It is important that OSHA data be further segmented to show safety incidents on maritime construction projects.

Table 2: Comments and recommendations for safe maritime projects

Phase	Comments	Recommendations
Planning and Design	• Lack of Support for Safety, safety office was not involved throughout project, so not enough of thorough review for plans and specifications. USACE safety team has too many tasks.	• Safety is led from above, led by example. Emphasize Safety Program. Need to support safety by funding. Involve safety office early and throughout project from development of Plans and Specs to construction completion. Develop Dredging Specific Team, develop and train. Take safety refresher course to keep safety in mind.
Pre-Construction	• Lack of anticipation due to not having job specific training, not understanding job ahead. Lack of job specific experience. New employees are not spending enough time following the experienced, to learn from experienced personnel. Don't have the proper PPE, equipment, and tools. Equipment not well maintained. Need to have thorough review of APP’s, AHA’s.	• Take time to prepare. Improve Communication and address the Challenges of specific job ahead. Look out for each other have team building activities. Be prepared, be proactive. Have job specific education (electrical, crane, dredging, etc.). Don't be afraid to ask questions and follow the experienced personnel while learning. Use proper equipment for the job and keep it well maintained, and know the Safety Requirements study plans/specs, take necessary time to review APP's, AHA's.
Construction	• In dredging most times, can't close the beach so must be aware of public. Public doesn’t know of hazards during construction.	• Communicate with public, have handouts. Communicate and cooperate with the Harbour and other entities that can help with public safety. Start communication early in project to get into mind-set, let different public agencies know ongoing work to avoid surprises.
	• In dredging, there's not enough oversight, difficult to oversee project entire time since many times dredging is 24/7 work, to complete within small window due to environmental concerns. 24/7 work also brings issue of fatigue.	• Oversee construction at different times to see how construction is being performed at different times. Maintain awareness of workers that may look fatigued. Do not be afraid to ask questions.

Phase	Comments	Recommendations
	• On a barge during dredging there's sudden movement, there's moisture on the deck, slippery surfaces, there may be oils, beware of slips, trips, falls. Possibility of falling in the water and getting between barges. Marine construction equipment is large, there's more opportunity of getting hurt.	• Keep your site clean, house cleaning helps eliminates tripping and slipping hazards. Around large equipment be with someone with radio or have a radio. Need to take things slower and communicate and maintain line of sight. Pay attention to details and small things and anticipate.
	• In marine environment hazards are on a different level, Environment-weather, swell, winds, waves. Need to be aware of changing conditions. Foggy mornings and nights, have high safety exposure.	• Be aware of weather, wind factors and rapidly changing conditions. Make sure weather is part of look ahead schedule.
	• In dredging complacency is a factor due to same contractors being awarded the contracts, they build habits that may not be good and may not look at things as carefully as they would if they were doing the project the first time. Also, towards the end when project is near completion, contractor becomes complacent.	• Team on both contractor and USACE side have employees with different levels of experience, have different team members discuss safety to keep them engaged.
Post-construction	• Learn from previous experiences and make changes necessary	• Develop an after-action report requirement to understand the positives and negatives. What went well and what didn't, improve upon it. Look at other companies performing similar work, see how they do things different.

5. CONCLUSIONS AND RECOMMENDATIONS

Responses from the interviewees on hazards of maritime construction are many of the same as traditional heavy civil construction projects. Maritime construction combines these hazards with the hazards of working on a floating vessel. Weather becomes a much more critical part of construction when working on the water, due to swells and waves which increase risks. Some of these maritime construction projects like dredging are 24 hour, seven days a week work due to the short dredging window given because of weather and environmental factors, the issue of fatigue is a major concern.

A common hazard of maritime construction is the public. Being mindful of the public and paying close attention is important. In land-based construction, the site can be fenced off most times. On the water many times the public doesn't have the awareness of the hazards of the large equipment being used to dredge. Many times, equipment is underwater and out of sight for example the anchor wires which can be spread over 1000 feet apart. Much of the maritime crew and staff have worked on maritime construction for many years, this brings the issue of complacency, knowing the job and feeling that the job can be done very easily can add risk. The marine industry believes that more rules, regulations, and procedures are unlikely to improve safety performance (American Bureau of Shipping, n.d.).

Awareness during construction was also high on ways to improve safety. Understanding that maritime projects are some of the most dangerous. Communication with local officials to help engage the public and make them aware of the risks of the work. Be aware of the public, every job is different, highlighting any risks of public interference was also brought up by interviewees with the most marine construction experience. Contractor employee involvement in safety, empowering employees to give feedback through after-action reports (AAR's) was a great way of being able to receive the feedback necessary to improve. Effective communication was something discussed by all experts. Communicating in all stages of the project, beginning with communicating and agreeing on the safety specifications and all documentation, communicating about the schedule and type of work that will be going on, also recommending that most of the construction workers use a radio to effectively communicate between each other, and communication after the project is complete and having discussions about what went right and what could be improved.

The research team interviewed 12 highly experienced USACE staff and contractors in marine and heavy civil construction projects. During the interview they were asked to comment on issues experienced and recommendations to mitigate the issues related to maritime safety. Suggestions were shared by the interviewees on how to improve safety during all phases of a project from the planning and design phase to the post-construction phase. For example, one interviewee mentioned that the safety office was not part of the specification review before advertisement, therefore, the safety specifications were not reviewed by the safety experts before the contract was awarded. A recommendation shared by the interviewees was that the safety office should be part of the team in every phase of the project from beginning to end. This would allow safety experts to perform the following during the separate phases:

- Planning and Design Phase - Review plans and specifications before contract advertisement for deficiencies.
- Pre-construction phase - Review contract documents for example accident prevention plans and activity hazards analysis. Perform site investigations before construction begins to look for and anticipate construction hazards.
- Construction phase - Provide Safety expert oversight during construction.
- Post-construction - Discuss the overall project in the form of after-action reviews to understand things that went well and things that did not go well for improvement recommendations.

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SELECTION APPROACHES AND METHODS OF CONSTRUCTION INDUSTRY CONSULTANT: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Selecting the most appropriate construction industry consultant (CIC) is a crucial process if projects are going to be successful. However, poor performance of CICs and failure to meet a client's needs are common, and the CIC selection process has not been adequately analysed in previous research. A systematic literature review of the CIC selection process will help to clarify the different approaches and methods. The study concluded with three common approaches for selecting the appropriate CIC: price-based selection, qualification-based selection, and qualification-price-based selection. The selection approach is conducted either by using a direct or a comparative method. The direct approach is based on reputation or past experience with the client, while the comparative selection method occurs through an evaluation process and a list of selection factors. There are two processes involved in the comparative selection method: interview-based selection process and Multi Criteria Decision-Making (MCDM)-based selection process. However, while there are different opinions about what is the best way to select a consultant, the authors assert that the ideal process depends mainly on client and project conditions. Future study is recommended on this topic. This study contributes to the literature on the CIC selection and open the door to further studies such as developing a new selection approach or method and studying factors and criteria of CIC selection.

Keywords: *Construction; Construction Consultant; Consultant Selection; Project Consultant.*

1. INTRODUCTION

Coinciding with rising complexity in projects, competent and dependable construction industry consultant (CIC) is crucial to successful construction projects (Alamiri, et al. 2014b; Ha, et al. 2015). Selection of trustworthy and competent consulting firms protects

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a business from issues related to changes in its environment and management (Jeon, et al. 2016; Razi, et al., 2020). Jeon, et al. (2016, p.1) stated that "in order to solve problems related to business environment and management changes, companies need to select competent and trustworthy consulting companies". Proper design and consultation can contribute to successful construction projects (Othman, et al., 2018). Choosing the best CIC is an important for achieving consulting results and especially project completion (Jadid and Idrees, 2006; Chow and Ng, 2007; Elbarkouky, et al. 2013; Choudhry, 2016; Jeon, et al. 2016; Razi, et al. 2020). Subsequently, CICs who have a proven good performance must be selected (Ling, 2002). Their appointment has a bearing on project accomplishment, value, quality and cost (Choudhry, 2016). When proposals are tendered, CICs must address how they will add value and benefit to the project and client (Lam, 2017). If the best CIC is not duly selected, extra time and cost will be incurred (Lam, 2016). Hence, they need to address the client's requirements in the tender proposal to increase the chance of winning the project (Lam, 2016). However, developing a useful CIC selection system is vital for both client and CIC (Kasma, 1987). It is a complex process involving both qualitative and quantitative criteria and subsequently important decisions (Razi, et al., 2020). So, retaining a CIC is important for one or more of five reasons: temporarily acquiring the necessary expertise, supplementing in-house personnel, providing absolute objectivity, performing or resolving unpleasant tasks and reducing liability.

However, although the selection of a CIC is a crucial part of the best performance for a given project, previous studies have shown that poor performance is common among construction CICs. Furthermore, the CIC selection process has not yet been considered and analysed appropriately in an independent way. There is a need for collecting and structuring the different types of CIC selection approaches and methods, to serve as the basis for further studies about the CIC such as demystifying differences and appropriate uses of each approach and/or method. With this in mind, the study aims to conduct a systematic literature review and explain the CIC selection approaches and methods.

2. RESEARCH STRATEGY/METHOD

Conducting a systematic literature review is an important scientific activity to clarify what is already known about a topic and to more knowledge and identify potential themes for future studies to investigated (Okoli, 2015; Mostafa, et al., 2016; Xia, et al., 2018). Consistent with the approach suggested by Xia, et al. (2018), Mostafa, et al. (2016), Denyer and Tranfield (2009) and Tranfield, et al. (2003), the systematic literature review here has been implemented in three stages as shown in Figure 1.

2.1 STAGE 1: PLANNING THE REVIEW

The first stage aims to prepare a plan for searching and reviewing relevant articles, conference papers and theses that are found on different electronic databases or search engines. It has been built based on the defined purpose and objectives of this research as stated in the introduction section. The analysis relies on English-language papers from three electronic platforms and academic databases: Scopus, Library of Western Sydney University and Google Scholar. The search is performed by using keywords in the title, abstract or keywords. These are ("Consultant" AND "Construction"), ("Consultant" AND "Select") and ("Construction" AND "Select"). The search was done before 1/3/2022. This stage concluded with finding 66 studies that were then subjected to a preliminary investigation. The best journals which have three or more studies are Construction Management and Economics, Journal of Construction Engineering & Management and Journal of Management in Engineering.

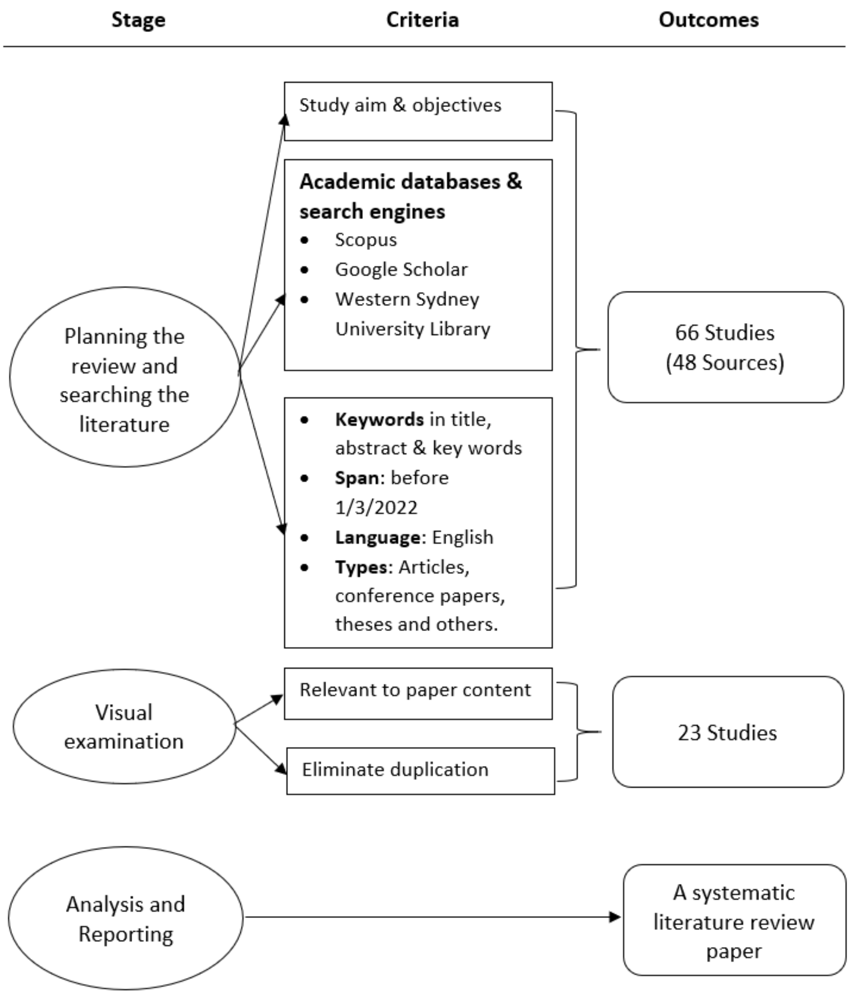

Figure 1: Plan for researching and incorporating literature into this study

2.2 STAGE 2: CONDUCTING THE REVIEW

A comprehensive and unbiased search is a vital difference between the traditional review and systematic review. During this stage, the studies have been assessed and filtered to generate a total of 23 studies that will be subjected to a systematic literature review. The distribution of the final studies in terms of the sources is outlined in Table 1.

Table 2: Distribution of the final studies based on their sources

Source	Source type
Journal of Management in Engineering	Journal
Journal of Construction Engineering and Project Management	Journal
Joint International Conference on Computing and Decision Making in Civil and Building Engineering	Conference
IOP Conference Series: Materials Science and Engineering	Conference

Source	Source type
International Journal of Research in Engineering and Technology	Journal
International Journal of Engineering & Technology	Journal
The International Conference on Civil and Architecture Engineering	Conference
Industrial Marketing Management	Journal
School of Civil Engineering and Built Environment, Queensland University of Technology	College
Faculty of The College of Graduate Studies, King Fahd University of Petroleum and Minerals	College
Engineering Your Future: The Professional Practice of Engineering	Book
Construction Management and Economics	Journal
Australasian Journal of Construction Economics and Building	Journal
Annual Conference of the Canadian Society for Civil Engineering	Conference
College of Environmental Design, King Fahd University of Petroleum & Minerals	College
Leadership and Management in Engineering	Journal
International Symposium on Construction in Developing Economies: Commonalities Among Diversities	Conference
Fourth International Conference on Cooperation and Promotion of Information Resources in Science and Technology	Conference
Civil and Environmental Engineering, Massachusetts Institute of Technology	College
The 5th International Conference and Workshop on Built Environment in Developing Countries	Conference
The American Public Works Association and The American Council of Engineering Companies	Private Study

2.3 STAGE 3: REPORTING AND DISSEMINATION

This stage consists of descriptive and thematic aspects according to Xia, et al. (2018) and Tranfield, et al. (2003). Descriptive analysis focuses on essential information of the selected studies which are closely linked to the construction industry and research topic based on a developed codebook as shown in Table 2. The thematic analysis was done utilizing a mix of aggregative and interpretative approaches, and clarifying the extent of consensus and argument across diverse themes.

Table 5: Codebook of the selected studies

Code	Description
Authors	Author(s) name(s)
Year	Year of publication
Title	Title of the research
Journal	Title and ranking of the journal
Research method	Questionnaire, case study, literature review or other
Project Type	Building, road, infrastructure projects

Code	Description
Consultancy Service	Architect, design, project management, supervision, others
Research aim and objectives	The stated aim and objectives in the research
Contribution	The contribution stated in the research

3. RESULT

3.1 CIC SELECTION APPROACHES

Clients of construction projects spend their money on getting the best quality and experienced project management team to achieve the desired objectives within determined time and cost. Therefore, the process of CIC selection is essentially driven by the natural tension between the quality and the total cost of that service (Walesh, 2012). There are three common approaches for selecting the appropriate CIC. The first approach is a price-based selection which depends on price rather than non-price factors (Omar, et al., 2009; Walesh, 2012; Elbarkouky, et al., 2013). The second approach is qualification-based selection which considers the quality and abilities of the CIC rather than proposed fees (Omar, et al., 2009; Walesh, 2012; Elbarkouky, et al., 2013). The third approach is qualification-and-price-based selection, which is a mixed of these two methods, starting with the technical evaluation and followed by the cost. Here, value for money is not necessarily based on the lowest price but instead reflects a balance between price, quality and performance (Omar, et al., 2009; Elbarkouky, et al., 2013).

3.1.1 Price-based Selection Approach

Price-based selection approach is the oldest approach used. Generally, and for many decades, project clients chose their preferred CIC based on financial proposal (Basham, 1983; Kasma, 1987). Ideally, clients should select the CIC based on the goal of minimizing total costs (Walesh, 2012). The advantage of this approach is that it is transparency and objectively (Cheung, et al., 2002). Walesh (2012) asserted that it tends to wield excessive influence. Low price selection does not mean that the actual job will be completed satisfactorily (Elbarkouky, et al., 2013) and does not guarantee the actual cost of the overall project once it is finished (Walesh, 2007; Sporrong, 2011). As stated by Walesh (2012, p. 389), “even much larger savings in up-front consulting fees will tend to result in only small savings in total project costs”.

3.1.2 Qualification-based Selection Approach

The qualification-based selection approach has become an essential part of CIC selection. Chinowsky and Kingsley (2009) stated that using this approach for procuring CIC will help to achieve a high degree of project satisfaction and control project cost. According to Cheung, et al. (2002), it is the most promising and the most widely recognized way for selecting a design CIC by overseas public clients. As well, it is recommended by the American Public Works Association, the Architects Council of Europe (ACE), the Australian Council of Building Design, the Association of Japanese Consulting Engineers and various other organizations around the world (Cheung, et al., 2002). Some examples of the qualifications are: general experience (Basham, 1983; Kasma, 1987; Al-Besher, 1998; Assaf, et al., 2002; Jadid and Idrees, 2006; Sporrong, 2011; Omar, 2012; Alamiri, et al., 2014a; Omar, et al., 2018), quality certificates (Alamiri, et al., 2014a, 2014b; Razi, et al., 2020) and manpower availability (Kasma, 1987; Al-Besher, 1998; Cheung, et al., 2002; Alamiri, et al., 2014a, 2014b; Razi, et al., 2020). Chinowsky and Kingsley (2009) and Walesh (2012) assessed the impact of this method on project outcomes and found the following: it ensures cost-effectiveness, results in better projects and highly satisfied clients, lowers risk for complex projects, encourages innovation, protects intellectual property, takes account of emerging societal issues, and supports client capacity-building.

3.1.3 Qualification-and-price-based Selection Approach

This method considers the financial proposal and CIC qualification and experience. The process of CIC selection is driven explicitly or implicitly by the natural tensions that occur between service quality and the total cost of that service (Walesh, 2012). Basham (1983) considered the two-envelope bidding approach of CIC selection, where the candidate CIC submits its proposals in two envelopes. The first one is the technical proposal which contains the firm's qualifications, experiences, teamwork involved in project execution and the technical approaches. The second envelope covers financial matters. Basham (1983) contended that the most important considerations of CIC selection for government projects, in particular, are the equities among all candidates, trying to avoid selecting the lowest bidder if there is a factor in selection other than price, and understanding that more competition is certainly in the public interest.

3.1.4 What is the Best Selection Approach?

There are many opinions and conflicts of interest about different selection approaches. The World Bank in 2004 recommended that construction CIC selection factors should focus on financial matters, whereas FIDIC in 2011 recommended that the selection should be more skewed to technical qualifications (Elbarkouky, et al., 2013). According to Basham (1983), in Canada, the Ministry of Transportation and Highways strives to avoid poor quality, while the Treasury Board put value-for-money as the highest priority. Some CICs felt that it would be unethical to provide a cost estimate for an unknown scope of work, while some CICs had no objections to selection based on cost, although they know that financial proposals would be the same due to the similarity in salary rates or fees that the market pays. Using Saudi Arabia as an example, Mohamed, et al. (2016) concluded in their research that 60% of respondents disagreed about selecting the CIC based on offered prices. In another study conducted by Cheung, et al. (2002), they found that CIC fee factor is the least important to for the selection of architectural CICs. Basham (1983) discovered in his study that selection can justly be based on a successful working relationship. In a study conducted by Sporrong (2011), local practices in the US vary widely and selecting the CIC is generally based on qualifications. However, Sporrong (2011) argued that it is difficult to specify and evaluate non-price-related criteria. Kasma (1987) and Sporrong (2011) noted that adequate fee is crucial for high-quality services so that the CIC has the ability to assign qualified staff properly. This consideration on the balance between the fee and qualification reinforces the mixed selection method, especially in light of the high competition and diversity of construction project types and sizes, and the rapid improvements in technology and tools employed in the construction industry.

3.2 CIC SELECTION METHODS

Processes concerning CIC selection methods were proposed by different authors, but no standard method emerged. The Architectural Institute of British Columbia divided these selection processes into two methods: direct selection method and comparative selection method. In the direct selection method, a single CIC is considered based on reputation, recommendation or personal acquaintance or past experience with the client (Assaf, et al., 2002; Cheung, et al., 2002). Moreover, Mohamed, et al. (2016) mentioned that political influence is one of the important factors for awarding a project to a specific CIC in some cases. However, this method is inappropriate if there are two or more CICs having virtually the same factors which subsequently requires a comparative selection method to be undertaken. In the comparative selection method, several CICs are considered and evaluated (Cheung, et al., 2002). Al-Besher (1998) and Assaf, et al. (2002) preferred to further divide this method into two types: competitive selection based on fee proposal, and/or design criteria, and competitive selection based on an objective evaluation of CIC qualifications and technical experiences. These two types are based on the same concept but employ different approaches as explained in the previous section.

Based on the literature review, there are two processes of comparative selection method: interview-based comparative selection process and Multi Criteria Decision Making (MCDM)-based comparative selection process. Awarding a contract that results from an interview is based on recommendations of the selection committee (Basham, 1983; Kasma, 1987). It is executed in three main steps as shown by Kasma (1987), Avila (1997) and Alamiri, et al. (2014a). These are highlighted in more detail below.

Step 1: Request for qualifications (RFQ) - where CICs provide information on their qualifications and capabilities to complete the works of a proposed project.

Step 2: Submit a proposal - the qualified CICs are asked to submit their proposals including project approach, proposed staff, resources and equipment, quality assurance program and project management techniques.

Step 3: Interview - this step involves conducting interviews with three or four chosen CICs from the previous step to present their abilities for completing the project successfully. What they present is then evaluated and scored by the evaluation committee based on certain criteria.

The MCDM-based comparative selection process is applied based on a list of criteria using MCDM methods. Ha, et al. (2015) used the Fuzzy Analytical Hierarchy Process (FAHP) in their study to devise a model for selecting construction project management CIC in Vietnam. They stated that the selection process of CIC should contain two stages: prequalification stage - based on a set of predetermined criteria; and selection stage - selecting the most appropriate CIC from the prequalified list. The process could be done in different and detailed ways. Al-Besher (1998) and Assaf, et al. (2002) proposed a procedure for selecting the CIC using the Analytical Hierarchy Process (AHP) and it consists the following steps: (1) list selection criteria; (2) check for major and common criteria; (3) add and modify criteria; (4) list prospective CICs; (5) prequalify for a shortlist; (6) apply the AHP model; (7) test for consistency; (8) conduct pairwise comparison; (9) synthesize findings for an overall result; (10) rank CICs; (11) select CIC;

(12) negotiate and agree with CIC; and (13) sign a contract. Razi, et al. (2020) studied the CIC selection issues in Malaysia and implemented the same method. Figure 2 outlines the hierarchical structure of CIC selection based on the literature review.

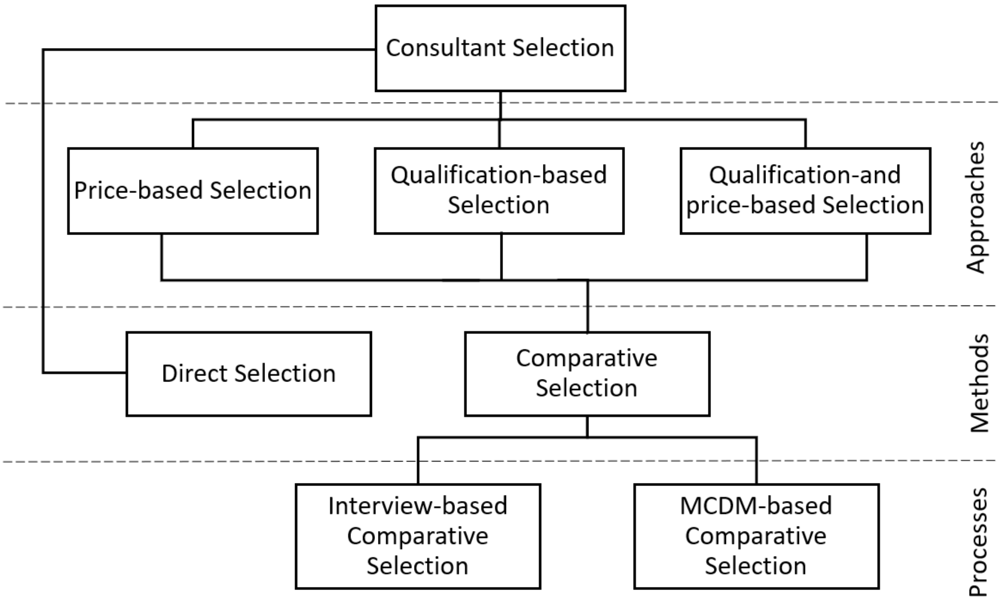

Figure 2: Hierarchical structure of CIC selection

Some studies devised their own selection processes using information technology as a key objective. For instance, Cheung, et al. (2002) developed a multicriteria evaluation model using AHP to tackle interpreting subjective judgements in a systematic and logical way. They developed software called the 'architectural CIC selection system' and written in Delphi 4.0. The software aims to provide an efficient, objective and consistent method for selecting architects in Hong Kong. The selection process using the developed software comprises four steps: (1) determination of project particulars, (2) fee comparison, (3) performance assessment, and (4) computation of the score. In the first step, the client has to take into account the nature of the client, the client's firm size, project type, and contract sum. The second step is comparing the proposed CIC fee by measuring the ratio of the actual amount of the lowest fee to the proposed fee by the candidate CIC. The third step involves evaluating the past performance of the CIC using a five-point rating scale - outstanding, good, average, fair and poor with respective ratings of 1.000, 0.500, 0.250, 0.125 and 0.063. The last step is calculating the scores automatically by adding the normalized weights for the selected ratings of each criterion multiplied by the global priority weight of the criteria.

However, although the authors could tailor the process to take into consideration client and project types and sizes, this method was tailored specifically for the Hong Kong market. Yet it failed to consider internal attributes of the client such as communication skills, commitments, ability to make decisions, and project conditions such as geographical conditions and market variables. Jadid and Idrees (2006) remarked that the selection of CICs is based on their experience, commitment, communications and availability. They presented a strategy for collecting and evaluating information of the CICs through four main steps: data collection, data evaluation, a web designed interface, and transferring information to a neural network model. Omar, et al. (2009) proposed a decision support system to support selection of the CIC using web technology, which consists of a database comprising three modules. The first is the *Operational module* - a simple web searching recommender aims to present few good candidates from the database. The second is the *Managerial module* where every candidate will be reviewed in the managerial module using Hierarchical Fuzzy TOPSIS for prioritizing the CICs. The third is the *Strategic module* which will evaluate and select the best CIC through a technical committee.

4. CONCLUSION

This study conducted a systematic literature review to integrate and analyse existing knowledge derived from various studies on the CIC selection process. Screening of the literature resulted in 23 studies for this study. Information was extracted from them and analysed and specifically these were descriptive and thematic analyses. It has been observed that limited and partial consideration was paid to the CIC selection process. The study concluded with a hierarchical structure of CIC selection as shown in Figure 2. It consisted of three approaches for selecting the CIC: price-based selection approach, qualification-based selection approach and qualification-and-price-based selection approach. These approaches are applied to the comparative selection method, wherein CICs are considered and evaluated based on one of two process types: Interview-based comparative selection process and MCDM-based comparative selection process. The other CIC selection method occurs through direct selection and it involves a single CIC being considered based on reputation, recommendation, personal acquaintance or past experience with the client. However, while there are different opinions and conflicts of interest about what is the most appropriate approach and method, the authors conclude that choosing the appropriate CIC selection approach, method and process depends on client and project conditions. Studies on the CIC selection process and factors are rare. Future study is recommended on factors and criteria of CIC selection.

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STATE OF THE ART IN RISK SENSITIVE URBAN DEVELOPMENT: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Risk-sensitive urban development is an innovative planning approach that can transform the way cities are built in order to face the uncertainties that arise from climate-induced disaster risks. There are many actions taken by individuals, households, communities, urban development companies and relevant regulatory bodies to manage the risk through the risk sensitive urban development methods. However, there is a disconnection between the existing urban development projects and urban risk management process. Therefore, urban developers and disaster risk managers should understand each other and collaborate in order to provide a solution for this disconnection. In this regard, identifying the state of the art of a risk sensitive urban development is beneficial for both urban development and disaster management authorities to achieve their objectives. This study therefore explores the state of art revealing indices, models, concepts, tools and approaches which guide both urban developers and disaster managers to achieve risk sensitive urban development. A systematic literature review using PRISMA method covering the publications from 2017 to 2022 was carried out to identify the state of the art in risk sensitive urban development. Having followed a systematic filtering process, a total of 45 out of 281 research contributions have been considered for an in-depth analysis. The study found storm surge disaster loss (SSDL), GRaBS assessment tool and early warning systems as the key approaches of risk sensitive urban development which can lead both urban developers and disaster managers to synchronise their ideas to achieve risk sensitive urban development.

Keywords: *Climate Change; PRISMA; Risk Sensitive Urban Development; Urbanisation.*

1. INTRODUCTION

Populations in rural areas move to cities in search of employment and better living conditions since there are existing infrastructure encourages investment in industry and commerce; increased standards of health and nutrition; increased life expectancy and lower infant mortality; the perception that the city offers better education, training, employment and leisure opportunities; and the occurrence of natural and human induced hazards in rural areas (Malalgoda and Amaratunga, 2015). Matsuoka and Shaw (2014)

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have explored that urban population, urban setting, urban structures, compact urban forms, and urban dependence on rural areas, urban primacy, urban informal settlement, urban economic imbalances, urban services, urban natural environment, urban built environment, and urban governance and management lead to urban risks and major challenges for Asian countries in future. According to Deely, et al., (2010), people are concentrating in large cities with poor housing with lack of basic protective infrastructure, hence will cause to generate higher urban risks. Further, the authors fear that this urban risk may be a major challenge for humankind in the 21st century.

"Risk-sensitive urban development is an innovative planning approach that can transform the way cities are built in order to face the uncertainties that arise from climate-induced disaster risks" (Roslan, et al., 2021). According to United Nations Economic and Social Council (2015), risk-sensitive development involves integrating disaster risk reduction into development planning across all sectors of development that help to protect gains made towards achieving development goals. Furthermore, it is promoted in order to reduce existing risk in the city and to properly address risk while planning new developments, which is typically done in the context of uncertainties and threats (Jones and Preston, 2011). The risk sensitive urban development, focused on more appropriate building design, construction and land-use planning, enhanced infrastructure access and maintenance, risk awareness raising, and planning for emergency response and reconstruction including social safety nets and insurance (Leck, et al., 2018a). There are several frameworks such as Sendai Framework, Hyogo framework, Community Resilience Framework (CRF) and Sri Lanka Comprehensive Disaster Management Programme (SLCDMP) which provide guidance to risk sensitive urban development projects (Saja, et al., 2020). Those frameworks have identified and designed several strategies such as hazard vulnerability and risk assessment, risk knowledge and risk governance, policy environment and legal/institutional framework, multi-hazard early warning and effective dissemination, disaster mitigation and DRR mainstreaming into development, reconstruction and rehabilitation, training and awareness, preparedness and response, and monitoring and evaluation which can be used for a risk sensitive urban development (Malalgoda and Amaratunga, 2015; Republic of Palau, 2016; Saja, et al., 2020; Yang, et al., 2021)

There are many actions taken by individuals, households, communities, urban development companies and relevant regulatory bodies to manage the risks through the risk sensitive urban development methods. However, there are gaps between what they have expected and what they have accomplished under risk sensitive urban development. The ability of urban cities to effectively manage their urban risks and well-being of the population, sustain balanced growth, and tackle climate change impacts is not only determined by sector legislation but also by the framework of outdated urban regulations that is still in force (Asian Development Bank, 2015). Moreover, it has been explored that, there is a disconnection between the existing urban development projects and urban risk management process. Pelling, et al., (2017) has also pinpointed that urban planning in many parts of the world, but particularly in developing regions, has become increasingly disconnected from contemporary urban challenges linked to rapid urbanisation, poverty, informality, spatial fragmentation and climate change. In order to provide a solution for this disconnection and the climate change risk, urban developers and disaster risk managers should communicate and collaborate with each other to move to risk sensitive urban development. This study explores the state of the art in risk sensitive urban development by analysing the currently used models, concepts, indices and approaches. The state of the art refers to the study on a phenomenon based on the level of development that has reached at a particular time, where the development can be in the form of a device, procedure, process, technique or science. Accordingly, the systematic literature review is followed to explore the state of art in the risk sensitive urban development. The next section discusses the research methodology adopted. Then the analysis of systematic literature review is presented followed by the conclusions.

2. RESEARCH METHODOLOGY

A systematic literature review was used to explore the state of art in risk sensitive urban development. A systematic literature synthesis was conducted by adopting Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) mainly to explore the research question of "What is the state of the art in risk sensitive urban development?" which was developed using the PICO (Population, Intervention, Comparison, and Outcomes) approach (Aslam and Emmanuel, 2010). The PICO approach provides a sound basis for formulating the research question and defining the keywords for the literature survey from the terms included in the research question. Following the PICO approach, the first step was to construct a logic grid (Table 1) and conduct an initial search using the key terms in the grid. Alternative terms or synonyms for the identified concepts were then added by scanning the titles and abstracts of retrieved articles in this initial search to populate a comprehensive logic grid (Table 2). According to Taylor (2017) a comparison is not always required or appropriate depending on the type of research question. As such the Comparator (C) component was neglected in this study since there is no comparator to compare with the intervention in the research question. Table 2 provides a comprehensive search strategy consisting of both keywords/free-text words and index terms. Accordingly, the index terms of the study were searched from the list of keywords offered by the initial literature search. As the final step in developing key terms for the search, search-field descriptors and wildcard characters were applied to the identified keywords and index terms in the logic grid (wildcards are indicated by the '*' sign in Table 2).

Table 1: Initial logic grid aligned with the PICO elements of the review question

Population	Intervention	Comparator	Outcome
Urban development	Risk sensitive urban development	-	State of the art

Table 2: Logic grid with identified keywords added

Population	Intervention	Comparator	Outcome
Urban development	Risk sensitive urban development		State of the art
Urban*	Hazard sensitive		Modern*
Sustainab* development	Disaster sensitive	-	New*
	Flood sensitive		
Land development	Landslide sensitive		
Urban water management	Ecological sensitive		
	Environment* sensitive		

Population	Intervention	Comparator	Outcome
	Vulnerab* sensitive Urban* sensitive		

Once all the search terms were collected and finalised, the final search strategy was developed. Initially, the key terms and synonyms in the logic grid were combined using Boolean operators: 'OR' to combine words/phrases within a column; 'AND' to combine words/phrases in different columns. Subsequently, the second search was undertaken across all the selected citation databases with the use of the developed search strategy shown in Figure 1.

"**State of the art**" OR "modern*" OR "new*" AND "**risk sensitive**" OR "hazard sensitive" OR "disaster sensitive" OR "flood sensitive" OR "landslide sensitive" OR "ecological* sensitive" OR "environment* sensitive" OR "vulnerab* sensitive" OR "urban* sensitive" AND "**urban development**" OR urban* OR "sustainab* development" OR "land development" OR "urban water management

Figure 1: Literature search strategy developed for the study

Once the final search was conducted, the search strategy was further refined by selecting relevant filters under search fields, publication year, subject/research area, document type, and language (Refer Table 3).

Table 3: Filters assigned for the literature search

Categories	Filters
Search Fields	Title, Abstract, Keywords
Publication Year	From 2017 to 2022
Document Type	Article, Proceedings paper
Language	English

After defining the scope of the research and search strategy, the next step of the systematic literature review is database selection process. The search was conducted within two highly recommended databases such as Scopus and Web of Science. These databases allowed a literature search within a broad range of international scientific journals, as well as in high-ranking conference proceedings. Furthermore, a Google search was also conducted to identify non-journal sources such as periodic reports issued by subject-related organisations. Finally, all the records generated from the above-mentioned databases were imported to the Mendeley software for screening and systematic analysis.

Having conducted the search strategy on the above-mentioned databases, 271 articles were identified and 2 duplicates were removed. From the 269 articles 136 articles were removed by referring the title of the paper, 37 articles were removed by referring the abstract and 56 articles were removed after reading the full research paper. After removing the non-suitable articles, 40 articles were selected from the main databases and 5 articles were added from the Google search. Finally, in depth literature synthesis was carried out on the 45 articles that were selected for analysis. The following section elaborates the state of art in risk sensitive urban development based on the systematic review of literature.

3. STATE OF THE ART IN RISK SENSITIVE URBAN DEVELOPMENT

Table 4 presents the outcome of the systematic literature review undertaken on 47 scientific articles. The key approaches used in risk-sensitive urban development are presented in Table 4.

Table 4: Approaches used in risk sensitive urban development

Approach	Description	References
3D Ecological Footprint Model	3D Ecological footprint model has been developed to measure natural capital utilisation pattern which directly affects the urban environment. The model has three dimensions such as Ecological Carrying Capacity Intensity ($EC_{intensity}$), Ecological footprint depth (EF_{depth}) and Partial Least Squares (PLS) model. EC intensity was calculated to optimize the accounting of ecological carrying capacity (EC) and EF depth and EC intensity were quantitatively investigated and influencing factors were further explored based on a partial least squares (PLS) model. The findings of the above-mentioned 3D model could provide guidance for risk sensitive urban development.	(Wang, et al., 2020; Ress and Wackernagel, 1996; Wackernagel and Ress, 1997; Galli et al., 2012; Wood and Garnett, 2009)
Malmquist - Luenberger (M-L) index	M-L index has been developed to analyse the changes in efficiency and the impact of technological innovation on risk sensitive urban development, and give policy recommendations to promote risk sensitive urban development.	(Wang, et al., 2020; Hong, et al., 2017)
Mobile Mapping System (MMS) with 3D GIS Model	3D Geographical Information System (GIS) support urban planners and consumers to improve their spatial perception and awareness of urban areas. In the long term, it is hoped that this work will help the public or increase community-engaged participation for additional urban planning. Currently, Mobile Mapping Systems (MMS) with 3D GIS are used to create precise and detailed 3D city modelling, which gives essential information for planning the urban development projects. 3D city modelling allows urban planners and the public to understand the areas of interest in the urban design-context in a spatial, timely, and virtual manner. Various approaches for building textures for a 3D model exist, e.g., 3D city modelling can use airborne images, airborne light detection and ranging (LiDAR), ground-based or vehicle-borne sensing techniques, and combinations of these.	(Yang, 2019; Kilicoglu, 2022; Wei, et al., 2020; Afzali, et al., 2021)

Approach	Description	References
Environmentally Sensitive Areas Index (ESAI)	Environmentally Sensitive Areas Index (ESAI) was developed to identify areas vulnerable to the threat of desertification. Variables and thematic indicators such as climate, soil quality, land use, amount of plant cover and management are included in the ESAI.	(Uzuner and Dengiz, 2020 ; Ding, et al., 2021)
Storm surge disaster loss (SSDL)	Storm surge is one of the most severe marine disasters in the world and it is affecting the whole coastal area. Therefore, to prevent from storm surge disasters, estimating the storm surge disaster loss (SSDL) is very useful and it will support the risk sensitive urban development process. When estimating the storm surge loss, hazards of the project, disaster causing factors, the vulnerability and resilience of disaster bearing bodies are considered. Accordingly, when planning an urban development project, the estimation of SSDL is beneficial as it provides a basis to make the decisions about project.	(Zhang, et al., 2022; Jin, et al., 2020; Guo, et al., 2022)
Marine Ecological Red Line (MERL)	Coastal marine ecosystems are sensitive to anthropogenic stressors and environmental change. The Chinese Government proposed an ecosystem-based marine spatial planning scheme called the "Marine Ecological Red Line" (MERL), which aimed at protecting ecologically sensitive areas. The assessment and mapping of ecosystem sensitivity provide important tools for regional MERL and setting conservation priorities. This model provides details to decide which area is suitable to develop an urban development project. It gives an operational approach to provide relevant scientific knowledge on the process of ecosystem-based marine spatial planning, and facilitates policy-making decisions in marine management with risk sensitive urban development.	(Hu, et al., 2019 ; Lu, et al., 2015)
Standardised Precipitation - Evapotranspiration Index (SPEI)	This index is explained about the impact of climate change on Land degradation and desertification (LDD) by detecting the temporal oscillations in drought in the context of climate change, and it is therefore a reliable climate parameter for this method. At present, LDD is one of the greatest environmental challenges caused by climate change resulting mainly from anthropogenic activities. SPEI is pointing to a link between not only environmental sensitive areas and climate change, but also the impact of other factors, such as vegetation, topography and soil. Therefore, the details received from SPEI is valuable for the risk sensitive urban development.	(Perović, et al., 2021; Stajkowski, et al., 2021)

Approach	Description	References
Early warning system	In order to face the uncertainties that arise from climate-induced disaster risks there is an urgent need of early warnings system. Through this system, people can be aware about the risk and prevent the risk before it leads to a disaster. As such, early warning system is a beneficial approach, for the risk sensitive urban development.	(Wang, et al., 2018; Ding, et al., 2021; Leck, et al., 2018b)
Driving-Pressure-State-Influence-Response (DPSIR) Model	Driving-Pressure-State-Influence-Response (DPSIR) model is based on environmental early warning system which combines three aspects such as ecology, resources, and environment. DPSIR model also includes human activities, stress, and environmental state, impacts on ecosystems, human health, and political responses. First, the DPSIR model covers important elements of economy, society, resources, and environment, which can clearly and simply reflect the relationship between the environment and other factors, thus it can provide a scientific theoretical basis for policymakers. Secondly, it not only indicates the influence of society, economic development, and human behaviour on the consumption of resources and ecological environment, but also shows the feedback of human behaviour and its final lead to the state of resources and environment, which makes the whole system a cycle. Thirdly, it provides a basic framework for the construction of the environmental index system which is suitable for early warnings and the assessment of the environment. Lastly, its evaluation process is relatively easy to operate and use, which brings convenience to scientific researchers. Therefore, when countries go for a risk sensitive urban development this model will be very useful in minimising the risk of urban areas.	(Wang, et al., 2018 ; He, et al., 2019; Stajkowski, et al., 2021)
Sustainable design	Urban designs that consider regional climatic conditions are one of the most important approaches in risk sensitive urban development. The design of the urban development should be developed by considering the climatic conditions of the area.	(Watanabe, et al., 2017; Petrea, et al., 2021; Ding, et al., 2021; Petrea, et al., 2021)
Climate change risk assessment tools	Assessment of climate change risks and vulnerability is essential in order to inform and implement appropriate adaptation strategies. Assessment of climate change risk helps to improve the resilience of urban areas since, it is provided information to develop strategies to reduce future risks associated with climate change impacts. There are several climate change risk assessment tools such as decision-making frameworks, portals or platforms and screening models. These tools are used to manipulate and visualise the general risk or impact of the climate change.	(Lindley, 2009; Malalgoda and Amaratunga, 2015, Shaw., 2009; Archer, 2016)

Approach	Description	References
GRaBS assessment tool	GRaBS has been developed as a collaborative, innovative, cost effective and a user friendly assessment tool to highlight the climate change risks and vulnerabilities in urban areas in order to aid the strategic planning and delivery of climate change adaptation responses.	(Lindley, 2009; Malalgoda and Amaratunga, 2012; Kazmierczak and Handley, 2018)
Community engagement	Community views have been identified as one of the major approaches that can be used when planning an urban development project. Community is the party who is facing the risk of urban development projects and their views and suggestions will be very useful to reduce such risks to create a risk sensitive urban development project.	(Archer, 2016; Abeje, et al., 2019; Archibald, et al., 2017; Malalgoda and Amaratunga, 2012; Ding, et al., 2021)
Smart urban plans	Smart urban planning is an innovative method of risk sensitive urban development since it is planned to develop all the urban facilities by considering the environmental aspects.	(Kaur and Garg, 2018; Yang, 2019; Abid, et al., 2021)

According to Pei, et al. (2022), when analysing the impacts of urbanisation on cities' adaptation to climate events, the fitting effects of these approaches were far better than those of traditional development approaches which is not considered the risks related to the urban development. The approaches discussed in Table 4 have emphasised the ways of urban development with minimal impact to the environment. Among the identified risk sensitive urban development approaches, storm surge disaster loss (SSDL), GRaBS assessment tool and early warning systems directly address disaster risk reduction while providing guidance to both urban developers and disaster risk managers. Whereas other approaches are focusing on mitigating the disaster risks during the urban development projects. Moreover, it has been highlighted that community engagement to the risk management process in the urban development projects will be one of the major approaches that will lead to a risk sensitive urban development.

Figure 3 shows the conceptual framework on the state of the art in risk sensitive urban development that was explored through this study. The framework presents the identified risk sensitive urban development approaches that can minimise the disconnection between urban development and disaster risk management activities. The main beneficiaries of this study are the key stakeholders related to disaster management and urban development authorities who should work together in creating risk sensitive urban development projects.

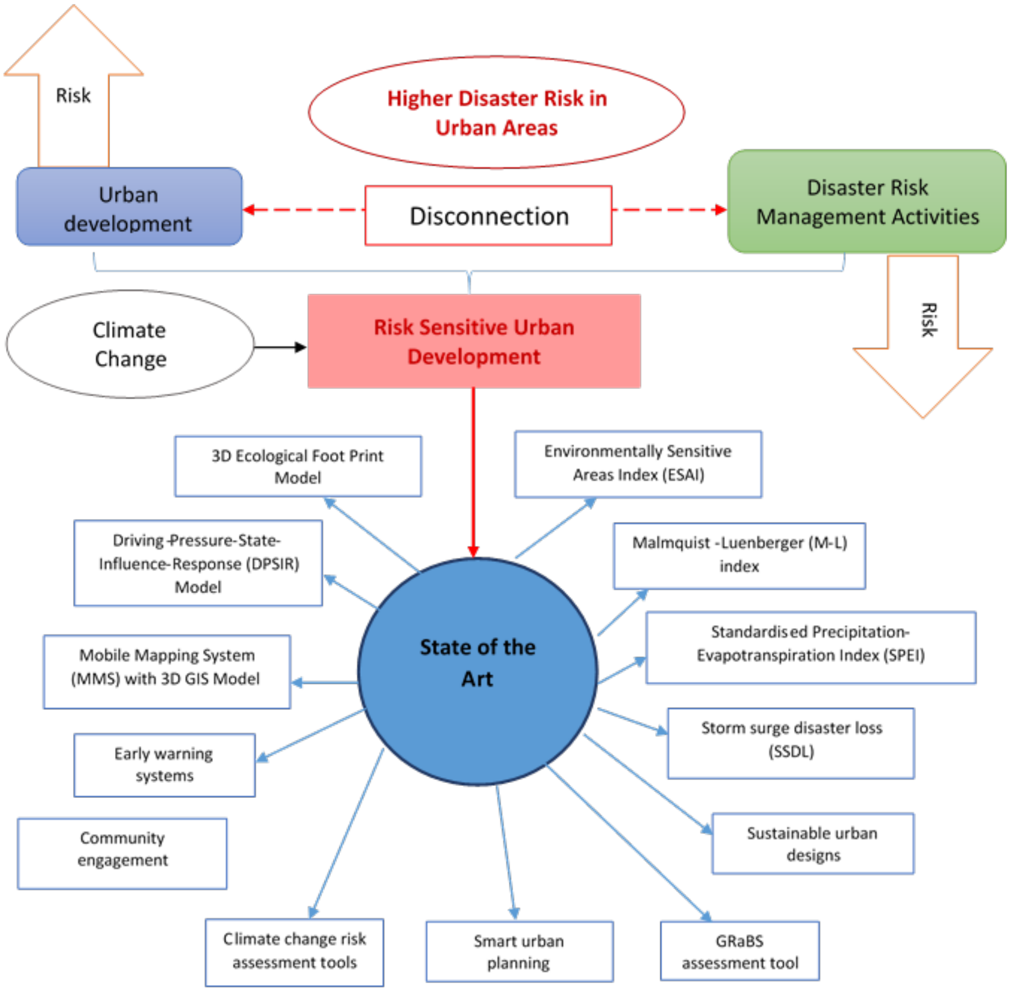

Figure 2: Conceptual framework

4. CONCLUSIONS

The increasing vulnerability of urban areas to disasters has been recognised in recent years, due to the rapid urbanisation and unplanned urban development without considering the urban risks. In providing a solution for this issue, urban development and disaster management activities needed to be linked to establish a risk sensitive urban development. This research conducted a systematic literature review to establish a sound understanding on the state of the art in risk sensitive urban development. This research explored several approaches for risk sensitive urban development; they are 3D ecological foot print model, Malmquist -Luenberger (M-L) index, Mobile Mapping System (MMS) with 3D GIS Model, Environmentally Sensitive Areas Index (ESAI), Storm surge disaster loss (SSDL), Marine Ecological Red Line (MERL), Standardised Precipitation-Evapotranspiration Index (SPEI), Early warning system, Driving-Pressure-State-Influence-Response (DPSIR) Model, Sustainable design, Climate change risk assessment tools, GRaBS assessment tool, Community engagement and smart urban plans. Accordingly, the approaches presented in this paper illustrate the considerable potential for urban planners and disaster managers to support a transition towards a more integrated vision, process and practice of risk management. Thus, the findings of this study are beneficial to the stakeholders who are involving in both urban development and disaster management to make informed decisions in creating risk sensitive urban development.

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STRATEGIES ADOPTED BY DESIGN AND BUILD CONTRACTORS TO ENHANCE THE IMPLEMENTATION OF SUSTAINABLE CONSTRUCTION PRACTICES

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ABSTRACT

Despite of design and build (D&B) procurement being a feasible solution, the status of the implementation of sustainable construction practices (SCP) in the Sri Lankan construction industry is below the trend. Since unwillingness and unawareness of the D&B contractors have identified as a cause for the issue, strategies to overcome the problem are required. Accordingly, an extensive literature review was conducted to identify the SCP, and D&B concepts to provide a basis for a reliable set of strategies. Subsequently, the survey strategy under the qualitative research approach was accompanied to derive strategies. Accordingly, collected data from nine expert interviews from the purposively selected clients, contractors, consultants, and subcontractors have been analysed using deductive thematic analysis under eight main pre-defined themes. Appointment of a sustainability manager, market survey to recognise the status of sustainability, concern on passive construction technologies and identification of sustainable design requirements have identified as key strategies. Finally, this can be used by D&B contractors to identify the loopholes and enhance sustainable development.

Keywords: *Design and Build (D&B); Strategies; Sustainable Construction Practices (SCP).*

1. INTRODUCTION

Sustainability concerns the long term performance (Saunders and Hughes, 2018) to accomplish the needs of the present generation by maintaining the potential for future generation to accomplish their needs (Visser, 2017). It is a procedure planned for people, the planet, and prosperity with the aim of strengthening collaborative partnerships and development (United Nations, 2015). Consequent to the high resource demand in the construction industry, its focus on sustainability has increased (Ahuja, 2013). Sustainability has structured on the maintenance of the equilibrium in social, economic, and environmental aspects to maintain consistency in the persistent world (Roufechaei, et al., 2015). Since society, economy, and environment have become the key aspects to be kept in equilibrium, they have been recognised as the triple bottom lines of sustainability (Zuo, et al., 2012).

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According to the views of Akadiri, et al. (2012), and Goh, et al. (2020), the status of sustainable development in the construction industry is depraved. An extension of project schedules, knowledge deficiencies, less integration of stakeholders (Ahn, et al., 2013; Tokbolat, et al., 2020), and the fragmented nature of construction activities (Goh and Rowlinson, 2015) lead to the cause. Subsequently, Solaimani and Sedighi (2020) intensify the necessity of incorporating sustainable construction practices (SCP) to minimise negative influences. To strengthen the view, Gebre (2011) demonstrates the importance of structured planning and early involvement of the design team, and the concern for SCP in the design and development stage is vital (Majdalani, et al., 2006; Wang, et al., 2012; Zuo, et al., 2012).

Construction procurement is a prominent construction activity, which is oriented toward forecasting the future to create and manage the construction contracts (Ruparathna and Hewage, 2015) from the inception of the project. It is a key concern to accomplish the constructability of a project (Turina, et al., 2008), which ensures the successful implementation of construction techniques (Mathonsi and Thwala, 2012). Construction procurement has expanded over the years as separated, integrated, and management-oriented (Masterman and Masterman, 2013), which is later on classified as traditional, design and build (D&B), management related, and collaborative (Jaafar and Nuruddin, 2012; Rahmani, et al., 2017). Among the variety of available construction procurement systems, D&B is the widely used procurement method to ascertain sustainable construction requirements (Chen, et al., 2016; Rubasinghe et al., 2019). It is an effective project delivery method, that is practised with a single entity for both the design and construction phases of a project (Xia and Chan, 2012).

Even though the D&B procurement has been suggested as a favourable technique to successfully incorporate SCP, less implementation of SCP is noted in the construction industry (Molavi and Barral, 2016). Weerasinghe and Ramachandra (2018) assert less implementation of sustainable practices in the Sri Lankan context. Despite being a crucial participant in construction projects, several limitations have resulted in the less adaptation of SCP by construction contractors (Hwang, et al., 2018). Further, Karunasena et al. (2016) establish a similar argument, emphasising the deficiencies in willingness and awareness of the contractors as a key cause to hinder the implementation of SCP. Accordingly, this study investigates the strategies to be adopted by D&B contractors in enhancing the implementation of environmental, social, and economic SCP in Sri Lanka.

2. LITERATURE REVIEW

2.1 SUSTAINABLE CONSTRUCTION PRACTICES

Feasibility of economy, awareness, sustenance from project stakeholders, policies and regulations, ability to operate in a sustained framework, reduced resource risks, and project management models are the criteria that influence to derive the SCP (Gan, et al., 2015). Accordingly, a variety of SCP have revealed in literature sources, which are structured under the three pillars of sustainability: social, economic, and environment.

Hakkinen and Belloni (2011) emphasise SCP which support all three pillars of sustainability as efficient use of resources, the reduction of harmful emissions, managing cost and productivity over the life cycle, and enhancing the performance of the stakeholders. Significantly, Durdyev, et al. (2018) and Tokbolat, et al. (2020) have identified enhancement of health and safety, uplifting cultural values, favourable interaction with the community, widening of stakeholder relationship channels, providing quality output, and acquiring reputation and recognition on projects as the SCP with social impact. Serpell, et al. (2013) and Goh and Rowlinson (2015) illustrate SCP with an emphasis on the economy as conducting an economic feasibility study at the initial stage to acknowledge the life cycle cost of building, initiating cost-efficient construction practices, developing the proposals concerning the viability, and accomplishing competitive advantage. Furthermore, efficiency and conservation of energy, water, and resources, reduction of waste generation and active recycling of construction waste, the reduction of chemical generation, and environmentally friendly energy technology have identified as environmentally SCP (Manoliadis, et al., 2006; Ahn, et al., 2013).

A recent study by Tokbolat, et al. (2020) highlights the importance of the integration of SCP under the three pillars as the construction industry impacts the environment, significantly contributes to the economy, and provides the infrastructure to society. Hence, a collective investigation to amplify the status of the practice of SCP is vital and this study has structured it under the concepts of D&B procurement as themes.

2.2 DESIGN AND BUILD PROCUREMENT

D&B is a project delivery method that incorporates a single contract for both project design and construction (El Wardani, et al., 2006; Lam, et al., 2008). In the attribute of the contractor, D&B procurement increases the responsibility of the contractor within a fixed budget (Ramabodu and Verster, 2012). Further, Chan, et al. (2005) have emphasised that a D&B contractor performs the role of a designer, design manager, and contractor in D&B procured projects. Accordingly, there are a huge amount of duties to be performed by the D&B contractor.

Minchin, et al. (2013) have depicted that the emergence of the concept of sustainable construction, has strengthened the practice of D&B procurement consequent to its' feature of integration. Furthermore, the integration of two main aspects of a construction project, "design" and "construction" has provided D&B projects with positive impacts (Seng and Yusof, 2006) on sustainability. The key concepts of D&B procurement can be identified under the main categories of time, cost, quality, complexity, technical expertise, responsibility (Suratkon, et al., 2020), knowledge, and communication (Muriro, 2015).

2.2.1 Concepts of Design and Build Procurement

D&B projects exhibit different concepts in major attributes of a construction project. As evidence from the mentioned literature, the summarized concepts of D&B procurement have stated in Table 1.

Table 1: Key concepts of D&B procurement

Source	Category	Concept
(Seng and Yusof, 2006; Lam, et al., 2008; Chen, Jin, et al., 2016)	Time	• Shorter the duration of the construction project • Early commencement of activities • Use of fast tracking
(Chen, Xia, et al., 2016; Saaidin, et al., 2016)	Cost	• Mitigate cost overruns • Cost certainty • Fewer variation orders

Source	Category	Concept
(Lam, et al., 2008; Al Saudi, 2011; Suratkon, et al., 2020)	Quality	• Low cost • Ability to meet quality targets • Satisfaction in terms of function and aesthetic • Low mechanism to ensure quality and integrity
(Davis, et al., 2008; Gambo and Gomez, 2015; Ghamdamsi, 2016)	Complexity	• Less control of the employer over the detailed design • Integration of design and construction • Appropriate for complex projects
(Seng and Yusof, 2006; Al Saudi, 2011; Gambo and Gomez, 2015)	Technology	• Easy application of innovation and the latest technology • Higher level of specialisation • Advantageous for constructions with more technological inputs
(Davis, et al., 2008; Xia and Chan, 2010)	Responsibility	• Solo point responsibility • High involvement of the contractor • Requires clients' provision of information
(Seng and Yusof, 2006; Lam, et al., 2008; Suratkon, et al., 2020)	Knowledge	• The ability of multiple design options for the client • Use of both contractor's and consultant's knowledge at one firm to improve buildability • High understanding of the contractor regarding the design
(Xia and Chan, 2010; Muriro, 2015; Ghamdamsi, 2016)	Communication	• Eliminate second hand blames • Increase team spirit • High interaction between the client and the contractor

Overall, insufficient strategies for D&B contractors to successfully implement sustainable construction practices, extend this study to discuss the strategies for the successful utilisation of D&B procurement by contractors to enhance the implementation of SCP.

3. METHODOLOGY

Creswell (2014) has stated that the qualitative approach as the most appropriate approach for the exploration and understanding of factors related to human and social issues. Further, Myers (2009) has intensified that it helps the researcher to collect meaningful data on people's actions, beliefs, and motivations. Accordingly, a qualitative research approach with a survey strategy was utilised in this study to investigate the research problem. The reason for the selection of the approach was the necessity to conduct an in-depth exploration of the combination of two different attributes to extract rich and valid opinions. Since the researcher focused to identify strategies for the contractor to successfully contribute to promoting SCP by capturing a vivid set of opinions and experiences of the experts in the relevant sector, a survey strategy was incorporated.

A comprehensive literature review was conducted to identify the SCP, D&B procurement concepts, and the role of the contractor in D&B procurement. Polonsky and Waller (2018) insist that the consideration of correctness, reliability, applicability, and volume of data required are vital in selecting the data collection techniques. Accordingly, for the process of data collection expert interviews were considered appropriate. Concerning the saturation of data obtained, nine semi-structured interviews were conducted with experts in the construction industry. Consequent to the deficiency of strategies in D&B procurement to address SCP in the global context, semi-structured interviews were utilised for the data collection. The guideline was structured under the main categories of D&B procurement concepts. The respondents were provided with examples of SCP in the construction industry, to get a general idea about the scope. Then, they were requested to provide strategies for contractors to successfully adapt the mentioned SCP, by utilising the key features of D&B procurement. Here the researcher mentioned the key concepts under each theme to obtain a versatile set of findings. The questions were raised under each theme of D&B procurement as the findings will be helpful for contractors to identify the possible strategies with the applicable concepts of D&B procurement.

To ensure the validity and reliability of the strategies provided, experts in the construction industry who have versatile knowledge of both aspects with the minimum experience on two sustainable projects and five D&B projects were selected as experts. The selection criteria were defined considering the status of SCP and D&B procurement in the Sri Lankan construction industry and respondents were selected through purposive sampling. Respondents from all attributes of the client, the contractor, the consultant, and the subcontractor were selected to eliminate the biased strategies. Table 2 presents the profile of the experts selected for the data collection.

Table 2: The profile of the respondents

Respondent	Discipline	Organization	Industry Experience	Sustainable projects	D&B Projects
R1	Senior Consultant (Structural Engineer)	Consultant	41 years	More than 10	More than 50
R2	General Manager Operations (Civil Engineer)	Contractor	26 years	More than 10	More than 40
R3	Civil Engineer	Contractor	18 years	2-5	10-15
R4	Project Chief Quantity Surveyor	Contractor	19 years	2-5	10-15
R5	Senior Technical Officer	Client	31 years	2-5	More than 15
R6	Quantity Surveyor	Contractor	9 years	2-5	5-10
R7	Civil Engineer	Consultant	11 years	More than 10	5-10
R8	Project Quantity Surveyor	Contractor	13 years	2-5	10-15
R9	Quantity Surveyor	Sub-contractor	10 years	5-10	5-10

The deductive approach of thematic analysis was adopted as the data analysis technique as thematic analysis is a popular method to analyse qualitative data findings with the flexibility (Braun and Clarke, 2012). Caulfield (2019) states two (02) thematic analysis approaches: inductive and deductive. This study utilised deductive thematic analysis for the analysis of the findings as the pre-determined concepts of D&B procurement were incorporated to provide a detailed set of findings under each category. Accordingly, the researcher became familiarised with the concepts of D&B procurement to classify the concepts and developed the themes. After, the data collection was conducted with semi-structured questionnaires arranged based on themes. Reviewing process was conducted for the collected data to identify the emerging themes (if any) and the write-up was completed.

4. RESULTS: STRATEGIES FOR D&B CONTRACTORS TO ENHANCE SUSTAINABLE CONSTRUCTION PRACTICES

The respondents suggested distinct ideas for the improvement of the implementation of SCP, through the adaptation of time, cost, quality, responsibility, knowledge, technology, complexity, and communication. However, some strategies were of multiple applicability under two or more categories. Accordingly, based on the status of the involvement of D&B contractors, and their knowledge of the concepts, strategies can be selected and followed.

Early commencement of activities and concurrent design and construction are the two main concepts of D&B procurement that help to manage the time for construction. The construction contractors can use these features in favour of SCP as it allows the contractor to identify the ultimate requirements of the clients in terms of sustainability. Further, consequent to the early commencement, the possibility to practice passive sustainable technologies like incorporating the available land orientation features for the building, is high. It was validated by the view of R3, that *"if contractor occupies early, he takes steps to ensure sustainability from the points at the early stage of control. For example, building orientation in the site can be well designed encountering the practicality of constructing…"*. Moreover, R2, R3, R6, and R9 suggested that the detailed exploration resulted in the contractor filtering the mentioned SCP by the client, based on the time availability and the realism of practising as appropriate. Further, it allows the contractor to schedule the construction program considering the practical barriers and it helps to maximise the incorporation of SCP.

The respondents highlighted the degree of favour provided in D&B projects to apply general cost-efficient options. Accordingly, R5 mentioned that *"I say, all the techniques I mentioned are good to be implemented with any procurement system, but may easy with D&B and can do with high efficacy."* Accordingly, the contractors can explore cost cut options to ensure value for money. Further, with D&B, contractors are provided with the opportunity to conduct a close examination of the project to identify, the prior flags of price deviations, and the costs in terms of sustainability. There is a general perception that the implementation of SCP is costly. However, with D&B, the contractor can contribute to identify additional costs which can be incurred consequent to sustainability and design to tally with costs. Moreover, as per views of R2, R3, R5, R7, and R9, if the contractor is working with a less experienced client, he can introduce more SCP with the idea of their additional costs or savings and can agree on the procedure to handle later stage cost deviations in the beginning. More importantly, the contractor is required to prepare cost reconciliation reports to benchmark the costs consequent to the implementation of SCP.

Quality is a key concern in any construction project and contrast views on the quality of D&B projects have identified through the literature. Accordingly, to take the successful use of quality features of D&B, R2, R4, R7, and R8 demonstrated the importance of expanding the capabilities of the design team with the provision of adequate knowledge of sustainable concepts. R8 expressed a unique view regarding the importance of monitoring the design development simultaneously with the budget schedule to check the affordability of implementing SCP from the initial stage. Moreover, contractors are required to be strict with the quality requirements of the client and inform about possible deviations at the earliest possibility and this can be successfully practised by D&B contractors, as they involve in the construction project from the beginning. Further, ensuring the performance of subcontractors to meet the implementation requirements of SCP is a vital requirement to be performed by D&B contractors.

Construction contracts consider to be complex however, there are mechanisms to adjust flexibility. In the identification of actions of D&B contractors to contribute to enhance SCP, the legal component of the project was considered the most critical strategy. Accordingly, clarification of ambiguous terms and conditions in the contract, actively participating in the establishment of dispute resolution mechanism, and a clear understanding of laws and regulations are important. Further, irrespective of the complexity incurred consequent to the SCP, the contractor requires to be confident in the decisions made. Similarly, with the view of the R2, it was because *"there is no one to pass the ball"*.

Correct identification of the technological concepts and applications of them ensures the success of the requirements of any project. Specifically, R8 depicted that *"contractor permits to fully familiarize of both design and construction technologies moves in parallel with sustainability and therefore can expand the firm and resources…… So…. design-build contractor achieves personal improvements also when try to practice sustainability"*. Further, they can use passive green technologies and expand their knowledge of the latest construction technologies to effectively utilise the technology in the implementation of SCP.

D&B is well known for single-point responsibility and accordingly the project responsibility and the majority of risks are aligned with the contractors. The main strategy identified by the respondents was to initiate a new job role as a sustainable manager to ensure coordination in design and construction. R6 emphasised the importance of the concept expressing that the *"continuation of sustainability is more feasible with one party and clustered responsibility"*. Additionally, the importance of being accountable, developing attitudes towards the sake of the project, and assigning technical responsibilities to parties have been identified as favourable to implement.

The respondents' ideas clearly emphasised the importance of the knowledge of both design and construction teams. Further R9 asserted that *"Sri Lanka is at the initial level of sustainability"* and consequently the role of the contractor is vital. Consequently, construction contractors have to examine the market well in advance before capturing sustainable construction techniques and make the design and construction teams familiarise themselves with the latest concepts and technologies. Specific attention to measuring the competencies of the design team to proceed with sustainability is vital as otherwise, the project failures are unavoidable. More importantly, record keeping is required to proceed smoothly because it is a root for future projects to eliminate the practical barriers. Further, records help to ensure the acknowledgement of organisational staff on emerging concepts.

Communication of D&B contractors in construction projects has identified under three main methods as internal communication of the D&B team, communication between key stakeholders, and communication with external stakeholders. Accordingly, the conduct of morning meetings, keeping shreds of evidence of instructions provided, and feedback to ensure the proper communication between design and construction teams are the strategies to adopt. As the view of R9, the D&B contractors in Sri Lanka have less knowledge on designing to implement SCP.

Figure 1 represents the strategies suggested for the D&B contractors to enhance the implementation of SCP. Accordingly, some strategies overlap among the concepts of D&B procurement, which suggests that even though the status of D&B differs, there are practices that can be collectively used.

5. DISCUSSIONS

Research publications distinctly explore the role of the contractor to enhance SCP and D&B procurement. However, the construction industry of Sri Lanka suffers from the low implementation of SCP which portrays the malpractice of the identified strategies and the unavailability of the combined set of strategies. The findings of the empirical study identified the emerging strategies simultaneously with modifications in the available strategies.

The empirical findings of this research disclose similar ideas to the view of Rekola, et al. (2012), and Holloway and Parrish (2015) that suggest the requirement of making their own company sustainable and simultaneously practising the front end planning approach. It has further supported the idea of Akadiri, et al. (2012) that the strength of the decision making process with timely involvement of stakeholders as a practice for contractors. Further, the view of Riley, et al. (2003) and, Tiwari, et al. (2018) have strengthened through this study. Accordingly, the study identified the importance of value engineering proposals for the effective use of cost and knowledge concepts of D&B procurement. Further, the necessity of effective communication with the subcontractors is also verified through this study.

The outcome of this study to measure the competencies of the design team and familiarise them with the latest technology tally the findings of Tiwari, et al. (2018) which emphasise the balance of knowledge of the team as a strategy for D&B contractors to successfully contribute to D&B procurement. Accordingly, it is proved that some strategies for the success of D&B procured projects can be used for the enhancement of the implementation of SCP. The empirical findings of this study highlighted the importance of documentation and contract administration to effectively manage the complexity and responsibility of the projects. It coincides with the view of Papajohn, et al. (2019), which illustrates the importance of successful contract administration tools. Technological applications in D&B procurement have emphasised as the development of knowledge on technical based integration using Information Technology (IT) based communication systems (Rekola, et al., 2012).

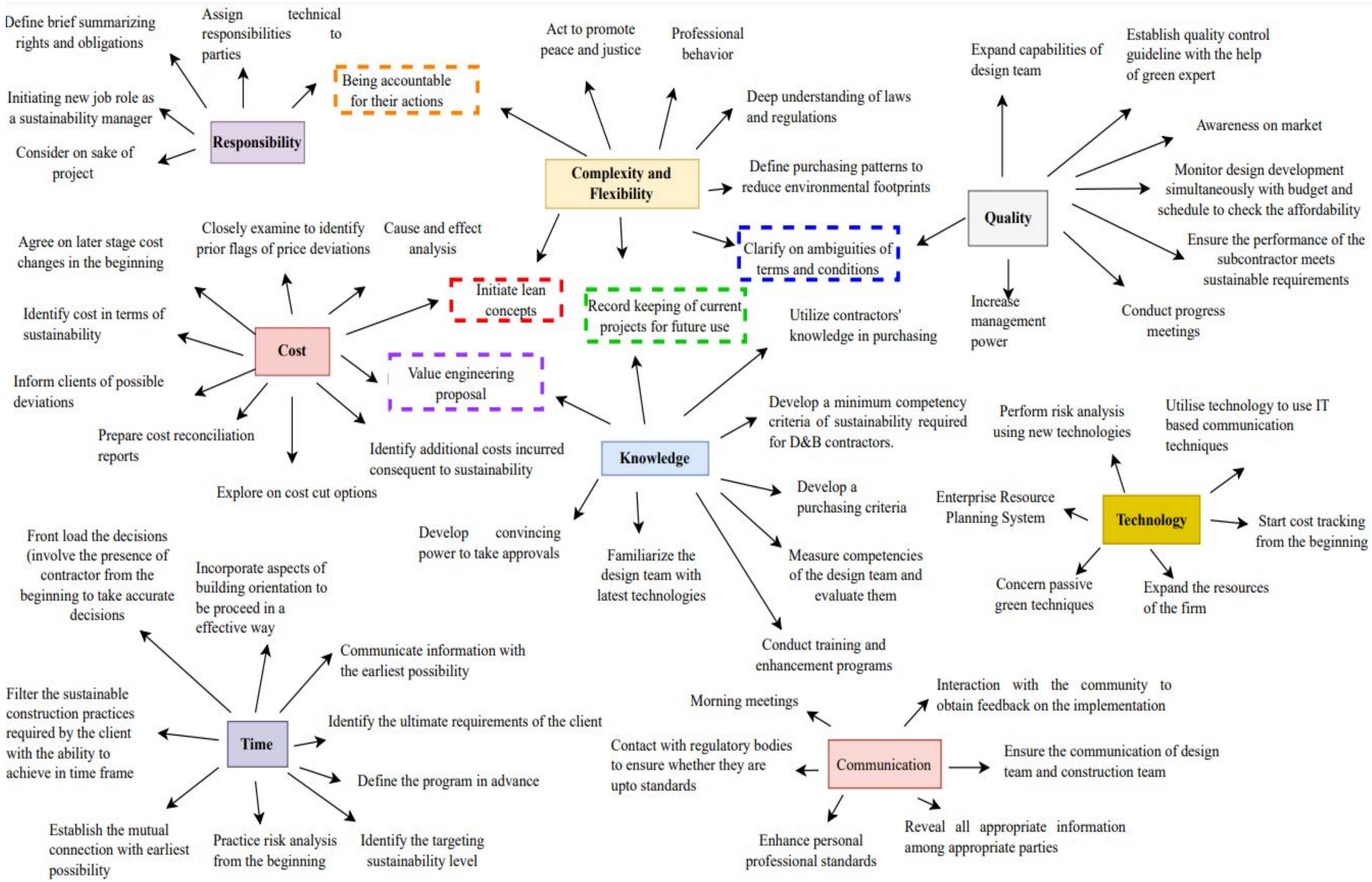

Figure 1: Strategies to successfully implement SCP

This view strengthens the empirical findings and accordingly, it can be positively adopted in the implementation of SCP. Overall, the researcher argues that distinct practices to improve SCP and D&B procurement are competent and can collectively be incorporated as strategies to enhance SCP by D&B contractors.

6. CONCLUSIONS

The dynamic nature of the construction industry creates the necessity for the implementation of SCP to assure sustainability. Even though a variety of actions to be followed have introduced, the implementation of SCP is not at a prolific level. Even though the D&B procurement method also have identified as a suggestion made for the successful practice of SCP, it is not successfully utilising consequent to the less contribution of D&B contractors. Accordingly, the importance of the strategies to follow as a guide has emerged. Strategies and opinions disclosed by nine experts have analysed based on themes to derive strategies that can be adapted based on the nature of the construction project, and the status of the knowledge and experience of the contractor.

Conduct of value engineering practices, strength in the decision-making process, and familiarise with the latest technologies are some prominent strategies which considered favourable to uplift D&B procurement and in this context can also be applied with SCP. Novel strategies of appointing a sustainable manager, a market survey to recognise the status of sustainability, concern on passive construction technologies, and identification of sustainable design requirements have identified as emerging considerations for D&B contractors.

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STRATEGIES TO ENHANCE THE APPLICABILITY OF GRID POWER SOLAR NET METERING CONCEPT IN SRI LANKA

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ABSTRACT

The whole world is utilizing its all-non-renewable energy sources to power their social, economic, and cultural needs. Hence, the significance of renewable energy is considered all around the world at this moment. Especially compared to other renewable energy sources, solar energy shows more reliable and available in the whole world. As a result, the cleanest solar energy makes a huge contribution to the global energy balance. To power the grid with solar energy all countries around the world expanding their technologies related to solar power generation. Accordingly, the net metering concept becomes a platform to inject and strengthen the grid with solar energy. However, some conventional methods such as NCRE power generation facility, DC-AC inverter, and islanding protection system are used to expand the grid-connected solar net metering in Sri Lanka. Therefore, it is required to improve the newly applicable solar net metering expansion strategies. Hence, this study aims to propose suitable strategies for the increment in the application of grid power solar net metering in Sri Lanka. A qualitative research approach was selected to conduct this study. Initially, a literature review was completed. Then, data is collected through semi-structured expert interviews with 4 experts, who have experience and engagement in the solar industry. The collected data were analyzed through manual content analysis. Findings revealed the key driving forces and the barriers to expanding the grid power solar net metering in Sri Lanka. With regards to the identified barriers, the newly applicable strategies have shown a significant amount of importance in Sri Lanka to expand the grid power net metering concept.

Keywords: *Hybrid Inverters; Renewable Energy; Solar Farms; Solar Net Metering; Sri Lanka.*

1. INTRODUCTION

Renewable energy is a rapidly growing energy source, contributing to half of the world's energy consumption growth, and will be the primary energy source by 2040 (BP PLC, 2019). According to Apergis and Payne (2011), the global use of renewable energy for electricity production will increase from an amount of 3% per year and the use of renewable energy by 2.6% per year in the period 2007 to 2035. Coal power generation

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would be a significant source of around 40% of the Global Electricity Generation from 1996 to 2016 (Ceylon Electricity Board [CEB], 2017). Khani, et al. (2018) highlighted that gas power production has risen from 15% to 23%, while the output of oil power has declined from 9% to 3% over the last two decades.

Among those power sources, solar power has achieved the highest degree of attention throughout the world in past years (Malinowski, et al., 2017). Research has shown that world energy requirements can be achieved comprehensively using solar energy because it is available in nature and is a widely available energy source at no cost (Kannan and Vakeesan, 2016).

Solar photovoltaic technologies use the direct transformation of sunlight into electricity (Shivalkar, et al., 2015). The world average solar photovoltaic power generation proportion of 69 % is composed of Sunbelt regions with a typical solar photovoltaic electricity, a portion of 90% (Hoffmann, 2015). Therefore, photovoltaic Cell is now commonly seen as a source of energy in most residential and business premises, safe and renewable energy from available solar energy resources (Pacis, et al., 2016). Introducing solar roofs for middle-income families and linking to the national grid through net metering, paying for excess power generated and fed to the grid, and unblocking people's savings for such a purpose is economically feasible (Dharmadasa, 2016). When the amount of residential solar installations has grown significantly, utilities and other investors have expressed the perception that the Net Metering Policy delivers an incentive to solar power paid to the overall population of tariff payers (Comello and Reichelstein, 2017).

Net metering is an efficient reward program for consumers who produce electricity through their limited alternative energy systems (Sedghisigarchi, 2009). It accounts for the rooftop solar energy supplied back to the grid and can gain credits for all the excess energy supplied back to the grid over a year and can trade them for a financial benefit from the utility (Yue, 2018). Net metering allows the user to store excess energy on the grid instead of storing it in large batteries (Bedhi, et al., 2016). Besides, that net metering creates a market for solar energy systems, which, in effect, creates more jobs for installers, electricians, and manufacturers working in the solar supply chain (Cetin and Egrican, 2011). A well-designed net metering policy provides a precise, low cost, and simple plan to deal with residential photovoltaic systems (Poullikkas, et al., 2013). Historically, inverters used to convert the DC power to AC power were the primary cause of PV(Photovoltaics) malfunctions because the lifetime of an inverter usually does not exceed ten years, and the cost of maintenance is also very high (Barnes, 2013). Throughout Sri Lanka, the period of a net metering contract is restricted to 10 years from the execution date; therefore, there is a confusion that the net metering contract may proceed once the preliminary contract period has been confirmed (Wickramasinghe, 2019). Lack of knowledge or interaction of distributed generation programs and lack of awareness of the quality and advantages of the system among potential clients is holding as other barriers to implementation of solar net metering (Khurana, et al., 2020).

Consumer perception of and adoption of RTPV (Roof Top Photovoltaic) remains the most crucial obstacle in the development of solar energy that has a societal stigma (Eid, et al., 2014). Consumers have not only increased accessibility and perception of consumer rights but have also instigated flexible national policies and applicable subsidies (Matisoff and Johnson, 2017). During a survey awareness of residential heads using the net-metering solar system was studied and results revealed that 77% of the domestic heads surveyed were mindful of energy savings through solar panel installations and the residual 23% were not aware of the gird power solar net metering (Weerasooriya, et al., 2019). Furthermore, studies illustrate that regulatory concerns do not significantly contribute to consumer attractiveness toward net-metered solar PV technology (Luthra, et al., 2015). There are no moderating effects of consumer education level and their social values on the attractiveness of net-metered solar PV (Kumara and Mahakalanda, 2019).

In the Sri Lankan context, a sufficient and expected amount of solar energy is not added to the grid due to the many barriers and interventions in the system; therefore, it is vital to be aware the general public increase the knowledge regarding solar power electricity generation (Apergis and Payne, 2012). However, the relevant bodies open to the solar industry are not adequately informed about these incentives, and the awareness of the grid power solar net metering is doubtful. Besides, several studies and projects for enhancing and developing the grid power solar net metering have been carried out in Sri Lanka. This research has identified the lack of perception among the community that impacts grid power solar net metering, and it proposes the strategies that would increase the application of the grid power solar net metering system. Hence, this study aims to propose suitable strategies for the increment in the application of grid power solar net metering in Sri Lanka.

2. LITERATURE REVIEW

In 2018, the contribution to the global energy demand for electricity production by sources seems to be 38% for coal, 23% for natural gas, 10% for nuclear power, 19% for hydropower, 7% for other supplies (solar, wind, geothermal, biomass, etc.) and 3% for oil (IEA, 2019). In addition, global renewable energy exceeded an amount of 2,351 GW by the end of 2018, of which half was still hydroelectric power. According to IEA (2019), global renewable energy production increased 7% in 2018, with wind and solar PV technologies together making provisions for 65% of this increase. Solar PV generation grew 22 % (+131 TWh) in 2019 and was the second-largest relative generation development among all renewable energies, only behind wind and ahead of hydroelectricity (Bossong, 2019). Therefore, in most countries, the production of wind and solar PV energy has become more cost-effective than the introduction of new coal-fired power plants (World Energy Organisation [WEA], 2019).

In Sri Lanka, the current level of electricity demand is around 12,000 GWh, with a rise from 6.5% to 9% per year (Kolhe, et al., 2015). The Ceylon Electricity Board has stated that Sri Lanka required an estimated 4000GWh by the end of 2025 (Ministry of Power and Renewable Energy, 2017). This amount is expected to be generated by solar power, other renewables, and native energy supplies (Laufer and Schafer, 2011). Figure 1 illustrates the solar electricity generation in recent years in Sri Lanka.

According to statistics in recent years, solar power generation and its use have observed significant improvement and accelerated production (Wijesena and Amarasinghe, 2018). To further enhance the generation of solar PV electricity in Sri Lanka, the Government of Sri Lanka promoted an incremental solar development plan in 2016 to encourage solar power projects in Sri Lanka (CEB, 2018). Following that Sagasolar power plant (10MW), Laughs solar plant (20MW), and Welikanda Solar Project (10MW) are a few industrial-scale solar energy stations that have been installed in the last 3 years (World Bank [WB], 2018).

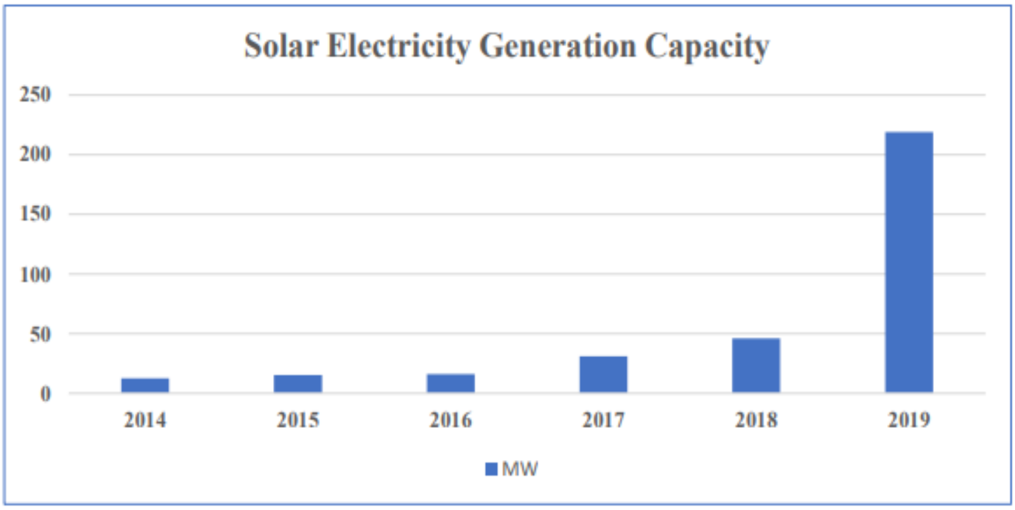

Figure 1: Sri Lanka's solar electricity generation

Source: Ceylon Electricity Board [CEB] (2018)

Grid Solar Power Systems and Net Metering are very popular in the world, particularly in the USA and Europe (Watts, et al., 2015). Many states and other countries in Europe, such as Austria, Belgium, France, Germany, and Denmark, have successfully turned their solar energy into electrical energy and power supply the surplus energy in the grid (Meena, et al., 2014). Many countries that are now generating power from solar panels have changed their off-grid solar systems to on-grid solar systems using net metering (Qamar and Khan, 2016). Small-scale grid-connected photovoltaic systems deliver renewable, carbon-free, and environmentally friendly power generation (Mitscher and Ruther, 2012). Grid-connected PV is commonly viewed as an energy system for developed countries, while independent, stand-alone PV is seen as more appropriate for applications in emerging countries where too many people often lack access to the national electricity grid (Goop, et al., 2017). However, considering the cost of the batteries it is advisable to use a grid connect system over a standalone solar power system in developing countries including Sri Lanka (Kolhe, et al., 2015). According to Hittinger and Siddiqui (2017), through this system, PV panels are installed on the roof or built into the building and the building's energy demand is met. The authors further stated that the grid is connected to the PV network and the surplus electric power is transmitted to the grid. The main advantage of a grid-connected rooftop solar system is when the power generated by the roofing system is used at the same location, the generation and distribution losses are minimized (Saxena, et al., 2017). The key components of the grid connected RTPV network are solar photovoltaic panels, module mounting mechanism, inverter, interconnecting cables and switches, and a net energy meter (Narula and Reddy, 2015).

3. RESEARCH METHODOLOGY

This study aims to propose suitable strategies for the increment in the application of grid power solar net metering in Sri Lanka. To achieve the aim, a brief literature review was carried out to identify the contribution of solar energy to the global electricity system, and the contribution of solar energy to the Sri Lankan electricity system to get an idea about the grid solar power systems with grid power solar net metering through books, conference proceedings, internet, and journals in the first stage of research. Since it is required to collect in-depth information from professionals involved in the solar industry, a qualitative approach was carried out. Even though the aim is stated as the perception of consumers, experts were interviewed to get in-depth knowledge to identify suitable strategies for Sri Lanka to expand the grid-connected solar net metering, which helps to make it benefit the customers. Semi-structured interviews and open-ended questions were chosen in this study. Because it is increasingly realistic, and a lot of data can be obtained in a relatively cost-effective way over a shorter period. The interview guideline is prepared by incorporating the background information about the interviewee, fundamental details of solar billing schemes and grid solar power system application in Sri Lanka and the possible strategies to implement grid power system in Sri Lanka. Due to the unavailability of experts with adequate knowledge in Grid power solar systems and time constraints, the interviews are limited to four experts who have reasonable experience and broad knowledge of the solar panel industry, and experience in the solar panel whole life process in Sri Lanka. Table 1 provides those professionals' profiles selected to conduct the expert interviews. Further, the manual quality review method is used for expert interview analysis. The primary goal of the qualitative content review is to decrease the scale of the broad textual information to a reasonable size (Magenheim, et al., 2010).

Table 1: Profile of the interviewees

No	Profession	Experience	Interview code
1	Assistant Director	8 years	R_A
2	Engineer	7 years	R_B
3	Assistant director	5 years	R_C
4	Engineer	6 years	R_D

4. RESEARCH FINDINGS AND DISCUSSION

4.1 GRID POWER SOLAR NET METERING IN SRI LANKA

According to interviewee RB, Ceylon Electricity Board (CEB) and Lanka Electricity Company (Pvt) Limited (LECO) have given their customers the potential to generate energy and feed into the national grid in Sri Lanka. The current capacity of solar power that the grid is feeding by suppliers is 282MW. RA said *"Grid-connected solar is powered through net metering, net accounting, and net plus. Net metering is not like an investment in the Sri Lankan context. The consumers are intending to just pay off the electricity bill and the export credit will go to subsequent months' consumption. Due to that customer intention and other schemes are available for investment purpose from grid-connected solar power the net metering looks more important and inject more energy than other schemes"*. The respondent RB supports that by mentioning "Net metering powered the grid-connected much more than others". Interviewee RC argues that *"Sri Lankan domestic rooftop solar installations are higher because of that grid power solar net metering is shown a more significance than others"*. According to the respondents' view, solar net metering is highly applied in Sri Lanka and the grid also gets received a considerable amount of power through it.

4.2 DRIVERS AND CHALLENGES FOR IMPLEMENTATION OF GRID-CONNECTED SOLAR NET METERING IN SRI LANKA

Driving forces shows more importance when achieving the established objectives to power the grid with solar energy up to 1000MW in 2025. A mentioned that” the *tariff paying for one unit is attractive”*. Furthermore, C supports that “*The export energy is paying under an attractive and profitable tariff (1-7 years = 22.00, 8-20 years = 15.50 per unit) to the suppliers and it is the major driving force and the challenge to CEB and LECO”*. Respondents R_B and R_D argue that “*This tariff is introduced by the CEB to promote the rooftop solar generation and it is successes up to now. But to continue this much of a rate is costly to CEB and now they are going to give a flat rate to export energy”*. The views of the respondents look a little complex, but they conclude that the tariff paying is crucial to act as a driver in grid-connected solar net metering.

According to R_C, “*The companies available in Sri Lanka are not dealing with a big profit margin due to competition in the market. Therefore, it acts as a driving force to implementation of the net metering concept”*. Moreover, R_D said, “*The competitive solar companies in Sri Lanka is increased in the last decade so the net metering looks more reliable and expanded”*. Therefore, the two interviewees, R_C and R_D mentioned that the solar companies' market structure also enables the solar net metering expansion in Sri Lanka. R_B said, “*The employment is over 8000 in solar net metering in Sri Lanka”*. The employment opportunities in the solar industry are increased and it has grown dramatically in the last decade. Support that “*The local entrepreneurship has expanded through the grid-connected solar power projects”*. According to interviewee R_D, ‘*Policy framework is more stable when comparing with other countries*. R_B insists that “*The regulatory bodies and policy framework are more reliable in Sri Lanka”*. All interviewees support that local entrepreneurship, employment, and a stable policy framework in Sri Lanka act as a driver to expand the grid-connected solar net metering power generation.

According to R_A**,** “*The biggest challenge is on CEB that they have to pay 22.00 per until the supply end from the consumer and it is expensive than other energy sources”*. As mentioned above a driver this tariff rate is introduced to promote grid-connected solar in Sri Lanka. But from another perspective, this tariff rate is a challenge to CEB and LECO. Because when compared with other sources the unit cost is higher on the utility. According to R_B, **“***Solar power is intermittent and there will be sudden drop and fluctuation on solar penetration, therefore, the system monitoring is difficult”*. Similarly, R_A, the interviewee argues that “*Divergence and voltage difference. The solar energy provided by the photovoltaic system depends largely on the abundance of sunlight”*. As an example, “*Areas like Battaramulla in Sri Lanka the voltage imbalance, frequency changes and instability are highly concern by CEB. In this area, the solar energy is prominently available but due to transmission and voltage fluctuations grid-connected solar is in danger sometimes”*. R_A said, “*The solar power is only available in the daytime, and it has to be stored up to a capacity”*. Respondent R_B support it *“Installed battery capacity is depending on the solar radiation and the location. At nighttime the electricity demand is higher, therefore, the export energy in the daytime has to be higher than the nighttime consumption”*. So, the battery capacity is a limitation in grid-connected solar net metering. Furthermore, interviewee R_A emphasized that “*To improve the quality of the system technicians, they need to be aware with knowledge and training”*. Training and development in the industry to expand the grid-connected solar net metering has slowly progressed in nowadays. R_D highlighted that "*Present virus pandemic situation and climate pattern affects much on solar net metering application and development*". Furthermore, R_C said, "*The companies also in the industry have to be stable*". To improve the trustworthiness of the consumers the firms in the industry need to act as a driving force. Current global conditions and trends look challengeable to the expansion of the market.

4.3 CURRENT PRACTICES IN GRID-CONNECTED SOLAR NET METERING IN SRI LANKA

The literature identifies the various types of solar net metering practices and supportive strategies for solar net metering. Moreover, information concerning the existing practices which are unable to collect through literature review was collected through expert interviews. Soorya Bala Sangramaya and Rivi Bala Saviya (Supportive strategy) were identified through both literature and interviews, additionally, Rivi Aruna was identified through interviews.

4.3.1 Sooriya Bala Sangramaya

Under this whole scheme of Soorya Bala Sangramaya Rs.16.00 per unit of electricity, electricity is charged to power plants to get 01MW of electricity from each. Power is supplied from Rs.11.82 to 12.50 at the rate of buying 10MW from power plants. This can be decreased as large-scale solar parks are installed. Under this project, the government paid Rs.22.00 at the first stage and expected solar power generation systems on the rooftops of the customers and earns an income thereof. According to interviewee R_A, *"Soorya Bala Sangramaya is made up of four stages. A variety of initiatives to develop clean energies and power using solar energy have been initiated under this program. In the first point, every user of energy can produce electricity by deploying a photovoltaic solar system on residential rooftops."*. The current capacity and expected grid-powered solar energy capacity from Soorya Bala Sangramaya is illustrated in Table 2.

Table 2: Current capacity and expected grid powered solar energy capacity

Phase	Year	Capacity
I	2010	100MW
II	2017	150MW
III	2020	250MW
IV	2025	700MW

According to Table 2, the solar generation capacity was around 250MW in 2020, and the established goal is to power the grid up to 700MW in 2025. According to the interviewees, the most spread solar net metering practice in Sri Lanka is Soorya Bala Sangramaya. Moreover, R_A and R_D mentioned that "*Capacity of the projects have increased with the development. Relevance to the facilities of the project People can install a solar panel on their roof without obstructions and lengthy procedures*". Therefore, three interviewees mentioned, "*The Soorya Bala Sangramaya become more applicable in the country*". R_C highlights that "*In Soorya Bala Sangramaya net metering scheme is the most used scheme to power the grid with solar power. Net accounting and net plus scheme are looking more forward as an investment so the domestic rooftop solar installations are more used as a grid-connected net metering system*". Furthermore, R_B argues that "*The only difference* *is the solar schemes in Soorya Bala Sangramaya is based on the building type and the customer decision. Therefore, anyhow Soorya Bala Sangramaya is expanding whole over the country with that grid-connected net metering capacity is upgrading".* R_C said that "*Soorya Bala Sangramaya project is designed not only to solar net metering development. The aim is to aware and expands all three schemes and power the grid with solar energy".* Therefore, according to interviews, Soorya Bala Sangramaya becomes the frontline in the solar net metering in Sri Lanka.

According to R_A, "*Prosumers (stakeholders) generating electricity have risen. In Soorya Bala Sangramaya, the prosumer is a client linked to a distribution grid that holds an entity to produce electricity from a renewable source, at which energy produced is used for its use, does not own a certificate for the generation of electricity, and the surplus power is supplied in the distribution".* The opportunity of the Soorya Bala Sangramaya is it expands the stakeholders that produce electricity and power the grid with solar energy. Furthermore, R_A highlighted "*Employment and local market on solar appliances have strengthened".* R_C supports that *"Soorya Bala Sangramaya have expanded the local employment in Sri Lanka".* Therefore, all interviews support similarly with the introduction of Soorya Bala Sangramaya local entrepreneurship, and spare parts market demand has rapidly increased. The growth of the Soorya Bala Sangramaya has been slowed by some limitations in this project. R_A highlighted "*The utility party (CEB, LECO) may incur loss".* The tariff rate (22.00,15.50) paid by CEB, and LECO is high per unit. This is the major cause that CEB has to expend a considerable amount of cost to implement this project. R_B said, *"Solar energy is that it is difficult to calculate precisely the payback period of installing a solar system".* Support that "*Solar radiation is fluctuating and not available consistently. Therefore, the investment on solar is not easy to earn in quick period".* Furthermore, R_C said, "*Government interference is affecting their renewable energy policies. As an example, the newly appointed government looks to expand the wind power plants in Sri Lanka and this could affect capital investment in solar projects.*

4.3.2 Rivi Aruna

Rivi Aruna program has been launched by the Ministry of power, CEB, and SSEA in 2017 to provide solar rooftops to religious places. The total cost of this program was Rs.58 million. 135 solar systems were installed in religious places under the "Rivi Aruna" adding 270KW to the system. The summary of solar installations and capacities is presented in Table 3.

Table 3: Summary of solar installations and capacities

Religious Place	Number	Capacity (kW)
Temples	126	252
Mosque	4	8
Kovil	3	6
Churches	2	4
Total	135	270

According to Table 3, in 2017 to Transform religious properties into rooftop solar power systems by supplying affordable solar panels to chosen religious sites. The surplus power from these ventures is purchased by CEB either by a net metering or a net accounting scheme. R_A highlighted that opportunity of this project is "*This system is become more attractive to people due to viability in many religious places".* The people get aware, and they are going to find out about this project, and it produces new opportunities to expand the grid-connected solar net metering and net accounting schemes. According to R_B, "*CEB launched this program to install solar panels in religious places and observe the beneficially of the energy feed into the grid". R_A* said that *"The Rivi Aruna project becomes successful because the energy consumption of the religious place is low and the export credit energy is high towards the grid".* According to interviewees, they support that the Rivi Aruna program is beneficial and has made opportunities to expand the grid-connected solar systems. R_B argued, "*The main limitation in this system is that capital investment needs to be done by the authority".* R_A insisted that *"Rivi Aruna is a fully government-funded project. Therefore, it is difficult to carry the project whole over the country".*

4.4 SUITABLE STRATEGIES FOR SRI LANKA TO EXPAND THE GRID-CONNECTED SOLAR NET METERING

Current practices in Sri Lanka related to grid-connected solar net metering are identified in sections of the literature review. In addition, literature recognized different practices from professionals who are experts in the solar industry. According to expert opinion, can be further classified into various main sub-topics.

4.4.1 Flat Traffic Rate on Soorya Bala Sangramaya

According to R_A, "Install solar panel on roof with net metering with a fair tariff to consumer and the utility. As an example, encourage Soorya Bala Sangramaya in Sri Lanka with a flat rate that is beneficial to both utility and customer. R_B highlighted that the "Most attractive thing in the Soorya Bala Sangramaya is the tariff rate. The contract agreement of this project is 20 years and an average of Rs.17.75 per 1kW is paid by the CEB. Therefore, the rate needs to be cost-effective to both parties". R_C argues that "In this project Rs.22.00 is paying in first 7 years because the investor needs to get back his investment at a minimal time". All four interviewees seem, to amend the project proceeding with the cooperation of the Ministry of power, CEB, LECO, PUCSL, and SSEA is the easiest alternative to expand the Soorya Bala Sangramaya in Sri Lanka.

4.4.2 Introduction of Hybrid Inverters

Hybrid solar systems combine the best of the grid and off-grid solar systems. These systems can be defined as either off-grid solar with backup power or grid-tiled solar with excess battery capacity. Hybrid inverters, on the other hand, can store energy in batteries as well as provide energy to the grid. R_B highlighted "*Hybrid solar panels are more inexpensive than off-grid solar projects. Customers do not need a backup generator, and the capacity of the battery pack can be reduced. Off-peak power from the grid is cheaper than petrol".* R_A said, "*Sri Lanka has taken steps to approve hybrid inverters in the country through a draft specification published by the Standards Institution (SLSI) this month". R_C* said, "The *regulations and feasibility study regarding the hybrid inverters in Sri Lanka are going to approve in this year".* Moreover, R_C said, "*Authorized for such inverters would mean that Sri Lanka would be able to deploy far more powerful solar systems than those currently in operation".*

4.4.3 Establishment of Solar Farms in Sri Lanka

Apart from residential and commercial schemes, they are dispersed and typically consist of ground-mounted solar panels in built-in wide areas. In certain cases, rather than supplying power to a local end-user such as a resident or a corporation, solar farms supply electricity to the electricity grid and are part of the energy balance of the utility. According to R_A, "*The Sri Lankan Government has launched up the production of solar energy to the private industry through a group entitled 'other' among the defined NRE tariffs proposed on cost-based tariff concepts.'* Furthermore, R_A, said, "*Neither of the privately solar projects was launched, as the tariffs on negotiation rendered all solar projects economically inaccessible"*. R_B highlighted that "*Through this project to approve the 100MW solar farm in Siyambalanduwa, the focus has been placed on the use of barren land not suitable for agriculture or other construction activities for the production of solar energy".*

As an example, "*Territory used to create solar farms offers a safer ecosystem for animals and plants. Land surrounding solar panels are usually wetland that can be preserved with trees and bushes*". Solar farms earn a strong return on investment, particularly when utility bill reductions, maintenance costs, and the encouragement of steady income are considered." R_C said to argue, "*Solar farms will require a lot of lands. Solar farms need a lot of sunny, unlocked space that could need some property to be cared for. This may cause some backtracking results that are not environmentally sustainable like deforestation and habitat loss".* Therefore, to expand the grid-connected solar net metering connections, the establishment of solar parks is a good strategy.

4.5 DISCUSSION OF FINDINGS

The findings include the introduction of grid power solar net metering in Sri Lanka, drivers and challenges for the implementation of grid-connected solar net metering, current practices in grid-connected solar net metering, and strategies to expand the grid-connected solar net metering. According to the literature findings grid integration barriers, lack of clearly allocated institutional responsibility, and financial barriers are identified as the significant challenges for the implementation of grid-connected solar net metering. However, the interviewees highlighted the high prices of solar PV technology, the solar subsidy program, policy makers' constraints, hegemony of power providers, financial incentives for rooftop solar installations, and other conceptual and technological limitations as challenges to the implementation of grid-connected solar net metering in Sri Lanka.

Literature findings emphasized that there are several drivers to expand the grid-connected solar net metering in Sri Lanka. Similarly, interviewees highlighted that net metering initiatives, the advantageous and beneficial tariffs for producers, competitive solar firms in Sri Lanka and local enterprises, jobs, and a sound policy system in Sri Lanka are indeed the drivers to implementing grid-connected solar net metering in Sri Lanka. Further, the respondents and the literature findings revealed that Soorya Bala Sangramaya, Rivi Bala Saviya (Supportive strategy), and Rivi Aruna are the current practices in grid-connected solar net metering in Sri Lanka. Moreover, suitable strategies are provided to expand the grid-connected solar net metering in Sri Lanka. The strategies include a flat tariff rate on Soorya Bala Sangramaya, the introduction of hybrid inverters, and the establishment of solar farms in Sri Lanka.

5. CONCLUSIONS AND RECOMMENDATIONS

Increasing demand for renewable energy is the key cause of the extension of traditional net metering growth policies, and the industry is looking to introduce new practices to extend grid-connected net metering. From traditional solar net metering to developing activities such as industrial policy, government legislation, and mechanisms, market understanding, information creation, promotion, and financial subsidies, the environment is heading towards fresh concepts such as VNM and feed-in tariffs. As a result, attention has risen in developing counties. Developing countries including Sri Lanka are increasingly defining and seeking to extend the grid-connected solar net metering in the coming concepts. The drivers for expanding the grid-connected solar net metering power generation in Sri Lanka were identified through expert interviews. Local entrepreneurship, employment, and a stable policy framework in Sri Lanka act as a driver to expand the grid-connected solar net metering power generation. However, several challenges such as the tariff rate, battery capacity, present Covid-19 pandemic situation, lack of training and development, and climate pattern were identified as the challenges for the implementation of grid-connected solar net metering in Sri Lanka. To overcome the identified challenges, suitable strategies are proposed to expand the grid-connected solar net metering in Sri Lanka. Accordingly, the Flat tariff rate on Soorya Bala Sangramaya, the introduction of hybrid inverters, and the establishment of solar farms in Sri Lanka are the strategies proposed to mitigate the prevailing challenges.

Further, grid power solar net metering policymakers and deploying solar panel entities, both suppliers and consumers, will benefit from the final research as follows. Using the findings of the research, the effect of current grid power solar net metering practices and the influence of emerging methods to enhance grid power solar net metering will be defined, preparing policies and guidelines for grid power solar net metering expansion to implement in the solar panel industry. Research findings can be used as a study material when leading awareness programs on-grid power solar net metering.

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STRESSORS OF QUANTITY SURVEYORS WORKING ON-SITE: FEMALE VS MALE

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ABSTRACT

The World Health Organization has identified stress, which can cause a devastating effect on the emotional and physical wellbeing of a person, as the health epidemic of the 21st century. Occupational stress is a severe problem among male and female professionals. This study aimed to compare the significant stressors of male Quantity Surveyors (QSs) working on-site with their female counterparts. A mixed approach consisting of a series of interviews and a questionnaire survey was adopted to collect the data required for the study. Purposive sampling was used to select the interviewees and questionnaire survey participants from among the QSs working on-site for contractors. Heavy workload/overtime/inflexible work was identified as the most significant stressor of both male and female QSs. Heavy domestic responsibilities and inadequate earned income were the second most significant stressor of female and male QSs, respectively. Shortcomings of the tendering process (document discrepancies, under-priced quotations) were the third most significant stressor for male and female QSs, though not mentioned in the literature. The study findings revealed that the stressors affecting male and female QSs working on-site must be considered separately.

Keywords: *Contractor's Quantity Surveyor; Female; Male; Site; Stressors.*

1. INTRODUCTION

Stress is "the non-specific response of the body to any demand", (Selye, 1975). According to Fink (2016), the World Health Organization has identified that stress can have a devastating effect on a person's emotional and physical wellbeing, and it is the health epidemic of the 21st century. O'Driscoll and Dewe (2001) identified stressors as work environment characteristics that cause strain. Accordingly, strain is the poor psychological or physical wellbeing caused by stress. Ill health, anxiety, and burnout are examples of strain that could result from workplace stressors (Webster, et al., 2010). Several studies have investigated the sources of stress (Johnson, et al., 2005), called 'stressors', in the construction industry (Leung and Chan, 2012).

Malagris and Fiorito (2015), as cited in Costa and Pinto (2017), identified the stress experienced by professionals as occupational stress. According to Salam (2016), stress can negatively impact the work quality of a professional. Abdullah, et al. (2013) stated that being a construction professional, a quantity surveyor (QS) working in a construction project has to minimise project cost and achieve value for money while meeting the required standards, which is a challenging task. Bowen, et al. (2013) highlighted that 98%

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of the QSs working in South Africa are not satisfied with their jobs despite being entitled to overtime payments. They underpinned that 86% of the QSs working in the country believed that increasing the time spent with their families and on personal activities would enhance their job satisfaction. Only a few past studies have dealt with the work stress of QSs (Bowen, et al., 2013; Panojan, et al., 2019; Chan, et al., 2020). Even those studies have considered the QSs generally without focusing on the QSs working for consultants or contractors.

The job roles of the QSs working for contractors and those of the QSs working for consultants are different (Lee and Cullen, 2018). Unlike a consultant's QS, a contractor's QS works at the head office or on-site, where the work is complicated, stressful, and accountable (Mbachu, 2015; Towey, 2017). Contractor's QSs (both male and female QSs) working on-site could have a stressful working environment because they perform many tasks within a limited period to achieve the project's cost, time, and quality targets (Mas-Machuca, et al., 2016).

Gender becomes vital in any discussion on the stress management of construction professionals (Love, Edwards, and Irani, 2010) since female professionals also work in the construction industry. As opined by Bowen, et al. (2013), the stress level of a QS depends on the gender of the QS. This gender dependence on stress is due to the different roles played by male and female QSs in their jobs, families, and personal lives (Panojan, et al., 2019). As the traditional family became a dual-earner family, scholars studying work stress became concerned about the impact of gender differences on workplace stress (Mason, 1995; Bowen, et al., 2013; Lup, 2017; Ojo, et al., 2019). Within this context, the industry would value an in-depth study on gender-related stressors of QSs because the stressors are gender-dependent and comparing the stressors of male and female QSs based on gender would be necessary. Therefore, this study compares significant stressors of male and female QSs working on-site for contractors.

The paper is structured as follows: First, the literature review and the adopted research method are presented. Next, the results obtained by analysing the collected data are presented and followed by a discussion.

2. LITERATURE REVIEW

2.1 CONTRACTOR'S QUANTITY SURVEYORS WORKING ON-SITE

The construction industry is a high-speed, dynamic, complicated, and crisis-ridden industry (Leung and Chan, 2012). In the construction industry, profit margins are narrow, and construction schedules are tight, while project delays and time overruns cause serious financial repercussions (Lingard and Francis, 2004). Consequently, construction professionals have to deliver safe projects on time and within the budget. Project work is stressful due to its dynamism and uncertainty (Asquin, et al., 2010; Mohr and Wolfram, 2010). The stressfulness of project work makes construction professionals criticise themselves and wish that their next projects would be different (Enshassi, et al., 2018).

According to Badu and Amoah (2004 cited in Okeke, et al., 2018), a QS is a construction professional who can analyse both the cost components and physical construction works of a project successfully so the analysis results can be used to solve the problems specific to each project. According to Seely, et al. (2009), and Dada and Jagboro (2012), as cited in Ranasinghe, et al. (2018), QS is a professional who adds value primarily to the financial and contract management of construction projects during pre-construction, construction, and post-construction stages of projects through contributing to overall project performance by acquiring, enhancing, and deploying the required competencies adequately. Okeke, et al. (2018) studied the four main construction stakeholders who employ QSs: constructing firms, consulting firms, academic institutions, and the civil service.

According to Lee and Cullen (2018 as cited in Perera, et al., 2021a), a considerable difference exists between the job roles of QSs working for contractors and those working for consultants. Nisansala, et al. (2018) have cited that the basic duties of contractor's QSs would be estimating and tendering, post-contract administration, sub-contractor selection, evaluation and payments, preparation of interim applications, conducting negotiations, preparation of claim reports, and preparation of final accounts and agreements (Abiramy, et al., 2016). Similarly, Ashworth, et al. (2013) identified that a contractor's QS must look after the financial interests of the contractor and work in conjunction with the project QS when preparing interim payments and final accounts.

A contractor quantity surveyor's role extends further than the day-to-day running of a building project, covering sub-contract formation, forecasting of costs and values of the project, cash flow forecasting, and the collation of the operation and maintenance manuals of the project (O&M Manuals) (Jongo, et al., 2019). Further, the quantity surveyor is likely to have extensive dealings with subcontract organisations, including the bulk of work and managing their demands for payment and claims (Ramus, et al., 2006). During the post-contract period of a project, a contractor's QS is most likely to be involved in commercial project activities and project and contract administration to deliver the project (Towey, 2017). On-site construction personnel, in particular, are required to work long hours, even during weekends (Lingard, et al., 2007, as cited in Perera, et al., 2021). Thus, site QSs also will have to work long hours, being on-site personnel. Mas-Machuca, et al. (2016) reported that long working hours would affect a person's work-life balance.

2.2 STRESS AND STRESS MANAGEMENT

The word *stress* is derived from the Latin word *stringere*, which means to *draw tight*. (Oladinrin, et al., 2014; Ross, 2020). Ross (2020) mentions that in the 14th century, the term "stress" was associated with adversity, hardship, or some type of affliction. In the 17th century, stress was described as hardship, strain, adversity, or affliction (Oladinrin, et al., 2014). Fontana (1989), as cited in Chow (2009), defines stress as those challenges that excite us and keep us on our toes, and without stress, life for many people would ultimately become dull and not worth living. This study focussed on the harmful effects of stress which could be overcome by managing it. Jeffrey (2006) defined stress as a state of cognitive, emotional, and physical arousal (Oladinrin et al., 2014), which links up in the perspective of the human body. Kalia (2002) and Spielberger et al. (2003) identified stress as an epidemic (Ajayi, et al., 2019). Thus, its management deserves attention. Greenberg (2002) mentions that the goal of stress management should not be to eliminate stress but to learn how to manage and use it effectively.

2.3 STRESS/STRESS MANAGEMENT: MALE VS FEMALE

Bowen, et al. (2013) opined that QSs are highly stressed, and their stress levels vary with gender. According to Loosemore and Waters (2004), in the construction industry, the sources and levels of stress differ statistically and significantly between males and females, although they also have similarities. Researchers, mostly feminist researchers, pinpointed that in dual-career households, men are more likely than women to let their job commitments limit their family work, whereas women are more likely than men to take time off (often at very short notice) to attend to unexpected family demands (Coltrane, 2004). A study among counsellors in domestic call centres of Korean financial institutions found that work-family conflicts have a significant effect on female workers' job stress in call centres and on reducing internal motivation (Jeon, et al., 2022). Ojo, et al. (2019) disclosed a significant difference in the perceptions of males and females on the usage of all identified stress response strategies except continuing professional development, offloading/delegation of work, time-off work, specialist assistance, sports, exercises, or hobbies, and leaving the organisation to join another organisation.

2.4 IMPORTANCE OF IDENTIFYING STRESSORS

A stressor refers to a threatening or challenging event that can cause stress (Lazarus, et al., 1984; Selye, 1956). Stressors in working environments are defined as *job stressors* (Nixon, et al., 2011; Brockman, 2014; as cited in Leung and Chan, 2012). Johnson et al. (2005) cited five sources of stress using Cooper and Marshall's (1976) ASSET - a shortened stress evaluation tool.

Different occupations have different stressors, such as the threat of violence, lack of control over work decisions or extended working hours (Johnson et al., 2005). Stressors, such as time pressure, are causal triggers of strain reactions, such as irritation (Rauschenbach, et al., 2013). Leung and Chan (2012) categorised the stressors of construction professionals into four categories:

- *interpersonal stressors,* such as the perceived personal traits of the locals, the perceived work traits of the locals, language barriers, poor workgroup-related relationships, home-work conflicts,
- *task-related stressors,* such as qualitative work overloads, quantitative work overloads, role ambiguities, and role conflicts,
- *organisation-related stressors,* such as organisational formalisation, organisational centralisation, organisational complexity and lack of organisational support, and
- *physical stressors* such as general living conditions, transportation, and wage differentials.

According to Wallace (2007), many people are unaware that daily hassles like traffic jams are linked to hypertension, migraine headaches, ulcers, heart attacks, depression, and death. A relationship exists between the causal effect of work stressors on human wellbeing (Ganster and Rosen, 2013).

According to Chan, et al. (2016), stress coping behaviours impact the construction professionals' health and their subsequent tasks and organisational outcomes directly. Identifying mental stressors would help the government, health institutions, and policymakers develop a preventive policy to tackle the stressors (Tijani, et al., 2020). Thus, identifying stressors is essential to cope or managing stress.

Worral (2010) stated that women are faced with white, male-dominated organisational cultures in the United Kingdom (UK) construction industry. Ness (2012) revealed that in the UK construction industry, women could do most construction jobs. The dominant ideology about who does what work appears to be challenged but strongly classed and gendered roles in society and the job market are actually reproduced. Furthermore, a study on construction professionals in Spain revealed that almost all women interviewed acknowledged that balancing work and family life was a severe problem (Navarro-Astor, 2011).

In today's social, economic, and political environment, masculine discourses and practices, and even their macho celebrations, dominate organisations and institutions, and the impact of the feminist movement has surfaced a reactionary backlash now (Knights, 2019). Sunindijo and Kamardeen (2017) revealed that women professionals in the Australian construction industry suffer from anxiety and acute stress more than their male counterparts. However, the symptoms of depression do not significantly differ between the two genders. Tijani, et al. (2020) found that socio-psychological factors can affect gender-related stressors in an organisation. Therefore, it is evident that a distinct difference exists between stressors and reasons for stressors according to their gender. Thus, this study separately considered males and females.

3. METHODOLOGY

A mixed approach was used to collect qualitative and quantitative data for the study. Selecting a research approach depends on whether the research problem is of exploratory, explanatory, descriptive, predictive, evaluation, or historical type (Grover, 2015). First, a literature review was conducted to identify the concept of stressors stress, stress management, and the link with gender differences in the construction industry.

Yin (2006) stated that the mixed approach could help find answers to different research questions, covering the requirements of quantitative and qualitative data collection, analysis, and interpretation. Therefore, both interviews and questionnaire surveys were employed for data collection. Semi-structured interviews, which help collect qualitative information, lead to a thorough understanding of the research question (Saunders, et al., 2016). Forty-seven stressors common among construction professionals were identified from the literature. The interviews were held with construction experts with more than 15 years of on-site experience working for contractors. The sample included 15 male and 15 female QSs. Each face-to-face interview lasted for 45-60 min. The interviewees and questionnaire survey respondents were selected via purposive sampling. Semi-structured interviews helped to identify whether the common stressors identified in the literature impact on-site QSs.

A questionnaire survey is a suitable method of data collection when the respondents are knowledgeable in the subject concerned and competent to answer any subject-related question (Preston, 2009). Questionnaires were distributed among 300 contractors' QSs working in sites within and outside Sri Lanka. Purposive sampling was used to select QSs to participate in the survey based on their professional qualifications, experience, and knowledge. The sample included 150 female and 150 male QSs. From the 300 questionnaires distributed, 211 completed questionnaires were returned (more than 70% of the distributed questionnaires) by 102 female QSs and 109 male QSs. Table 1 presents the details of the questionnaire survey respondents.

According to Elo, et al. (2014), content analysis is a systematic and abstract process of analysing the information generated through interviews, observations, and diaries. Hence, the interview findings were analysed using manual content analysis to identify the stressors specific to site QSs. As stated by Roszkowska (2013) and Madushika et al., (2020), the Mean Weighted Rating (MWR) can rank factors according to their importance level. Thus, the present study used MWR to analyse the data collected from the questionnaire survey. Warmbrod (2014) emphasised that the score yielded on the Likert scale by a factor is its composite score given by individual respondents. Thus, the sum of the mean values of each rating value can be obtained on a scale. Chyung, et al. (2017) confirmed that Point 3 on a 5-point Likert scale represents neutrality. The positive responses would score 4 or 5 (Dawes, 2008). Thus, stressors that had an MWR equal to or above 4.0 were considered significant stressors and ranked.

Table 1: Details of the questionnaire survey respondents

Work Experience (Years)	**0-5**		**6-11**		**11-15**		**16-20**		**Total**	
Designation	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
QS	18	19	5	5	2	2			**25**	**26**
Senior QS	11	11	13	12	6	5			**30**	**28**
Chief QS	8	6	7	8	10	10	3	4	**28**	**28**
Contracts Specialist	2	1	6	6	2	1	5	3	**15**	**11**
Commercial Manager			3	2	2	3	4	4	**9**	**9**
Assistant General Manager							2		**2**	
Total	**39**	**37**	**34**	**33**	**22**	**21**	**14**	**11**	**109**	**102**

4. FINDINGS AND ANALYSIS

4.1 SIGNIFICANT STRESSORS AFFECTING ON-SITE MALE QUANTITY SURVEYORS WORKING FOR CONTRACTORS

Thirty-seven stressors were identified from the literature as stressors for professionals and validated through the interview outcomes of the selected sample of male quantity surveyors who have on-site experience working as contractor QSs working on-site. Some 20 stressors were confirmed by the interviews applicable to the male QSs working on-site for contractors, ten were removed as they are not applicable to the QSs work on-site, seven factors were modified, and ten new factors were identified by the interviewees. Therefore, the questionnaire considered 37 factors identified from the literature.

Table 2 presents the stressors of male QSs working on-site for contractors ranked according to the answers given in 109 questionnaires received from male site QSs. The ranking was made according to the MWR of each stressor. The stressors not mentioned in the literature but introduced by the interviewees are marked in bold italicised text in Table 2.

Table 2: Significant stressors of male QSs working on-site for contractors

Rank	Male	MWR
1	Heavy workload/overtime/inflexible work	4.900
2	Inadequate earned income	4.837
3	***Shortcomings of the tendering process (document discrepancies, under-priced quotations)***	4.766

Rank	Male	MWR
4	***High employee turnover (Departing employees and difficulty in maintaining job continuity)***	4.722
5	***Unplanned/frequent changes made to employer requirements***	4.695
6	Need to shoulder responsibility without authority	4.633
7	***Poor information flow (Improper coordination with head office, lack of details and delays in approving variations and issuing drawings)***	4.605
8	***Inadequate attention paid to site safety***	4.548
9	Behaviour of supervisor/colleagues/subordinates	4.511
10	***Poor planning by QSs***	4.487
11	The pressure exerted by superiors	4.423
12	***Clients' lack of knowledge***	4.341
13	***Lack of employee motivation, welfare, and performance evaluations***	4.300
14	***Obsolete technologies used at sites***	4.261
15	***Favouritism/Discrimination at work***	4.000

Thus, heavy workload/overtime/inflexible work is the most significant stressor of male QSs working on-site for contractors. According to Lingard, et al. (2007), as cited in Perera, et al. (2021), on-site construction personnel must work long hours, even during weekends. The second most significant stressor of male QSs working on-site for contractors is the inadequate earned income. Thus, even though QSs can work overtime and earn an additional income, they appear to be dissatisfied with their total income. Only the QSs and other construction professionals working at the head office of the contractor or consultant are involved in the tendering process; on-site QSs are not involved in the tendering process. Nevertheless, the stressor, shortcomings of the tendering process (document discrepancies, under-priced quotations) introduced by the interviewees, has become the third most significant stressor of male QSs working on-site for contractors.

4.2 SIGNIFICANT STRESSORS AFFECTING ON-SITE FEMALE QUANTITY SURVEYORS WORKING FOR CONTRACTORS

Thirty-nine stressors were identified from the literature as stressors for professionals and validated through the interview outcomes of the selected sample of male quantity surveyors who have on-site experience working as contractor QSs working on-site. The interviews confirmed some 22 stressors applicable to the female QSs working on-site for contractors, and eight were removed as they are not applicable to the QSs working on-site. Nine factors were modified, and the interviewees identified ten new factors. Therefore, the questionnaire considered 41 factors identified from the literature. Table 3 lists the stressors of female QSs working on-site for contractors, ranked according to their level of significance obtained using their MWRs. The MWRs of the stressors were calculated using questionnaire survey findings. The stressors introduced by the interviewees are presented in bold and italic text.

Thus, even in the case of female QSs working on-site for contractors, *heavy workload/ overtime/inflexible work* is the most significant stressor. Asquin et al. (2010) and Mohr and Wolfram (2010) have stated that construction professionals (responsible for the safe delivery of projects on time and within the budgets) find project work stressful due to the dynamic and uncertain nature of project work.

Table 3: Significant stressors of female QSs working on-site for contractors

Rank	Female	MWR
1	Heavy workload/overtime/inflexible work	4.900
2	Heavy domestic responsibilities	4.837
3	***Shortcomings of the tendering process (document discrepancies, under-priced quotations)***	4.766
4	***Poor information flow (Improper coordination with head office, lack of details and delays in approving variations and issuing drawings)***	4.722
5	Uncomfortable/unfavourable working environments	4.695
6	***Inadequate attention paid to site safety***	4.633
7	***Favouritism / Discrimination at work***	4.605
8	***Comparison of oneself with those with the same qualifications and working for other contractors***	4.548
9	***Unplanned/frequent changes made to employer requirements***	4.511
10	Behaviour of supervisor/colleagues/subordinates	4.487
11	***Lack of employee motivation, welfare and performance evaluations***	4.423
12	***Lack of support from family members***	4.341
13	***The pressure exerted by superiors***	4.300
14	***Obsolete technologies used at sites***	4.261

Heavy domestic responsibilities were the second most significant stressor of on-site female QSs working for contractors. The literature identified this factor, which was validated by the interviews for female site QSs working for contractors. Hochschild (1997) claims that although both men and women may prefer to get away from childcare responsibilities by spending time at the office, society expects women to look after the children, making them less committed to work than men.

As in the case of male QSs, the *shortcomings of the tendering process (document discrepancies, under-priced quotations)* is the third most significant stressor of female QSs working on-site for contractors.

4.3 GENDER-WISE COMPARISON OF SIGNIFICANT STRESSORS OF QSS WORKING ON-SITE FOR CONTRACTORS

Table 4 lists the stressors of both male and female site QSs working for contractors in descending order of their significance level. The stressors were ranked based on their MWRs. The stressors identified in the interviews but not mentioned in the literature are presented in italic, bold text. The shaded cells contain stressors that are not common to male and female QSs.

The first two most significant stressors of male and female QSs were identified from the literature and validated for site QSs working for contractors. The third most significant stressor was common to female and male QSs, and identified only in the interviews; the literature does not mention this factor.

Table 4: Significant stressors of QSs working on-site for contractors

Rank	Female	MWR	Male	MWR
1	Heavy workload/overtime/ inflexible work	4.877	Heavy workload/overtime/ inflexible work	4.900
2	Heavy domestic responsibilities	4.839	Inadequate earned income	4.837
3	***Shortcomings of the tendering process (document discrepancies, under-priced quotations)***	4.805	***Shortcomings of the tendering process (document discrepancies, under-priced quotations)***	4.766
4	***Poor information flow (Improper coordination with head office, lack of details and delays in approving variations and issuing drawings)***	4.780	***High employee turnover (Departing employees and difficulty in maintaining job continuity)***	4.722
5	Uncomfortable/unfavourable working environments	4.736	***Unplanned/frequent changes made to employer requirements***	4.695
6	***Inadequate attention paid to site safety***	4.110	Need to shoulder responsibility without authority	4.633
7	***Favouritism/Discrimination at work***	4.688	***Poor information flow (Improper coordination with head office, lack of details and delays in approving variations and issuing drawings)***	4.605
8	***Comparison of oneself with those with the same qualifications and working for other contractors***	4.646	***Inadequate attention paid to site safety***	4.548
9	***Unplanned and frequent changes made to employer requirements***	4.609	The behaviour of supervisor/colleagues/subordin ates	4.511
10	The behaviour of supervisor/colleagues/subordin ates	4.531	***Poor planning by QSs***	4.487
11	***Lack of employee motivation, welfare and performance evaluation***	4.500	Pressure exerted by superiors	4.423
12	***Lack of support from family members***	4.444	***Clients' lack of knowledge***	4.341
13	***Pressure exerted by superiors***	4.392	***Lack of employee motivation, welfare and performance evaluation***	4.300
14	***Obsolete technologies used at sites***	4.109	***Obsolete technologies used at sites***	4.261
15			***Favouritism/Discrimination at work***	4.000

The study findings indicate that heavy workload/overtime/inflexible work is the most significant stressor of both male and female site QSs working for contractors. It was mentioned in the literature and validated at the interviews for site QSs working for contractors. The second most significant stressor of female site QSs is heavy domestic responsibilities, mentioned in the literature and validated in the interviews for female site QSs working for contractors - it was not among the significant stressors of male site QSs working for contractors. Manzoni (2012) revealed that some women employed in the construction industry had left the industry because of maternal responsibilities. The study findings indicate that most of the identified stressors are common to both female and male QSs of contractors.

5. CONCLUSIONS

Contractor QSs working on-site have to bear heavy workloads and attend to inflexible work because of tight project targets. Consequently, they are compelled to work overtime to achieve tight project goals. The interviewees could identify several stressors not mentioned in the literature but applicable to site QSs working for contractors. Evidently, some stressors are unique to males, such as, Inadequate earned income, High employee turnover (departing employees and difficulty in maintaining job continuity), Need to shoulder responsibility without authority, Poor planning by QSs, and Clients' lack of knowledge. The stressors to females were, Heavy domestic responsibilities, Uncomfortable/unfavourable working environments, and Lack of support from family members.

There are common stressors such as Heavy workload/overtime/inflexible work, Shortcomings of the tendering process (document discrepancies, under-priced quotations), Poor information flow (Improper coordination with head office, lack of details, and delays in approving variations and issuing drawings), Inadequate attention paid to site safety, Favouritism/Discrimination at work, Comparison of oneself with those with same qualifications and working for other contractors, Unplanned and frequent changes made to employer requirements, Behaviour of supervisor/colleagues/ subordinates, Lack of employee motivation, welfare and performance evaluation, Pressure exerted by superiors, and Obsolete technologies used at sites. The contractor organisations have to focus on strategies that would overcome or minimise the stressor common to both genders, such as heavy workload/overtime/inflexible work of site QSs working for contractors to ensure the wellbeing of the QSs. Therefore, the site work can be more efficient and effective. The findings that the stressors of male and female QSs working on-site for contractors are different will again give contractors the idea about what stressors are critical for each gender and how to address them separately. Ultimately, the research will be beneficial in enhancing the mental health of QSs working on-site for contractors.

Literature that identifies stressors specific to male and female contractors' QSs working on-site is scarce. Thus, the study findings, which fill the research gap by identifying the stressors specific to contractors' QSs working on-site, will solve the dearth of literature on stress management of Quantity Surveyors considering gender differences.

This study could be a benchmark for similar studies in other countries. It focused only on the stressors of contractors' QSs working on-site but could be extended to identify the strategies to overcome all identified stressors. Future studies on the subject could be in the global context.

The present study was limited to the QSs working in the sites of contractor organisations, both within and outside Sri Lanka. It did not consider the specific experiences of each participant.

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SUCCESSFUL DELIVERY OF PUBLIC-PRIVATE PARTNERSHIP (PPP) IN THE CONSTRUCTION PROJECTS OF SRI LANKAN HIGHER EDUCATION SECTOR

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ABSTRACT

To gain economic advantages in the competitive world, governments tend to adopt new financing methods in construction projects. Accordingly, Public-Private Partnership (PPP) projects are a popular choice mainly due to the reduction in transaction cost and innovation. PPP projects have spread from the typical use on infrastructure projects such as airports, roads, railways, ports, and water sanitation to the more recent use for projects in the higher education sector such as universities and colleges. Thus, adopting PPP for the higher education sector related construction projects in Sri Lanka is vital to consider. Accordingly, this research aims to observe the Critical Success Factors (CSF) for the successful delivery of PPP projects in the construction projects of the higher education sector in Sri Lanka.

A comprehensive literature review was first conducted to identify the CSFs of PPP in higher education construction projects and 22 CSFs were identified. The survey method was used under quantitative phenomenon since this research required evaluating the identified CSFs. The identified factors were evaluated through a questionnaire survey, which was conducted among the 30 selected professionals who are aware on PPPs, such as Quantity Surveyors, Project Managers, Government Professionals, and Academic Professionals. As the key findings derived through analysis, "communication between parties", "transparency in the procurement process", financial capability and support", "project technical feasibility" and "appropriate risk allocation and risk-sharing" were determined as the top five CSFs for PPP projects in the higher education sector related construction projects in Sri Lanka. Furthermore, strategies were also proposed to ensure the successful implementation of CSFs in the higher education sector in Sri Lanka.

Keywords: *Critical Success Factors; Higher Education Sector; Public-Private Partnership Projects; Sri Lanka.*

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1. INTRODUCTION

Public-Private Partnership (PPP) is a mechanism for governments to procure and implement infrastructure or services with the help and expertise of the private sector by combining the skills and resources of both sectors by sharing risks and responsibilities (The World Bank, 2021). In a competitive global society, the governments try to adopt new financial methods for development and it has been a popular choice for implementing public sector construction projects. Due to many reasons such as reduction in transaction cost, innovation, benefits to government, etc. PPP is widely used in infrastructure projects such as airports, roads, railways, and ports (Cruz, et al., 2015). Developed countries, such as the United Kingdom, have adopted PPP for the construction of schools and universities. It is found that it has a significant impact on the quality of education such as improving the working conditions of teachers and students (Helmy, et al., 2020). Even though PPP is highly used in infrastructure projects it lacks the speed in the higher education sector.

The successful delivery of a construction project depends upon many success factors. According to Li (2005), there are three key factors, such as strong private consortium, available financial market and appropriate necessary risk allocation emerge as the most important CSFs in the development of successful PPP projects in the UK. Further, many independent CSFs, such as political and economic stability, good financial package, technology transfer, good project identification, etc. in Build Operate Transfer (BOT) projects in China were identified (Qiao, et al., 2001).

Similarly, in Sri Lanka, with its advancement to a lower-middle-income country in 1997 the country's ability to obtain grants and soft loans from multi-lateral banks was gradually decreased (The World Bank, 2021). This made it a necessity in Sri Lanka to find various financial models to serve the development projects in Sri Lanka. Thereby new financial models, such as unsolicited, Swiss challenges, and strategic partnerships, such as PPPs were emerged. Sri Lanka has participated in 73 public-private partnerships (PPPs) for a total of $6 billion between 1990 and 2014 mostly in the sectors such as electricity, telecommunications, and ports. However, United States Agency for International Development (USAID) identified that Sri Lanka still requires a high enabling environment for PPPs (USAID, 2017).

Further, higher education is the hub for the creation of a society filled with knowledge that primarily affects the development of a country. Even though there are many economic and social benefits gained from higher education, Sri Lanka is allocating only a 2.1% share of the Gross Domestic Product (GDP) to the development of higher education (The World Bank, 2021). This insufficient allocation has led to severe consequences leading to finding new ways to fund the higher education sector. Thus, adopting PPP as a suitable procurement method in the higher education sector is vital to consider. For a country like Sri Lanka, funding of projects by means, such as treasury funds, foreign loans, and grants is restricted to a certain extent due to the prevailing situation of the country. Therefore, new concepts to face the challenge of funding are needed to be found. Therefore, PPPs, which are used in infrastructure development can also be used in the higher education sector. Thereby many CSFs are affecting the successful project delivery of PPP in higher education. Further, Sri Lankan government has expressed the intend of open up the higher education system to private sector investment and service provisions which could be achieved by promoting PPP in the construction sector (Aturupane, 2013).

Accordingly, this research is more focused on filling the research gap on identifying CSFs in construction to integration with higher education sector along with PPP for its successful delivery and the scope of the research is to investigate on PPP as a procurement method rather educational aspect. Therefore, the research question is developed as "What are the CSFs for successful delivery of PPP projects in the Sri Lankan higher education sector? This paper is aimed to present the findings relating to the following objectives in answering the research question:

1. To determine CSFs a successful delivery of PPP projects in the Sri Lankan higher education sector, and
2. To propose strategies to ensure successful implementation of the identified CSFs.

Further, the research was limited into construction of higher education sector projects in Sri Lanka.

2. LITERATURE REVIEW

2.1 PUBLIC-PRIVATE PARTNERSHIPS (PPPS) IN HIGHER EDUCATION SECTOR CONSTRUCTION PROJECTS

PPP is a contested concept for many years. It has had to deal with a variety of theoretical and practical challenges from the beginning. However, despite the challenges and concerns, PPPs can be seen in many nations throughout the world. The basic concept of public debt reduction in a country has encouraged their governments to engage with the private sector in economic and social development such as prisons, car parks, schools, etc (Grimsey and Lewis, 2002). According to Spackman (2002), it was the labour government of the United Kingdom that first introduced the PPP concept in the 1990s. But PPP has been in use since the 1970s according to literature (Anderson, 1983). Then, it was spread to parts of the world including the Middle East, Australia, Europe, and Canada. Further, Singapore was the first Asian country to use PPP as a method for project finance. According to Gereffi, et al. (2005), the understanding various definitions is useful to figure out what to believe, analyze, and anticipate. Yescombe and Farquharson (2018) stated that PPP has no legal meaning and can be used to specify the number of different contractual arrangements for the private and public sectors working together. ADB (2016) defined PPP as a variety of feasible connections between public and private enterprises. Private sector participation and privatization are other terms for this type of activity. Even though the three names are frequently used interchangeably, there are some. Therefore, despite the definitional variations, the general idea of a PPP can be concluded as a long-term arrangement between public and private sectors with common intentions. In its adoption, private sector participation in PPPs has become very important in developed and developing countries across the world (ADB, 2014). In developing countries, the overall growth of private sector participation in PPP has been remarkable where it has increased from 58 projects to 288 projects from 1990 to 2007 (Yong, 2010). There has been remarkable private participation in PPP, which is not uniform (Yong, 2010).

The PPP plays a pivotal role in developing/emerging economies where huge investments are required to finance public infrastructure due to fiscal constraints (Fernando and Nanayakkara , 2020). Accordingly, many developing nations including Sri Lanka have been slow to adopt public-private partnerships including universities, particularly where strong traditions of government engagement in economic activity exist (ADB, 2014). That is basically due to Sri Lankan public universities relying on public funding (ADB, 2016). However, many examples of university partnerships can be seen across the world applying PPP in higher education construction projects. For example, in India, the London School of Economics is collaborating with the Reliance Foundation, a corporate-sponsored foundation in India, to elevate numerous Indian institutions to world-class status. Also, the Singapore University of Technology is partnering with the Massachusetts Institute of Technology in the United States and Zhejiang University in China. Furthermore, the Sampoerna University of Indonesia with Massey University in New Zealand to train students in higher standards (ADB, 2016).

2.2 ADOPTING PUBLIC-PRIVATE PARTNERSHIPS IN THE HIGHER EDUCATION SECTOR CONSTRUCTION PROJECTS IN SRI LANKA

Sri Lanka has tried to engage in a variety of (PPP) initiatives during the 1990s but the results have been less than acceptable. Sri Lanka lags behind India and Pakistan in terms of financial investment in project implementation when compared to other countries in the region (Weththasinghe, Gajendran, and Brewer, 2016). Sri Lanka has participated in 73 PPPs with a total investment of over $1 billion between 1990 and 2014 (ADB, 2014). These projects were mostly from the sectors of electricity, telecommunication, and ports (United States Agency for International Development, 2017). However, 90% of the total indicated investment is in the telecommunication sector. As Asian Development Bank (ADB, 2014) stated, the construction projects in the higher education sector of Sri Lanka have faced many challenges in long term, such as cost of construction, cost of the transaction, and maintenance. Public universities are largely reliant on state money, making them responsible to both the state and the broader public. 90% of total public university income is from the government and the rest is from sources such as interest, rent, etc. (ADB, 2014).

The higher education sector in Sri Lanka is divided into three kinds which are universities under the Ministry of higher education, other government ministries' institutes, as well as private universities, and higher education institutions (Aturupane, 2013). The majority of higher education in Sri Lanka is ownership of the government sector (Aturupane, 2013). Furthermore, there are foreign university degree programs that are registered under the Companies Act of 1982, which are independent and function without the intervention from the University Grants Commission (UGC). UGC under MOHE is the main body responsible for the regulation of higher education in Sri Lanka (ADB, 2014). Sri Lanka's government has said expressly that it intends to open up the higher education system to private sector investment and service provision. This could be achieved by promoting PPPs in the higher education sector (The World Bank, 2020).

2.3 CRITICAL SUCCESS FACTORS OF PUBLIC-PRIVATE PARTNERSHIPS IN HIGHER EDUCATION SECTOR CONSTRUCTION PROJECTS

The concept of CSFs is not specifically a concept related to construction. CSF refers to the generally small number of critically significant concerns on which a given industry should concentrate its efforts to succeed. They indicate the factors which are essential to the industry's success (Rockart, 1982). Further to the author, the CSFs are related to certain conditions of an industry. It will differ from nation to nation, based on the working environment, norms, and legal restrictions in existence. Therefore, it is vital to recognize that CSFs aren't a universally applicable collection of measurements or important indications. On the other hand, CSFs are a set of factors which has major importance to a certain industry. According to Cooke-Davies (2002), CSFs are elements that are required for project stakeholders to meet their objectives. In the construction business, project performance, productivity, and success have long been a major concern. The success of a construction project is the ultimate goal for every project. There is no standard definition of project success in construction since each situation is diverse and unique (Pheng and Chuan, 2006), but it has been widely accepted that time, cost, and quality are the major concerned factors in the performance measurements of a construction project (Leong et al., 2014).

Different CSFs regarding construction were identified by many researchers. Chua, et al. (1999) brought out four (04) aspects of CSFs in construction, namely: (i) characteristics of the project, (ii) contractual agreements, (iii) participants in the project, and (iv) interactive processes. Morledge and Owen (1998) identified 14 factors, such as well-defined purpose, early identification of consortium and integration of design, etc., which are critical in Private Finance Initiative (PFI) projects. Chua, et al. (1999) identified eight CSFs in BOT projects in China as appropriate project identification, a stable political and economic climate, an appealing financial package, an acceptable toll, fair risk distribution, subcontractor selection, and management control, and technology transfer. 18 critical factors have been identified by Li, et al. (2005), such as good governance, political support, social support, etc.

Despite a lot of previous research that has been investigated on the CSFs of PPP projects, studies on PPP in the higher education sector remain scarce. 18 CSFs were identified by Boye and Mannan (2014) good governance, public and private sector commitment and accountability, a favorable legislative framework, competent economic policies, and a viable financial market identified as the five top most critical factors under the factors identified such as managerial and operational factors, legal factors, political factors, economic and financial factors. Further, it has been determined that management and operational factors are the most important influencing factors for successful implementation of PPPs in higher educational sector related construction projects in Egypt (Boye and Mannan, 2014). Although political factors are important, they were not ranked first as policy as the benefits of a strategy that supports and encourages public-private partnerships in all areas of the economy were clear in Egypt (Helmy, et al., 2020).

Through the review of key literature, 22 CSFs were identified as presented in Table 1 by focusing on main three construction project constraints which are time, cost and quality.

Table 1: CSFs identified through literature

#	CSFs	Source of Reference				
		(1)	(2)	(3)	(4)	(5)
1	Competitive procurement process	X		X		X
2	Transparency in the procurement process	X		X		X
3	Project technical feasibility	X		X	X	X
4	Strong private consortium	X		X		X
5	Appropriate risk allocation and risk-sharing	X				X
6	Good governance	X				X

#	CSFs	Source of Reference				
		(1)	(2)	(3)	(4)	(5)
7	Social support	X		X		X
8	Communication between parties		X			X
9	Approval and negotiation process			X		
10	Favourable legal framework	X		X		
11	Existence of alternative dispute resolution methods	X				
12	Existence of PPP law		X			
13	Political support	X		X		
14	Commitment/responsibility of public/ private sectors					
15	Stable macro-economic environment					X
16	Sound economic policy	X		X		X
17	Available financial market	X				X
18	Financial capability and support					
19	Existence of explicit policy documents for PPPs	X				
20	Existence of Procedures for PPP appraisal and prioritization		X			
21	Well organized and committed public agency		X			X
22	Developing a culture of partnership		X			

References: [1] Helmy, et al., 2020; [2] Zhang, 2005; [3] Jefferies and Cook, 2001; [4] Tiong, 1996; [5] Li, et al., 2005

Accordingly, the identified factors were considered in developing the questionnaire to get the specific views relating to the Sri Lankan context.

3. RESEARCH METHODOLOGY

Research approaches can mainly be classified into Quantitative and Qualitative approaches (Yin, 2009). According to Fellow, et al. (2003), quantitative approach tends to seek and collect factual data, as well as investigate links between facts and theories that have been tested. In this research, identified CSFs in a successful delivery of PPP construction projects through the comprehensive literature review were tested by focusing on the Sri Lankan higher education sector. Therefore, quantitative research approach is utilized in this research to assess and indicate the importance of CSFs to the successful delivery of the PPP construction projects in the higher education sector. This research has covered a study of CSFs relating to construction and PPPs. To meet the objectives, the researcher has validated and prioritized the CSFs that were found during the literature study in the Sri Lankan context. Therefore, survey research was adopted under quantitative phenomenon as the most effective and appropriate strategy for this research.

Data collection is the process of transferring data from the responder to the researcher, which includes data collecting and compilation (Fellows, et al., 2003). To carry out the objectives, a questionnaire survey was to identify the most important success elements for adopting PPP in the higher education sector in Sri Lanka. The questionnaire prepared to collect the data consists three sections. The first section collected the respondent's demographical data such as their profession and their years of experience in the construction industry. In the second section, the respondents were provided with CSFs, which were identified through literature to assess and indicate their importance. Five-point Likert scale was used to appraise the importance of identified factors (1=Not important, 2=Slightly important, 3=Moderately important, 4=Important, 5=Very important). The third section two semi-structured questions requesting to state the challenges and to propose strategies to ensure a successful implementation of the identified CSFs.

Construction professionals who were having more than 5 years of experience in the field of PPP, such as Project Managers, Civil Engineers, and Quantity Surveyors, to name a few were selected as the targeted population to distribute the questionnaire. Furthermore, 7 academic professionals who were having a sound knowledge on PPPs and having more than 5 years of experience in the higher education sector were also selected. According to Chan, et al. (2001), the sample size should be anywhere from 10 to 50 participants. Therefore, sample of 40 professionals were decided to be considered in this research. Accordingly, 40 questionnaires were distributed to the selected professionals, 30 were returned as shown in Table 2. As stated by Richardson (2005 as cited Nulty, 2008) response rate of 50% is regarded as an acceptable response rate in social research surveys. Hence, the overall response rate of the respondents was 75% in this research, which is an acceptable value.

Table 2: Response rate

Designation	Distributed	Returned	Response rate
Academic professionals	7	5	71.42 %
Professors	4	2	50 %
Quantity surveyors	22	18	81.81 %
Directors	3	2	66.6 %
Government professionals	2	1	50 %
Project managers	2	2	100 %
Total	**40**	**30**	**75%**

The collected data were analysed by using Weighted Mean Average (WMA) and Relative Importance Index (RII) techniques as given in Eq. 01 and Eq. 02. For each factor, WMA and RII values were calculated and ranked to indicate their level of importance.

$$MWR = \frac{\sum(V_i x F_i)}{n} \qquad \textit{(Eq. 01)}$$

Where, Vi=Rating of each Performance indicator, Fi=Frequency of Responses.

$$RII = \frac{\sum(Wn)}{AN} \qquad \textit{(Eq. 02)}$$

Where, W= The weighting of each response is expressed by a constant, A= The highest weighting, n= The frequency of responses, and N= Total Number of the Responses.

Data analysis and key findings are described below.

4. DATA ANALYSIS AND FINDINGS

4.1 ASSESSMENT OF CSFS FOR PPP IN THE HIGHER EDUCATION SECTOR IN SRI LANKA

The 22 CSFs identified through the literature review were appraised by using MWA and RII. The related MWA and RII values along with the respective ranking of each factor are shown in Table 3.

Table 3: Assessment of CSFs

Factors	MWR	RII	Rank
Transparency in the procurement process	4.367	0.873	1
Communication between parties	4.333	0.867	2
Appropriate risk allocation and risk-sharing	4.200	0.840	3
Project technical feasibility	4.133	0.827	4
Approval and negotiation process	4.067	0.813	5
Good governance	4.000	0.800	6
Social support	3.967	0.793	7
Favourable legal framework	3.967	0.793	7
Financial capability and support	3.967	0.793	7
Available financial market	3.867	0.773	10
Existence of alternative dispute resolution methods	3.833	0.767	11
Commitment/responsibility of public/ private sectors	3.800	0.760	12
Strong private consortium	3.767	0.753	13
Existence of PPP law	3.733	0.747	14
Existence of procedures for PPP appraisal and prioritization	3.667	0.733	15
Competitive procurement process	3.633	0.727	16
Sound economic policy	3.600	0.720	17
Existence of explicit policy documents for PPPs	3.600	0.720	17
Well organized and committed public agency	3.567	0.713	19
Stable macro-economic environment	3.533	0.707	20
Developing a culture of partnership	3.500	0.700	21
Political support	3.367	0.673	22

According to the data analysis, transparency in the procurement process (WMR=4.367; RII=0.873) was ranked first as a necessary factor to ensure the successful implementation and delivery of PPPs in the higher education sector in Sri Lanka. This states that the respondents have a greater concern regarding the transparency of a project. Effective procurement process through transparency enhances the value for money of a project. Communication between different parties (WMR=4.333; RII=0.867) was the second most important CSF as rated by the overall respondents. Appropriate risk allocation and risk-sharing (WMR=4.200; RII=0.840) ranked as the third most important factor. One of the main characteristics of a PPP is its high level of risk, which is mostly due to the contract's extended duration and the multiple partners involved. Thereby procedures to ensure risk allocation amongst PPP stakeholders by transferring the risk to the party capable of controlling them and risks out of control to be shared among the parties are critical to its success.

As the WMR ranges from 3.367 to 4.367 show that respondents consider all 22 CSFs to be either "moderately important" or "important" in ensuring the success of PPP project implementation and delivery in the higher education sector in Sri Lanka. Among the CSFs listed in Table 3, 6 factors recorded RII values that exceed 0.800, which are identified as highly important. These highly important CSF have RII values ranging from 0.873 to 0.800 as highlighted in Table 3.

4.2 STRATEGIES PROPOSED TO ENSURE A SUCCESSFUL IMPLEMENTATION OF THE IDENTIFIED CSFS

The challenges to successful delivery of CSFs were identified through a questionnaire survey and the selected experts were asked to propose strategies to ensure a successful implementation of the identified important CSFs as shown in Table 4.

Table 4: Proposed strategies

CSFs	Challenges	Proposed strategies
Transparency in the procurement process	Lack of trust for the government	Clearly defining the project requirements Using digital technology to transform the transparency in public procurement
Communication between parties	Lengthy delays and long time for starting the projects Lack of social awareness on PPP projects in Sri Lanka	Creating awareness among the general public and students stating the difference between privatization and PPPs Initiating extended discussion and negotiations before the start of the project. organizing public awareness programs about the project
Appropriate risk allocation and risk-sharing	Conflicts of interest between different parties	Facilitate a common ground regarding duties, obligations, and benefits of parties engaged Understanding other parties' objectives and priorities
Project technical feasibility	Lack of funds for government to invest in higher education projects	Selecting experienced parties to the project
Approval and negotiation process	Complications in procurement projects ang high negotiations	Making a proper hierarchy for decision making
Good governance	Lack of proper policy with regards to the higher education sector	Introducing a new policy or enhancing the existing policies of PPPs with the participation of professionals from different sectors

CSFs	Challenges	Proposed strategies
	Lack of regulatory and legal framework to back up PPP	Creating a National Educational Policy that supports PPP.
		Ensuring work regardless of political opinions
		Considering legislation changes to be addressed in the earlier stages

As stated by many respondents, working with a true determination of enhancing private education is a strategy proposed to ensure successful delivery of PPP in the higher education sector in Sri Lanka. Further, creating a National Educational Policy that supports public-private partnerships to benefit from the synergies between the two parties is proposed. Most of the respondents highlighted that awareness among the general public from lower levels to higher levels is important in achieving success. In addition, improving communication between parties, and selecting experienced parties were stated by quantity surveyors. Further, many respondents stated that communication between different parties could highly ensure the successful delivery of PPP projects in Sri Lanka. Furthermore, cultural change within public and private sectors can be identified as another strategy.

5. CONCLUSIONS

Higher education is the hub for the creation of a society as it primarily affects the development of a country. Hence, the higher education sector needs to be obtained a high priority in any nation. However, many developing nations including Sri Lanka have been slow down to adopt PPPs in the higher education sector, particularly where strong traditions of government engagement in economic activity exist. Hence, it lacks speed in the higher education sector. With a timely need of promoting PPPs in the higher education sector, this research identified many CSFs, which are highly important to ensure successful delivery of PPPs in the higher education sector in Sri Lanka. The outcomes of this research can be used as a basis to evaluate the status of PPPs in the higher education sector to ensure their successful delivery. Further, the proposed strategies can be used in implementing the identified CSFs, which will call for actions from industry professionals and policymakers towards successful delivery of PPPs in the higher education sector in Sri Lanka. Since this research is limited to a quantitative evaluation, the next step will be to carry out the research qualitatively to investigate the identified CSFs with a sufficient depth.

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SUSTAINABLE CHALLENGES AND STRATEGIES FOR MANAGING STAKEHOLDERS IN MEGAPROJECTS: REVIEW OF CASES FROM AUSTRALIA

Sepani Senaratne[1] and Siryana Rai[2]

ABSTRACT

Megaprojects are an essential part in social, economic, and environmental developments and they attract a consortium of stakeholders ranging from governments, communities, international consumers, and suppliers. Hence, stakeholder management in these projects contributes significantly to projects' success and sustainability. The research project, on which this paper is based on, aims to identify key challenges and propose suitable strategies to manage stakeholders in megaprojects for better sustainability outcomes. In achieving this aim, the research re-viewed key concepts related to project stakeholder management in megaprojects, explored sustainable challenges and analysed appropriate stakeholder management strategies through a secondary review of two major case studies of megaprojects in Sydney, Australia. The key findings discovered that the main factors influencing stakeholders were related to social, economic and environmental impacts of the project and, the need for managing them through proactive stakeholder management strategies. The implications of this research guide project managers on managing stakeholders on megaprojects and inform on possible challenges and solutions to achieve sustainable outcomes. Further research could extend and replicate on other case studies in different contexts and project types.

Keywords: *Megaprojects; Project Management; Stakeholder Management; Sustainability.*

1. INTRODUCTION

Megaprojects are essential in the development of communities, which offer employment, economic growth, innovation and for sustainable development. Project Management Institute (2017) defined projects as a series of distinctive, multifaceted, and associated tasks, which possess a shared goal and are assigned to result in a definite time, a fixed budget and recognised requirements. Megaprojects can be identified as a significant investment of more than a few billion dollars such as large-scale engineering and infrastructure projects, which generally necessitates collaborative effort from main participants in terms of resources, skills and expertise. According to Mok, et al. (2015), in megaprojects, there is a significant chance that projects fail to meet the required outcome due the poor project stakeholder management.

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Project stakeholders are defined as the group of people, individuals and organisations that are directly or indirectly affected by project activities and outcome (Oppong, et al., 2017). Cummings and Patel (2009) found out that there are five groups of stakeholders in projects such as employees, shareholders, customers, suppliers and community. Mok, et al. (2015) explained that in megaprojects within these five stakeholders' groups, there is a considerable number of people involved, interested, and affected compared to small to medium-sized projects. In recent years, stakeholder management for megaprojects drew special research interest due to significant challenges encountered in managing stakeholders, in particular external stakeholders, who are sensitive to sustainability outcomes. Therefore, stakeholder management approaches and strategies could differ in these projects in ad-dressing these challenges. However, the extant literature lacks in providing a thorough understanding of stakeholder management strategies that are appropriate for sustainable related challenges in megaprojects. The aim of this research project is to identify key challenges and propose suitable project stakeholder management strategies for megaprojects through review of cases in Sydney area for better sustainability outcomes.

The paper is structured in four main sections, with this first section explaining the research problem and background of the research. The second section synthesises literature findings into three key areas on 'generic' and 'modern' stakeholder management theories, including a review into current research on stakeholder management challenges and strategies as applicable for megaprojects.

2. KEY LITERATURE FINDINGS

Managing stakeholders is a key project management competency. Literature offers various theories in managing stakeholders in different types of projects as discussed in below sub-sections, followed by a review into challenges and strategies for managing stakeholders.

2.1 GENERIC STAKEHOLDER MANAGEMENT THEORIES

The early stakeholder management theories indicate the importance of compliance with various factors such as human rights, environment regulations, fairness and equality (Preston and Sapienza, 1990). A company's business management should reflect the ethics and morals of the business with their stakeholders (Cummings and Patel, 2009) and include 'corporate social responsibility'. Literature highlights three early stakeholder management approaches, namely, descriptive, instrumental, and normative approaches.

- The descriptive approach aided to describe the characteristics and attitudes of project organisations, including how establishments are managed and how the executive committee contemplates corporate communities (Crawford, et al., 1997).
- The instrumental approach utilised the framework building method to recognise the links, which exist between the management of stakeholder associations and the accomplishment of corporate objectives (Preston and Sapienza, 1990).
- The normative approach, labelled as the essence of the theory by Donaldson and Preston (1995), explored the appropriate function of the project organisation and classified the moral or philosophical guidelines for the operation and management of the corporation (Cummings and Patel, 2009).

The above mentioned three stakeholder management approaches confirmed why and how stakeholders are important in business regardless of the size of the project. These approaches have helped researchers study in-depth to understand the stakeholder perspective, expectations, outline moral and ethical regulations including the stakeholder management framework and has helped businesses understand their stakeholders. However, in megaprojects, many factors and tools need to be further investigated. Therefore, the following sub-section discusses some modern stakeholder management theories, which aids to understand how the knowledge on stakeholder management developed overtime and how it can be useful in megaproject contexts.

2.2 MODERN STAKEHOLDER MANAGEMENT THEORIES FOR MEGAPROJECTS

Modern stakeholder management theories such as resource-based view theory, institutional theory perspective and temporal model of stakeholder theory were identified as applicable to megaproject context and briefly described below.

- The resource-based view (RBV) is the project organisation's way of conceptualising the resources available including resources for choice, admittance, collection and mixture according to Verbeke and Tung (2013). In terms of megaprojects, RBV provides some strategic fundamental guidelines for project organisations to utilise the available resources at hand such as manpower, skills, and expertise from the community. Further, RBV was found to be supportive of the development of innovation process in megaprojects (García-Quevedo, et al., 2018).
- The characteristics of Institutional Theory Perspective were the tendency of being vulnerable to social influence, accustomed to old tradition and prospects (Bakhshi and Touran, 2014). According to Fong (2010), RBV has more weight on economic optimisation and normative rationality, whereas institutional theory focuses more on the social justification and social obligations.
- The temporal model of stakeholder theory is divided into two stages according to Verbeke and Tung (2013), namely: early stage and later phase due to the enormous size of stakeholders and the project lifecycle (Engwall, 2003). In order to achieve the trust of the stakeholders, it was recommended that organisations initiating megaprojects must aim to be value creating projects to the stakeholder.

While above three modern theories were found more applicable to megaprojects, RBV was observed to be the most effective as it takes into consideration sustainability aspects, which has been a major concern among stakeholders in modern days (Ninan, et al., 2019). The next section offers a literature synthesis on stakeholder management processes and tools with specific reference to megaprojects.

2.3 STAKEHOLDER MANAGEMENT CHALLENGES AND STRATEGIES IN MEGAPROJECTS

Megaprojects involve many activities before proposing the project, during operation and after the project has been completed (Ma, et al., 2021; Eskerod, et al., 2015). These activities range from practicability analysis, safety and environmental impact evaluation, project assessment and goal settings, project alternative identification, submissions for government authorisations, de-sign, tendering, construction, handover, operation and maintenance (Kakar and Khan, 2021). According to Yang, et al. (2021), megaprojects have a complex network of stakeholders. As such, megaprojects involve dynamic stakeholders' patterns and compositions during different stages (Windsor, 2010). However, as Jergeas, et al. (2000) stated, megaprojects tend to be more problem-orientated rather than stakeholder-driven. However, at times such as nuclear power plant, external stakeholders had more power compared to governments (Banerjee and Bonnefous, 2011). Hence, stakeholder management is a must in order to acquire positive support from stakeholders for the implementation of the project and its activities (Littau, et al., 2010). Among various stages such as stakeholder identification, planning, engagement and monitoring, 'stakeholder engagement' is the most important stakeholder management step in case of megaprojects (Mok, et al., 2015).

The main purpose of stakeholder engagement in mega-projects is to acquire transparency in decision making by way of stakeholder participation and inputs of feedback. Stakeholder perspective highly depended on the communication and transparency of the megaproject because most of the stakeholders considered mega-projects as closed organisation (Zulch, 2014). Greenfield, et al. (2013) found that stakeholders perceived megaprojects as private systems and do not communicate with their stakeholders early enough. This is confirmed in a study, where project managers' incompetency to manage stakeholders through proper communication and sharing of sufficient information at early stage of projects led to project failures (Agle, et al., 2008).

Pomeranz, et al. (2014) emphasised to carry out activities such as understanding the norms, awareness of the political influence and natural environmental implications, be-fore initiating megaprojects, which Mok, et al. (2015) suggested to obtain in terms of stake-holder expectation and behavioural attributes through a stakeholder engagement plan. However, not all stakeholders' expectations could be fulfilled due to various reasons including interest and pressure groups. It was found that environment, social and economic interests driven by sustainable principles were key areas that the stakeholders are mostly interested in megaprojects due to the size, duration and the motive of operation (Kakar and Khan, 2021). While some stakeholders, who resided close to the megaproject, mostly had concerns about the environment pollution, others were more concerned about the social benefits and the compensation provided due to different stakeholder perspectives.

The challenges discussed above in relation to megaprojects can be grouped under stakeholder identification & relationships, communication & transparency and diverse stakeholder interests as depicted in Table 1. The subsequent discussion will explain various strategies and tools that could help to overcome these challenges as revealed through the literature (see Column 2 of Table 1).

Table 1: Literature synthesis on key challenges and strategies on megaprojects

Key challenges	Strategies and tools
Stakeholder identification & relationships	Stakeholder mapping and analysis, client relation tool, SNA and ANT
Communication and transparency	Value creation, traditional and modern communication tools such as meetings, newsletters, websites and social media
Environment, social and economic interests with sustainable principles	Social responsibility, LCA, persuasion and deputation, rewards & benefits

As summarised in Table 1, various proactive strategies and tools to overcome key challenges were introduced by various scholars, which may be more applicable at certain phases and types of projects. According to Banerjee and Bonnefous (2011), there could be strengthening strategy for supportive stakeholders and/or stabilisation strategy for passive stakeholders; and/or, containment approach for obstructive stakeholders. Hence a mixture of all strategies would be required in megaprojects to deal with various types of stakeholders. Lim, et al. (2005), classify stakeholder management strategies in four ways as reactive, defensive, accommodating and proactive. The reactive strategy is referred to the reaction taken, when an unexpected event occurs. The defensive strategy is the approach, where project organisation would provide only what was promised to their stakeholders. The accommodating approach is where project organisations accommodate strategies and make frequent changes, when facing challenges. Finally, the proactive strategy approach is when the project organisation represents themselves as leaders in stakeholder management (Chinyio and Vogwell, 2007). Among these, it is the proactive strategies that are needed most for project managers to manage stakeholders in megaprojects.

The importance of stakeholder analysis methods was further confirmed by Mok, et al. (2015) for megaprojects. The stakeholder management strategy that was highlighted in a hospital was to use the client relation tool for stakeholder mapping and analysis (Collinge, 2016). Furthermore, Social Network Analysis (SNA) method was widely proposed in determining the indicators of megaprojects with stakeholder perspective (Yang, et al., 2011; Hwang and Ng, 2013), while Maqsood, et al. (2004) applied Actor Network Theory (ANT) to observe stakeholder relationships.

It was also observed that stakeholders responded positively, if transparency and communication with social, economic, and environmental sustainable benefits were presented. The value creation was observed to be a project success for megaprojects (Zulch, 2014). Jergeas, et al. (2000) supported the value creation approach that was effective due to its transparency, effective communication, and awareness. Furthermore, monthly meetings, look ahead programme, behavioural expectation cards, complains/queries database, contact photo sheet, notification of work bulletin and handouts were some of the tools used to communicate and provide project transparency (Collinge, 2016). Other common traditional communication tools were council newsletters and announcements, newspapers and radio, the project websites, signage and traffic information boards and websites (Que, et al., 2019), whereas modern methods included social media.

Megaproject social responsibility is important in managing stakeholders and covers a diverse range of challenging responsibilities, including pollution control, environmental protection, occupational health and safety, anticorruption and public participation (Ma, et al., 2021). Life Cycle Assessment (LCA) is one of the tools widely used in megaprojects to assess the environmental impact in the community (Neville and Menguc, 2006). According to Ninan, et al. (2019) the stakeholder strategies to address economic interests included persuasion, deputation, rewards and benefits to achieve positive feedback from stakeholders in megaprojects in India. Since mega-projects are generally carried out by sub-contractors mainly for government development, the best strategy to influence secondary stakeholders were through incentives and benefits (Knol and Tan, 2018). However, with stakeholders who had greater value for sustainability, project managers found it challenging to convince and influence them alone with project benefits and rewards.

Therefore, the research question for this study is whether above discussed tools and strategies (see Table 1), including individual sustainability assessment tools, are sufficient in case of managing megaprojects, with multiple stakeholders and increasing sustainable challenges. This research attempts to fill this gap by bringing insights from two megaprojects in Sydney that had holistic stakeholder management strategies to overcome such sustainable challenges. The next section explains the research method adopted in this study.

3. RESEARCH METHOD

The research method selected for undertaking this research was a secondary review of case studies to identify stakeholder management challenges and strategies in megaprojects around Sydney area. The specific case studies chosen included megaprojects in Sydney area on a railway project and an airport project, which satisfied the case selection criteria such as 'megaprojects', 'projects in Sydney region' 'sustainable impacts' and, 'availability of secondary data.'

Government records were one of the vital sources of data collection in carrying out this secondary research. In particular, for this re-search, the relevant government website and the collection of documents on project over-view and documents published by subcontractors were reviewed along with the stakeholder and community engagement documents and newspaper articles. Furthermore, past research journals and articles on the chosen projects were evaluated using search engines such as Google Scholar, Science Direct, Elsevier, Project Management Journal (PMI) and Australian Institute of Project Management (AIPM) by using specific keywords related to the selected project name. In total, around fifty files were shortlisted for the case studies. The data collected and sorted are further analysed in the case studies based on initially found challenges and strategies from the literature and later in the discussions, specific case findings. The next section presents and discusses the key findings.

4. RESEARCH FINDINGS

The research findings from these two projects were analysed through within-case and cross-case analysis. They are reported in this section, first with some key findings from each case followed by the cross-case analysis and discussion.

4.1 KEY FINDINGS FROM WITHIN CASE 1

The first case study used for this research project was Railway project in Sydney Australia, which was worth AUD $12.5 billion. The project owner was the New South Wales government, who sub-contracted the project to various contractors in order to complete the project. There were three Australian construction companies, who were subcontracted to carry out the tunnels and civil works. Railway project was mainly aimed to connect various parts of Greater Sydney area with Sydney Central Business District, which included the Bankstown airport, Parramatta City and the North West area. It consisted of 31 metro stations with more than 66km of new metro rail, with underground bridges and tunnels constructed. At the time this research was carried out, the project was on-going with completion of stage one and therefore, the challenges and strategies were identified for stage one.

Railway project followed the Construction Environmental Management Plan/Framework (CEMP/F) for New South Wales, which included air, water and soil management, construction management, heritage management, environmental manage-ment, business management and stakeholder management. For stakeholder management, an overarching stakeholder management approach was used, which ensured that the project included their stakeholder for important decision-making and satisfied stakeholders equally and fairly (Pomeranz, et al., 2014) by gathering information from their stakeholder through calls to the information line and community emails, community information sessions during exhibition periods for environmental assessment, meetings and door knocks. This proactive approach offered many benefits such as gaining the trust of the community, effective communicative strategies, development of shared solutions for complex challenges and stakeholders getting their chance to make the project hear their opinion. The specific challenges and strategies identified through the secondary review of this case are summarised in Table 2.

Table 2: Identified challenges and strategies in Railway project

Challenges faced in the case study	Strategies used to tackle respective challenges
Communication and engagement	Community information sessions and other communication tools & techniques
Fairness and equality	Maintain ethics and values
Availability for engagement	Attempts and documentation
Business visibility	Providing local business support program
Impact on local business performance	Local business advertisement options and campaigns
Buried heritage	Mitigation plan for heritage conservation
Flora and fauna impact	CEMF implementation
Access to public facilities	Providing alternative public facilities
Impact on utility services	Construction activity updates and notifications
Noise and vibration	CEMF guidelines
Nuisance noise by workers	Employment condition contract
Infrastructure damage due to vibration	Property damage claim

4.2 KEY FINDINGS FROM WITHIN CASE 2

Second case study, Airport project was established to deliver and operate the airport and operation after completion (Commonwealth of Australia, 2015). This project was estimated to cost approximately AUD $5.3 billion according to the budget report 2017/2018 (Western Sydney airport (WSA), 2018). Some of the main scopes of the project were meeting the high demand of aviation in the Greater Sydney area, providing value assets to the community and the state and, boosting opportunities locally and internationally in terms of employment and tourism.

Airport project stakeholders included many organisations, groups and individuals, making it a collaborative service environment and the project has prepared strategies that were established after thorough assessment with stakeholders and the potential challenges that are likely to occur during the planning, designing, execution and operation of the project. The project aimed to use the overarching stakeholder management model with a holistic approach that covers the effective communication and engagement process including the management of transparency. This holistic management approach is a framework especially designed for decision-making, which follows the triple bottom line sustainability principles i.e., the balance between environment, economy and society (WSA, 2019). WSA also adopted the CEMP guidelines to develop standards and requirements in collaboration with the aviation, environment and social regulations with the government and international standards. While engagement strategies such as project briefings through meetings, seminars, surveys and open days were used, project communication was through websites, government website, social media such as Twitter and Facebook, newspapers, council newsletters and so on. The specific challenges and strategies identified through the secondary review of this case are summarised in Table 3.

Table 3. Identified challenges and strategies in airport project

Challenges faced in the case study	Strategies used to tackle respective challenges
Communication and engagement	Project briefings and other communication tools and techniques
Less concerned about socio-economic aspect	Communication and engagement plan, maximise engagement activities
Cultural heritage	Archaeologist assessment of the site, heritage management plan, stakeholder engagement
Threat to the natural environment	Environment assessment and evaluation, relocation of flora and faunas to natural reserve parks
Construction impact (air, noise and vibration)	Notification to stakeholders regarding upcoming construction activities, noise barriers, water spray system, renewable energy, turn-off machines and engines which are not operating
Heavy traffic in the area with heavy vehicle	Variable speed limit, traffic management implementation, updates and notification to stakeholders regarding heavy vehicles movement in the morning and afternoon hours
Noise pollution during airport operations	Ground rules implementation, turn-off machineries and vehicles not in use and flight pathing
Traffic getting busier due to airport operations	Wider lanes, variable speed limits, signages, RMS notification about possible delays, designated lanes to enter and exit the airport
Value of properties	Property survey, property damage claim

4.3 KEY FINDINGS FROM CROSS-CASE ANALYSIS

There were several similarities in the challenges faced between the two cases, where the strategies established were somewhat similar. Common challenges and strategies related to stakeholder management of the two megaprojects are discussed in this section.

The strategies employed to mitigate and minimise these challenges were aligned with the overarching stakeholder management model utilised by both projects, which provided stakeholders the opportunities to influence project decisions towards the development of the projects and address their sustainability concerns. Feedbacks, surveys, communications and engagements with the stakeholders and mitigation strategies for construction activities were implemented in both projects.

With more challenging stakeholders in the airport project, they seemed to have applied a resource-based view approach for its stakeholder management that is more sustainability driven. This approach aided the team to communicate, engage and provide opportunities to the local communities for their economic and skill developments, not only to institutes, unions and groups but also to individuals. The airport project's survey during stakeholder assessment revealed that the transparency and frequency of engagement and communication carried out by the project team resulted in significant number of stakeholders supporting the airport project. The reactive, accommodating and proactive strategies for stakeholder engagement were used in the stakeholder management of the airport project. Hence, this research also revealed that relationship with stakeholder was important to understand their stakeholders' expectations and influencing factors and by having a better communication and engagement plan, many stakeholder challenges could be overcome.

This finding is consistent with recent research on megaprojects conducted in different contexts. For example, Mangioni (2018) stated that it is the project organisation's responsibility to ensure that adequate communication and engagements are carried out before stakeholders take actions further to the court. As mentioned by Mok, et al. (2015), projects fail, when stakeholder management is poor and, when stakeholders not being aware of the true benefits on the development of their community from megaprojects through proper communication. Mathur, et al. (2021) observed how social media could further provide in-formation to the public about the megaprojects. Ninan, et al. (2019) confirmed that social media could be a competitive advantage for 'persuading, framing and hegemonizing' external stakeholders in megaprojects, as also observed in the case studied projects. They further recorded how different information communication technologies are used for communication and engagement with external stakeholders. Yang, et al. (2018) explain that with the development of these types of new approaches to solve stakeholder management communication and engagement in megaprojects, at times internal stakeholders tend to restrain to consider new approaches and project managers should be skilled on persuading them.

In addition to stakeholder communication and engagement, the challenges identified in Cases 1 and 2 (see Table 2 and 3) revealed that stakeholders' attitude towards megaprojects such as railway and airport construction was mostly connected with sustainability concerns such as construction and operation impacts, environmental pollution impacts and property impacts on their community, where majority of the opposing groups were among residents, businesses and institutes. However, when considering the community groups, the airport project had more negative stakeholder perspectives compared to the railway project. The reason behind this was mainly the potential environment and health implications in the surrounding areas.

5. CONCLUSIONS

This research aimed to propose suitable project sustainable stakeholder management strategies grounded on a comprehensive review of two megaprojects in Sydney area. After establishing the theoretical base through a literature review into stakeholder management in megaprojects and research gaps into lack of strategies for sustainability driven stake-holder management challenges, a secondary research method was used to collect and analyse data related to the two case studies that offered significant insights and lessons learned. The limitations of the research was due to reliance on secondary sources to explore answers to the research question. However, the chosen projects had ample published documents that assisted in overcoming this limitation.

The stakeholder management strategies were proven to be effective in the case studied megaprojects, when project managers carried out the stakeholder mapping analysis to identify all their internal and external stakeholders, including the influencing sustainable factors such as social, environmental and economic impacts. Influencing factors were observed to be strongly linked with the power hierarchy of the megaproject, where the government plays a key role. The level of engagement was also proven to be the most effective way of stakeholder management as it aided to make the megaproject transparent to the public and stakeholders. The two case studies further revealed several common sustainability driven challenges associated with construction and operational impacts on the residential, business and institution stakeholders due to the noise, vibration and environment pollution. It was evident that stakeholders' interest and expectations depended highly on the environmental aspects compared to the socio-economic aspects from the megaprojects, due to increased awareness and consciousness on sustainability. Possible strategies to mitigate the challenges were identified to achieve stakeholder satisfaction as reported in the research findings.

Overall, these findings offer significant implications for project managers of mega-projects to identify influential stakeholders, their sustainability related needs and challenges and proactively utilise strategies and tools to manage them with minimum disruptions and gain positive project outcomes. Research also offers wider policy implications for government driven megaprojects in other contexts to comply with holistic stakeholder management approaches as practiced in Sydney projects. The increasing development in megaprojects in the infrastructure and transportation sector in developed counties re-quires intense stakeholder management approach due to the developed urbanisation. The research findings from this research project can offer useful implications for theory and practice, to foresee similar challenges and employ suggested strategies in similar mega-projects. Further research could extend and be replicated on other case studies in different contexts and project types to bring more insights and lessons-learned.

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SUSTAINABLE FACILITIES MANAGEMENT PRACTICE AND ITS PERCEPTION IN HEALTH CARE ORGANISATIONS: A DELPHI SURVEY

F.S. Nazeer[1], T. Ramachandra[2] and Sachie Gunatilake[3]

ABSTRACT

Health Care (HC) is one of the most polluting industries and recognised as the second energy-intensive sector. Integrating sustainability into Facilities Management (FM) is imperative and could significantly contribute to reduce energy consumption, waste and day-to-day operational costs. However, operations of FM vary upon facility types, business sector, organisation characteristics, cultural context and organisational scale. Thus, this study examines the current practice of sustainable FM and its perceptions in HC organisations in Sri Lanka. A Delphi survey was administered to 10 experts in two rounds, who are specialised in FM practices in the HC organisations. A semi structured questionnaire was deployed and collected qualitative data were analysed using content analysis whilst quantitative data were analysed through mode, mean and quartile ranges to reach consensus. With respective to FM practice in HC it was found that 8 out of 10 organisations had no separate departments for FM to conduct FM practices. The functions were collectively carried out among departments namely; engineering, quality assurance and housekeeping. Operations delays incur additional costs and disputes were reported constantly. Also, building services was found to be the topmost FM service practiced. Integration of sustainability is at a moderate level and FM practitioners face higher level of constraints of which "high costs" obtained the highest rank. The study is novel in offering the state of the art of FM practice in HC organisations and adds values and provides recommendations for further research to maximise the contribution of FM towards sustainable practice. It thus directs FM practitioners to support the future enhancement of HCFM.

Keywords: *Facilities Management (FM); FM services; Health Care (HC).*

1. INTRODUCTION

Health Care (HC) is one of the fastest growing industry in this 21st century as the demand for health related services are high due to growing and ageing population and elevated standard of living around the globe. For example; the growth of global hospitals and clinics reached $3,693.4 billion in 2018, and has a compound annual growth rate (CAGR) of 8.2% since 2014 (The Business Research Company, 2020). In particular in US alone

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for the next five years the growth of HC sector is predicted to grow annually at a rate of 2.8% to $1.2 trillion, with an expected increase of 1.6% in 2020 (IBIS world, 2020). The ever-increasing demand and the growth of the HC industry is also lead by the force of urbanisation and created an avenue for the need of more complex HC related facilities.

On the other hand, HC sector is observed as the second largest industry that emits and pollutes environment whilst in Brazil HC industry accounts for 10.6% of total energy consumption (WHO and HCWH, 2009). In a recent study, CO2 emission in England specific to HC sector accounts for 18 million tonnes of these emissions 59% from procurement, 22% from building energy use and 18% from travel (Tomson, 2015). Similarly, US also generates over 3 million tons of solid waste per year along with other hazardous solid, toxic, infectious and radioactive wastes. Amongst, clinical waste is ranked among the top 4 sources in emitting and spreading harmful substances which lead to cause respiratory diseases and other illnesses to the community. Thus, integrating sustainability to HC will aid environment protection, occupants' wellbeing and stakeholder welfare (Diyer, et al., 2013). Buffoli, et al. (2014) emphasised that integrating sustainability into HC sector is a priority globally as these facilities play an active role in keeping the quality of the users' lives.

Integrating sustainable practices identified as an absolute solution to reduce the impact caused as workplace and productivity has a direct impact. This is where FM was recognised initially among building professionals and in time, FM found to be in a unique position in influencing the operational phase of a built facility in defining, analysing and examining the sustainability issues and to convert the physical product to a liveable and habitable built environment (Sarpin, et al., 2016). As being in charge of handling the operational phase of a built facility, FM was expected to handle sustainable practices. In regard, FM was found to be a "significant contributor or a key actor" in achieving sustainability in built environment (Elmualim, et al., 2010). Shah (2007) points out that SFM has evolved parallel with sustainable development and climate change concerns.

However, Meng (2014) indicates that the implementation of sustainable practice is not easy or straightforward as it tends to differ in number of ways according to facility types. These facilities differ from technical building components to the usage and economic contexts and has been evidenced through a number of studies. Further, the government of Sri Lanka provide medical service for free for all citizens of Sri Lanka. This has raised the life expectancy of people to reach 71 years, and the infant mortality rate at less than 13 per thousand live births (Rannan-Eliya and Sikurajapathy, 2009). Even though, HC medical delivery of Sri Lanka perform well an article in Sunday Times (2012) titled exposes the current HC system's approach as "hospital standards, doctors' ethics and profits" in which, the current practice of 'take-it-or-leave-it' attitude. Further the article highlights "channelled private practice has become a necessary evil and patients (rich or poor, big or small) are at mercy of doctors". This portrays the fact that HC organisations are ill-treating patients and its visitors, comparative to other industries. Given the information of the current status of HC system in Sri Lanka, the current research aims to explore the current FM and sustainability practice, and its perceptions in HC organisations.

The paper is structured in five main sections. The first and second sections presents literature review and research methodology respectively. Next section presents findings on the current state of the operations of FM in HC organisations in Sri Lanka. Finally, discussion and conclusions are presented.

2. LITERATURE REVIEW

2.1 FACILITIES MANAGEMENT (FM) AND ITS PRACTICES

The development of FM is diversified as every country has its own culture with different type of requirements resulting to consider different approach of FM applications to meet the organisational goals (De Silva, 2011). Although, FM is one of the emerging and fast-growing disciplines, the evolution of FM is unpredictable in another 20 years of time. Thus, capturing the true essence of FM to create a common platform is challenging and solely rely upon FM practitioners who understands the real context of FM.

The operations of FM is not adapted as same for all organisation rather it is firm-specific and can differ. Hence, the selection of appropriate FM practice is very important and a hectic challenge borne by FM in organisations. Further, forming a separate department in organisations allows FM practitioners to handle and organise their FM operations. It gives the freedom for FM to decide on their FM operations and provides a platform for them being accountable for the operations they perform (Sarpin, 2015). In developed countries such as: Singapore, Hong Kong Australia, UK, and USA, majority of organisations comprise a department for FM to conduct operations of FM (Shi, et al., 2016). This enables FM to develop own strategies and determine the appropriate practice to support the core objective of the organisations.

2.2 FACILITIES MANAGEMENT (FM) AND HEALTH CARE (HC) ORGANISATIONS

In developed countries such as; UK, Australia, Singapore and USA etc. FM profession is recognised at the forefront in the delivery of successful medical care, ensuring zero defects by operating the facility without encountering minimum rate of failure for 24 hours (Lavy and Fernández-Solis, 2010). Unlike in other facilities, working as FM in HC requires different skills and standards (AHA Certification Center, 2017). In USA, the American Hospital Association (AHA) recognised the criticality and special requirements and introduced "Certified Healthcare Facilities Manager (CHFM)" certification programme (AHA Certification Center, 2017). FM practitioners who wish to practice in any HC organisation were required to obtain this certificate, which shows the gravity and importance of HC and FM practitioners' contribution towards the HC. Thus, optimal running of the non-medical services interaction requisite of a great variety of FM services.

Healthcare FM by definition means,

> *"a healthcare facilities manager to manage the facility that they're in charge of. Facilities managers should understand the building's design as well as the equipment, both medical and not, that is used within". (AHA Certification Center, 2017, p. 2)*

FM and HC sector intersect the concept of "healthcare FM" in which firm-specific FM operations needs to be recognised (Lucas, 2012). However, the concept of healthcare FM is different from other sector or type of building management, such as office buildings, or educational or industrial facilities as HC is highly critical and consist of many unique features for caring for the health. Therefore, healthcare FM is one of the key elements for the successful delivery of medical care as they are in a position of managing multiple services and coordinates among many other departments. Further, it was found in the literature that there is a gap to be matched, as FM context in the HC sector was not researched whereas office, residential and hotel are researched for a certain extent.

3. RESEARCH METHOD

Delphi is a widely used and accepted survey method for achieving convergence of opinion concerning real-world knowledge solicited from experts (Thangaratinam and Redman, 2005). This is also known as a consensus method to achieve a general agreement upon a certain problem. The Delphi survey endeavours to ascertain experts' opinions on the present issues and set future directions of any subject area to derive suitable solutions (Latif, et.al., 2016).

Delphi survey is a structured process requiring two or more rounds with the purpose of achieving consensus on the subject matter (Cassar, et al., 2014). The decision about the number of rounds is largely pragmatic depending on reaching the consensus (Thangaratinam and Redman, 2005). However, rounds for the Delphi survey require a minimum of two rounds (three if round one is open-ended). Further, the duration for a minimum of two round take as long as thirty days. Within the Delphi survey method, the experts have the possibility of modifying the previous round results in later iterations based on their ability to review and assess the comments and feedback provided by the other Delphi panelists. Thus, the key strength of the Delphi survey is the anonymous expert participation in a controlled feedback process initiated to reach an agreement (Hsu and Sandford, 2007). The first round of questionnaire was based on open and semi-structured questions. This comprised of question types such as; list, category and rating questions. Also, this questionnaire was designed in two sections. Amongst, the first section of the questionnaire designed to grab the background information of the experts' participants. The second section of the questionnaire comprised of open-ended and semi type questions to identify the current FM practice in HC sector. For example, how FM functions are performed, whether the organisation facilitate a separate FM department, what FM services are mostly practiced, how sustainability is integrated, difficulties and benefit they expect by integrating sustainability. This comprised of gathering both qualitative and quantitative data. The second round of the questionnaire was fine-tuned based on the first round results. This round intends to reach consensus on the factors that did not meet an agreement in the previous round. The first section of the questionnaire was given to revisit the experts' opinion on the previous round. The factors were provided with dichotomous questions by giving two options to select from "agree" or "disagree" to the previous round results. Accordingly, this paper presents the findings of the Round I and II of the Delphi survey and highlights the consensus of the experts on the current FM practice in HC organisations.

In a Delphi survey, Fiander and Burns (1998) criticised the use of larger participant sample as it leads to issues of data handling and difficulties in analysis. On the same view, Davidow, et al. (2001) argues the larger participants sample size as the results of the survey tends to give diminishing returns. Sekayi and Kennedy (2017) suggested the use of a sample of fifteen and in which minimum of seven number of participations is widely accepted. Given the details on the selection of the experts, a group of experts was selected to provide opinions on the integration of sustainable practices into the FM practice in the HC sector. Since the information solicited sound experience and in-depth knowledge about the various sustainable practices in an HC industry, a purposive sampling was adopted. This is also referred as a judgmental, or expert sampling and the experts are chosen deliberately for the qualities or knowledge they possess (Bryman, 1996). In simple terms, the researcher decides what needs to be known, what details are needed and sets out criteria's and finds the suitable participants to take part in the research. Unlike random studies that focus on diverse cross section of backgrounds, ages, and culture the purposive sampling intends to concentrate on the nature of knowledge the participant possess and how he will support the relevant research (Etikan, 2016). The selection of the criteria for the experts were set as;

- should possess a minimum of ten years' experience in the field of FM practice
- have extensive working experience of a minimum of five years (past or current) in the FM practice in the HC industry

Accordingly, this research employed 10 experts consisting of (05) Facility managers, (03) Engineers, (01) Medical director and (01) Quality manager, who met the above requirement. Demographics of the respondents to the Delphi survey is as below;

As shown in Figure 1, all the experts hold either a bachelor's degree or master's degree. A 50% of them had master's degree while 3 and 2 of them hold a bachelor's degree in engineering and management, respectively. This distribution of participants shows that the experts participated in Delphi survey are knowledgeable and in capacity of understanding the subject matter.

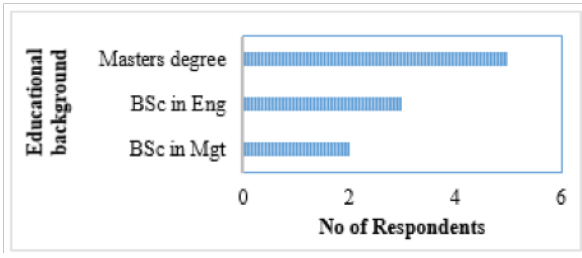

Figure 1: Educational background of Delphi survey participants

As presented in Figure 2, all participants had more than 10 years of experience in FM operations. Amongst, 2 of them had 16 to 20 years of experience while 8 of them had 11 to 15 years of experience. This shows that participants are well experienced in FM operations and in a position to understand the context of FM.

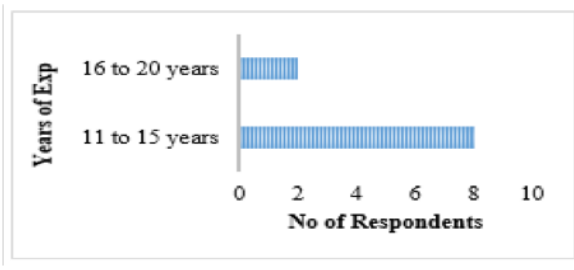

Figure 2: Years of experience in FM operations

Experiences of Delphi survey participants in HC operations were clustered as shown in Figure 3. Six participants had experience below 10 years in the HC operations, of which 2 experts had 1 to 5 years and 4 had 6 to 10 years. The remaining 4 participants out of 10 experts had substantial experience in HC operations with their involvement in the field for more than 11 years. These qualities of Delphi survey participants ensure the creditability and quality of findings of the current study.

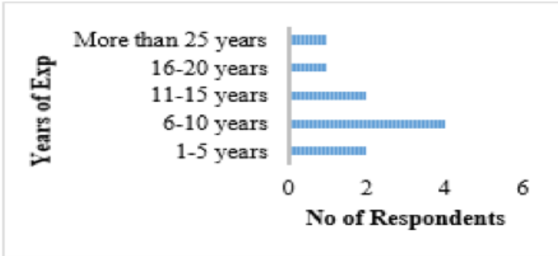

Figure 3: Experience in HC operations

With regard to the analysis of data, qualitative results were analysed using a content analysis. Similar words were grouped together whereas different terms were also looked into as it could mean the same issue. Researcher thereby grouped these into one universal description to provide a meaningful explanation of the topic. Central tendencies (mode and mean) and levels of dispersion (inter-quartile range) were used to analyse the quantitative data and to provide the feedbacks. To provide participants with information about collected opinion requires the functions of using these mathematical functions. Also past studies namely; Hsu and Sandford, (2007) and Thangaratinam and Redman (2005) had used these functions to communicate their feedbacks these are circulated in the prior rounds in the form of 30% disagreed with the statement, 25% strongly agreed with the statement, and so on. Thus, this study uses mean (Eq. 01), mode and quartiles to analyse the participants view and to provide the feedbacks. These were calculated as;

Mean

$$M = \sum_{i=1}^{5} (Fi \ x \ \% \ R) \qquad (Eq.\ 01)$$

Where: M = Mean weight for an attribute; Fi = Frequency of responses for an attribute (ranging from 1-5); %R = Percentage response to rating point of an attribute.

Mode

The mode is the most commonly occurring data point in a dataset. It is calculated to analyse the aggregate value of the respondents for each of the Likert scale points.

Quartile range (QR)

Quartile range is a measure of variability, where the quartiles represent the values divided into four equal parts. QR allows understanding of where the bulk of the values lie, whether it is in the lower quartile (Q1) or interquartile (IQ2) or upper quartile (Q3).

Further, to provide feedback on each round, the decision on the consensus level should be set at the beginning of the study (Walker and Selfe, 1996). Consensus levels have been established as low as fifty-one percentage and as high as eighty percentage (Thangaratinam and Redman, 2005). Flores, et al. (2014) suggest the consensus level to establish at seventy percent as higher consensus levels mean majority of Delphi participants agree to the subject matter and it is more reliable to achieve the research objective. Accordingly, the overall consensus was set at 70% i.e. the accumulation of the “4-agree and 5-strongly agree” frequency obtained in all rounds of Delphi survey.

4. RESEARCH FINDINGS

In order to determine the current FM practice among the HC organisations in Sri Lanka the participants were asked to state their response in terms of; the existence of separate FM department to perform FM practice, what extent the FM services are practiced, how effective sustainability is integrated into the existing operations of FM and what barriers they encounter in adapting sustainability endeavours.

4.1 FM OPERATIONS IN HC ORGANISATIONS IN SRI LANKA

As shown in Figure 4, only 2 of the selected organisation had formed a separate department for FM related operations and they were solely undertaking maintenance and housekeeping related functions. Similarly, with rest of the 8 organisations the same functions were carried out but in a collective manner among engineering, quality assurance and maintenance departments. These collective measures in performing FM practice was not accounted by any person or a specific department which resulted in many disputes, delays in the operations, poor coordination. On the other hand, it was found that the organisations that had a separate department for FM had less disputes as accountability was explicit and borne by a single department.

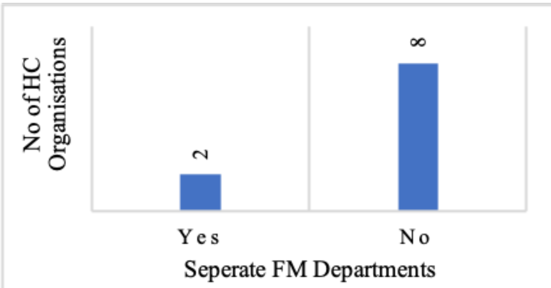

Figure 4: HC organisations with separate department for FM Vs Non FM

4.2 INTEGRATION OF FM SERVICES IN THE CURRENT OPERATIONS OF FM

The experts were asked to state, FM services which has been practiced in their HC organisation in the given five point Likert scale "1-not at all practiced, 2-rarely practiced, 3-moderately practiced, 4-often practiced and 5-always practiced". Not at all practiced meant that the organisation never integrated the given FM service whereas always practiced meant that the organisation 100% practice that particular FM service.

According to Table 1, the majority of the participants stated that they always practice BS into their current operations of FM (as it received a mode value of 5). However, the lower quartile (Q1) and upper quartile (Q3) ranges got a value of 3.75 and 5, suggesting BS was either often or always practiced. Accordingly, an average mean value was calculated and BS received the highest mean value of 4.10 suggesting it is often practiced and integrated by all the selected HC organisations. On the other hand, quality management (QM) and risk management (RM) were often practiced as the results of mode had a value of 4. Also the quartile ranges, Q3 and Q1 suggested either often integrated or moderately integrated. Accordingly, the mean value determined the ranks and both FM services had a very slight difference that made QM the second most practiced service and RM as the third with the mean values of 3.60 and 3.50 respectively. Thus, both were considered to be moderately practiced in all selected HC organisations.

Table 1: Status of FM services adapted into the operations of FM

	FM services	Mode	Mean	Quartile range	
				Q1	Q3
1	Building Services (BS)	5	4.10	3.75	5.00
2	Quality Management (QM)	4	3.60	3.00	4.00
3	Risk Management (RM)	4	3.50	3.00	4.00
4	Human Resource (HR)	3	3.00	3.00	3.75
5	Operations Management (OM)	2	2.90	2.00	4.00
6	Project Planning (PP)	2	2.80	3.00	3.00
7	Financial Services (FS)	3	2.70	2.00	3.00
8	Information Technology (IT)	2	2.60	2.00	3.00
9	Space Planning (SP)	2	2.20	1.25	3.00
10	Real Estate (RE) management	2	2.10	1.25	2.75
11	Marketing Management (MM)	1	1.60	1.00	2.00

Majority of the experts had same opinion on stating that they practice human resources (HR) and financial services (FS) moderately (mode had a value of 3). However, in terms of the quartile values, Q1 obtained a very lowest value of 2.00 for FS and 3.00 for HR suggesting that first quartile range of experts were in the opinion of moderately practicing HR and rarely practicing FS in the selected organisations. Even for operations management (OM) and information technology (IT) had the same 2.00 first quartile value suggesting that 3 organisations practice these services rarely. Whereas, space planning (SP), real estate management (RE) and marketing management (MM) received Q1 value below 1.50 suggesting that in 3 organisations it is not at all practiced. In majority of the selected organisations, these services are either not at all integrated or rarely practiced because the upper quartile also had a value below 2.00. For example, five participants of Delphi survey informed that in their organisation, they do not practice or participate in MM functions and solely the marketing division handles it.

Accordingly, mean values were achieved for the remaining 9 FM services namely; OM, FS, PP and IT and it were determined to be rarely practiced. Whereas, SP, RE and MM were found to be least practiced as it had received a mean value of below 1.50. Lack of knowledge, poor coordination, and unwillingness of sharing information among departments are few of the reasons that participants stated for them to stick with the traditional practice in their organisations.

4.3 Integration of Sustainable Practice in FM Operations

This section of the Delphi survey requested the experts to comment on the level of integration of sustainability in the given scale of "1-not at all integrated, 2-rarely integrated, 3-moderately integrated, 4-highly integrated and 5-extremely integrated". According to Table 2, majority of the participants stated that they integrate sustainability moderately as the result of mode had a value of 3.00. In addition, the lower and upper quartile values also ranged in between 3.00 and 3.75 leaving us to conclude that the majority participants' view firmed around the moderate level. In addition, the mean value also received 3.30 indicating that practices of sustainability was at a moderate level in the current FM operations.

Table 2: Integration of sustainability in the operations of FM

	Mode	Mean	Interquatile range	
			Q_1	Q_3
Current level of sustainability integration	3	3.30	3.00	3.75

In another attempt, participants' opinions were gathered in terms of sustainability integration with regard to each individual FM services with same five point Likert scale as above.

According to Table 3, integration of sustainability into BS achieved the highest mean value of 3.60. Though the integration of sustainability is in a higher-level overall, one (01) of participants stated that they rarely integrate sustainable practices while another four (04) participants stated that they have moderately integrated sustainable practices and it is limited to aspects of HVAC, lighting sensors, water purification and waste water discharge.

Table 3: Extent of sustainability integration in FM services

	FM Services	Mode	Mean	Quartile range	
				Q_1	Q_3
1	Building Services (BS)	3	3.60	3.00	4.00
2	Quality Management (QM)	3	3.10	3.00	3.75
3	Project Planning (PP)	3	2.50	2.00	3.00
4	Financial Services (FS)	3	2.50	2.00	3.00
5	Information Technology (IT)	2	2.50	2.00	3.00
6	Operations Management (OM)	2	2.40	2.00	3.00
7	Human Resource (HR)	2	2.30	2.00	3.00
8	Space Planning (SP)	2	2.10	1.25	3.00
9	Risk Management (RM)	2	2.00	2.00	2.00
10	Real Estate management (RE)	2	1.60	1.00	2.00
11	Marketing Management (MM)	1	1.30	1.00	1.75

Also, QM service has integrated sustainable practices to an extent of moderate level with the mean value of 3.10. Amongst, two participants revealed that they rarely integrate sustainability whereas 3 participants stated that they highly integrate sustainable practice. Amongst these 3 organisations sustainability is frequently monitored with quality control standards whereas, in rarely practiced organisation it is only carried out if there is a need.

Similarly, services such as; PP, FS and IT received mean values of 2.50 indicating a moderate level of integration of sustainability. Although, all three services received similar values, majority of participants stated they rarely integrate sustainability with respect to IT and currently maintaining the same technical systems as conversion for other systems require a lot financial support and training. Meantime, rest of the services namely; OM, HR, SP, RM, RE, and MM received very low mean values below 2.50 indicating, lease level of sustainability integration. These limited levels of sustainable practice integrations are mainly due to barriers experienced by the selected organisations.

Thus, next section explores the barriers in integrating sustainable practices into these FM services in the selected 10 organisations.

4.4 BARRIERS IN INTEGRATING SUSTAINABLE PRACTICES INTO THE OPERATIONS OF FM

Level of constraints encountered in the process of integrating sustainable practices and identifying significant barriers in integrating sustainable practices opinions were collected. A five point Likert scale of "1-no opinion, 2-strongly disagree, 3-disagree, 4-agree and 5-strongly agree" was provided to state Delphi survey participants on their opinion on the existing barriers that mitigates integrating sustainability.

According to Table 4, all the participants of the Delphi survey strongly agreed to the statement that they encounter many difficulties in integrating sustainability into the operations of FM with respective to their organisation. A mean value of 4.20 was received.

Table 4: Level of constraints in integrating sustainability

	Mode	Mean	Quatile range	
			IQ1	IQ3
Constraints in integrating sustainability into FM operations	4	4.20	4.00	4.00

The collective opinion of all participants' opinion indicated that the constraints they encounter within the organisations are relatively very high in the process of integrating sustainability. Overall, in all 10 selected organisations integrating sustainability into the FM services is not easy but challenging. With regard, 32 barriers were listed and participants' opinion on the most significant barrier are shown in Table 5.

Table 5: Significant barriers in integrating sustainability - DS: R I

	Barriers	Mode	Overal consensus (A+SA)*	Mean	Consensus Achieved	Persue to Round 2
1	High cost	5	90%	4.40	Yes	No
2	Resistance to change	5	90%	4.10	Yes	No
3	Lack of finance	5	70%	4.10	Yes	No
4	Rigid requirement	4	80%	4.00	Yes	No
5	Long payback period	4	80%	4.00	Yes	No
6	Lack of legislation and forcing green building laws	5	80%	4.00	Yes	No
7	Political governmental issues	4	80%	4.00	Yes	No
8	Culture, attitude, norms and behavior of people	4	70%	3.90	Yes	No
9	Inadequate building laws	4	70%	3.70	Yes	No
10	Lack of green building material suppliers	4	70%	3.70	Yes	No

	Barriers	Mode	Overal consensus (A+SA)*	Mean	Consensus Achieved	Persue to Round 2
11	Lack of training	4	80%	3.70	Yes	No
12	Lack of tested, reliable green building materials locally	4	80%	3.70	Yes	No
13	Lack of knowledge and capability	4	80%	3.60	Yes	No
14	Risks and uncertainty	4	70%	3.60	Yes	No
15	Company size	4	70%	3.60	Yes	No
16	Lack of Green building guides or codes or regulation	4	70%	3.60	Yes	No
17	Lack of government initiatives or support	4	60%	3.60	No	Yes
18	Improper property valuation system	4	60%	3.50	No	Yes
19	Duration of project	4	60%	3.50	No	Yes
20	Scarcity of resources	4	60%	3.50	No	Yes
21	Insurance liability issues	4	60%	3.40	No	Yes
22	Distrust of green building products	1	50%	3.40	No	Yes
23	Project location	4	50%	3.40	No	Yes
24	Poor quality of green building design	4	50%	3.30	No	Yes
25	Project complexity	4	50%	3.30	No	Yes
26	Lack of certificate	2	50%	3.20	No	Yes
27	Lack of promotion	2	50%	3.20	No	Yes
28	Bureaucracy	3	40%	3.20	No	Yes
29	Lack of communication and interest among stakeholders	2	50%	3.00	No	Yes
30	Lack of interest or demand from clients	3	20%	2.90	No	Yes
31	Lack of Technology	2	10%	2.40	No	Yes

*Overal consensus (A+SA) = accumulated values of the scale: "4-agree" + "5-strongly agree"

Significance of barriers were determined through overall consensus of participants. In regard, overall consensus is referred to the accumulated values of the Likert scale: "4-agree" + "5- strongly agree", receiving a value of above 70% (see Section 3). Thus, 16 barriers had overall consensus of above 70%, indicating 70% of participants find these barriers as significant in mitigating the integration of sustainability in the selected organisations. Amongst, "high cost", "resistance to change," and "lack of finance" were the top most three barriers recognised with a mean value of above 4.00.

However, the overall consensus which obtained a value below 70% is considered as "consensus not reached" and carried forward to the next round as participants opinion had disagreement. For example; in table 5, "lack of promotion" barrier had an overall consensus of 50% agreeing that barrier being significant where rest of the 50% participants informed they do not consider it significant in integrating sustainability in their organisation. Similarly, 15 out of 31 barriers had split opinion with consensus of below 70% and regarded as "non-significant" and these factors are highlighted with grey colour thereby it is carried forward to the next round. Table 6 presents findings of Delphi survey round II.

Table 6: Significant barriers in integrating sustainability - DS: R II

	Results Round I		Results Round II			Persue to Round III
	Mean	Overall consensus (A+SA)*	Agreement to the Round I results		Consensus	
			Agree	Disagree		
Lack of government initiatives	3.60	60%	30%	70%	significant	No
Scarcity of resources	3.50	60%	20%	80%	significant	No
Lack of communication and interest among stakeholders	3.50	50%	30%	70%	significant	No
Lack of interest or demand from clients	3.50	20%	20%	80%	significant	No
Lack of certificate	3.40	50%	30%	70%	significant	No
Project complexity	3.40	50%	40%	60%	significant	No
Improper property valuation system	3.40	60%	30%	70%	significant	No
Lack of promotion	3.30	50%	30%	70%	significant	No
Bureaucracy	3.30	40%	70%	30%	non-significant	No
Lack of Technology	3.20	10%	80%	20%	non-significant	No
Distrust of green building products	3.20	50%	60%	40%	non-significant	No
Project location	3.20	50%	80%	20%	non-significant	No
Poor quality of green building design	3.00	50%	70%	30%	non-significant	No
Insurance liability issues	2.90	60%	80%	20%	non-significant	No
Duration of project	2.40	60%	70%	30%	non-significant	No

***Overal consensus (A+SA) =** accumulated values of the scale: "4-agree" + "5-strongly agree"

The round II of Delphi survey assist the participants to revisit their opinion. In other words, Delphi survey participants were given the chance to amend the results in this round by either agreeing to the previous round result or disagreeing to the previous round results allowing them to revise the results obtained. In essence, in Table 6, eight barriers were revised and regarded as significant whereas rest of the 7 barriers remained same and regarded non-significant and highlighted with grey rows. Accordingly, 24 out of 31 barriers are significant in integrating sustainability and contribute in mitigating the adaptation of sustainability into the operations of FM in HC organisations.

5. DISCUSSION OF THE DELPHI SURVEY RESULTS

FM has evolved drastically within the last three decades. In developed countries, FM plays a vital role and well recognised. According to the findings among the selected private HC organisations 2 had separate FM department and only maintenance and housekeeping related functions were undertaken. Whereas 8 organisations that had, no separate department for FM jointly performed operations amongst departments namely engineering, quality assurance and maintenance and performed the same functions i.e. maintenance and housekeeping. However, the organisations which jointly performed their FM operations were constantly faced with delays in FM tasks and disputes, as there was no specific person accountable for operations of FM. With regard to developed countries the operations of FM are handled by separate department and FM profession is well recognised among stakeholders as FM brings many substantial benefits to the organisations (AHA Certification Center, 2017). Thus, having a separate department in HC organisations will enable uninterrupted operations and support the organisations to achieve its core objective.

FM is a multi-dimensional (IFMA, 2016) or hybrid (Hodges, 2005) profession comprise of many varied services to support the core businesses. Apparently, in Sri Lankan HC organisations, operations of FM are being carried out fundamentally in BS while very few HC organisations have adapted quality management and risk management to a moderate level. Thus, it is very essential for FM practitioners in HC organisations to determine what FM services and how it could be integrated. On the other hand, the findings of identifying quality management and risk management being practiced next to building services, evidences the studies fundamental argument of FM operations being different to facilities. Quality management gained the next most moderately practiced service in HC organisations as they are vulnerable in spreading harmful substances and decease to the environment whereas in other facility types such as education, hotel, housing, and office quality and risk management does not take a level of importance. Even though, FM operations are regard as hybrid or multi task, in Sri Lankan HC organisations it is only recognised for maintenance, housekeeping and partially performing quality related activities. Thus, this study points out the lack of service integration that HC industry faces.

Sustainability has become an inevitable agenda in all business activities around the globe. HC sector is not an exception; in fact, it is the most vulnerable sector to adapt sustainability. In regard, Universal Health Coverage (UHC) of Sri Lanka has taken a notable recognition in adapting SDGs to ensure healthy lives and promote well-being for all. Although, measures had been taken, current status evidenced that integration of sustainability in HC organisations are at moderate level (see Table 2).

Further, integration of sustainable practices into the individual FM services also found below the moderate level as only building services and quality management received a mean value of above 3.00 whereas other FM services received a value below 2.50 (see Table 4). This indicated that sustainable practices are rarely integrated into those FM services whereas in few organisation not at all practiced. Drawbacks and numerous difficulties are a major reason why still sustainability is yet a mere thought in many organisations. Similarly, the participants of the Delphi survey also stated the challenges and the constraints they face in integrating sustainability. The root cause that mitigates the integration of sustainable practices in HC organisations is found to be "high cost" and "long payback period" (see Table 5). These obtained highest mean values of 4.58 and 4.46. Even though, these two were highlighted there are 24 significant barriers listed in the study that is applicable to the local context. However, these two barriers highly affect monetary aspects of an organisation.

6. CONCLUSIONS

Operations of FM is at an infancy stage and encounter many disputes and delays as there are no specific department to handle FM related functions. Also, operations of FM were highlighted in the aspects of building services and rest of the FM services were either moderately practiced or not at all practiced. Although, FM is recognised as one of the forefront professions in HC facilities in developed countries, in Sri Lanka it is seemed as an engineer's job with specific focus on hardware aspects. Even said that, one of the other important finding revealed that the operations of FM vary according to facility type as quality management and risk management claims important in HC industry.

Another reason FM being at the infancy stage is, in Sri Lankan HC organisations, sustainability concerns are at a moderate level and comprise of numerous challenges as highlighted by all the participants of the survey. Also the integration of sustainable practices are mostly practiced into the building services and rest of the other FM services are given less importance. Also, given all the barriers financial barrier seemed to be the biggest concern that limits FM practitioners to integrate sustainability.

The findings of the study offer a foundation to equip the researcher and to determine the state of FM practices in HC organisations. Knowing the current perception allows the researcher to set a direction to implement a successful research focus on achieving the aim of the study which is to develop a framework to assess sustainable FM practice through addressing the existing significant barriers exists in the effective delivery of FM practice in HC organisations. This will enhance the current state of noncore services delivery and promote a better successful sustainable HC.

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THE APPLICABILITY OF REGULATIONS FOR THE DISPOSAL OF CONSTRUCTION AND DEMOLITION WASTE IN SRI LANKA

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ABSTRACT

Effective and efficient waste management plans/systems are vital in reducing and maintaining the generation of construction and demolition waste. It was proved in previous research, proper rules and regulations affect the effectiveness of the waste management strategies used in disposing of construction and demolition waste. Therefore, this research aim is to identify the regulations applicable for the disposal of construction and demolition waste in Sri Lanka to propose improvements in the available rules and regulations. Comprehensive literature and document review were conducted to approach the aim of this research. Questionnaire surveys and expert interviews were carried out to validate the findings of the literature survey and to gather required data in identifying the issues related to current rules and regulations and proposing improvements. The findings revealed that many gaps can be identified with the current regulations used in the disposal of construction and demolition waste. The results of the research identified a lack of intention in government regarding recycling, avoiding improper landfilling, and avoiding illegal dumping of construction and demolition waste as major issues. The study finally concluded the necessity of modified rules and regulations regarding the disposal of construction and demolition waste.

Keywords: *Construction Demolition Waste; Law and Regulations; Waste Management.*

1. INTRODUCTION

The Construction industry holds a major role in Sri Lankan national economy while being the fourth largest industrial division with 6-7% of Gross Domestic Product (GDP) (Jayalath and Gunawardhana, 2017). Sri Lankan construction industry has contributed about 50% of the total GDFCF (Gross Domestic Fixed Capital Formation) with other benefits like tax revenue, profits, employment, etc. (Shen and Liu, 2003). At present, an increase in the number of commercial, industrial, and national scale mega projects can be seen all over the country which proves the contribution of the construction industry towards the national economy of Sri Lanka (Chanudha, et al., 2017).

According to Asgari, et al., (2017) construction industry is ranked as a top user of natural resources and generator of waste materials where 25% of timber resources and 40% of

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natural raw materials are being utilized by the construction industry worldwide. It is evident that a significant quantity of waste is produced worldwide due to construction-related activities (Omoniyi, Akinyemi and Nwosu, 2014) However, Sapuay, (2016) claims that much attention should be given to waste materials as improper management of waste materials can cause adverse effects to the environment and lifestyle of people and other living beings. Due to the enormous development processes and increase in human population worldwide, the demand for construction activities increases causing the amount of construction and demolition waste to increase. Previous studies reveal that 35% of municipal solid wastes in developed countries are due to construction activities, while it is 50% in developing countries (Ansari and Ehrampoush, 2018).

Sapuay (2016) stated the management, controlling, and disposal of construction and demolition waste is very crucial. Further, it is the main responsibility of a contractor of a construction project to maintain a sanitary working environment by acceptably disposing of the waste. Therefore, considering a disposal method, the first concern should be given to statutory framework/regulations available within the certain country related to the construction and demolition waste disposal (Asgari, et al., 2017). Hence, this research is based on regulations applicable for the disposal of construction and demolition waste in Sri Lanka.

2. LITERATURE REVIEW

The related literature review was carried out to identify the regulations applicable for the disposal of construction and demolition waste in Sri Lanka

2.1 WASTE MATERIALS AND METHODS

Construction waste materials and methods are presented here.

2.1.1 Construction and Demolition Waste

Construction and demolition waste is generally a mixture of additional materials produced during a construction project or the waste generated through a demolition activity of a constructed facility (Chowdhury, et al., 2016). Generally, the generation of waste due to demolition activities is more than the waste generated during the construction of a structure. The demolition waste can be defined as an assemblage of an unusable set of materials that priory benefits the demolished structure.

A Significant quantity of waste is produced worldwide due to construction-related activities (Omoniyi, Akinyemi and Nwosu, 2014). According to the reports of the Department of Sustainability, Environment, Water, Population and Communities (DSEWPC), from all the materials produced or manufactured, 50% is utilized for building materials and results in generating about 50% of solid waste in the world (Omotayo and Akingbonmire, 2017). It is reported that in the United States of America, about 136 million tons of construction wastes are produced annually due to construction-related activities. Similarly, in the United Kingdom, about 70 million tons of waste are collected and that amount is 10-15% out of the total waste materials collected in the United Kingdom (Ghafourian, et al., 2016). Further, through surveys carried out worldwide, it has been identified that China generates about 48% of waste out of the total construction and demolition waste generated in the world, while Japan, South Korea, and China are generating waste margins of about 21%, 7% and 4% respectively (Amirthakadesharan and Kalpana, 2017). Hence, Construction and demolition waste has converted into a worldwide problem with the current modernization period.

2.2 CAUSES OF CONSTRUCTION WASTE

The industry of construction is well known for waste produced during the production stage and the abstraction of raw materials in the implementation of construction projects (de Magalhães, Danilevicz and Saurin, 2017). The concerning fact is that construction waste is existing in many different forms and various quantities (Salgin and Cosgun, 2018). This has become a major challenge as these waste materials produced throughout the construction process is an issue in achieving the required performance and the sustainable goals of the project (Kulatunga, et al., 2006). Causative factors for the generation of these amounts of waste can be classified and described in many ways. Some of the main sources which contribute to the generation of construction-related waste materials can be categorized as given in Table 1.

Table 1: Causative factors for the generation of waste

Phases	Causative factors	Reference
Design stage	Design errors, Poor design quality, Frequent changes in design after construction is in progress, Complexity of the design, Inexperience of the designer, Lack of information to design	Nagapan, Rahman and Asmi (2011)
Handling	Improper handling & storage of materials, Damages, and delays during transportation, Equipment failures	Akhund, et al. (2019).
Working stage	The attitude of the workforce, absence of a proper reward, and a controlling system. Lack of experience of workers, and Skilled workers, Improper handling of tools and equipment, Irregular wear of equipment, and Working conditions and time.	Nagapan, Rahman and Asmi (2011)
	Lack of training among the workforce and the negative attitude towards the subordinates by the higher management	Kulatunga, et al. (2006)
Management	Poor planning, control, and supervision., Lack of interrelatedness between parties, lack of communication, Poor awareness of environmental conditions waste management plans	Akhund, et al. (2019)
Due to Procurement methods	Errors in ordering and under/over-ordering, shipment errors, ignoring provided specifications, waiting for any replacement's orders.	Akhund, et al. (2019)

2.3 CATEGORIZATION OF WASTE

At present, the growth in the construction industry influences the generation of enormous amounts of waste due to construction and demolition activities. Rajendran and Pathrose (2012) define construction waste as any damage caused by construction activities that cause both direct and indirect costs where it does not add any value to the final product from the client's point of view. The waste materials can be grouped according to many facts and areas. Common types of construction waste are given in Table 2.

Table 2: Common types of construction waste

Fact	Description	Reference
Natural Waste	Can be defined as the minimum amount of waste that will always occur, despite the type of the project	Khaleel and Al-Zubaidy, (2018)
Potential Waste	Potential waste is defined as avoidable waste materials.	Akhund, et al., (2019)
Physical Waste	Physical waste is the waste that can be seen in any kind of construction project due to activities like construction, renovation, and demolition.	Khaleel and Al-Zubaidy (2018)
	Physical waste can be further subdivided as structure waste and finishing waste.	Akhund, et al. (2019)
Non-physical Waste	The major forms of nonphysical waste in construction projects are time and cost overruns.	Khaleel and Al-Zubaidy (2018)
Inert Waste	Inert waste is chemically inactive and less harmful waste materials.	Poon, et al. (2013)
Non-inert Waste	Non-inert waste materials are chemically active materials.	Poon, et al. (2013)

2.4 CONSTRUCTION AND DEMOLITION WASTE DISPOSAL/MANAGEMENT SYSTEMS

Through the construction industry, massive quantities of waste are generated as by-products of rapid urbanization activities in most of the developing countries (Mah, Fujiwara and Ho, 2018). A major risk to the environment arises due to the illegal dumping of construction and demolition wastes. Therefore, to mitigate the negative effects caused by construction and demolition waste, it is vital to ponder the proper waste disposal systems in Sri Lanka.

The most common form of construction waste disposal method used around the world is landfilling in which, more than 50% of the waste generated ended up in landfills (Al-Hajj, Iskandarani, and Al-Hajj, 2012). Studies show that about 13-26% of wastes collected in landfills are waste materials related to construction works (Nagapan, Rahman and Asmi 2011). According to Devia, et al (2017) construction and demolition waste in landfills can cause effects on soil and groundwater as leaching of toxic materials can occur.

Another widely used system in managing construction and demolition waste is recycling, which can be defined as a simple treatment given to the construction waste materials, where the physical properties may slightly change (Asgari, et al., 2017). Generally, 50 to 80% of construction and demolition waste is recyclable (Asgari, et al., 2017). In developed countries, recycling of construction and demolition waste is regulated under laws and policies, where the recycling rates should be greater than 90% in most cases. Studies show that 90% of construction waste materials are recycled in Australia while Japan has achieved a 99.5% recycling rate in 2012. The highest recycling rate was reported by Singapore where the rate is 99.9 % (Mah, Fujiwara and Ho, 2018).

Another concept in managing the construction and demolition waste is reusing. Reusing does not need any processing to utilize the certain material. The items can be directly used after being collected through, without any conversion or energy input (Bansal and Singh, 2014). Reusing construction and demolition waste leads to saving natural resources, reducing negative environmental impacts, reducing adverse effects to CO_2 footprint, reducing large spaces required for waste dumping sites, and creating job and business opportunities across the world. Useful materials like mild steel, reinforcement, structural steel, doors and windows, bricks, and other metal items can be reused easily with minimum processing. Asphalt toppings can also be used as the base for new asphalt pavements (Kumbhar, Gupta and Desai,2013).

Researchers have also identified the importance of using construction and demolition waste materials as aggregates for new construction projects. Deiyagala, et al (2017) identified the potential of using crushed construction and demolition waste material like demolished concrete aggregate, ceramic tile coarse aggregate, demolished block fine aggregate as substitutions for mineral rock and sand in the preparation process of concrete mixtures and mortar (Deiyagala, et al., 2017).

2.5 CONSTRUCTION AND DEMOLITION WASTE IN SRI LANKA

The generation of construction and demolition waste has become a major issue in the Sri Lankan construction industry as it has surpassed the acceptable limits. Therefore, many researchers have considered researching construction waste management in Sri Lanka to propose effective waste management methods (Rameezdeen, Kulatunga and Amaratunga, 2004).

According to Jayawardane (1994), concrete and mortar wastage takes up to 21% and 25% of wastage in sites. The research was undertaken by Rameezdeen, Kulatunga and Amaratunga (2004) in Sri Lanka for quantifying construction material waste in Sri Lankan sites. According to the results, Sand is considered as the material to be having the highest wastage in Sri Lankan construction sites amounting to 25% out of the total collected waste amount. Respectively, Lime waste (20%), Cement waste (14%), Brick waste (14%), Ceramic Tile waste (10%), Timber waste (10%) are generated. The study further stated that material cutting processes and improper management are the major causes for waste generation.

2.6 LAWS AND REGULATIONS APPLICABLE IN THE DISPOSAL OF CONSTRUCTION AND DEMOLITION WASTE

The construction industry is a major generator of waste (Mah, Fujiwara and Ho, 2018). The contractor for a project is responsible for maintaining a sanitary working environment through disposing of waste generated through construction-related activities (Asgari, et al., 2017). As the period of a contractor is limited to the construction period, the common practice is the disposal of waste in the most convenient method, which will not be a considerable expense for the construction project. Therefore, minimum consideration is given to future consequences and proper waste disposal methods (Sapuay, 2016).

Legal policies and regulations become the basis for the project participants to perform construction, supervision, and management properly and effectively (Sapuay, 2016). When standard regulations and policies are applicable, implementation will affect all the participants of the project where all are responsible and liable under the regulations and policies up to a certain extent (Nguyen, 2016).

2.6.1 Laws and Regulations: Sri Lankan Context

The management of construction and demolition waste is governed under the National Environment Act of Sri Lanka. The title of the National Environment Act (1988) is, "for the protection, management, and enhancement of the environment, for the regulation, maintenance, and control of the quality of the environment; for the prevention, abatement, and control of pollution".

Under part iv A, Environmental protection section of the Act, no person is allowed to deposit, discharge, or emit waste into the environment unless the person holds a license for issuing waste. The Authority has the power to issue a license for persons who applies under the standards and criteria prescribed in the Act. At any time, the authority can suspend or cancel the license in case of violation of any terms, standards, and conditions of the license given.

Under part iv B, Environmental Quality section of the Act, the following offenses and penalties tabulated in Table 3 are applied.

Table 3: Offences and Penalties under Part iv B Environmental Quality Section of the Act

Violence	Punishable Offence	Penalty
Polluting inland waters	Releasing any harmful solids, liquids, or gases to water bodies. Releasing any waste material in the form of solids, liquids, or gases to water bodies. Causing the temperatures of inland, coastal or offshore water bodies to increase or decrease more than acceptable limits.	A fine not less than Rs.10,000 and not greater than Rs.100,000
Polluting atmosphere	Discharging of odors that are harmful to people Burning of prohibited fuels Burning waste materials at unsuitable times or places	A fine not less than Rs.10,000 and not greater than Rs.100,000.
Soil pollution	Illegal dumping makes the soil poisonous or impure Keeping waste in private lands or places that may be offensive to others	A fine not less than Rs.10,000 and not greater than Rs.100,000
Sound pollution	Emitting noises greater in volume, intensity, or quality than acceptable limits	A fine not less than Rs. 10,000 and not greater than Rs. 100,000

The authority has the power in issuing notices to remove waste or litter piles collected. Any person who fails to fulfill the requirements of the notice will be guilty and the authority can remove the litter and collect the spent amount in removing the litter by the person responsible (National Environment Act, 1988).

It has been identified that the general rules and regulations applicable for Construction and demolition waste management are not appropriate as the available regulations are not directly supportive enough in increasing the rates of recycling, reusing, and decreasing the rate of illegal disposal of waste. Although certain amendments were made regarding the act from time to time, no amendment includes clauses on recycling, reusing, or illegal disposal of construction and demolition waste.

3. RESEARCH METHODOLOGY

Considering the in-depth investigation required in this study, a mixed approach was used for this study. Data were collected using questionnaire surveys and expert interviews. The questionnaire was pre-tested through the pilot test. A pilot test was applied to identify the validity of the developed questions and was conducted by analyzing the results of the questionnaires gathered through five construction industry professionals. Afterward, the required modifications were applied and the questions were finalized.

Both quantitative and qualitative data were gathered through the questionnaire survey from thirty construction industry professionals including Project Managers, Engineers, and Quantity Surveyors. Six expert interviews were arranged with construction industry professionals to gather qualitative data in achieving the research aim. Interviewees were selected using the non-probability sampling technique. The sample is limited to the Colombo district as the number of ongoing construction projects was very high compared to other districts, which leads to the generation of an enormous amount of construction and demolition waste. The quantitative data collected through the questionnaire survey were analyzed using the descriptive analysis method. The collected qualitative data were analyzed using the content analysis method.

4. ANALYSIS AND RESEARCH FINDINGS

4.1 ANALYSIS OF QUESTIONNAIRE SURVEY

Data collected through a questionnaire had 30 professionals participating from the construction industry which comprised 10 Engineers, 6 Project Managers, 9 Quantity Surveyors, and 5 Technical Officers. 5 professionals had over twenty-year of working experience. 7 respondents had 10 to 15 years of experience while most of the professionals had 5 to 10 years of experience.

4.1.1 Construction Waste

Based on the construction site: 24 respondents out of 30, confirmed that Building projects produce the highest amount of waste, where 1 respondent has chosen Road projects and 4 respondents agree on Bridge construction. Based on Causes of Waste Generation: most have agreed that more waste is generated at the working stage of a project. And no respondent considered that management leads to generating higher amounts of waste. The respondents were provided with 10 common construction waste materials which can be seen in Sri Lankan construction sites to identify the 3 most abundant waste materials (refer Figure 1).

Note: • A - Timber, Concrete, Tile • B - Timber, Bricks, Steel • C - Concrete, Mortar, Tile • D - Concrete, Tile, Bricks • E - Concrete, Tile, Steel • F - Concrete, Bricks, Mortar • G - Bricks, Steel, Tile • H - Bricks, Mortar, Tile

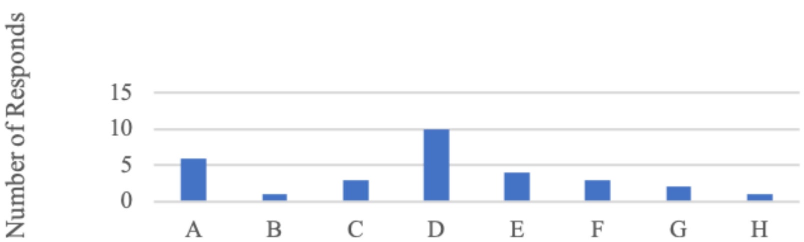

Figure 1: Construction waste materials

According to Figure 1, most of the professionals have agreed that category D which is concrete, tiles, and bricks can be considered as the most abundant waste materials which are being disposed of as waste at construction sites.

4.1.2 Construction Waste Management Systems

According to the analysis, landfilling has been considered by the respondents as the most utilized method in disposing of construction and demolition waste materials. However, on the contradictory, out of the 30, 21 respondents then recommended that, recycling as the best possible method to be applied on construction and demolition waste materials in Sri Lanka. Figure 2 details the responders' opinion on the suitable waste management for the Sri Lankan Context.

Figure 2: Waste management methods (Recommended)

4.1.3 Awareness on Environmental Act

Out of the 30 despondent, 70% of the respondents conveyed the fact that they have a general understanding of the environmental act thus a 30% which includes a project manager, 3 Engineers, and 5 QSs conveyed their unawareness regarding the act.

4.2 ANALYSIS OF EXPERT INTERVIEWS

6 current industry practitioners who are having more than 5 years of experience in their relevant profession had contributed their knowledge for the interviews. Expert interviews were carried out to gather required information on achieving the knowledge were improvements that need to be implemented in current regulations.

4.2.1 Identification of Problems in Current Regulations

All the interviewees pointed out that proper waste segregation upon disposal needs to be highly considered. Waste materials collected on most of the sites are piled up without any prior classification of the materials. Because of that, waste materials that can be recycled or reused will directly be discarded. Moreover, the responsible authorities for collecting and disposing of the wastes, do not attempt the task properly as they tend to ignore the separation of material. Furthermore, improper supervision at dumpsites owned by municipal councils results in heavy pollution which also will result in creating adverse effects on human lives. Further, the wastes that end up in marshy lands could potentially cause adverse effects like floods, soil pollution which impacts directly on the environment and human activities.

The government's concern in providing necessary landfill locations to dump construction and demolition waste is another critically unaddressed factor. According to the ideas of interviewees, the available landfills which are owned by municipal councils are not sufficient to dump all the waste which generates in construction sites. Moreover, the approval process in getting permissions to dump waste to a landfill of the municipal council is time-consuming whereby it causes unnecessary delays in project completion. One of the professionals significantly doubted the authenticity of the approvals as the disposals are not monitored during the dumping process. The delays in permission prompt the contractors to dump waste illegally which will be resulting in saving money and time.

Recycling is considered the best option in managing construction and demolition waste in both questionnaire surveys and expert interviews thus less intention is given by the government in the recycling of construction waste. The expert's opinion behind the idea is that there would be a reduction of waste in a considerable amount as the waste can be processed and used again for construction-related activities, causing the quantities of waste in landfills to decrease. The government's involvement in providing required backgrounds for improving the recycling of construction waste is at a minimum level. In Sri Lanka, only one construction and demolition waste recycling plant available named COWAM (Construction Waste Management) which is situated in Galle, Sri Lanka, and is operated by the Galle Municipal Council. The main services provided by them are recycling of construction and demolition waste, guidance services for the management of construction and demolition waste, and arranging training sessions on construction and demolition waste management. According to the expertise, the functionality of the recycling Centre is limited to Galle area, due to high transportation costs which should be incurred by the contractors and vice versa by the Galle municipal council to transport the generated waste to the recycling center.

As confirmed by the literature previously, there are no separate laws or regulations related to construction and demolition waste management nor regular amendments in strengthening the law and acts. Management of Construction and demolition waste materials are governed under regulations applicable for ordinary waste which is coming under the national environment act of Sri Lanka. Interviewees point out the need in improving or modifying the available regulations in favor of a better management plan for construction and demolition waste.

5. DISCUSSION

5.1.1 Identification of Probable Suggestions through Expert Interviews

Implementation of waste sorting during collection and disposal is a critical activity as unsorted construction and demolition waste is a direct threat to the environment in the disposal. Therefore, the regulatory authorities need to appoint adequate personnel to monitor landfills and evaluate waste statistically during the dumping process. A statistical evaluation process will help the government in amending any regulation related to waste materials or to identify the need for alternate methods for construction waste disposal. Furthermore, through statistical data, the government can identify the areas where high amounts of waste are discarded and take necessary regulatory steps in managing the waste quantities. Further, the waste-collecting units of the municipal councils should have the right to reject waste, which is not segregated. The implication of these suggestions could be effective in reducing environmental pollution and increasing the rate of recycling and reuse of construction and demolition waste.

Illegal dumping of construction and demolition waste is environmentally unfriendly. The main suggestion proposed by the interviewees was that the amount of penalties should be increased to discourage people from doing illegal dumping. Moreover, proposing a tax system for dumping construction and demolition waste at landfills could also be considered as a suggestion to be used, as the people who are going to dump waste will have to find more cost-effective alternatives like recycling. Implementation of these actions by the regulatory bodies can aid in reducing the quantities of illegally disposed of construction and demolition waste.

As per the expertise, improving regulations on recycling and recycled products of construction and demolition waste is a much-needed alternative to Sri Lanka. The fabrication of construction and demolition waste recycling centers across the country would be a good initiative. With proper regulations, the wastes then could be transported to the nearest facility for processing. where the contractors could be financially provided as well. As the process is involved with the government, regulatory arrangements can be made, and utilizing recycled materials for the government's construction projects will create a market for the recycled products. As the government is a main stakeholder in the construction industry, the increasing trend of recycled products will prompt private parties in purchasing recycled materials due to the quality assurance as the government is involved. With that, the involvement of private parties in the recycling industry also can be expected, which will allow diversified technologies related to recycling of construction and demolition waste to reach Sri Lanka. To get the participation of local people in this recycling process, it was suggested that the people should be encouraged by the government by regulating prices for different construction and demolition waste materials to be collected publicly. The initiative will result in massive reductions in construction waste quantities due to the involvement of both contractors and local people.

Central Environmental Authority is responsible for solid waste management in Sri Lanka and all rules and regulations which govern solid waste management are mentioned under the National Environment Act. According to the literature and the findings of interviews and questionnaires, no provisions in the National Environment Act separate construction and demolition waste. According to the perception of interviewees, the government should implement new/modified rules and regulations related to construction and demolition waste through introducing amendments in the National Environment Act. All the above-mentioned suggestions are needed to be included in the National Environment act to be validly active in Sri Lanka.

5.1.2 Identification of Probable Suggestions through Questionnaire survey

Building construction projects were identified as the highest waste generated type of projects through the questionnaire survey. Analysis suggests that the government should pay more concern to waste materials collected from building construction projects on dealing with regulatory activities regarding waste management processes. According to the findings, the respondents' insight was that more waste is generated at the working stage of a construction project. To reduce waste generation at the working stage, the concern should be given to identify the most effective causes where waste can be generated on the working stage of a construction project. After analyzing these causes, the government can provide guidelines to be followed in operating a construction project, where waste can be minimized through properly following the provided guidelines. The questionnaire identified the most abundant waste materials in Sri Lanka as concrete, tile, and brick. The government could pay attention to real quantities of waste generated due to construction activities to statistically analyze the required solutions whereby uplifting the constructions along with sustainable construction with fewer wastages. The questionnaire also revealed that about 30% of the professionals were not aware of the

Environmental Act. The awareness of these available rules and regulations is very important for industry professionals to properly carry out disposal works and to assess any situation related to construction and demolition waste. Therefore, workshops alongside professional development should be arranged to uplift the knowledge levels.

6. CONCLUSIONS

In conclusion, it can be said that the environment act governs all the regulations related to waste management including the construction and demolition of waste is not sufficient in minimization of construction waste. Building construction generates the highest percentage of waste during construction and demolition activities in Sri Lanka and identified that work implementation on site is the main cause for waste generation during a project. The study proved that Landfilling as the most used waste management system in Sri Lanka and it was found that recycling was suggested to be used in the future instead of landfilling to manage construction and demolition waste. Further, this research proved that the main issue is in current rules and regulations related to the disposal of construction and demolition waste. No actions were taken place to sort and classify the construction and demolition waste at the collection process and dumping process to landfills. Therefore, it is highly recommended to improve recycling as a management method of construction and demolition waste to reduce waste quantities and its effects along with well improved, prioritized governance acts.

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THE EFFECT OF LABOUR PRODUCTIVITY ON SUCCESSFUL COMPLETION OF MAJOR CONTRACTS DURING THE COVID PANDEMIC IN SRI LANKA

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ABSTRACT

The COVID-19 outbreak is the greatest global health crisis in many years. It has had a dramatic effect on workforces and workplaces all around the world. The construction industry has been significantly affected by the COVID-19 pandemic and has been challenged to improve the safety and wellbeing of its workforce and control the collapse of construction productivity. The objectives of this study were to identify and rank the factors affecting lack of labour productivity in major contracts during the COVID pandemic and effect of labour productivity on successful project delivery in major contracts during the COVID pandemic in Sri Lanka and to recommend management strategies to combat them. A thorough literature search on recently published literature, industry experiences, reports, and other related documents was performed to collect and categorize the required data. 40 COVID-19 challenges were identified, and the results revealed that 19 factors including absenteeism at work site, travel restrictions, supply chain disruptions, cash flow delays and social isolation due to teleworking. 27 strategies were identified to overcome these challenges, and 14 results demonstrated including avoid material shortage at the site, conduct a risk analysis, create an end-end supply chain map, initiate flexible work schedules to promote social distancing, increase of hygiene of construction. The findings of this study will help the project managers and authorities in the construction industry understand the challenges of the pandemic and adopt effective strategies that will improve the health and safety of their workforce.

Keywords: *Construction Cost; COVID 19; Labour Productivity; Time Overrun.*

1. INTRODUCTION

In the development of the construction industry human resource is an important factor. So that understanding the effect of labour productivity is much more important to improve the construction productivity in building construction projects (Prabhu and Ambika, 2013). Identification and evaluation of factors affecting labour construction productivity have become critical issues facing project managers for a long time. Both positive and negative can be used to understand the critical factors affecting productivity, formulate a strategy to reduce inefficiency and improve project performance.

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Some factors which affect the labour productivity are lack of labour supervision, payment delays, lack of communication, shortage of materials, lack of training, rain, shortage of experienced labour, construction method and so on (Hickson and Ellis, 2014). Other than these factors, many other factors, which influence for the labour productivity have been found by the researchers.

The coronavirus, commonly known as COVID-19, is caused by the coronavirus 2, a serious acute respiratory disorder. On 31 December 2019, the first known infections from SARS-CoV-2 were discovered in Wuhan, China. As of January 2021, the virus had spread to more than 200 countries, affected 91.5 million people, and caused 1.96 million deaths (Hendrickson and Rilett, 2020).

The construction sector, like many other sectors, has been affected in a number of ways. Since the pandemic began, there have been fewer employment opportunities, partially due to the work disruptions that were caused by following constraints that were put in place 3 to stop the progression of the virus, and a shortage of personal protective equipment (PPE) that was caused by the more pressing need for it by healthcare employees. Due to an interrupted supply chain and employee shortages due to quarantines, many projects have been halted or postponed.

A shortage of workers is always a concern for the construction industry, but the pandemic has intensified it as a large percentage of construction staff has reportedly screened positive for the coronavirus (Karim, et al., 2013). As the propagation of COVID-19 is largely related to individual contact, encounters between construction employees have played a major role in the delays in reopening projects. Physical distancing policies intended to decrease the virus spread have affected the number of workers permitted to work in an area, how the staff handles their jobs, and how project managers foresee the working environment (Araya, 2021).

Although recent studies have focused on the impacts of COVID-19 on the construction industry, few insights have been provided for the construction workforce in particular. Therefore, this study aimed to identify the effect of labour productivity on the efficiency of the major contracts in Sri Lanka during this pandemic period and explore how improved labour productivity can increase project efficiency in the pandemic situation.

2. LITERATURE REVIEW

2.1 FACTORS AFFECT TO THE TOTAL PRODUCTION OF A PROJECT

Hickson and Ellis (2014) ranked the factors affecting construction productivity and stated that "labour productivity" is the most affecting factor for total construction production followed by "management strategies", "technological factors" and "external factors".

2.2 CHALLENGES FOR LABOUR PRODUCTIVITY DURING THE COVID-19 PANDEMIC

Pamidimukkala and Kermanshachi (2021) come up with a research paper "Impact of COVID-19 on field and office workforce in construction industry". The authors have mentioned the challenges for labour productivity during the pandemic period and categorized as organizational, economic, psychological, and individual. They have presented four organizational factors for labour productivity during the pandemic period as; lack of safe working environment, challenges due to work-from-home practices, managing a heavier workload and management team's lack of leadership knowledge and skills.

Reduced accessibility to updated tools and equipment needed to accomplish the tasks, uncertainty regarding future of workplace, supply chain disruptions and cash flow delays are identified as economic challenges for labour productivity.

Pamidimukkala and Kermanshachi (2021) mentioned two psychological challenges for labour productivity during the pandemic period as; social isolation due to teleworking and stress and burnout. They have identified four individual factors as; responsibility for personal and family needs when working, learning various communication tools and overcoming technical difficulties, feelings of not contributing enough to work and adjusting to new work schedules. Also, they have presented three moderating factors challenging for labour productivity during the pandemic period as, effect of COVID-19 on vulnerable groups (age), gender-based impacts and impacts on migrant workforce.

2.3 IDENTIFIED FACTORS AFFECTING LACK OF LABOUR PRODUCTIVITY DURING THE COVID-19 PANDEMIC

As a conclusion, the factors which affect lack of labour productivity in major construction projects during the COVID-19 pandemic are summarized in Table 1.

Table 1: Factors affecting lack of labour productivity during the COVID-19 pandemic

Researcher	Factors
(Halwatura, 2015)	Poor medical care for labours
	Lack of Labour supervision
	Late payments for the labours
	Low job security
	Communication problems between labours and staff members
	Lack of Accommodation facilities for labours
	Lack of incentives and respect for workers
	Schedule changes
(Palop, 2016)	Changes and errors in the original scope of work and the complexity of works
	Poor resource planning
	Schedule changes
	Morale problems at workplace
	Qualifications and educational problems
(Dixit, et al., 2017)	Rework
	Owner's financial status
	Poor communication among the parties involved
	Material shortage at site
	Lack of skilful labours
(Muhammad, et al., 2015)	Poor weather conditions
	Crew

Researcher	Factors
	Labour disruption
	Entrance to the site
	Absenteeism at work site
	Congestive work area within the project site
(Prabhu and Ambika, 2013)	Lack of safety
	Lack of quality materials
(Hickson and Ellis, 2014)	Method of construction
	Working overtime
	Inspection delays by site management
	Lack of incentives and respect for labours
	Lack of periodical meetings with leaders
(Gopal and Murali, 2015)	Shortage of materials and tools
	Management Practices
	Environmental conditions
(Pamidimukkala and Kermanshachi, 2021)	Lack of safe working environment
	Challenges due to work-from-home practices
	Managing a heavier workload
	Management team's lack of leadership knowledge and skills
	Reduced accessibility to updated tools and equipment needed to accomplish the tasks
	Uncertainty regarding future of workplace
	Supply chain disruptions
	Cash flow delays
	Social isolation due to teleworking
	Stress and burnout
	Responsibility for personal and family needs when working
	Learning various communication tools and overcoming technical difficulties
	Feelings of not contributing enough to work
	Adjusting to new work schedules
	Effect of COVID-19 on vulnerable groups (age)
	Gender-based impacts

2.4 IDENTIFIED METHODS OF IMPROVING LABOUR PRODUCTIVITY DURING THE COVID-19 PANDEMIC

As a conclusion identified methods of improving labour productivity in major construction projects during the COVID-19 pandemic can be summarized as shown in Table 2.

Table 2: Methods for improving labour productivity during the COVID-19 pandemic

Researcher	Methods
(Hickson and Ellis, 2014)	Increasing labour supervision
	Arranging training Programs for labours
	Arrange periodical meetings with crew leaders
	Increase site safety and conduct site meetings to aware the labours about site safety
	Avoid material shortage at the site
(Dixit, et al., 2017)	Provide proper tools and equipment for labours and maintain
	Creating a schedule for works
	Proper resource planning in the site
(Thiyagu, et al., 2015)	Increasing of hygiene of construction
	Providing temporary shed for labour
(Jain, et al., 2016)	Measure the work done of the labours
(Warren, et al., 2009)	Increasing proficiency splitting
	Helping educated workers in their use of casual procedure
(Prabhu and Ambika, 2013)	Presuming quality camping conditions
	Timely payments to the labours without delays
	Good communication between labours and supervisors
	Minimizing work pressure
	Arranging suitable rest areas for labours in the site
(Halwatura, 2015)	Proper site management
	Arrange periodical meetings with crew leaders
(Pamidimukkala and Kermanshachi, 2021)	Redefine worksite safety
	Support personnel who work remotely
	Initiate flexible work schedules to promote social distancing
	Teach employees to recognize and manage stress symptoms
	Expand use of technology
	Educate the employees about COVID-19 policies and procedures, and train them to incorporate them
	Establish a system to maintain effective communication
	Allow longer timelines for project delivery
	Perform a contractor assessment to increase productivity
	Conduct a risk analysis
	Create an end-end supply chain map

3. RESEARCH METHODOLOGY

Initially a comprehensive literature survey was carried out by referring books, journals and other publications to identify the factors affecting labour productivity and labour productivity improving methods, which suits to pandemic period.

Data collection process was done through the questionnaire surveys. The data analysis part of the project was done through two different methods. The qualitative data collected through the open-ended questionnaire were analysed by the manual method. All the quantitative data collected through the closed ended questionnaire were analysed using MS excel software and the results were produced in tables in order to carry out the discussion part of this chapter through final result.

The empirical survey was conducted adapting questionnaire research approach. Due to the Pandemic situation in the country, access to working sites was restricted and data collection had to be done through google forms. This limited the sample size to 30 participants. The Relative Important Index (RII) was used to evaluate the ratings of the respondents and got the average deviation. The approach was recommended in past studies as the appropriate analytical approach to group rings of the variables in a given set. The analysis involved the computation of the RII, which is the representative rating point for the collective rings made for each variable in the subset (refer Eq. 01).

$$RII = \frac{\sum_{i=1}^{5} W_i X_i}{A \times N} \qquad \textit{Eq. 01}$$

Where, RII - Relative Importance Index; W - Weighting given to each factor by the respondents and ranges from 1 to 5; X - Frequency of i^{th} response given for each cause; and A - Highest weight (5 in this case).

4. RESULT AND DISCUSSION

The data collected from the resource persons through the questionnaires were analysed by MS Excel software. When analysing gathered questionnaire data, every factor related to the research topic were analysed separately and they are presented below.

4.1 RANKING OF FACTORS AFFECTING TOTAL PRODUCTION OF THE PROJECT

Objective of this question is to identify and rank the factors affecting total production of a project. Received data were analysed and find the average deviation to find the significant factors and not significant factors affecting total production of the project. Findings are presented in Table 3.

Table 3: Ranking of factors affecting total production of the project

Factor	Relative Important Index	Average Deviation	Rank
Labour	0.96	0.23	1
Management	0.88	0.15	2
Technology	0.83	0.10	3
External	0.56	-0.17	4
Other	0.40	-0.33	5

4.2 REASONS OF AFFECTING COVID-19 PANDEMIC DIRECTLY TO THE PRODUCTIVITY OF A PROJECT

The objective of this question is to get opinions of the professionals on affecting of the COVID-19 pandemic on the productivity of a project. In the first part of the question, 28 out of 30 respondents have answered as the COVID-19 pandemic directly affect to the productivity of a project. Findings are summarised in Table 4.

Table 4: Reasons of affecting COVID pandemic directly to the productivity of a project

Factor	No of respondents	Total
Increase of material prices	R1, R11, R12, R16, R25, R27	6
Labours often get sick due to pandemic condition	R1, R24	2
Minimize the workforce of construction sites /Lack of labour	R4, R7, R8, R10, R13, R14, R15, R16, R17, R21, R23, R25	12
Material shortage/Supply chain disruption	R8, R10, R12, R13, R14, R15, R16, R17, R18, R21, R23, R25, R26, R28, R29	15
Have to keep personal distance	R9	1
Travel restrictions/Transportation problems	R9, R22, R24	3
Health Issues	R9, R22	2
Workers are afraid to work at sites	R12, R18, R28, R29	4
Delay in cash flow	R19, R25	2
Shutdown the construction sites temporally	R24, R25, R27, R28, R30	5
Lockdown the country	R26	1

According to the analysed data, "Material shortage/ Supply chain disruption" is the most affecting factor for the productivity of the project during the COVID pandemic. Respectively "Minimize the workforce of construction sites/Lack of labour" and "Increase of material prices" are the next significant factors affecting productivity of the project during the COVID pandemic.

4.3 RANKING THE FACTORS AFFECTING LABOUR PRODUCTIVITY DUE TO THE IMPACT OF COVID-19 PANDEMIC

Objective of this question is to identify and rank the factors affecting labour productivity of major contracts due to the impact of COVID pandemic. Affecting factors were identified through the literature review and designed the question to rank them according their significant due to the COVID pandemic. Findings are presented in Table 5.

Table 5: Ranking of the factors affecting labour productivity due to the impact of COVID pandemic

Factor	Relative Important Index	Average Deviation	Rank
Poor medical care for labours	0.71	0.09	8
Lack of labour supervision	0.67	0.05	12
Late payments for the labours	0.61	-0.02	21
Low job security	0.67	0.05	12

Factor	Relative Important Index	Average Deviation	Rank
Communication problems between labours and staff members	0.59	-0.03	23
Lack of Accommodation facilities for labours	0.72	0.09	7
Lack of incentives and respect for labours	0.53	-0.09	32
Schedule changes	0.67	0.04	15
Changes and errors in the original scope of work and the complexity of works	0.64	0.01	17
Poor resource planning	0.69	0.06	11
Morale / motivation problems at workplace	0.49	-0.13	37
Qualifications and educational problems	0.44	-0.19	40
Rework	0.57	-0.06	29
Lack of quality materials, tools and machinery	0.75	0.12	6
Lack of skill	0.54	-0.09	31
Poor weather conditions	0.49	-0.13	37
Labour disruption	0.57	-0.05	27
Absenteeism at work site	0.84	0.21	1
Congestive work area within the project site	0.65	0.02	16
Lack of safe working environment	0.70	0.07	10
Supply chain disruptions	0.83	0.20	3
Method of construction	0.64	0.01	17
Working overtime	0.53	-0.09	32
Inspection delays by site management	0.58	-0.05	25
Lack of periodical meetings with leaders	0.57	-0.05	27
Environmental conditions	0.47	-0.16	39
Travel restrictions	0.83	0.21	2
Challenges due to work-from-home practices	0.71	0.08	9
Managing a heavier workload	0.61	-0.01	20
Management team’s lack of leadership knowledge and skills	0.58	-0.05	25
Uncertainty regarding future of workplace	0.63	0.01	19
Cash flow delays	0.77	0.15	4
Social isolation due to teleworking	0.77	0.15	4
Stress and burnout	0.60	-0.03	22
Responsibility for personal and family needs when working	0.55	-0.07	30
Learning various communication tools and overcoming technical difficulties	0.53	-0.10	34
Effect of COVID -19 on vulnerable groups (age)	0.51	-0.12	36

Factor	Relative Important Index	Average Deviation	Rank
Gender-based impacts	0.67	0.05	12
Impacts on migrant workforce	0.51	-0.11	35

According to the data received, 19 factors have identified as significant factors affecting labour productivity of major contracts due to the impact of COVID pandemic. “Absenteeism at work site” is identified as the most significant factor affecting to the labour productivity during the COVID pandemic. Respectively “Travel restrictions” “Supply chain disruptions”, “Cash flow delays” and “Social isolation due to teleworking” are identified as the top five factors affecting labour productivity of major contracts due to the impact of COVID pandemic.

Absenteeism may mean a loss of productivity of project, time overrun and cost overrun of a project. With the impact of COVID pandemic, many labours reported a decrease in work reporting in construction sites. The COVID-19 pandemic has seen government implementing restrictions on travel such as imposing travel bans or restricting or closing border checkpoints including ports. The travel bans have undoubtedly impacted the progress of many projects and disrupted the construction and projects sector. Material delays that stalled overall project progress and triggered major schedule disruptions were experienced due to the social distancing and quarantining requirements that resulted in a smaller workforce within supply chain organizations.

4.4 RANKING THE METHODS OF IMPROVING LABOUR PRODUCTIVITY DUE TO THE IMPACT OF COVID PANDEMIC

Objective of this question is to identify and rank the methods of improving labour productivity due to the impact of COVID pandemic. Affecting factors were identified through the literature review and designed the question to rank them according their significant due to the COVID pandemic (Refer to Table 6).

Table 6: Ranking of the methods of improving labour productivity during the COVID pandemic

Factor	Relative Important Index	Average Deviation	Rank
Increasing labour supervision	0.70	0.00	13
Arrange training Programs for labours	0.55	-0.15	24
Arrange periodical meetings with crew leaders	0.70	0.00	13
Increase site safety and conduct site meetings to aware the labours about site safety	0.72	0.02	11
Avoid material shortage at the site	0.85	0.15	1
Provide proper tools and equipment for labours and maintain them	0.79	0.09	4
Create a schedule for works	0.77	0.08	8
Proper resource planning in the site	0.77	0.08	8
Increase of hygiene of construction	0.79	0.09	4

Factor	Relative Important Index	Average Deviation	Rank
Provide temporary shed for labours	0.72	0.02	11
Measure the work done by the labours	0.50	-0.20	27
Increase proficiency splitting	0.54	-0.16	25
Help educated workers in their use of casual procedure	0.53	-0.16	26
Timely payments to the labours without delays	0.66	-0.04	19
Ensure the good communication between labours and supervisors and establish a system to maintain effective communication	0.68	-0.02	17
Minimize the work pressure	0.65	-0.04	20
Arrange suitable rest areas for labours in the site	0.68	-0.02	17
Proper site management	0.78	0.08	7
Support personnel who work remotely	0.69	-0.01	15
Initiate flexible work schedules to promote social distancing	0.79	0.09	4
Teach employees to recognize and manage stress symptoms	0.63	-0.07	22
Expand use of technology	0.69	-0.01	15
Educate the employees about COVID-19 policies and procedures, and train them to incorporate them	0.76	0.06	10
Allow longer timelines for project delivery	0.56	-0.14	23
Perform a contractor assessment to increase productivity	0.65	-0.04	20
Conduct a risk analysis	0.84	0.14	2
Create an end-end supply chain map	0.83	0.13	3

According to the data received, 14 methods have identified as significant methods for improving the labour productivity of major contracts during the COVID pandemic. “Avoid material shortage at the site” is identified as the most significant method for improving the labour productivity during the COVID pandemic. Respectively “Conduct a risk analysis” “Create an end-end supply chain map”, “Initiate flexible work schedules to promote social distancing”, “Increase of hygiene of construction” and “Provide proper tools and equipment for labours and maintain them” are identified as the top methods for improving the labour productivity of major contracts during the COVID pandemic.

COVID-19 has interrupted and will likely continue to disrupt sub-contractor scheduling as well as the supply of goods and materials. Prioritize critical shortages by supplier and buyer and identify the root causes, optimize VMI thresholds, unlock ERP, collaborate with suppliers and increase transparency, accountability, and ownership among buyers may help to avoid material shortage during the COVID pandemic. Conduct a risk exercise is an effective way to update the risk registers. This consists of considering a variety of ways that the project could unfold, including risks such as disturbances with supply chains; lack of cash flow of investors, subcontractors, and contractors; and permitting challenges. The benefits and costs of project closures and delays should be considered, and priorities for responses and prevention initiatives should be assigned, based on the likelihood and severity of the potential threats.

5. CONCLUSION

The coronavirus, commonly known as COVID-19, is caused by the coronavirus 2, a serious acute respiratory disorder. The construction sector, like many other sectors, has been affected in a number of ways. This study aimed to identify the effect of labour productivity on the efficiency of the major contracts in Sri Lanka during this pandemic period and explore how improved labour productivity can increase project efficiency in the pandemic situation.

“Labour” is identified as the most affective factor to total production of a project. According to the analysed data, “Material shortage/Supply chain disruption” is the most affecting factor for the productivity of the project during the COVID pandemic. Respectively “Minimize the workforce of construction sites/Lack of labour” and “Increase of material prices” are the next significant factors affecting productivity of the project during the COVID pandemic. “Absenteeism at work site” is identified as the most significant factor affecting to the labour productivity during the COVID pandemic. Respectively “Travel restrictions” “Supply chain disruptions”, “Cash flow delays” and “Social isolation due to teleworking” are identified as the top five factors affecting labour productivity of major contracts due to the impact of COVID pandemic.

“Avoid material shortage at the site” is identified as the most significant method for improving the labour productivity during the COVID pandemic. Respectively “Conduct a risk analysis” “Create an end-end supply chain map”, “Initiate flexible work schedules to promote social distancing”, “Increase of hygiene of construction” and “Provide proper tools and equipment for labours and maintain them” are identified as the top methods for improving the labour productivity of major contracts during the COVID pandemic.

The results of this study will greatly benefit project managers and contractors by helping them understand the workers’ COVID-19 challenges and prioritize their plans so that they can provide safe working conditions that protect their employees and support them both mentally and physically to increase the project productivity. The outcomes can be useful to government entities also as they address the adverse impacts of the pandemic.

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THE EFFECT OF ORIENTATION AND PLANT TYPE ON THE THERMAL BEHAVIOUR OF LIVING WALL SYSTEMS IN BUILDINGS

H. Merve Yanardag Erdener[1] and Ecem Edis[2]

ABSTRACT

Living wall systems are the vegetated wall systems where growth layer is located behind the plant and integrated onto the wall. They started to be used widely due to their many benefits such as increasing the energy efficiency of the building. Living wall can contribute to wall's thermal performance by its shading, insulation and wind protection effects. However, there are limited studies which is done by simulation to investigate its insulation effect. In the previous studies, its shading effect is usually simulated, and evaporation and transpiration were not taken into account which are the major effect of being a live mechanism. In this study, it is aimed to see the effect of living wall's orientation and the plant types on interior thermal conditions, by using a microclimate simulation program ENVI-met. ENVI-met provides a vegetation model that simulates evapotranspiration and interaction between the outdoor microclimate with indoor climate. In this context, the temperature differences that occur between the wall layers and interior surface temperature of the living walls are compared with those of bare wall for two cities in Turkey which are representatives of hot and humid climate and temperate climate. Thus, it has been seen especially the west and south facades of the building and also the plant types according to their leaf area index (LAI) affect the efficiency of the building depending on the climate.

Keywords: *Living Wall; Performance Simulation; Vegetated Wall Systems.*

1. INTRODUCTION

Vegetated walls have been used in construction in the world for centuries due to its both functional benefits such as shielding and shading the building and aesthetic benefits. One of the first examples of using the vertical garden in construction is known to be Hanging Gardens which is one of the seven ancient wonders of the world (Manso and Castro-Gomes, 2015). Especially in countries with hot climate, covering the building envelope with vegetation is a timeless architectural precaution in order to block the undesired heat gain (Susorova, 2015). New vegetated wall systems have been developed since decades, and recently, instead of climbing plants, living wall systems have been designed and constructed more. These are vegetated wall systems where growth layer is located behind the plant and integrated onto the wall.

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The use of living wall systems is increasing day by day in the world because of their advantages. Improving air quality by working as a natural air filtration element, improving sound insulation, providing biologic diversity and habitat creation, protection of the building, adding aesthetic and economic value to the building, reduction of urban heat island effect and increasing energy efficiency are some of the advantages of living walls (Besir and Cuce, 2018; Manso and Castro-Gomes, 2015; Riley, 2017). Particularly, the increased energy efficiency provided by living walls is achieved by decreasing heating loads by being an insulation and a wind barrier mainly, and its effect on cooling loads by shadowing primarily (Besir and Cuce, 2018; Riley, 2017). Additionally, transpiration also creates small zones of cool air, between the green wall and the building envelope, and helps reducing cooling loads. For example, at the Consorcio project in Santiago, Chile, the 43% of its west façade is covered by greenings. According to the reports, the solar radiation is reduced 60%, and 48% less energy is used than other comparable buildings (Wood, Bahrami and Safarik, 2014).

In buildings with living walls, the required interior comfort conditions while using less energy can be achieved by taking the right decisions about living walls' design variables influencing energy efficiency. Specifically, as a part of building envelope the living wall system's thermal performance is affected by the characteristics of wall and insulation materials behind the greenery system, and the plant type and frequency (Susorova, 2015). However, studies which focus on the effect of plant type on thermal behaviour of the living walls, including different seasons in different climates for different orientations are very limited. In this respect, the study presented here aims to compare and discuss changing thermal responses within the wall, i.e. between building envelope layers for different plant types in different climates for different orientations based on numerical simulation results. To this end, two different cities in Turkey; Antalya and Istanbul with hot-humid and temperate climates respectively were considered to investigate the behaviour of living walls and to compare with that of bare wall (i.e. without greenery system) depending on wall orientation. In terms of plant type, their leaf sizes are considered, and two different Leaf Area Indexes (LAI) were studied. In the following sections, after a short theoretical background on living wall systems, the methodology of the study is explained. The simulation results are then presented and discussed in terms of changing behaviour in respect to aforementioned variables.

2. THEORETICAL BACKGROUND

Living walls are newly developed, completely artificial wall systems where not only the plant is attached to the building façade, but also the growing medium is integrated onto the building envelope surface. This feature separates them from green facades where plants are rooted at the ground level (Bustami, et al., 2018). Living walls are divided in two main groups as (i) continuous (felt) and (ii) modular systems. Continuous systems are lighter systems where plants are rooted in, on the contrary of traditional growing medium such as soil, between two lightweight fabrics in the form of pockets which is supported by a rigid substructure system. These fabrics are usually recycled lightweight felts. Modular systems with specific dimensions, on the other hand, include the growing media (e.g. soil, coconut fiber, volcanic stones, hydro stones, stone wool). Each element is supported by a complementary structure or fixed directly on the vertical surface (Manso and Castro-Gomes, 2015).

In a living wall system, independent from the aforementioned subtypes, irrigation of the growing layer is an indispensable part of the facade system, which differs it from a traditional wall that is not intentionally exposed to water and its effects. As a result of having a wet part, i.e. regularly irrigated growing medium in the section of the wall, the whole thermal behaviour of the wall is expected to be affected. For instance, in a study that can be related to living walls and evaluates the growing layer temperatures of green roof systems mentions for achieving a cooling effect that, in order to increase the radiant heat exchange, the temperature of the back face of the green roof system has to be kept as low as possible, which could be achieved by keeping the substrate wet (Lazzarin, Castellotti and Busato, 2005). In another study on the effect of air flow in the vertical greening systems, it has been observed that the temperature differences in the mean values were 9^0C at various points of the wall section (Perini, et al., 2011).

Malys, Musy, and Inard (2014) explain that the most sensitive parameters are the thermal characteristics (particularly the thermal conductivity - λ) and the thickness of the growing medium which allows to calculate thermal inertia that appears in the substrate temperature evaluation. They also notice the decrease in the thermal conductivity maybe due to a drier substrate in their sample (Malys, Musy, and Inard 2014). Thus, it is expected to increase thermal conductivity relying on the water coefficient level which depends on irrigation. Consequently, the temperature on different layers for the same living wall can differ.

Apart from the limited number of studies where the effect of the growing layer of the living wall's temperature is observed, there are studies on green roofs where the growing layer has a similar effect. In the study examining the temperature values in green roof systems made by Ouldboukhitine, et al. (2011), it is observed that there are temperature differences up to 10^0C between outdoor air temperature and the substrate layer temperature.

In another study it is mentioned that for dry substrate where evapotranspiration is very limited, a green roof reduced the heat gain by 60% mostly due to solar reflection and absorption by the plants and the substrate. Additionally, for a wet substrate, instead of 40% entering heat flux into the building, a slight outgoing heat flux is resulted due to an increase in evapotranspiration rate is revealed. (Lazzarin, Castellotti and Busato, 2005; Raji, et al., 2015). Additionally, the water content of substrate influences the thermal performance of a green roof in each season in a different way. During hot seasons or in equatorial climates (i.e. where summer-winter temperature difference is not considerable), a wet green roof can increase the heat dissipation through evapo-transpiration cooling. Therefore, it reduces the need for indoor cooling. However, in winter, thermal resistance of a green roof improves with less water content in the substrate due to water having a higher thermal conductivity (Morau, et al., 2012; Raji, et al., 2015).

The other important component which is a part of living wall is the plant. Plant to be used at the living wall system is not only an important decision area for architects due to aesthetical reasons, but also it is another factor that may affect the thermo-physical characteristics, and in turn thermal performance of the wall system. Type, albedo and transmittance of the leaves, leaf area density (LAD) profile, leaf area Index (LAI) are some of the characteristics of plants which may affect the whole performance of the wall (Raji, et al., 2015). In terms of thermal effect of living walls, five different leaf types are present, which are; (i) fronds, (ii) conifer, (iii) angiosperm, (iv) lycophytes, and (v) sheath. Albedo of the leaf is the measure of the diffuse reflection of solar radiation out of the incident total solar radiation on leaf and measured on a scale from 0 (corresponding to a black body that absorbs all incident radiation meaning black), to 1 (a body that reflects all incident radiation meaning white) (GenScipt, 2022). Smoothness and colour of the plants are significant parameters which affect albedo. Whiteness and smooth surfaces has high albedo values compared to dark and textured surfaces (Jain, Kuriakose and Balakrishnan, 2010). LAD is the total leaf surface area per unit volume of space (m^2/m^3) (Dearuz, 2016). Transmittance of the leaf can be explained as the transmittance factor of the leaf for shortwave radiation (Bruse, 2009). LAI is a dimensionless quantity that characterizes plant canopies. It is defined as the one-sided green leaf area per unit ground surface area in broadleaf canopies (m^2/m^2). LAI ranges from 0 for bare ground to over 10 for dense conifer forests (Xu, 2020). Plant layers with different leaf area indexes are shown in Figure 1.

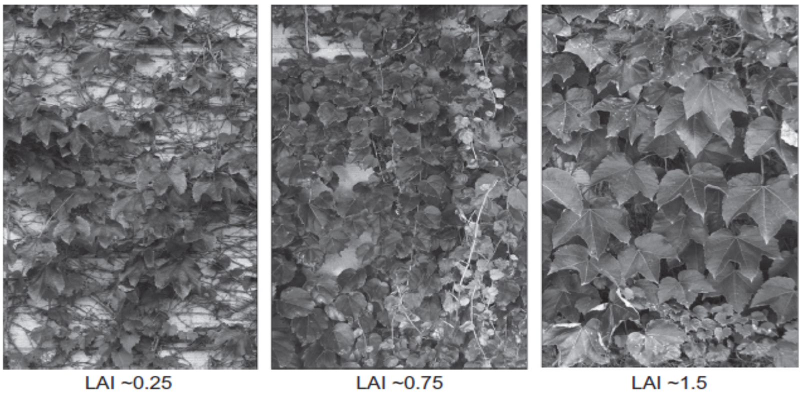


Figure 1: Plant layers with different leaf area indexes

Source: Susorova (2015)

3. METHODS AND MATERIALS

The study that aimed to investigate the effect of plant type and characteristics on interior environmental conditions in different climates was based on dynamic computer simulation performed by Envi-met software. It was consisted of five main stages, which were (i) selection of cities to be studied, (ii) determining critical dates to investigate, (iii) designing living wall and building wall, (iv) preparation of building simulation model and running simulation, and (v) assessment of the simulation results. In the following subsections these stages are detailed.

3.1 SELECTION OF CITIES

The use of living walls at buildings is not widely spread in Turkey. Istanbul, by being the most populated city of Turkey which contains ca. 11% of the buildings in the country (Tuik, 2015*)*, and by being the city where almost 20% of the total construction in Turkey is done in last 7 years, has a great potential for adopting this system. It was therefore determined to be one of the cities to be studied. Istanbul, with its temperate-humid climate, is within 2nd zone according to the mandatory Turkish Standard TS 825 Thermal insulation requirements for buildings which divides Turkey into five climate zones (TS 825 Thermal Insulation Requirements for Buildings, 2013). Knowing that the performance of livings walls varies depending on the climatic conditions, another city with a hot-humid climate, i.e. Antalya, which is located at the southern parts of Turkey were decided to be studied. According to the Turkish Standard TS 825, Antalya is in 1st climate zone with the least thermal insulation requirements among other zones.

3.2 SELECTION OF DAYS FOR INVESTIGATION

To see the effect of the exterior air temperature, two different days with high and low average temperature values with most constant solar radiation were determined from weather files (i.e. epw file) of both cities. Dates selected for each city and solar radiation and temperature values for these days are given in the Table 1.

Table 1: The outdoor air temperature and normal radiation values for selected days (*Source: Climate data for building performance simulation*, 2021)

City	Date	Direct Normal Radiation (W/m^2)		Dry Bulb Temperature (^oC)	
		Total	Maximum	Average	Maximum
Istanbul	April 9th	6987	855	10.3	14
	August 7th	6904	796	28.6	36
Antalya	February 2nd	6069	837	10	15.3
	August 14th	5954	804	29.5	31

3.3 LIVING WALL AND BARE WALL DESIGNS

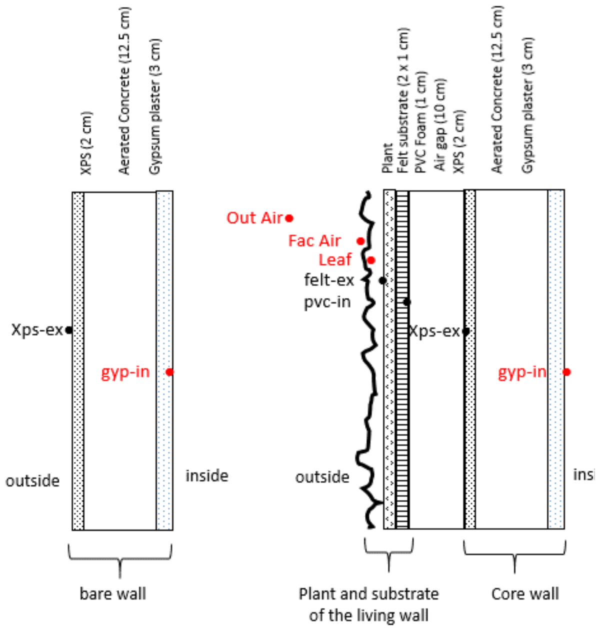
Bare wall and core wall of the living wall were designed considering the commonly used wall materials in Turkey and the thicknesses of materials were determined considering the U-value limits identified in TSE 825 for both climate zones, which are 0.66 W/m^2K and 0.57 W/m^2K for Antalya and Istanbul respectively. The schematic sections of these walls and materials' thermal conductivity values used in in the simulations are given in Figure 2. Since the simulation software allows to use only three layers in the core wall, exterior render is omitted both in bare wall and in living wall design.

In the living wall, double layer felt system is investigated as a growing medium. In the material database of the software, felt is not present. However, it allows to add new materials, and felt is introduced accordingly. Characteristics of the substrate and plant layers as used in the simulations are given in in Table 2. Since it is desired to see the effect of leaf property, two different LAI values, i.e. 1.5 and 5 m^2/m^2 are examined.

3.4 PREPARATION OF SIMULATION MODEL AND RUNNING SIMULATIONS

In the study Envi-met which is a 3D prognostic microclimate model based on computational fluid dynamics and thermodynamics was used. The software is capable of simulating exchanges of energy and mass between vegetation and its surrounding (ENVI-met 3.1 Manual Contents, 2022).

A building with 10 m width, 10 m depth and 14 m height with a flat roof was modelled for the study within a site of 26 m x 26 m. In the grid systems of both building and the site, except the first floor of the building, cell size was taken as 2 m. The program has an option to split into 5 sub-cells on the vertical axis grid for the first floor of the building. The building modelled in these respects is shown in Figure 3-a. 12 different simulations depending on location, time and wall type in terms of LAI were run as given in Figure 3.b.



	Thermal Conductivity W/(m K)
Plant	-
Felt Substrate	0.04
pvc foam	0.1
Airgap betw. substrate and wall	-
insulation XPS	0.03
Aerated concrete	0.11
Gypsium Plaster	0.58

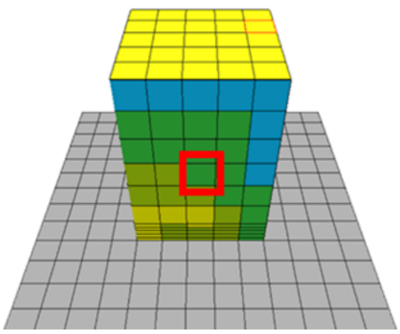
Monitoring locations

Out Air	Outside air dry bulb temperature (C°)
Fac Air	Air Temperature in front of the façade (C°)
Leaf	Leaf Temperature (C°)
Felt-Ex	Outside surface of the substrate (C°)
Pvc-In	Inside surface of the substrate(C°)(pvc-in)
Xps-ex	Outside surface temperature of the bare wall(C°)(xps-ex)
Gyp-in	Inside surface temperature (C°) (gpy-in)

Figure 2: Schematic sections of investigated bare wall and living wall, thermal conductivities used and locations of temperature monitors.

Table 2: Characteristics of Greenery system (i.e. substrate and plant)

Plant Characteristics	Value used	Substrate Characteristics	Value used
Albedo (0-1)	0.25	Albedo (0-1)	0.3
Height (cm)	2	Emissivity (-)	0.95
Leaf angle distribution (-)	0.5	Water coefficient (-)	0.5
Transmittance	0.2	Type of material	Artificial
LAI (-)	1.5 and 5	Air gap bet. sub. and wall	10 cm

a) 

b)

CODES	Location	LAI	Wall Type	Date
LiAn1,5Win	Antalya	1,5	Living wall (felt system)	2nd Feb
LiAn1,5Sum	Antalya	1,5	Living wall (felt system)	14th Aug
LiAn5Win	Antalya	5	Living wall (felt system)	2nd Feb
LiAn5Sum	Antalya	5	Living wall (felt system)	14th Aug
BareAnWin	Antalya	-	Bare wall	2nd Feb
BareAnSum	Antalya	-	Bare wall	14th Aug
LiIst1,5Spr	Istanbul	1,5	Living wall (felt system)	9nd April
LiIst1,5Sum	Istanbul	1,5	Living wall (felt system)	7nd July
LiIst5Spr	Istanbul	5	Living wall (felt system)	9nd April
LiIst5Sum	Istanbul	5	Living wall (felt system)	7nd July
BareIstSpr	Istanbul	-	Bare wall	9nd April
BareIstSum	Istanbul	-	Bare wall	7nd July

Figure 3: a) Grid system of the building simulated and the location of the area on the building considered for assessments; b) Simulations according to their location, wall properties and dates

In the simulations, the heating and cooling systems were accepted to be not operating in order to observe the individual effect of living wall system. In relation to this preference, in order to allow a settling time for the interior air temperature, the starting day of the simulations were determined to be two days prior to the selected day, and simulations were run for a 3-day period. The initial interior air temperature was set to be equal to outside temperature, and the balance was confirmed to be occurred within 48 hours. In the assessments, the results of the 3rd day are being evaluated.

3.5 ASSESSMENT OF THE SIMULATION RESULTS

The results of each cell specified in the grid plane are different from that of others depending on its place on the building height, amount of radiation and shade, wind direction and its effect. Therefore, for the four facades of the building, the results of the cell, which is at the midpoint of the facade, are taken into consideration, and the temperatures obtained were evaluated in terms of the effect of building orientation, LAI and environmental climate conditions by comparing with each other and with that of bare wall.

4. SIMULATION RESULTS AND DISCUSSION

The changes in the behaviour of living wall in respect to (i) change in the orientation, (ii) change in LAI, and (iii) change in exterior environmental conditions are discussed separately in the following sections considering the simulation results.

4.1 THE EFFECT OF ORIENTATION ON WALL TEMPERATURES

Temperature change in the living wall layers facing different orientations were compared with each other for the days selected. As given in Figure 4 for simulation LiAnWin1.5 as an example, the general temperature distribution pattern within the wall at a particular hour of the day was similar in all directions, but with changes in the temperature values observed. The temperature of pvc-in for instance was nearly always lower than that of other layers, while sometimes the temperature of gyp-in and sometimes the temperature of xps-ex was higher when these two were compared with each other. Experimental studies reported a similar behaviour where the temperature of substrate was lower than that of the leaves (Dearuz, 2016; Ouldboukhitine, et al., 2011).

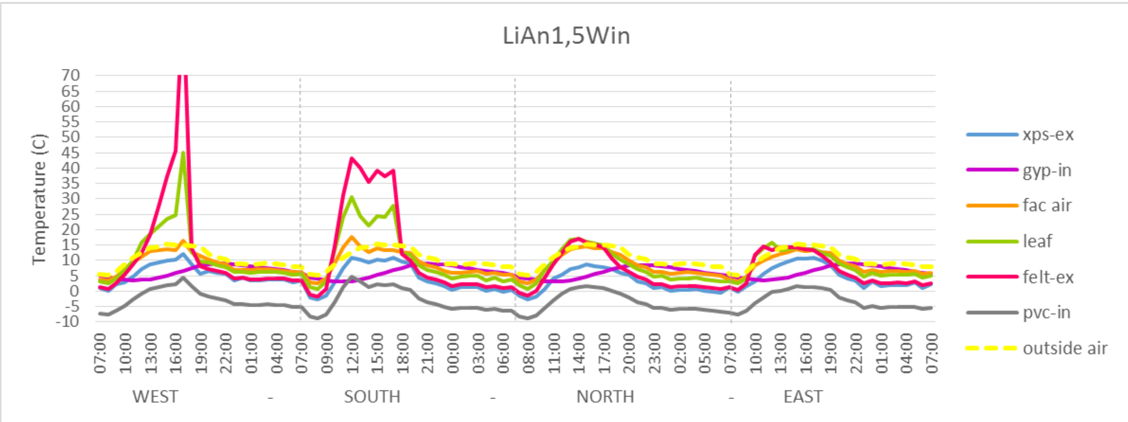


Figure 4: LiAn1,5Win - Temperature change during the day in the wall layers facing different directions.

Significant temperature variation depending on the orientation was observed especially at the exterior layers of the living wall, i.e. at the plants and the exterior side of the substrate. The temperatures of these layers were relatively similar during the whole day when north and east facing facades were compared with each other. On the other hand, the temperatures of these layers at south and west facing facades were considerably higher when there was solar exposure. Even though temperature of leaves reached up to ca. 45°C and 30°C at west and south facing facades respectively, and these were lower than that of felt-ex during these hours, the temperature of pvc-in which is the inside surface of the substrate layer is lower than that of felt-ex for all four orientation. The biggest temperature difference between leaf temperature and gyp-in is obtained at west façade. Also, it is observed in the study of Perez, et al. (2017) that the west façade is more efficient due to its contribution of the temperature difference between inside and outside, although the south façade has been exposed to higher sun radiation.

It is important to note that the interior surface temperature (i.e. gyp-int), which is an important factor in terms of providing interior thermal comfort conditions, was observed to be not changing much during the whole day depending the orientation of the façade. The maximum temperature difference between different orientations is observed to be 0.7^{0}C.

Consequently, it has seen whereas in winter, in Antalya, using bare wall at south façade is more advantageous than the other orientations, in summer conditions living wall gives the best results for west façade orientation.

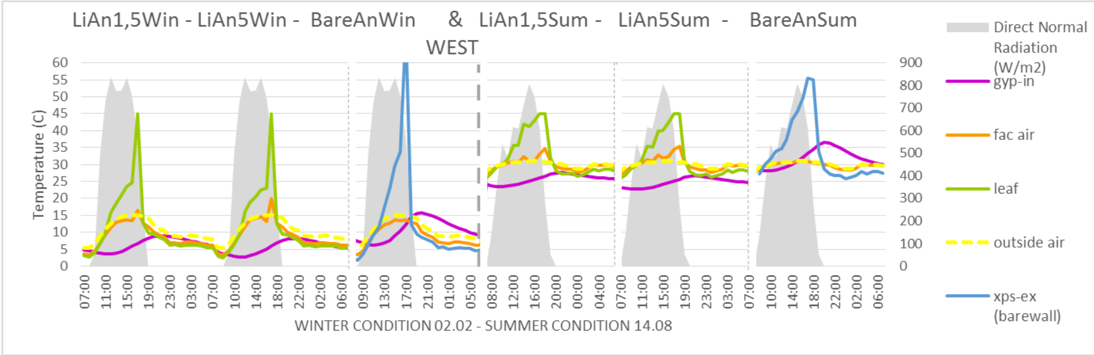
4.2 THE EFFECT OF LIVING WALL AND PLANT TYPE ON WALL TEMPERATURES

In order to understand the effect of living wall on interior conditions in general and of the plant type in particular, the interior surface temperatures of walls with plants having different LAI (i.e. 1.5 and 5) were compared with each other and with that of bare wall without any plant. These comparisons showed the followings.

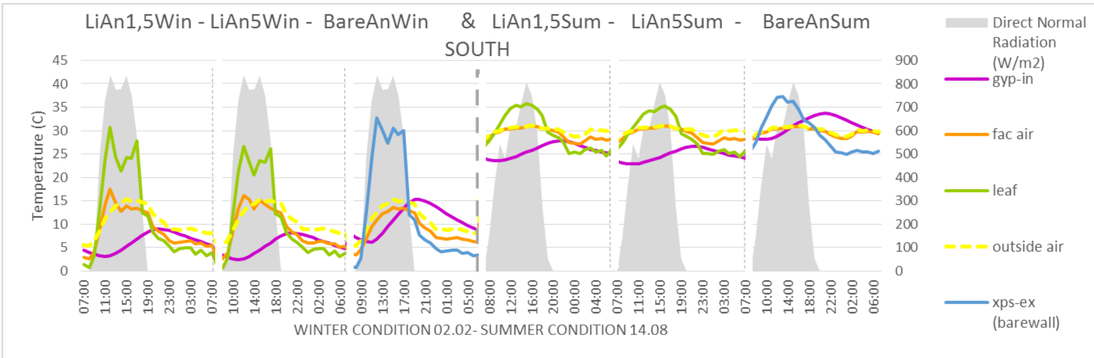
High LAI creates multi layered barrier against radiation by providing a shadow. So, high LAI prevented interior surface temperature increase due to solar exposure, as expected. It created a disadvantage in winter/spring conditions but created an advantage in summer conditions by contributing to the shading (Figure 5a). In winter conditions, as the LAI rises from 1.5 to 5, gyp-in (i.e. interior wall surface) temperatures drop by an average of 0.8 °C on all facades. In summer conditions, as the LAI rises from 1.5 to 5, the gyp-in temperatures decrease on the west, east, south and north facades, by 0.9, 1.1, 1.0, 0.8 °C respectively.

Interior surface temperatures of both living walls were lower than that of bare wall. Again generating an advantageous situation in summer, while the opposite in winter. In winter conditions interior surface temperature of bare wall are higher which shows that using living wall may not be advantageous for Antalya in winter period (Figures 5a and 5b). Between 11 a.m. and 7 p.m. in Antalya, the gyp-in temperature is 7^{0}C higher and more advantageous in the bare wall compared to that of the living wall because of the sun exposure on the western and southern fronts in winter conditions.

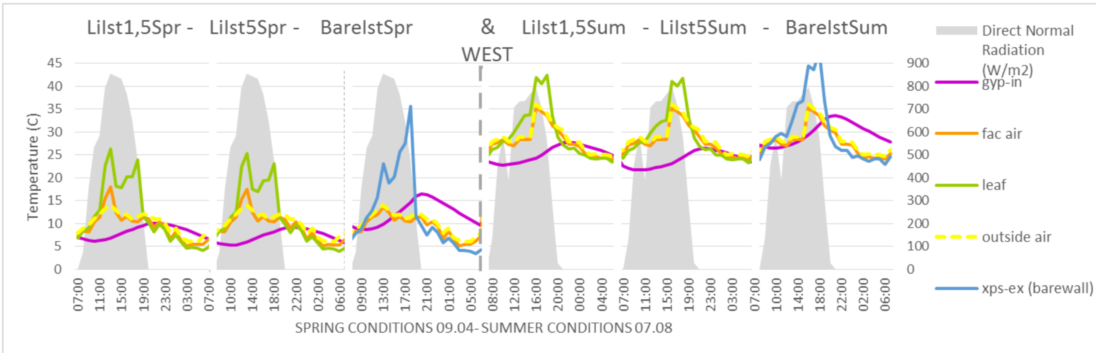
In winter conditions, for the case where bare wall and living wall with LAI of 1,5 are compared, the average temperature difference for gyp-in between bare wall and living wall is 4.0 ,3.5, 4.5 and 3.8 ^{0}C respectively for west, east, south and north (see Figure 5) In summer conditions on the other hand, when the average temperature differences of gyp-in between bare wall and living wall are compared, the living wall gyp-in temperatures decrease 6.0, 5.0, 5.2 and 5.5 °C on the west, east, south and north sides, respectively.



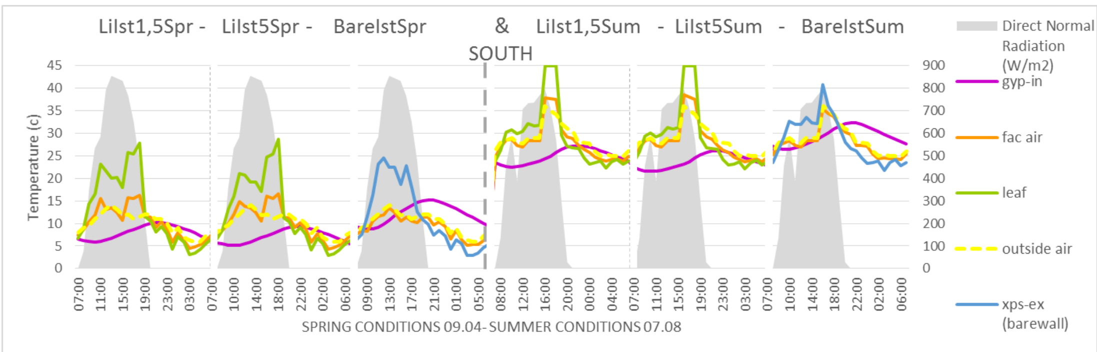
a)



b)



c)



d)

Figure 5: Temperature variations (a and b) in Antalya for west and south facades respectively, and (c and d) in Istanbul for west and south facades respectively for the selected days and investigated LAIs

Moreover, the bare wall xps-ex temperatures reaches 48^{0}C in summer conditions for west façade, whereas living wall with LAI of 1.5 reaches 42^{0}C for the same day (Figure 5a). For winter the xps-ex temperature difference between the bare wall and living wall with LAI of 1.5 is also higher around 10^{0}C in Istanbul. Another study also shows that the bare wall's outside surface temperatures can reach to 58^{0}C while the living wall's exterior surface temperature stays maximum at 35ºC (Chen, et al., 2013).

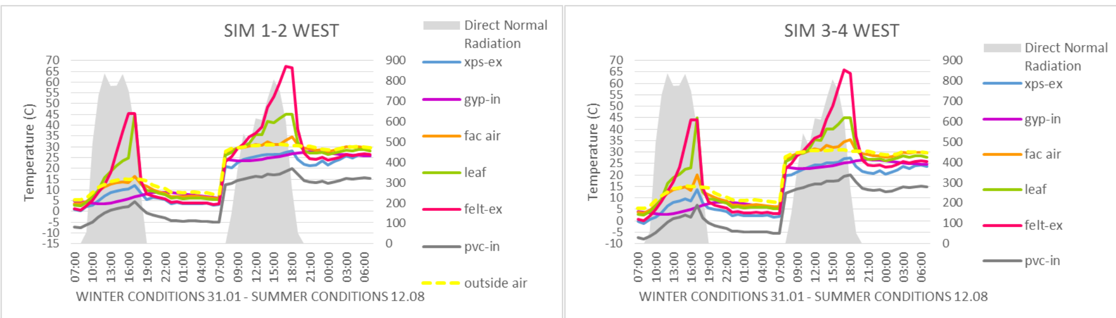
4.3 THE EFFECT OF CLIMATIC CONDITIONS

The comparison of outside air temperature and interior surface temperatures observed in different seasons showed that the difference between them was higher on the west and south side in summer conditions than winter/spring conditions for both cities as can be seen in Figure 5a and 5c. Additionally, bare wall is observed to be affected from outside air temperature especially in the summer conditions. Thus, the gap between indoor surface temperature (gyp-in) and outside air temperature is lower than that of living walls during summer time in İstanbul and Antalya.

In winter and in summer conditions in Antalya, even though the leaf temperature in the afternoon depends on the outside air temperature, due to the effect of having same amount of radiation during the daytime, the leaf temperature reaches to the same peak temperature which is 45°C on the west facade (Figure 5a-5c). However, on the east façade, the leaf surface temperature is parallel to the outside air temperature. The reason behind it can be predicted as the accumulated radiation in the morning. The comparison of outside air temperature and interior surface temperatures observed in different hours during the day shows in Antalya that, for the first half of the day from 8:00 am to 8:00 pm (during the daytime), the gyp-in (wall inside surface temperature) is lower than the outside air temperature, whereas in the evening the outside air temperature is almost equal to gyp-in. Thus, in summer, especially during the daytime living wall is more advantageous.

For the same conditions, in summer, in Antalya, during the daytime, bare wall gyp-in is slightly lower than the outside temperature compared to the living wall and in the evening, gyp-in is higher than the outside temperature. The reason behind it can be shadow effect of living wall or the studied bare wall's heat capacity with the appropriate U value according to the standard may not be enough for summer conditions in Antalya. However, living wall's performance is better in terms of heat storage and it releases unwanted heat gain slowly and it keeps its gyp-in temperature constant (Figure 5a-5c).

Substrate layer's outer surface (felt-ex) temperature reaches to high temperatures in comparison to that of other monitoring points in all green wall types and in all cities, especially on the western facade and later on the south, as exampled in Figure 6 for Antalya.



a) b)

Figure 6: Winter and summer conditions for 1,5 LAI and 5 LAI Living wall systems in Antalya

Its reason can be explained with the wet substrates increased heat storage capacity; thus high solar exposures cause a dramatical temperature increase for felt-ex (i.e. front face of the substrate layer). The temperature of Pvc-in on the other hand is more stable, without a peak like that of felt-ex, which can be associated with the wet substrate.

5. CONCLUSION

In this study, where the effect of plant type, orientation and climatic conditions on living walls thermal behaviour is examined, two different LAI values as 1.5 and 5, four different orientations (i.e. cardinal directions) and two different climates (i.e. hot humid and temperate climates) are studied to see their effect on living walls compared to bare walls without any vegetation.

The results of the study can be summarized as follows;

- The living wall systems provide benefit in summer conditions both in Antalya and Istanbul, while they negatively affect indoor environment in winter conditions, when their effect on interior surface temperatures are considered.
- Both in Istanbul and Antalya, the increase in the value of LAI contributes to the interior surface temperature in a positive way for all façade directions in summer, while in the winter it has a negative effect.
- The use of the living wall system causes significant variations in the temperature values within the wall. Because of the irrigation requirements of the plants and the lack of sun exposure on the back surface of the growing layer, the wall's interior surface temperature decreases both in winter and summer conditions.
- In order to have an effective result in the living wall design, the façade direction that it must be applied is west and then south to see the difference on wall section. This is because the wall is exposed to solar radiation with a horizontal angle.

According to the results obtained, it was observed that the properties of the substrate layer may have effect on the indoor temperature as much as the plant. For this reason, in further studies, it is desired to see the effect of the irrigation frequency and thermal conductivity value of the substrate layer and the air gap on wall layer's temperatures.

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THE IMPACT OF COVID-19 ON THE BUSINESS CONTINUITY OF THE SRI LANKAN APPAREL INDUSTRY: HUMAN RESOURCE MANAGEMENT (HRM)

M. Gowsiga[1] and T. Kartheepan[2]

ABSTRACT

The Sri Lankan apparel industry is having a high demand for exports all over the world and is a leading apparel producer in the South Asian region. It has started to fight for its survival due to the pandemic, Covid-19. It guesses a bracing for a 50% drop in demand by the following one to one and a half years from Covid-19. Thus, the industry is in a position to reinvent itself by forcing itself to live. Thus, business continuity is necessary to proceed with the business without any interruption at this time. Moreover, human resource professionals act a major role to continue the business after the new normal, as handling the main resource of the organisation which is humans. Hence, this study aims to investigate the level of impact and consequences of Covid-19 in the business continuity process of the Sri Lankan apparel industry from the human resource management perspective. Initially, the literature review delivered a theoretical understanding of the research area and three large-scale apparel organisations were selected, a case study research strategy with a quantitative approach. Collected data were analysed using the Likert scale and weighted average manual content analysis. The findings revealed that Training and development help to compensate for the labour shortage, and technology improvements have modified the recruitment pattern. The difficulty of measuring performance has a negative impact on employee engagement; however, job uncertainty and providing satisfactory opportunities for development have increased employee engagement; thus, there is a balance in employee engagement, and communication plays an important role in that. Furthermore, flexible working hours have a positive impact on employee performance and job satisfaction.

Keywords: *Apparel Industry; Business Continuity Process; COVID-19; Human Resource Management; Sri Lanka.*

1. INTRODUCTION

The Sri Lankan apparel industry is having a high demand for exports all over the world and is a leading apparel producer in the South Asian region (Central Bank of Sri Lanka [CBSL], 2013). This industry is purely privately owned in the Sri Lankan context and also exploited the opportunities in the international market successfully (Muthukumarana, et al., 2018). Moreover, the production of this industry caters to many internationally reputed brands like Nike, Victoria's Secret, Ralph Lauren, and Tommy

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Hilfiger (Board of Investment Sri Lanka, 2016). Revenue from the apparel industry is accounted for 43% of the total export revenue of the country (Kapuge and Smith, 2007). This sector is the prime foreign revenue maker (Board of Investment Sri Lanka, 2016), and it generates around 4.4 billion USD in export income each year (The World Bank, 2016). Primarily, this industry offers more than three hundred thousand direct employment opportunities, and also nearly 350 garment factories are operating in various parts of Sri Lanka (Akanbi, et al., 2018). Thus, The Sri Lankan apparel industry is vital to the manufacturing industries in terms of employment and output (UNIDO, 2000). Further, one of the prime factors which have added to the rapid development of the Sri Lankan apparel industry has been a highly trainable, skilled, and literate workforce (Welmilla, 2020). Thus, human resources are a basic need for the apparel industry, as it is a labour-intensive industry (Silva, et al., 2012). Human resource management (HRM) is also one of the important success factors for the competitiveness of the apparel industry (UNIDO, 2000).

It is obvious that the pandemic Covid-19 has had an impact on the Sri Lankan apparel industry. The coronavirus outbreak, which has affected hundreds of thousands of people, is first and foremost a human tragedy. The impact of the coronavirus on the global economy has been profound, not just from the spread of the disease and virus, but also from the measures taken to stop it (Tkach and Kurpayanidi, 2020), In particular, because of the complete shutdown of all industries in Sri Lanka at the beginning of Covid-19 in March 2020. And the situation hasn't totally recovered yet. Thus, there is a mandate in place for all businesses to continue operating since the Covid-19 outbreak. Business continuity necessitates the participation of all professions, but it demands greater involvement from human resource professionals (Maurice and Bassey, 2021).

There are plenty of researches undertaken in each domain, such as business continuity, Covid-19, and HRM. Despite the fact that Covid-19 is new to the world and Sri Lanka, there is a sufficient amount of study in both global and Sri Lankan contexts, particularly in the apparel industry (Bolonne, 2020). Furthermore, few research articles combine the terms "business continuity and Covid-19," "business continuity and HRM," and "Covid-19 and HRM." (Wediawati, et al., 2020). However, there is scant research that incorporates all three of the aforementioned elements as well as a research study in the chosen industry. Also, less attention has been paid to HRM to improve company continuity. Hence, this study aims to investigate the level of impact and consequences of Covid-19 in the business continuity process of the Sri Lankan apparel industry from the human resource management perspective. The structure of this paper starts with a literature review lining the key concepts of the study. Then it presents the method used in achieving the aim of the study and finally, it presents the discussion and conclusions based on the research findings.

2. LITERATURE REVIEW

Human Resource Management (HRM) is “an approach to managing people that supports an organisation’s long-term goals with an overall planned and coherent framework” (Chartered Institute of Personnel and Development [CIPD], 2021). According to the author, most organisations now recognise that people are critical to long-term value development, which is why they are frequently referred to as a company's most valuable asset. More effective and profitable organisations build-up by talented, qualified, and trainee employees, thus the employee issues in an organisation are well known as the lifeblood of an organisation (Thammita, et al., 2010). Therefore, when an industry is facing challenges like new normal, it is more important to pay attention to the human resources asset (Ranaweera, 2014). Moreover, the Sri Lankan apparel industry is actively connecting with the working population; hence it is necessary to pay attention to the HRM, especially in this new normal situation like Covid-19. Covid-19 has had a huge impact on employees and businesses all around the world (Kniffin, et al., 2020). While Covid-19 abruptly upended normal work routines, it also caused an acceleration of trends that were already underway involving the migration of work to online or virtual environments (Gartner, 2020). Unemployment and layoffs, wage flexibility, presenteeism, social distancing, loneliness, salary reduction, the prevailing absence of performance measurement, and workplace connectivity, etc. are some of the prime effects of Covid-19 on HRM (Alon, et al., 2020). The virus is a potential threat to organisational sustainability and HRM in the new world. The pandemic has caused such a shock that it has significantly hampered every aspect of human and economic activities. Organizations must now rely on their human resource department more than ever as a business strategy to keep their employees and customers safe, comfortable, and productive throughout the pandemic. There are many human resource functions such as recruitment and selection, learning and development, performance management, compensation and benefits, human resource planning, reward management, safety and health, employee engagement and communication, labour relation, and regulatory compliance. Among which recruitment and selection, performance management, employee engagement, and compensation and benefits will only be discussed in this research study, according to a preliminary interview conducted with five directors of Sri Lanka's large scale apparel sector, these four functions were selected as crucial functions in the case of business continuity in the apparel industry.

2.1 RECRUITMENT AND SELECTION

Recruitment and Selection are finding the right people for the right roles at the right time (CIPD, 2021). It involves attracting and selecting individuals for a job role. Recruiting the right individuals is crucial for organisations that need people with the right skills and capabilities to deliver their goals. Effective resourcing is not just about filling an immediate vacancy but about having an impact on the long-term success of the business (CIPD, 2021), thus it is a critical activity. Recruitment has undoubtedly been affected by the Covid-19 pandemic. Although hiring has increased in some sectors, many recruitments have been reduced or been on hold. many organisations increasing training and retention. One impact is the increased use of technology in recruitment processes. This was already on the rise pre-pandemic, but it has become a necessity where traditional ‘in person’ interview and assessment processes are not appropriate. As it is likely to continue in some form after the pandemic, organisations should evaluate and monitor their use of technology. Almost all leading organisations would work on re-skilling their employees or recruiting according to the new normal requirements (Meister, 2020). Moreover, this new normal threatened many employees with the termination of employment mainly because several jobs cannot be done at home, among those major production activities which need to be done using machines, like the apparel industry (Venclova, et al., 2013).

2.2 PERFORMANCE MANAGEMENT

"Performance management is a continuous process of managing the performances of people to get desired results" (Sahoo and Mishra, 2012). It is an attempt to maximise this value creation and ensure that employees contribute to business objectives (CIPD, 2021). Performance management is the process of creating a work environment in which people can perform to the best of their abilities (Hartog and Verburg, 2004). It is a whole work system that begins when a job is defined as needed and expectations are communicated to the employee (Heinen and O'Neill, 2004). Performance management encompasses activities such as joint goal-setting, continuous progress review, frequent communication, feedback and coaching for improved performance, implementation of employee development programs, and rewarding achievements (Hartog, et al., 2004). When employees are working remotely or more flexibly, their performance may be harder to observe (CIPD, 2021). In the short term, whilst the pandemic and its immediate implications are ongoing, employees may not be able to be as productive as normal, and managers may need to adjust their expectations (and formal objectives) accordingly. Longer-term, instead of assessing employees via time in the office (or in virtual meetings), managers will need to adjust to assessing performance through outcomes, contribution, and value. Managers will not be able to monitor every aspect of an employee's work when they are working remotely, nor should this normally be necessary (CIPD, 2021). The loss of social connections due to social distancing and loneliness is a less obvious impact of Covid-19 (Mogilner, et al., 2018). It has a strong negative impact on performance. Both positive and negative concerns are available for working from home on productivity, Overall, people feel they are more productive and more focused when working from home. There will be a need to ensure people feel able to work effectively using technology from a distance, which may require some additional training (Kettleborugh, 2013).

2.3 EMPLOYEE ENGAGEMENT

Employee engagement is a workplace approach resulting in the right conditions for all members of an organisation to give their best each day, be committed to their organisation's goals and values, motivated to contribute to organisational success, with an enhanced sense of their well-being (CIPD, 2021). Engagement and commitment can potentially translate into valuable business results for an organisation. Employee engagement is based on trust, integrity, two-way commitment, and communication between an organisation and its members. It is an approach that increases the chances of business success, contributing to organisational and individual performance, productivity, and well-being. Among those continuing to work in the wake of Covid-19, there is likely to be growth in presenteeism. Workplace loneliness has been shown to have a strong negative relationship with employees' affective commitment and affiliative behaviors (Ozcelik and Barsade, 2018). Some of the greatest challenges confronting HRM within the business organisation in the new normal range from loss of jobs, salary reduction, the prevailing absence of performance measurement, and workplace connectivity. Working time flexibility, and hour flexibility also increases impact both positively and negatively for an organisation. Moreover, Covid-19 will impact profoundly employment and can cause career shock for employees (Akkermans, et al., 2020).

2.4 COMPENSATION AND BENEFITS

Employees' willingness and ability to help their company succeed, largely by providing discretionary effort on a sustainable basis (Perrin, 2003). It is defined as the involvement with and enthusiasm for work (Markos and Sridevi, 2010). Institute of Employment Studies gives a clear insight that employee engagement is the result of a two-way relationship between employer and employee pointing out that there are things to be done by both sides. communication is the top priority to lead employees to engagement CIPD (2022). Most drivers that are found to lead to employee engagement are non-financial in their nature, such as two-way communication, give satisfactory opportunities for development and advancement and give employees appropriate training. In addition, a strong feedback system, Incentives have a part to play, employee engagement is closely linked with organisational performance outcomes. People are getting more insecure about jobs. Some are losing their jobs. During this Covid-19 situation, it is hard to keep employees engage for a while, especially due to working from home is going on. Another way is must maintain better employee relations and employee engagement in this pandemic for the smooth running of any business. (Abrol and Madan, 2020; Kaushik and Guleria, 2020; Prasad, 2020). There has been significant wage flexibility in the employer response to date, Wage cuts, delays, and freezes have been most extensive in some higher value-added services (CIPD, 2020). some of the greatest challenges confronting HRM within the business organisation in the new normal range from loss of jobs, salary reduction, the prevailing absence of performance measurement, and that workplace connectivity.

3. RESEARCH METHODOLOGY

This research aims to investigate the level of impact and consequences of Covid-19 in the business continuity process of the Sri Lankan apparel industry from the human resource perspective. The data collection method should be selected based on its rationality, appropriateness, validity, and amount of data needed (Polonsky and Waller, 2011), thus quantitative approach was selected in this study to achieve the aim of this research, which is more toward quantitative. An online questionnaire survey with closed-ended questions was carried out based on the findings of the literature reviews and preliminary interviews. According to the purpose of the survey; the questions were short and simple for easy understanding to the users, and targeted to fill within 15 minutes. Since this study focuses on the level of impact and consequences of Covid-19 in the business continuity of the apparel industry and it was only done for a unique industry which is the apparel industry, selecting multiple cases is the most appropriate way to collect data. Multiple case studies allowed us to compare the collected data and subject studies to attain comprehensive knowledge of research practices. Accordingly, a multiple case study design was selected for this research. Since there were constraints with limited accessibility and time, only three large-scale apparel organisations were selected to collect data and which were coded as Case A, Case B, and Case C. Moreover, one of the prime case selection criteria was the size and number of employees of the cases to avoid the cross-case analysis. To carry on the questionnaire survey, 36 respondent samples were selected, 12 respondents from each case, whoever engaged in business continuity in the middle and top-level hierarchy of the organization. But only 27 respondents have completed the questionnaire respectively 09, 07,11 from Cases A, B, and C, due to the Covid-19 situation professionals are well tightened with their work schedules. Therefore, the response rate is 75%. The background information of the respondents comprises details on their designations and work experience of the respondents. Managers or assistant managers of different departments such as finance, merchandising, administration, planning, operations, general, marketing, human resources, and information and communication have participated in this survey. In addition, assistant accountants, executives from facilities, human resources, occupational health & safety, administration, engineering, and sustainability were engaged by the middle-level professionals of the selected cases. The year of experience in the apparel industry is varying from 01 years to 27 years as the respondents were selected from both middle and top management levels of the organisations. Figure 1 demonstrates the respondents' work experience in the apparel industry.

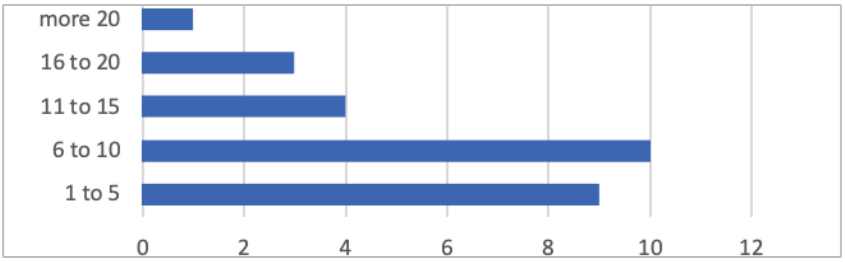

Figure 1: Respondents' years of experience

33% of the respondents have work experience of fewer than 5 years, 37% of the respondents have work experience between 6 to 10 years, 15% of the respondents have work experience between 11 to 15 years, 11% of the respondents have work experience between 16 to 20 years and only 4% of the respondents have work experience more than 20 years.

Data analysis is a process that relies on methods to take raw data that are relevant to the study (Robinson, 2013). Accordingly; after the data collection, it is required to convert raw data into something meaningful and readable. Quantitative data analysis techniques are used to analyse the collected data. The Likert scale method that includes five points namely; strongly disagree, disagree, neutral, agree, and strongly agree is supposed to utilise and, the weighted average is used as the data analysing technique which could help to generalise the statements. The equation used for weighted average calculation is given below in Eq. 01. The next section presents the analysis and research findings of the research.

$$\text{Weighted Average} = (1R1+2R2+3R3)/R \qquad \text{(Eq. 01)}$$

Where R1 - number of respondents belonging to low, R2 - number of respondents belong to medium, R3 - number of respondents belong to high and R - total number of respondents (R1+R2+R3).

4. RESEARCH FINDINGS AND DISCUSSION

This section consists of two subsections such as the level of impact and consequences of Covid-19 in the business continuity process of the Sri Lankan apparel industry & the level of involvement of human resource professionals in the business continuity process of the apparel industry in the context of the Sri Lankan apparel industry.

4.1 THE LEVEL OF IMPACT AND CONSEQUENCES OF COVID-19 IN THE BUSINESS CONTINUITY PROCESS OF THE SRI LANKAN APPAREL INDUSTRY

In this survey, out of 27 respondents only 2 (7%) of respondents have selected the option NO, to the question 'Have you experienced any negative impact on your business from COVID-19?', accordingly those two respondents were unable to fill the balance part of the questions which belong to the level of impact and consequences of Covid-19 in the business continuity process of the apparel industry. Thus, for the balance questions of this section, the total can be counted for 25 responses only (93% of respondents). The majority 93% of the respondents revealed that Covid-19 has a negative impact on the business of the Sri Lankan apparel industry. Moreover, Figure 2 demonstrates the level of impact on the Sri Lankan apparel business process due to Covid-19.

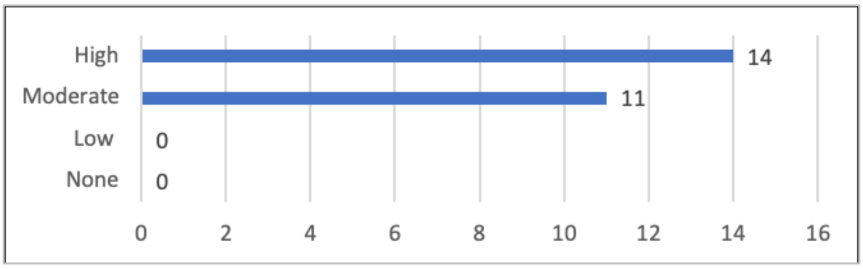

Figure 2: The level of impact of Covid-19 on the business process of the Sri Lankan apparel industry

In here questionnaire responses of 25 were considered for analysis and it was disclosed that Covid-19 had a moderate and significant level of impact on the Sri Lankan apparel business process with 44% and 56%, respectively. Although the respondents were offered the options None and Low, no one has chosen. Thus, this clearly shows that Covid-19 has a slightly high level of negative impact on the Sri Lankan apparel business. Following that, the questionnaire was directed toward the consequences of Covid-19 in the business continuity process of the Sri Lankan apparel industry. As the first question, it was 'How long did it take for your enterprise to fully (or more than 80%) restore operations?'. Figure 3 exhibits the time take to fully (or more than 80%) restore the business operations of each case separately and also as a whole.

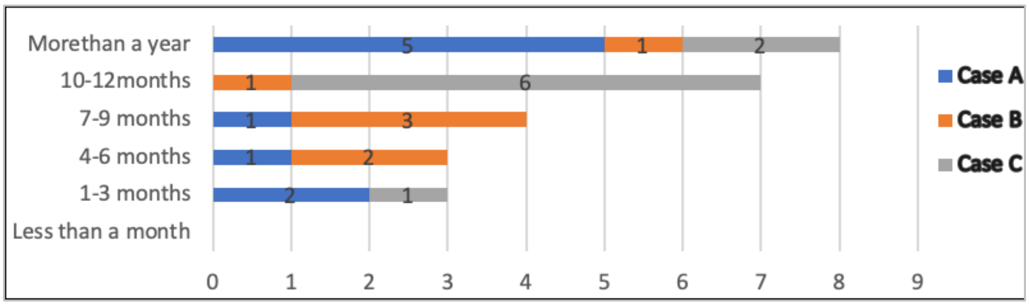

Figure 3: The time taken to fully (or more than 80%) restore the business operations

Accordingly, around 60% of the Sri Lankan apparel industry has taken more than 10 months to restore fully (or at least 80%) their business operations. Only 24% of the Sri Lankan apparel industry has taken less than 6 months to restore fully (or at least 80%) of their business operations. When analysing each case separately, in Case A and Case C respectively 56% and 89% of the respondent stated that it has taken more than 10 months to fully (or at least 80%) their business operations. However, in Case B only, 29% of the respondent stated that it has taken more than 10 months to fully (or at least 80%) their business operations. Thus, this is explicit that the recovery period of the majority of the Sri Lankan apparel organisations is more than 10 months. Moreover, the estimated revenue decrease due to Covid-19 in the Sri Lankan apparel industry is displayed in Figure 4.

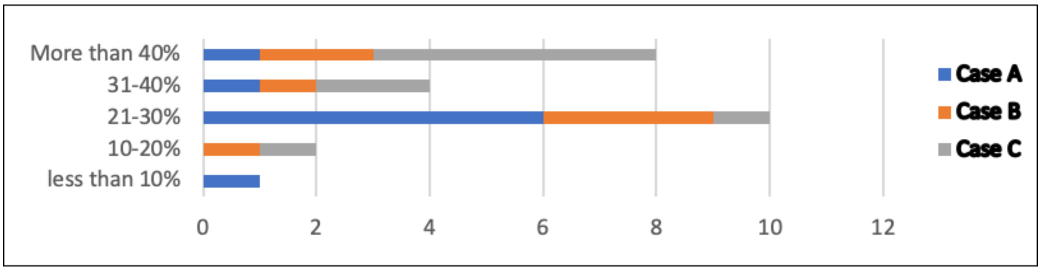

Figure 4: The estimated revenue decreases due to Covid-19

The majority, 40% of the respondents stated that the estimated revenue reduction in the apparel industry is between 21-30%. At the same time, both Cases A and B fall under the 21-30% range of estimated revenue reduction as the majority. The next highest estimated revenue reduction range is more than 40% of their revenue and Case C belongs to this range. In addition to the revenue reduction, one of the other prime consequences of Covid-19 is employee reduction. To identify that, the following question, 'If your organisation had faced a reduction in the workforce, how many employees have been affected?' has been asked from respondents and then analysed answers of the respondents is displayed in Figure 5.

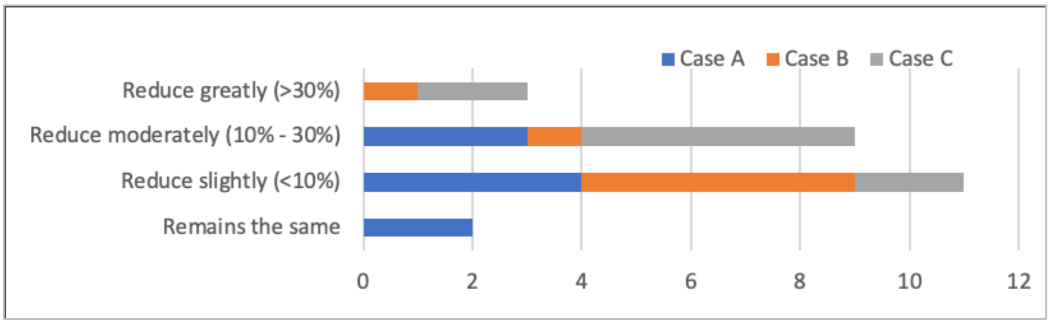

Figure 5: Employee reduction due to Covid-19

Among those 25 respondents, only 2 respondents have stated as the employees remain the same. 44% of the respondents stated as reduced slightly (less than10%). Cases A and B have respectively, 4 out of 9 and 5 out of 7 respondents belonging to reduce slightly option. But Case C only falls under Reduce moderately (10-30%) with 5 out of 9 respondents. 12% of responses only express that number of employees reduces greatly (>30%) in their organisations.

4.2 The Level of Involvement of Human Resource Professionals in the Business Continuity Process of the Apparel Industry in the Context of the Sri Lankan Apparel Industry

From the literature, 25 statements were summarized, and categorised according to the functions of HRM such as recruitment and selections, performance management, employee engagement, and compensation and benefits. Based on the data collection results of case respondents, the weighted average for each statement was calculated. Even though, the questionnaire was designed with five Likert scales such as strongly disagree, disagree, neutral, agree, and strongly agree. The weighted average ranges were categorised into three to explain clearly whether the statement is agreed with Sri Lankan apparel industry or not. Table 1 shows the adopted weighted average ranges and categorisations.

Table 1:The adopted weighted average ranges and categorisations

Weighted Average Range	Category
1.0-2.3	Disagree (D)
2.4-3.6	Neutral (N)
3.7-5.0	Agree (A)

Each four selected human resource functions are discussed separately. At first, the statements belonging to recruitment and selection will be discussed and Table 2 provides the weighted average interpretation of recruitment and selection statements for each case separately and also the overall.

Table 2:The weighted average interpretation of recruitment and selection statements

Code	Statements	Case A	Case B	Case C	Mean
R1	Recruitment and selection are negatively impacted during Covid-19	4.0 (A)	3.7 (A)	4.2 (A)	4.0 (A)
R2	The hiring of employees has been reduced	3.0 (N)	3.7 (A)	4.3 (A)	3.7 (A)
R3	Recruitments have been on hold so to balance that training and retention has been increased	3.3 (N)	3.0 (N)	4.2 (A)	3.5 (N)
R4	Technology usage for recruitment has been increased	4.0 (A)	4.4 (A)	4.0 (A)	4.1 (A)
R5	Recruitment has been changed according to the new normal requirements	4.3 (A)	3.6 (N)	4.1 (A)	4.0 (A)
R6	Termination of employment has been increased	2.9 (N)	4.0 (A)	3.4 (N)	3.4 (N)

According to Table 2, The weighted average of four of the six statements summarised is greater than 3.6, indicating that those are agreed in the context of the Sri Lankan apparel industry too. Thus, the recruiting and selection has been badly damaged during Covid-19, with the hiring of personnel being drastically limited. Moreover, the usage of technology in the recruitment process has been increased after Covid-19 and it has been changed according to the new normal requirements, for example avoiding in-person interviews (Meister, 2020). However, the other two statements, R3 and R6 are belonging Neutral according to the author's norms. The statement R3 is having a weighted average of 3.5, which is closer to agree, thus, it can be assumed to be slightly agreed with the Sri Lankan apparel industry. R3 statement is having an action, which is training *and retention has been increased* with the reason, *recruitments have been on hold.* Already from R2, it is obvious that recruitment has been reduced or it can be taken as on hold due to Covid-19, thus the second part of the statement must be neutral or not strongly agree with the Sri Lankan context which is the training and retention have been increased to balance the need of manpower. Along with Venclova, et al. (2013), that new normal threatened many employees with the termination of employment mainly because several jobs cannot be done at home, like the apparel industry which requires machinery, from the case studies also *R6 statement has* a neutral response. Because, when considering as an organisation other than production workers who require machinery to complete their task, there are more other job roles available such as middle level, managerial level and top managements who can complete their certain job role from home. Additionally, most of the production employees of the Sri Lankan apparel industry are economically unstable and they are relying on their job, thus, the termination of employees from their side is very much less than there is a serious situation.

Next is the performance management function of human resources management and Table 3 demonstrates the weighted average interpretation of Performance management statements for each case separately and in whole as well.

Table 3:The weighted average interpretation of performance management statements

Code	Statements	Case A	Case B	Case C	Mean
P1	Performance management is negatively impacted during Covid-19	3.2 (N)	3.6 (N)	4.2 (A)	3.7 (A)
P2	Harder to observe and measure the employees' performance	3.4 (N)	3.9 (A)	3.9 (A)	3.7 (A)
P3	The loss of social connections due to social distancing and loneliness has a strong negative impact on performance	3.3 (N)	3.4 (N)	4.0 (A)	3.6 (N)
P4	Employees are more productive and more focused when working from home	2.4 (N)	3.0 (N)	3.3 (N)	2.9 (N)
P5	Wage cuts, delays, and freezes of wages impacted negatively on employee performance	3.6 (N)	3.0 (N)	4.1 (A)	3.5 (N)
P6	Technology is playing a negative impact on performance	2.6 (N)	3.4 (N)	3.7 (A)	3.2 (N)

Along with Table 3, only two statements have got the weighted average which belongs to agree, even equal to 3.7. Statement P1, two cases have summarised as Neutral and only one case has got 4.2, strongly agreed. Even though this is different from organisation to organisation, when considering as an industry in Sri Lanka, it can be concluded as agreed, it may be due to the positive performance management of the industry only it has been restored even after 10 months or less than or more than that. Then, P2 concluded that it is harder to observe and measure the employees' performance of Sri Lankan apparel organisations after Covid-19. For the P3 statement, it was expected to have the analysed answer as disagree, but it is neutral which is much closer to agree. Thus, this survey results explicit that social connection is important for the mental wellbeing of the employees. P5 is not agreed or disagreed, so, there may be a negative impact on employee performance due to one of those factors such as wage cuts, or delays, or freezes of wages. On other hand, the P5 statement is agreed to a certain level of employment and disagreed with some other levels of employment. Technology is playing a negative impact on performance is not agreed or disagreed, it can be summarised as technology is not impacting of employee performance whether negatively or positively. At last, P4 is having a neutral summary for all three cases separately and also in the overall Sri Lankan apparel context, hence, there are no changes in the productivity and focus of the employees due to working from home.

Following to that, employee engagement function of human resources management will be discussed and Table 4 exhibits the weighted average interpretation of employee engagement for each case separately and in whole as well.

Table 4:The weighted average interpretation of employee engagement statements

Code	Statements	Case A	Case B	Case C	Mean
E1	Employee engagement is negatively impacted during Covid-19	3.8 (A)	3.6 (N)	4.0 (A)	3.8 (A)
E2	There is likely to be growth in presenteeism	3.3 (N)	3.4 (N)	4.1 (A)	3.6 (N)
E3	Workplace loneliness has been shown to have strong negative relationships to employees' commitment and engagement	2.6 (N)	3.6 (N)	3.7 (A)	3.3 (N)
E4	Uncertainty on the job has increased the employee engagement	3.7 (A)	4.1 (A)	4.0 (A)	3.9 (A)
E5	Salary reduction has a negative impact on employee engagement	3.4 (N)	3.1 (N)	3.8 (A)	3.5 (N)
E6	The absence of performance measurement has a negative impact on employee engagement	3.3 (N)	3.6 (N)	4.3 (A)	3.7 (A)
E7	An increase in working time flexibility and hour flexibility have been impacted positively on performance	3.9 (A)	4.0 (A)	3.6 (A)	3.8 (A)

Based on the analysed results, 4 out of 7 statements have been agreed to Sri Lankan apparel contexts such as E1, E4, E6, and E7. Even though, employee engagement is negatively impacted during Covid-19, the increase in job uncertainty and the increase in working time or hour flexibility are helping to balance the employee engagement towards the job. P2 from the Previous table evidence that performance measurement is difficult to proceed with and it is essential in the private sector to motivate employees, thus it has a negative impact on employee engagement. The other three statements such as E2, E3, and E5 are belonging neutral in the Sri Lankan apparel industry. Alon, et al. (2020) have mentioned that an increase in presenteeism is one of the prime effects of Covid-19, but that is not strongly agreed to by the Sri Lankan apparel industry. Likely to the P3 statement, social distancing or loneliness has no impact on employee engagement as well. According to Akkermans, et al. (2020), loss of a job is one of the major consequences of the new normal and it has happened for Covid-19 as well, due to this, the salary reductions have not impacted employee engagement. Employees are in the mindset of without losing their job, less salary is better to lead their life in this pandemic situation.

Finally, the discussion will be on compensation and benefits statements and Table 5 shows the weighted average interpretation of compensation and benefits statements for each case individually and also the overall weighted average.

Table 5:The weighted average interpretation of compensation and benefits statements

Code	Statements	Case A	Case B	Case C	Mean
C1	Compensation and benefits are fully impacted during Covid-19	3.4 (N)	4.1 (A)	4.3 (A)	4.0 (A)
C2	It is hard to keep employees engage for a while without monetary benefits	3.3 (N)	2.7 (N)	4.0 (A)	3.3 (N)
C3	Communication is the top priority to lead employees to engagement	4.1 (A)	4.3 (A)	4.7 (A)	4.4 (A)
C4	Flexibility of working time has been increased the employees' enthusiasm towards the work	3.7 (A)	3.7 (A)	3.8 (A)	3.7 (A)
C5	Wage cuts, delays, and freezes of wages impacted negatively on employee interest in the job	3.7 (A)	2.7 (N)	4.0 (A)	3.5 (N)
C6	Give satisfactory opportunities for development and advancement will lead to more engagement of employees	3.9 (A)	3.3 (N)	4.3 (A)	3.8 (A)

According to the analyses of the compensation and benefits statements, C1, C3, C4, and C6 are having more than 3.6 values, which are agreed to the Sri Lankan apparel background. It is obvious that compensation and benefits are fully impacted during Covid-19, which can be evidenced using the literature of Sukumaran (2020), without profit compensation and benefit is impossible. Although, employee engagement is somewhat there because of communication, yes communication is playing a vital role to continue the business during this type of new normal, Covid-19. Moreover, C5 is also adopting the same explanation given to E5. Among those 25 statements, 14 statements have been agreed to the Sri Lankan apparel context and the balance of 11 have a neutral weighted average. This shows that even one statement has not disagreed.

5. CONCLUSIONS

This research aims to investigate the level of impact and consequences of Covid-19 in the business continuity process of the Sri Lankan apparel industry from the human resource perspective. Questionnaire survey data collection and analysis were contributed to achieving this study. Moreover, this study has mutually significant academic and practical aspects. There are plenty of researches untaken separately for every three areas such as business continuity, Covid-19, and HRM, even in pair combination. However, there is a lack of researches on the combination of all three of the above. Also, this research is significant in the selected industry, the apparel industry. The coronavirus outbreak is first and foremost a human tragedy, affecting hundreds of thousands of people. The spread of the coronavirus and the restrictive measures imposed everywhere in countries, along with self-restrictions of the population, have had a rapid impact on all most all the businesses not from the disease and virus, but from the measures taken to stop it. Thus, there is a requirement available for all the businesses to continue their business during the Covid-19 outbreak. This research summaries that, training and development serve to compensate for the shortage of staff employment, and the recruitment pattern has changed as a result of technological advancements. Employee engagement is negatively impacted by the difficulty of measuring performance; however, job uncertainty and providing satisfactory opportunities for development have increased employee engagement; thus, there is a balance in employee engagement, and communication plays an important role in that.

Furthermore, flexible working hours have a favourable impact on performance and employee excitement about their jobs. Thus, the practical significance of this study will be helpful to maintain the continuous business operations during new normal conditions, especially at this post-Covid-19 stage.

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THE IMPACT OF COVID-19 PANDEMIC ON THE DEMAND AND SUPPLY OF APARTMENT PROJECTS IN SRI LANKA

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ABSTRACT

Apartment market can be recognized as one of the marketplaces severely affected due to the unprecedented global pandemic of COVID-19, which is currently driving towards a disequilibrium state. Hence, this paper aimed to investigate the impact of COVID-19 pandemic on the demand and supply of apartment projects in Sri Lanka. The qualitative research approach was followed in order to accomplish the research aim. A comprehensive literature review followed by fifteen semi-structured interviews were conducted with apartment industry experts during the empirical investigation. Collected data was analyzed using manual content analysis. The findings revealed, how each market determinant affected the demand and supply of apartments respectively during the COVID-19 pandemic resulting numerous challenges on the market participants, directing the apartment market towards a disequilibrium state. Urban living fears, demographic shifts, unemployment shocks, consumers' financial concerns, tourism crisis along with several other factors caused demand to be dropped while approval delays, lesser investments, lack of funding, developers' failures, market imperfection and construction delays majorly affect the supply of apartments. Although demand for apartments in some market segments showed recovery with the new normal adaptation followed by several positive market aspects, demand dropped within the rental market and upper tier remains constantly. However, supply side is worsening overtime since financial losses are lessening developers' supplying capabilities, while the crisis within the construction sector getting more affected due to the country's economic downturn.

Keywords: *Apartment Market Equilibrium; Apartment Rental Market; COVID-19 Pandemic; Demand and Supply.*

1. INTRODUCTION

In 1776, Adam Smith defined a principle known as "law of supply and demand", which is effective in predicting the market behaviour, while it stands among the peak of several factors that influencing the market behaviour (Torab, 2018). Moreover, Akinbogun et al. (2014) identified the property market as an imperfect market, where the interaction of demand and supply is affected by constraining factors such as product heterogeneities, information scarcity, government interference, localized market and both demand and supply determinants. Koçi, et al. (2021) stated that COVID-19 pandemic has hit both

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demand and supply of almost every economic market resulting shocks within the demand and supply sides respectively. Therefore, with respect to the apartment market, implications of the COVID-19 pandemic have caused changes in the consumer behaviour and aggregate consumption patterns, ultimately affecting the factors that determine the overall housing demand, while overall supply is affected due to the market closures and economic downturn (Duca, et al. 2021). Since demand and supply of the housing units act as the key elements, which stabilize the fundamentals of the housing market, impact by the COVID-19 pandemic on both demand and supply has resulted market instability (Pomeroy, 2020). Gurran, et al. (2015) stated that continuous fluctuation can be observed in the housing markets with the imbalance between demand and supply that remains until the marketplace returns to a balanced situation where, both demand and supply are comparatively equal and acceptable. Although there are some researches on the COVID-19 pandemic impact on global real estate, there is a lack of a study on its impact on the demand and supply of apartment development projects. Hence, this paper aims to investigate the impact of COVID-19 pandemic on the demand and supply of apartment projects in Sri Lanka. This paper starts with a literature review on demand and supply of apartment projects with a special reference to COVID-19 pandemic period. Section 3 presents the research methodology followed in this study to achieve objectives. Section 4 presents the research findings and discussion followed by conclusions and recommendations in Section 5.

2. LITERATURE REVIEW

This section reviews the demand and supply determinants and the impact of COVID-19 pandemic on demand and supply of apartment projects.

2.1 DEMAND AND SUPPLY DETERMINANTS OF APARTMENT PROJECTS

Torab (2018) identified two parties who involves in any purchase procedure at residential real estate market as (a) supplier who offers residential unit for sale, and (b) consumer who desires to purchase that unit. Total product amount, which is desired by the consumer is defined as the "demand" and the total product amount offered by the supplier is identified as the "supply" (Tem and Yilmaz, 2018). Senaratne, et al. (2006) stated that factors affecting the demand for apartment projects can be mainly categorized into customer related factors and natural factors. A further review on the factors affecting the demand for apartment projects are tabulated in Table 1.

Table 1: Factors affecting demand for apartment buildings

Factor	**References *(Details given below)***					
	[1]	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**
Facilities and amenities	X	X	X	X	X	X
Population growth	X	X	X		X	X
Migration to cities and urbanization	X	X	X		X	X
Housing unit prices	X	X		X	X	
Investment trends			X	X	X	X
Location and infrastructure	X	X	X			X
Unemployment rate	X	X	X			

Factor	References *(Details given below)*					
	[1]	[2]	[3]	[4]	[5]	[6]
Household income	X			X		X
Tax level		X		X	X	
Level of rents	X	X				
Consumer preferences	X	X				
Economic data	X			X		
Loan policy	X				X	
Interest rates	X			X		
Household affordability	X		X			
Developers' marketing	X		X			

Sources: [1] Zarin and Bujang, 1999; [2] Ariyawansa and Udayanthika, 2012; [3] Shoory, 2016; [4] Sing, 2001; [5] Van Doorn, Arnold and Rapoport, 2019); [6] Senaratne, Zainudeen and Weddikkara, 2006

Property developers are always concerned about the factors behind the demand for apartments since, once the project initiated there is no turning back due to lack of demand and developers have to ensure the effectiveness of the project, where it involves a large amount of money (Zarin and Bujang, 1999).

Generally, inelastic behaviour can be noticed in supply side where it explained as slow adjustment process to meet demand due to the inefficiencies in the market such as less transparency, insufficient regulations and time-consuming development processes (De Wit and Van Dijk, 2003; Van Doorn, et al., 2019). As the key regulatory authority and policy maker of the apartment market, government influence the supply of apartments through zone management, incentives, and fiscal and monetary policies (Senaratne, et al., 2006). The factors affecting the supply of apartment projects are tabulated in Table 2.

Table 2: Factors Affecting Supply of Apartment Projects

Factor	References *(Details given below)*				
	[1]	[2]	[3]	[4]	[5]
Land cost and availability	X	X	X	X	X
Financial availability	X	X	X		
Policies and regulations	X	X		X	
Profitability	X		X	X	
Timely approval	X	X			
Resource availability	X				
Market competition	X				
Existing housing stock			X		

Sources: [1] Senaratne, Zainudeen and Weddikkara, 2006; [2] Shoory, 2016; [3] Sing, 2001; [3] Van Doorn, Arnold and Rapoport, 2019; [5] Ariyawansa and Udayanthika, 2012

Factors affecting the supply of apartment can be recognized under developer related factors and external factors (Senaratne, et al., 2006). Most importantly, factors affecting supply in the housing markets are slightly different from the factors affecting demand since supply is more subjective to the internal elements in the society (André, 2010).

2.2 IMPACTS OF COVID-19 PANDEMIC ON DEMAND AND SUPPLY OF APARTMENT PROJECTS

The current situation in housing market with the COVID-19 pandemic can be recognized with related to several factors including, economic downturn of both developers and homeowners, unfavourable trends in the labour market and increase in the cost limits of housing units (Tretyachenko, et al., 2021). According to the same report, crisis within the housing market, which resulted by the shocks in both demand and supply have led to the economic collapse of stakeholders in the sector.

Therefore, Balemi, et al. (2021) indicated that significant reduction in demand for housing units can be noticed due to financial difficulties faced by households resulting property sales drops. Liu and Su (2021) expressed that tenants become more concerned about living in high density locations, identifying potential exposure to the virus due to several reasons including dense neighbourhoods and shared amenities like elevators. Moreover, Alexander and Karger (2021) recognized that this community is more prone to lockdowns because of higher case rate of dense areas, which turns their lifestyle more complicated. Increasing unemployment rate and pay cuts across all economic sectors due to preventive measures and restrictions, have posed a significant impact on the tenants' inability to pay rents and mortgages, since it directly affects household income (Biddle, et al., 2020; Marona and Tomal, 2020; Nicola, et al., 2020). Balemi, et al. (2021) identified that even though the Return on Investment (ROI) initiated, investors' income streams are already being affected by the uncertainty of rental incomes due to tenants' financial instability with the financial crisis imposed by the pandemic. Pomeroy (2020) stated that this situation has resulted more difficulties on the investors' mortgage payments, since majority of them are relying on revenues from short-term rentals to cover the mortgage costs. Therefore, PricewaterhouseCoopers (PwC, 2020) stated that considering the pandemic situation, the demand for the apartment projects is likely to shift with the expectation of recovery over medium-long term as the economy recovers. Furthermore, same report stated that this recovery will be developed through urbanization, income levels, increasing land prices, high net worth individuals and multiple investment assets.

Bohingamuwa, et al. (2020) stated that this pandemic caused suspension of construction activities in several projects resulting cash flow constraints for developers. Same report mentioned that cash flow issue has also an impact on the ability to repay loans they acquired to fund these projects. Moreover, COVID-19 pandemic has led many businesses to close down since number of successful transactions has reduced due to lack of interest from investors and customers in properties and scarcity of supply by developers (Ngoc, Tien and Anh, 2020). Additionally, population shifts from urban areas to suburbs and rural areas have resulted less demand for housing units in the rental market causing property developers more financially vulnerable (Byrne, 2021). Enactment of government policies of restrictions on imports has negatively affected the property developer's profitability and caused considerable delays in the constructions since they have to pay higher price for alternatives and procurement takes time (Hamid and Huam, 2020; Hantono, 2020). Furthermore, Uma and Gujar (2020) emphasized the potential threat for developers in decreasing housing sales count, since rising material prices resulted by factory closures and logistic disturbances have led to higher housing prices, which affects home buyers' affordability negatively. Therefore, with the social distance policies and other restrictions, number of issues have arisen in construction projects, since there was no preparedness for this sort of situations (Laing, 2020). Therefore, on the supply side less investment for apartment projects could be expected since property developers are considering in completion of existing projects and wait for demand to increase within short-medium period (PwC, 2020). There is therefore a need to investigate the impact of COVID-19 pandemic on the demand and supply of apartment projects. However, the scope of this study is limited to the apartment projects in Sri Lanka.

3. RESEARCH METHODOLOGY

The aim of this research which is to investigate the impact of COVID-19 pandemic on the demand and supply of apartment projects in Sri Lanka requires in-depth investigation. Adapting a qualitative approach is suggested if the existing literature is not comprehensive or if identified variables are unknown (Creswell, 2014). Thereby, after analysing the facts namely, insufficient literature on the research area, existence of less number of experts as respondents in the local context, inability to establish research conditions since the research is related to an ongoing pandemic and research focuses on observing the reasons behind the impacts, the qualitative approach was approach was adopted to conduct this research. Factors affecting the demand and supply of apartment projects and impact of COVID-19 pandemic on apartment projects in the global context were reviewed through the literature synthesis. Data collection was performed through interviews with 15 experts selected through purposive sampling using semi-structured interview guideline. The collected data were analysed through manual content analysis. Finally, the impact of COVID-19 pandemic on apartment projects in Sri Lanka was investigated through this research process.

4. RESEARCH FINDINGS

The semi-structured interviews were conducted with 15 experts representing different stakeholders in the apartment sector. Profile of the respondents is shown in Table 3.

Table 3: Respondents profile

Code	Designation	Organization Type	Experience
R1	Manager - Projects and Properties	Property Developer	10
R2	Assistant Manager - Planning and Project Management	Property Developer	6
R3	Residence Manager	Property Developer	7
R4	Manager - Operations	Property Developer	13
R5	Senior Manager - Sales and Marketing	Property Developer	7
R6	Senior Manager - Finance	Property Developer	10
R7	Senior Manager - Sales and Marketing	Property Developer	15
R8	Project Engineer	Property Developer	10
R9	Head of Sales	Property Developer	15
R10	Head of Operations and Services	Property Developer	20
R11	Director - Projects	Contractor	30
R12	Quantity Surveyor	Consultancy Organization	8

Code	Designation	Organization Type	Experience
R13	Managing Director	Real Estate Consultancy	20
R14	Deputy Director General/Senior Lecturer	Government Institution	27
R15	Property Manager	Managing Agent	12

Among 15 respondents of the study, 10 respondents had represented apartment property developers, while remaining 5 respondents were indirect market participants. The respondents have experience and knowledge on the impact of COVID-19 pandemic on the Sri Lankan apartment market. They have both pre and during COVID-19 period experience in the sector. Research findings are discussed below.

4.1 IMPACT OF COVID-19 PANDEMIC ON THE DEMAND FOR APARTMENTS

Sri Lankan apartment market can be broadly categorized into three market segments, i.e., upper tier, middle tier and lower tier, where this classification is based on apartment price ranges and how well the apartments are facilitated. With regard to the respondents' opinion on the demand for apartment projects, it was revealed that demand for apartments is formed majorly for two purposes as living (consumer market) and investment (investor market). Apartment investment can be separated into two aspects as renting out and price appreciation where price appreciation involves purchasing the apartment with the purpose of gaining a profit by reselling it once the property value is increased over time. Respondents were asked to identify the factors affecting the demand for apartment projects. Impact of each factor affecting the demand for apartment projects in Sri Lanka are discussed below. Apart from the generic demand determinants, several other demand determinants were revealed from the interviews, with regard to the impact of the COVID-19 pandemic on Sri Lankan apartment market. Those demand determinants are rupee depreciation and inflation, digital marketing strategies and crisis in the tourism industry.

4.1.1 Increasing Apartment Unit Prices and Decreasing Rentals

Respondents were mainly questioned about price increments took place in the apartment units due to the COVID-19 pandemic. According to the respondents, all organizations had experienced different price increment percentages due to the pandemic and the increments had varied between 10-20% range. Further, it was revealed that the major cause behind the price growth was increasing construction cost, which occurred unexpectedly.

Moreover, they indicated that even though the developer cannot supply the apartment units within the agreed price due to the increased construction costs, price escalations could not be done on the units, where sales agreements are already signed. Highlighting the negative implications on the demand by increasing apartment unit prices, R2, R5, R9 and R11 mentioned that price upsurge has highly affected the rental market since landlords tend to demand less units. It can be observed that stagnant periodical price escalation of rentals has also caused less demand for the rental market by the landlords since less rental incomes discourage rental market investments and this demand drop exists in all the market tiers. On the other hand, according to R3, R7, R10 and R14, investors started to purchase apartments for profit gain through appreciation recognizing the potential appreciations due to foreseen under supply scenario of apartments due to COVID-19 pandemic. When it comes to the upper tier, majority of the investors and landlords cater apartment units to the tourists and expatriates, so less demand has resulted in upper tier due to the crisis in tourism industry, stated R7 and R9. Hence, it can be recognized that apartment unit prices were subjected to price upsurges due to the COVID-19 pandemic resulting less demand for apartments in the rental market and more upsurges could be expected in the future. However, they stated that significant impact cannot be noticed within the demand for consumer market since consumers left with no option but to purchase an apartment for the easiness of work purposes.

4.1.2 Unemployment Risks, Household Income and Affordability

Respondents were questioned about the relation between the unemployment shocks, household income and affordability against the demand for apartments within Sri Lankan apartment market with the COVID-19 pandemic. Majority of the respondents stated that, generally the apartment purchasing community in Sri Lanka is less exposed to unemployment risks since they mostly have stable occupational careers. However, diverging the above common opinion, R6 and R9 stated that unemployment rate has a substantial impact on the upper tier since unemployment shocks can be recognized within expatriates and foreign expatriate workers where they represent the mainstream of the buying community in the rental market in the upper tier. Accordingly, most of the respondents' opinion reflects the idea that, unemployment risks did not affect the demand for the apartments except in the upper tier rental market since buyers are least vulnerable to the unemployment risks. All the respondents stated that both income and affordability are interrelated and mostly depend on the unemployment rate. Majority of the respondents pointed out that apartment purchasing community belongs to the upper-level income community in Sri Lanka and they are least vulnerable to the income losses. Therefore, they stated that affordability of apartment buyers and tenants remains same even after the COVID-19 pandemic. Hence, apartment purchasing community is least affected with household income losses and affordability problems due to the COVID-19 pandemic which results least impact on the demand for apartments.

4.1.3 Lesser Migrations to Metropolitan Cities

Respondents were allowed to explain about their experience on tenants' migrations to the urban areas during the COVID-19 pandemic and its impact on demand. According to the respondents, a significant drop took place in both migration to metropolitan cities and urbanization due to the pandemic. During the interviews, several dynamic forces were revealed, which affect the urbanization and migration to cities such as work from home, travel restrictions and business and school closures. However, R6, R9 and R14 put forward an argument that, with the removal of travel restrictions, organizations are gradually normalizing their business functions as usual, improving the concerns for the apartment rental market once again. Therefore, lesser migration to cities and stagnant urbanization can be recognized as the major factors, which resulted less demand for the apartments in the metropolitan cities during the pandemic and negative impact is gradually getting recovered with the new normal adaptation.

4.1.4 Urban Living Concerns

The interviews further focused on the changes in buyers' attitude om urban living concerns towards apartment purchasing. A psychological mind-set change was recognized in buyers' attitude towards the purchasing of apartments after the pandemic due to the uncertainties embedded with the pandemic (R1, R2, R7 and R10). Hesitation was seemed to be in the buyers' decisions with the uncertainty arose during the period of first wave. According to R1, R2, R7 and R10, buyers were deciding either to live in an apartment surrounded by a dense community or to buy a land and build a house in a commuter city during that period. However, majority of the respondents further revealed that, the hesitation was gradually wiped out with the new normal adaptation of the country as the buyers realized the higher worth of the apartment investments in the future, once the situation is normalized. Therefore, buyers' negative attitude towards the apartment living can be recognized as the factor, which resulted lesser demand for the apartments during the pandemic and negative impact is gradually getting recovered with the new normal adaptation.

4.1.5 Location and Infrastructure

Interrelation between location and infrastructure factors with the demand for apartments were also observed in the discussions. R1, R4, R5, R8, R9 and R14 mentioned that increasing demand can be recognized in the apartments located by the highway transits and suburbs due to the appreciation of less dense areas among the community. Moreover, according to R5 and R11, less demand can be noticed for the apartments in the tourist attracted areas since investors are afraid to invest in those units with the crisis within the tourism industry. Hence, it can be recognized that due to the COVID-19 pandemic, people started to shift to the suburbs resulting more demand for the apartments in the suburbs and lesser demand for the apartments in metropolitan cities, while tourism crisis caused less demand for the apartments in the tourist attracted areas.

4.1.6 Rupee Depreciation and Inflation

Respondents recognized several aspects regarding the current economic downturn of the country which influence the demand for apartments. Although there are several economic factors act as apartment market dynamics, respondents recognized two major aspects whereas, Rupee value depreciation and inflation as the economic factors affecting the demand for apartments in Sri Lanka with the COVID–19 pandemic. R11 expressed his views stating, "*At a glance we can expect a negative impact on the apartment demand due to the economic downturn. However, the actual scenario is totally different since people are shifting away from liquid assets which ultimately resulting the growing demand for real estate. Among the lands and apartments, currently they prefer invest in apartments over lands due to the considerable ROI*". Consequently, R6, R10 and R13 highlighted how the impact of currency depreciation due to inflation driving the buyers' mind-set towards a growing demand for apartments where R6 explained "*With the increments in the apartment prices due to the rising inflation, people tend more towards to purchase apartments in surge before it gets more expensive, even it is not their essential need*". Therefore, according to the opinion of the majority of the respondents Rupee depreciation and inflation has a positive impact on the demand side of the apartment market by the local buyers. Contrastingly, worsening economic conditions have resulted less demand for the apartments by the foreigners according to the R3 and R14, since foreigners are worried about their returns due to the economic downturn in Sri Lanka, where return get lessened once they exchanged. Therefore, as a key demand determinant worsening economic data in Sri Lanka has both positive and negative impacts on the apartment market whereas, increasing demand for apartments by locals and decreasing demand for apartments by foreigners, respectively.

4.1.7 Loan Policies and Interest Rates

Respondents were asked about the changes in monetary policies which affected the demand for apartments. Central Bank of Sri Lanka declared several relief measures on the loan policies in terms of longer repayment tenors and release of penalty interests with the COVID-19 pandemic. Respondents' opinion was that with more flexible loan policies, people tend to obtain more loans which ultimately results the demand for apartments since majority of the apartment sales are relies upon the mortgage market. Moreover, they emphasized how the demand for apartments was quickly picked up once the Central Bank of Sri Lanka took measures to reduce the interest rates to the lowest levels in history with the intention of boost the economy which was severely affected by pandemic. On the other hand, it was found that low interest rates discouraged people to do savings in fixed deposits since they realized investing in other sectors such as real estate, gold and stock market is more profitable. However, according to most of the respondents, demand was increasing for the apartments once interest rates are reduced since people go for investing in real estate over gold and stock market. Therefore, reduced interest rates have acted as one of the key factors which boosted the demand for apartments in both consumer market and investor market in the COVID-19 scenario.

4.1.8 Digital Marketing Strategies

Emerge of the online marketing tactics were also revealed by the respondents as another key factor which influencing the demand for apartment market. As highlighted by all of the respondents, developers shift to digital marketing from conventional marketing after the COVID-19 pandemic once they realized the potential of the digital marketing tactics in an era where people spent most of their time on online platforms with agile work environments. Moreover, they underlined that most of the inquiries they received for apartment purchasing are coming through online platforms. Hence, most of them believed that adapting competitive marketing strategies helped them to boost the demand. Therefore, the digital marketing strategies and better customer services that were adopted during the COVID-19 pandemic have driven the customers' mindset towards the apartment purchasing resulting more demand for apartments.

4.1.9 Crisis in the Tourism Industry

Respondents revealed tourism downturn as a crucial factor which affecting the demand for Sri Lankan apartment market. As per respondents' opinion, Sri Lankan apartment market is highly relying on the tourism industry, since most of the foreigners purchase apartments as both investment assets and consumption commodities. Upper tier is the mostly affected market segment due to the pandemic, since most of the foreigners prefer luxury apartments with their intentions on quality of life. Moreover, R4, R7, R8, R11 and R15 highlighted that market gap is rapidly increasing due to the demand drop and situation is much worse due to the oversupply within the upper tier. Hence, crisis in the tourism industry can be recognized as a key negative factor which resulted a demand drop within the apartment market.

4.2 IMPACT BY COVID-19 PANDEMIC ON THE SUPPLY OF APARTMENTS

Respondents were asked to identify the list of factors affecting the supply of apartment projects and whether any shift took place in the supply of apartments with regard to any change in supply determinants due to the COVID-19 pandemic. The research findings are discussed below. Apart from the generic supply determinants, several other supply determinants were revealed from the interviews, with regard to the impact of the COVID-19 pandemic on Sri Lankan apartment market. Those supply determinants are inflation, apartment constructions and project delays.

4.2.1 Market Competition

Relationship between the market competition and supply of apartments were questioned during the interviews. Due to the hit of the pandemic on the property developers, new players will not enter the market and minor players will halt their operations allowing key players to control a significant percentage of market share in future. Therefore, R5 stated that "*Market will become more imperfect competitive, if the minor players could not survive due to the COVID-19 pandemic which ultimately resulting under supply of apartments*". Therefore, R5's and R15's explanation on this regard was, even though leading market players dominate the market in an imperfect market, they will not be able to fulfil the heterogeneous demand with their supply since product differentiation cannot be found in monopolistic markets. Hence, market imperfection has a negative impact on the supply of the apartments since overall market supply is decreased due to the elimination of new and minor market players.

4.2.2 Interest Rates

Impact by the changes in monetary policies towards the supply of apartments were also asked from the respondents. Majority of them mentioned that developers got the benefit in borrowing loans as interest rates are decreased after the COVID-19 pandemic. R3, R7, R8, R10 and R14 emphasized the importance of low interest rates in an environment where developers' financial availability is adversely affected mentioning business loans are the best option for the developers to overcome the financial challenges. Moreover, R5, R7, R10, R11 and R14 mentioned that not only the developers, but also contractors, resource suppliers, service providers and other indirect market participants who participate in the project delivery procedure receive the benefit out of the lower interest rates, since most of their businesses are count on the loan facilities. Therefore, most of the respondents' opinion was that reduced interest rates fortified the survival of majority of the market participants who contribute to the supply of apartments which ultimately avoiding a negative supply shock.

4.2.3 Inflation

Respondents came up with inflation as a new supply determinant which influence the apartment market due to the COVID-19 pandemic. Most of the respondents recognized different implications of the inflation as upsurge of material prices, machinery prices, transportation charges, and fuel cost which ultimately increase the construction cost. According to majority of the respondents, apartment unit prices are already subjected to the price increases within the middle and lower tier. Moreover, majority of the respondents stated that all the new project commencements will be subjected to the price increases and they believed that less supply will be resulted in the apartment market according to the law of supply. Hence, increasing inflation can be recognized as a factor, which has a negative impact on the supply of the apartment projects in Sri Lanka.

4.2.4 Government Approval Delays

Interviews further explored any delays took place in the government approvals related to the apartment sector. All of the respondents stated that government approval procedures are considerably delayed due to the COVID-19 pandemic. Moreover, they indicated that government office closures, inefficient documentation with distance working and inability in field inspections caused delays within the approval procedures.

4.2.5 Developers' Cash Flow Issues

Financial aspects related to the developers were also questioned from the respondents. Considering the opinions conveyed by R2, R9, R10 and R14, it can be argued that cash flow of the projects, which are still at the early construction stages have severely affected due to the COVID-19 pandemic. R9's comment can be taken as one which represent all the other; "*Since people prefer purchasing more constructed projects due to the uncertainties within project completions, less presales have been resulted in projects at initial construction stages. Therefore, cash flow through presales is lessened due to less presales count and cash inflow is not sufficient to proceed with further developments since lesser the level of completion, lesser the instalment payment can be collected where staggered payment is practiced*". Moreover, most of the respondents stated that within this pandemic period delays, grace periods and rearrangements in instalment payments affected the cash flow, which is always supposed to be ahead of the development cost. Although some developers were able to manage the cash flow through organizational capital and bridging loans, different aspect was highlighted by the R13 as "*All the market players will not be able to manage the cash flow due to several reasons such as shortage of capital and difficulties in obtaining loans in a background where banks monitor track records and restricted issuing loans due to financial vulnerabilities and uncertainties in repayments*". Accompanying with R14's opinion, R10 disclosed his experience as "*Most of the minor market players are struggling with cash flow issues and already several apartment projects halted due to lack of funding*". Therefore, cash flow issues can be identified as a factor, which has a negative impact on the supply of apartment projects in Sri Lanka especially among the majority of the market players.

4.2.6 Apartment Constructions and Project Delays

Respondents revealed construction project delays as a crucial factor that influenced the supply of the apartment market. The construction sector is currently severely affected due to the COVID-19 pandemic. Respondents were emphasizing that significance of construction of apartments is not restricted to the delivering apartment projects but also critical in determining the economic development of the country and reliance of several sub sectors on the apartment constructions was highlighted. As stated by all the respondents, COVID-19 pandemic has caused significant project delays distressing the supply of the apartment market in Sri Lanka. Considering all the aspects revealed through the discussions, site shutdowns, labour shortages, material scarcity, supply chain disruptions, import restrictions and procurement conflicts can be recognized as the major causes, which underlies the crisis within the apartment constructions.

5. CONCLUSIONS AND RECOMMENDATIONS

The apartment market is always subjected to momentums in terms of demand shifts and supply shifts, which is a common characteristic of a market that reflects the law of demand and supply. With the unexpected COVID-19 pandemic and its wide-ranging implications on the various aspects related to both demand and supply of the apartment projects in Sri Lanka got affected severely. Although, there was a sudden drop in the demand for the both consumer and investor market due to the COVID-19 pandemic, with the adaptation of new normal culture, demand within the consumer market gradually started to raise since necessity of a habitation remains constant even in a time of a pandemic. Moreover, this demand growth stimulated by several positive aspects related to the demand determinants. However, this demand recovery cannot be found in the rental market. On the other hand, supply of the apartments is severely affected due to the COVID-19 pandemic since apart from the generic supply related factors, construction related factors also influence the supply. However, noticeable positive recovery cannot be recognized in the supply perspective even after the new normal scenario since economic downturn in the country directly influences the majority of the supply related factors. With the above-mentioned factors, the apartment market of Sri Lanka is currently leading towards a market equilibrium state followed by an under-supply scenario which will ultimately result a supplier's market. Further, this research has contributed for the knowledge on understanding the interaction between demand and supply within the apartment market, identifying the impacts due to COVID-19 pandemic on demand and supply of apartment projects in Sri Lanka while understand the importance of the apartment market equilibrium. Hence, research findings of this study will be benefited to the relevant government authorities, property developers and financial institutions in taking necessary steps to explore the strategies for maintaining the apartment market equilibrium.

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THE IMPACT OF MATERIAL AND LABOUR COST VARIABLES ON CONTACTORS' BUDGETED COST

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ABSTRACT

An accurate budget is important for all construction stakeholders, but it is difficult to maintain the budget within the initial estimation. The contractors' financial stability tends to complete the projects within the budgeted cost without destructing the contractors' cash flow. The major impact for the contractors' budgeted cost overrun in construction projects has happened with the material and labour costs. Therefore, it is necessary to find the contribution of material cost and labour cost to the contractors' budgeted cost in construction projects to minimise contractors' budgeted cost overruns. This research aims to analyse the impact of material and labour costs on contractors' budgeted costs in building construction projects, Sri Lanka. Hence, three-building construction projects were selected, and documentary review was the main data collection tool to find the required data. Sensitivity Index (SI) in Sensitivity Analysis was adopted for data analysis. As research outcomes, the average contribution of material cost to the cost of civil work was assessed as 60%, whereas the cost of labour was indicated as 35%. Moreover, plastering, tiling and painting works were identified as the main civil work categories that can highly influence the material and labour cost overruns in Sri Lankan building construction projects and ultimately would impact the contractors' budgeted cost. Therefore, contractors should pay special attention to the budgeted cost of these work categories when preparing the initial budget.

Keywords: *Contractors' Budget; Cost Overrun; Labour; Material.*

1. INTRODUCTION

The construction environment is characterised by a high level of competition, complex operations, high-risk conditions, stressful and well knowledgeable clients (Tarawneh, 2014). According to the findings of Mokhtariani, et al. (2017), time, cost, and quality represent the main attributes of a construction project, which cannot be accurately determined or evaluated before contracting and cease of the project. Deferment in payments and overestimation of investment opportunities are the reasons behind the absence of money for maintaining a business (Anysz and Rogala, 2019). The loss of financial liquidity is a reason for most of the construction companies' bankruptcy (Alavipour and Arditi, 2018). Liu and Zhu (2007) suggested that accurate prediction of construction costs is heavily depending upon the availability of historical cost data and the level of professional expertise. Moreover, a clearer understanding of the cost

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determinants is vital to achieving the desired level of accuracy of anticipated costs of labour, material, plant, and equipment in total cost estimation (Enshassi, et al., 2009). Flyvbjerg, et al. (2007) mentioned that the misallocation of insufficient resources can be happened due to the inaccurate budget. The involvement of subcontractors, suppliers, and manufacturers during the estimation process will positively affect having an accurate budget (Arif, et al., 2015). Many types of research focused on factors affecting budget overruns, but there is an insufficient number of researches that focused on how to minimise the impact of those factors (Olawale and Sun, 2010). Consequently, there is a need to predict cost overruns, reasons for cost overruns, as well as the impact of variables that can influence cost overruns (Annamalaisami and Kuppuswamy, 2019). Hence, the paper presents how the material and labour cost can influence the contractors' budgeted cost adopting sensitivity index. The adjacent topics of the paper present literature review, research methodology, research findings and discussion and conclusions.

2. COST OVERRUN IN THE CONSTRUCTION INDUSTRY

As stated by Memon, et al. (2010), the cost is one of the major considerations and an important parameter of a construction project. Traditionally, the client and the contractor have a high influence on project cost performance as the main stakeholders of a construction project (Deshmukh and Menkudle, 2019). In most instances, the actual cost of a construction project can differ from the agreed contract amount concerning clients' decisions, project attributes, and contractual aspects (Skitmore and Ng, 2003).

2.1 COST OVERRUN IN CONSTRUCTION PROJECTS

The term 'cost overrun' in the construction industry is used, where the expected project cost is increased or the estimated budget of a project is exceeded (Al-Hazim, et al., 2017). Also, an accurate budget ensures that the design of the project is in line with the original scope (Odeyinka, et al., 2010). According to Potts and Ankrah (2014), most project owners are not working with flexible cost plans in construction projects. Therefore, if the budget is exceeded, the total arrangement of the project will be unsuccessful (Feng and Li, 2014). Huo, et al. (2018) reported that the average cost overrun in the Hong Kong construction industry is 39%, and it is nearly 34% for retail projects, 32% for road projects, and 37% for projects like bridges, tunnels. Cost overrun in Portugal construction projects is nearly 12% (Moura, et al., 2007).

2.2 CONTRACTORS' BUDGETED COST OVERRUN

The poor cost performance has become a major concern for the clients as well as the contractors in construction projects (Xiao and Proverbs, 2002). Most construction projects do not have satisfactory records regarding project completion within the budget (Aljohani, et al., 2017). Therefore, budget overrun is treated as a 'regular feature' in the construction industry (Morris, as cited in Aljohani, et al., 2017). Azis, et al., (2012) stated the budget as "a financial evaluation of the future courses of action set out in a business plan" (p. 626). According to Flyvbjerg, et al. (2003), contractors' budgeted cost overrun can define as the difference between initial budgeted cost and the actual cost of a project at completion. Dakhli and Lafhaj (2019) stated that there is a considerable difference between contractors' budgeted cost and the actual cost at completion in many construction projects. According to Shrestha, et al. (2013), large sized, and long duration projects have a higher percentage of budget overrun compared to the small sized, and short duration projects. Researchers stated that it is important to identify the factors that contribute to budget overrun to avoid and reduce the problems (Ali and Kamaruzzaman, 2012). The confined records available at the early stages of construction projects imply that the quantity surveyor must make assumptions on the design details of a project, which may not eventuate as the design, planning, and construction evolve (Liu and Zhu, 2007).

2.3 CRITICAL COST VARIABLES RELATE TO THE CONTRACTORS' BUDGET

According to Rashid (2020), material and human resources (labour) are critical cost variables that can highly influence the contractors' budget in construction projects. As mentioned by Ullah (2020), even small change in labour-related cost or material related cost can highly influence the cost overrun or time overrun in construction projects. Supporting the above statement, Norul Izzati, et al. (2019) have found that variables such as material related issues and labour related issues are affecting contractors' budget heavily. Joukar (2016) mentioned that the price volatility of material and labour is a prominent cause of contractors' budgeted cost overruns. A proper management of these two variables is essential to maintain the project budget within the expected amount (Rashid, 2020). Burke (as cited in Albtoush, et al., 2020) mentioned that the material cost and labour cost in construction projects should be well managed and controlled. Further, there is a necessity to investigate the level of contribution of material cost and labour cost to the contractors' budgeted cost in construction projects.

3. METHODOLOGY

To achieve the aim of the research, the case study was selected as the research strategy. Case studies are generally proceeding with organisational, institutional, geographical, provisional, or similar contexts that have boundaries around the cases (Cohen, et al., 2007). The cases for the study were selected based on the research problem and aim of the study. Accordingly, the case studies were limited to three cases due to the unavailability of required data to conduct the research, confidentiality of the cost data of contractor organisations and the ethical rules that they are following. Moreover, the selected projects have been faced with contractors' budgeted cost overrun due to several variables. Table 1 summarises the profile of the selected cases.

Table 1: Profile of selected projects

Case Code	Project Details
Case A (Organisation A)	Original Contract Amount is Rs. 6.0 Billions 13 Storey Apartment Complex The Construction Period - The year 2016 to 2019 Duration is 30 Months
Case B (Organisation B)	Original Contract Amount is Rs. 2.6 Billions 8 Storey Educational Building The Construction Period - The year 2016 to 2019 Duration is 36 Months
Case C (Organisation C)	Original Contract Amount is Rs. 3.1 Billions 8 Storey Educational Building (Laboratory) The Construction Period - The year 2018 to 2020 Duration is 22 Months

All organisations have higher gradings (CS2) for building works according to the gradings given by the Construction Industry Development Authority (CIDA) in Sri Lanka. Greener and Martelli (2018) stated that case studies included "more than one way of deriving data about the case or organisation under the study" (p. 119). Therefore, it includes methods of data collection such as referring documents, interviews, observations, consumer research about the case. Archival documents and records used to collect quantitative data from those projects such as Project progress reports, Project final reports, Profit analysis reports, Project final bill statements, Actual Cost Work Performed (ACWP) records and Budgeted Cost Work Performed (BCWP) records, Material cost records and labour cost records and cost records from ERP systems. "Sensitivity is the ability of research instrument to capture the variability in responses" (Adedokun, et al., 2019). Wong et al. (as cited in Adedokun et al., 2019) used sensitivity analysis as a better measuring instrument to analyse research data.

Sensitivity Index was the measure used to present the impact of key variables (material and labour costs) to the contractors' budget and the project cost and measured using Eq. 01.

$$\textit{Sensitivity Index (SI)} = \frac{\textit{\% Change in Cost Outcome}}{\textit{\% Variation in Estimating Variable}} \qquad \textit{(Eq. 01)}$$

As mentioned by Yeo (1991), the cost outcome has a major impact from variables that cause lesser SI than variables that cause higher SI.

4. RESEARCH FINDINGS AND DISCUSSION

All the projects were different from each other by their features. Two projects were government funded projects and the other project was funded by a private sector organisation within Sri Lanka. According to the available data and to get an accurate figure, the costs related to budgeted cost and the actual cost were taken only for the civil works of the project and the cost of variations was not considered for the analysis. Hence. six civil work categories such as 1) excavation and earth work (V1), 2) concrete work (V2), 3) masonry work (V3), 4) plastering (V4), 5) tiling (V5) and 6) painting (V6), and all other balance civil works considered as "other works". The main work categories are listed in Figure 1.

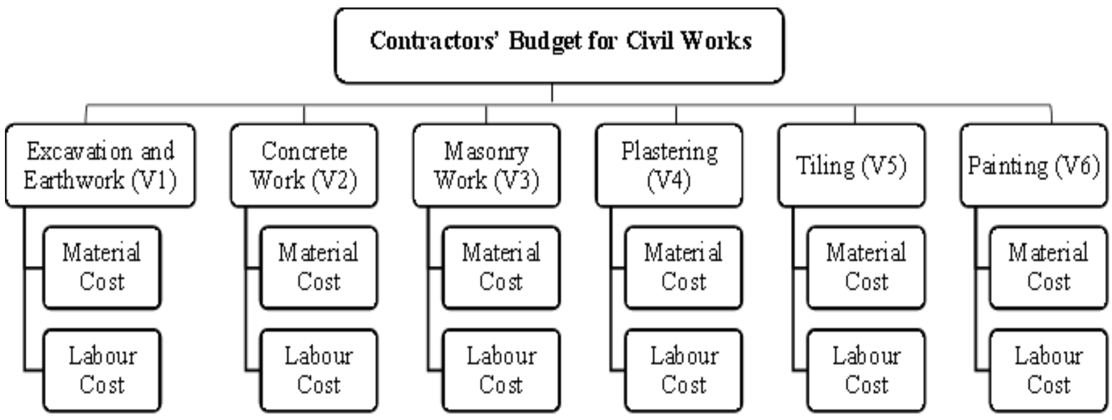

Figure 1: Levels of work categories

Figure 2 illustrates the cost contribution of individual categories from the total cost of civil works.

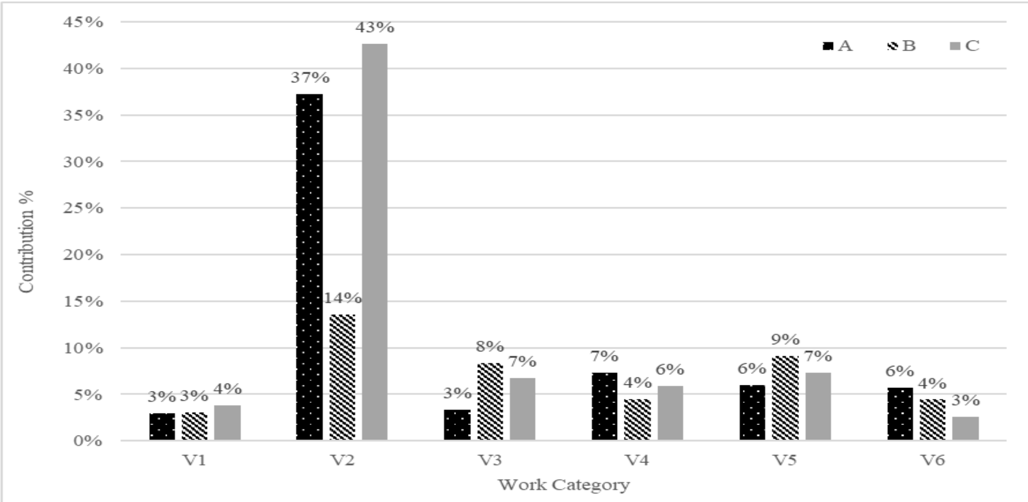

Figure 2: Contribution of work categories to the total cost of civil work

The highest contribution to the budgeted cost is from concrete work (V2) in three cases.

4.1 IMPACT OF COST OVERRUN OF WORK CATEGORIES ON CONTRACTORS' BUDGETED COST OVERRUN

Since the selected cases were remeasurement contracts, the impact on the cost from budgeted quantity changes can be ignored. The Overhead and profit component was not taken to account. Based on Actual Cost Work Performed (ACWP) and Budgeted Cost Work Performed (BCWP), the Sensitivity Index (SI) was calculated. Based on the Sensitivity Index formula, suitable equations were adapted (Refer Eq. 02) to present the impact of material cost and labour cost on the contractors' budgeted cost. The variables which have lesser SI can influence the contractors' budgeted cost significantly.

$$\textbf{Sensitivity Index (SI) for Work Categories} = \frac{\textit{\% Change in Cost Outcome}}{\textit{\% Variation in Estimating Variable}} = \frac{\dfrac{[\textit{ ACWP of Civil Work} - \textit{BCWP of Civil Work}] \times 100}{[\textit{ BCWP of Civil Work}]}}{\dfrac{[\textit{ ACWP of Work Category} - \textit{BCWP of Work Category}] \times 100}{[\textit{ BCWP of Work Category}]}} \qquad \textit{(Eq. 02)}$$

Table 2 presents SI values of overrun of work categories on contractors' budgeted cost overrun in Case A, B and C adopting Eq. 02. The impact of cost overrun of work categories on contractors' budgeted cost overrun was also calculated based on collected Actual Cost Work Performed (ACWP) and Budgeted Cost Work Performed (BCWP) data. In Case A, SI values of V1, V4, V5, and V6 were less than 0.5. In Case B, SI values of work categories are comparatively high and compared to other work categories SI values are low in V5 and V6. In Case C, results are almost similar to Case A and SI values of V5 and V6 are less than 0.5. Accordingly, V5 (Tiling) and V6 (Painting) work categories show smaller SI in all cases compared to the other four work categories.

Therefore, according to SI interpretation, the cost overrun from those work categories significantly influence the contractors' budgeted cost overrun.

Table 2: Distribution of budgeted cost overrun among work categories

Case	Description	Budgeted Cost Work Performed (BCWP)	Actual Cost Work Performed (ACWP)	%Change in Cost Outcome	%Variation in Estimating Variable	SI
A	**Total Cost of Civil work**	**3,986,185,883.90**	**4,068,867,733.72**	**2.07**		
	V1	111,216,916.00	125,675,115.08		13.0	0.16
	V2	1,492,578,856.00	1,504,347,745.03		0.8	2.63
	V3	134,722,080.00	137,416,521.60		2.0	1.04
	V4	287,455,088.25	301,827,842.66		5.0	0.41
	V5	235,190,526.75	246,950,053.09		5.0	0.41
	V6	221,522,206.00	235,921,149.39		6.5	0.32
	Other Works	1,503,500,210.90	1,516,729,306.87		0.9	2.36
B	**Total Cost of Civil work**	**1,257,180,902.23**	**1,476,430,889.29**	**17.44**		
	V1	40,280,051.12	42,375,416.43		5.2	3.35
	V2	182,984,319.28	185,247,720.75		1.2	14.10
	V3	110,952,593.63	115,979,893.90		4.5	3.85
	V4	59,532,997.53	61,135,037.19		2.7	6.48
	V5	115,635,656.54	134,125,505.72		16.0	1.09
	V6	56,547,568.28	64,287,516.69		13.7	1.27
	Other Works	691,247,715.85	873,279,798.61		26.3	0.66
C	**Total Cost of Civil work**	**777,281,350.04**	**808,189,970.68**	**3.98**		
	V1	29,715,973.34	30,148,410.13		1.5	2.73
	V2	336,551,945.33	338,691,881.98		0.6	6.25
	V3	51,975,682.19	55,247,891.21		6.3	0.63
	V4	45,192,123.55	48,657,232.40		7.7	0.52
	V5	55,507,899.39	60,844,822.55		9.6	0.41
	V6	16,931,572.38	24,272,833.56		43.4	0.09
	Other Works	241,406,153.85	250,326,898.85		3.7	1.08

Even though, V2 (Concreting) work category contributed to the contractors' budget significantly, the contribution to the budgeted cost overrun is extremely low because SI value is high compared to the other categories. The 'other works' category is also significantly influencing the contractors' budgeted cost overrun.

4.2 IMPACT OF MATERIAL AND LABOUR COST OVERRUNS ON THE CONTRACTORS' BUDGETED COST OVERRUN

The contribution of material and labour costs to the total cost of civil work is also evaluated and presented in Table 3. Therefore, the cost of material for the civil works and the cost of labour for the civil work was compared with the cost of civil work based on data availability. Furthermore, Eq. 02 has been adopted for the SI calculation for material and labour cost overruns. Accordingly, the impact of total material and labour cost overruns based on the collected data in Cases A, B and C are presented in Table 3.

Figure 4: Impact of material cost and labour cost overruns on the contractors' budgeted cost overrun

Case	Description	Budgeted Cost Work Performed (BCWP)	Actual Cost Work Performed (ACWP)	Average Contribution to the Civil Work	% Change in Cost Outcome	% Variation in Estimating Variable	SI
A	**Cost of Civil Work**	**3,986,185,883.90**	**4,068,867,733.72**		**2.07**		
	Material	2,683,031,028.87	2,739,374,680.47	67%		2.10	0.99
	Labour	1,055,581,333.55	1,076,692,960.23	26%		2.00	1.04
B	**Cost of Civil Work**	**1,257,180,902.23**	**1,476,430,889.29**		**17.44**		
	Material	678,877,687.20	797,272,680.22	54%		17.4	1.00
	Labour	528,456,409.97	620,618,214.88	42%		17.4	1.00
C	**Cost of Civil Work**	**777,281,350.04**	**808,189,970.68**		**3.98**		
	Material	449,212,710.51	466,120,263.12	58%		3.8	1.06
	Labour	276,745,337.86	287,665,431.56	36%		3.9	1.01

The average contribution was calculated for both material and labour costs and results are presented in Figure 3.

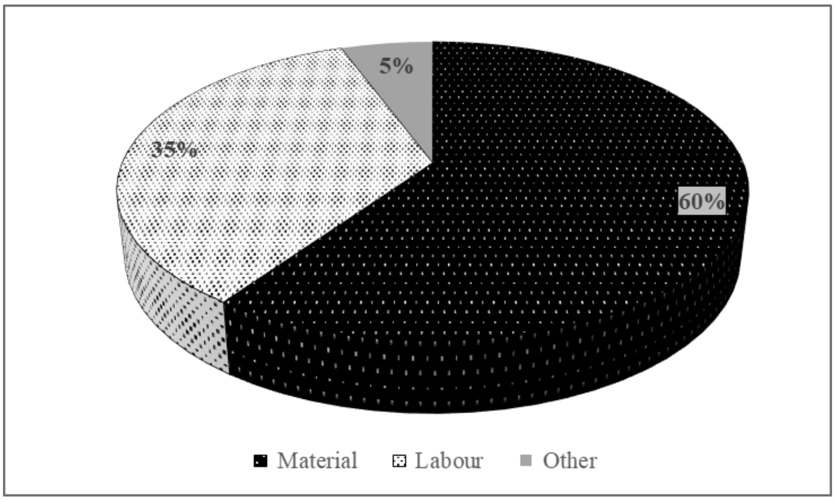

Figure 3: Average contribution of material cost and labour cost to the total cost

Accordingly, the contribution of material cost remains around 60 % and the contribution of the labour cost remains around 35 % of the total civil works. As per Table 3, the SI values of both material and labour cost overruns are around 1.0 in Case A, B and C. When considering the interpretation of SI, the cost outcome has a high impact from the variable which gives lower SI values. Therefore, in Case A contractor's budgeted cost overrun has a high impact from material cost overrun which has lower SI (0.99) than the SI of labour cost overrun (1.04) while Case C has the opposite results of Case A. In Case C contractor's budgeted cost overrun has a high impact from labour cost overrun which has lower SI (1.01) than the material cost overrun which has a 1.06 SI value. According to the calculations, the impact from material cost overrun and labour cost overrun is almost the same in Case B.

4.3 IMPACT OF MATERIAL COST IN EACH WORK CATEGORY ON TOTAL MATERIAL COST OVERRUN

Furthermore, the same analysis was done using Eq. 02 for each work category. Further, the impact of each work category on the total material cost overrun was analysed using Eq. 02 and presented in Figure 4. Accordingly, the work categories which were highly influenced the total material cost overrun in three cases can identify based on SI values.

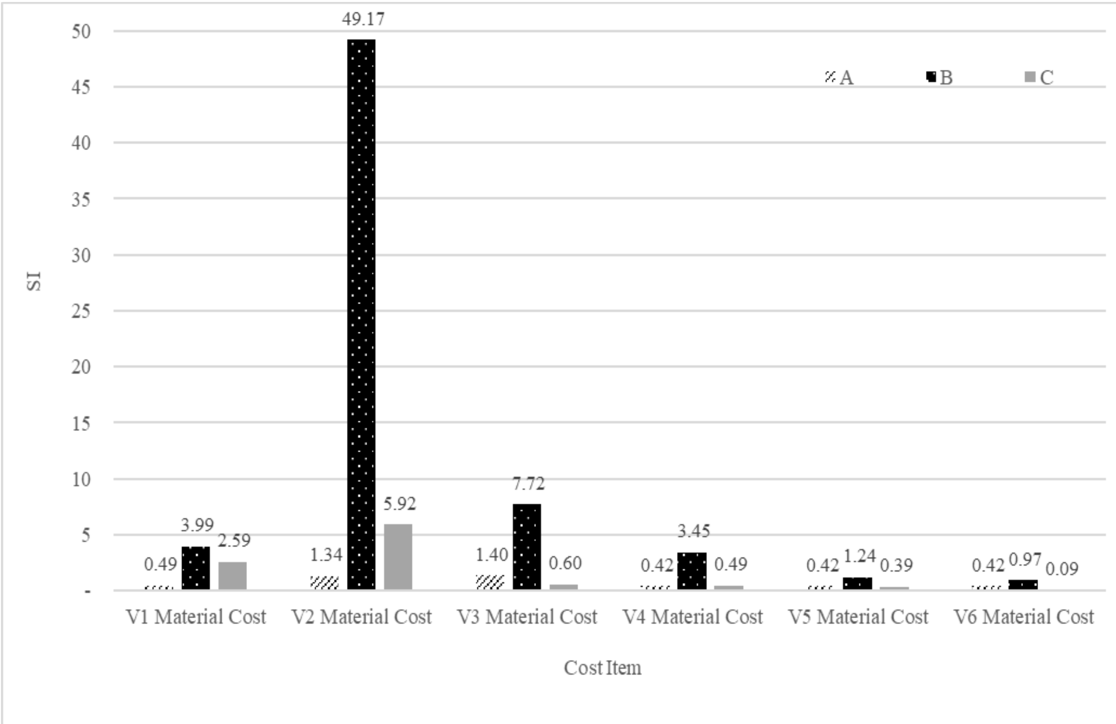

Figure 4: SI of material cost in each work category on total material cost overrun

In Case A, the calculated SI values using material costs of V1 (Excavation and earthwork), V4 (Plastering), V5 (Tiling), and V6 (Painting) were less than 0.5. In addition, the SI values of V4, V5 and V6 were almost the same (0.42). The highest SI value in Case A was found under V3 (Masonry work).

In Case B, the SI values of work categories are comparatively high compared to the other two cases. Also, V2 (Concrete work) has a significantly higher value (49.19) than other SI values from any work category in selected three cases. It is because the material cost overrun of concrete work in Case B is considerably a low amount. Therefore, the contribution of the material cost overrun of V2 to the total material cost overrun is ignorable. SI values of V5 (1.24) and V6 (0.97) are lower than the SI values of existing work categories in Case B.

In Case C, SI values of V4, V5, and V6 were less than 0.5 and V3 (Masonry work) has 0.60 SI value. The highest SI value was found under V2 (5.92) in Case C. When considered the SI values of three cases, it is clear that there are lower SI values for V4 (Plastering), V5 (Tiling) and V6 (Painting) work categories in the selected three cases. It was evident that the major impact for the material cost overrun has happened under V4, V5, and V6 categories and the minor impact for the material cost overrun has happened under V2.

4.4 IMPACT OF LABOUR COST IN EACH WORK CATEGORY ON TOTAL LABOUR COST OVERRUN

Similarly, the same analysis was done to find the impact of labour cost in each work category on total labour cost and results are presented in Figure 5.

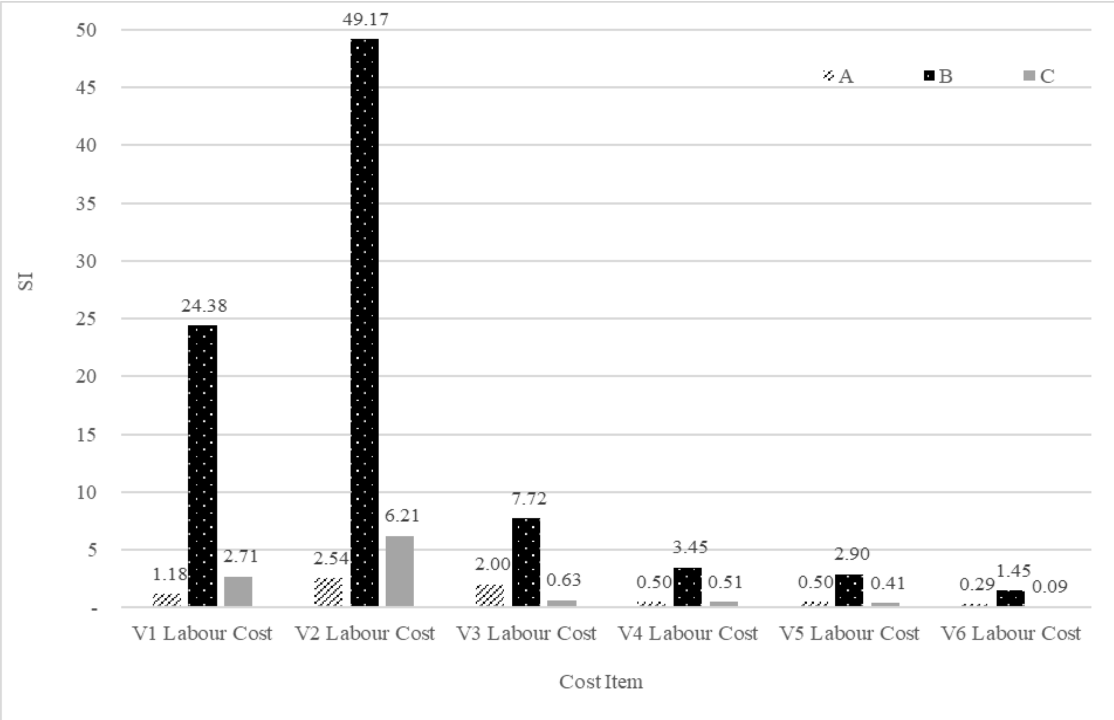

Figure 5: SI of labour cost in each work category on total labour cost overrun

The work categories which were highly influenced the total labour cost overrun in three cases can identify based on SI values. In Case A, the calculated SI values using the labour costs of V6 (Painting) was less than 0.5. In addition, the SI values of V4 and V5 were almost the same (0.5).

In Case B, the SI values of work categories are comparatively high compared to the other two cases. Also, V2 (Concrete work) has a significantly high value (49.17) than other SI values from any work category in selected three cases. It is because the labour cost overrun of concrete work in Case B is a considerably low amount. Therefore, the contribution of labour cost overrun of V2 to the total labour cost overrun is ignorable. SI values of V5 (2.90) and V6 (1.45) are lower than the SI values of existing work categories in Case B.

In Case C, SI values of V5, and V6 were less than 0.5. The SI value of V4 is 0.51 and V3 has a 0.63 SI value in Case C. Further, the highest SI value was found under V2 in Case C. When considered the SI values of three cases, it is clear that there are lower SI values for V4 (Plastering), V5 (Tiling) and V6 (Painting) work categories in the selected three cases. It was evident that the major impact for the labour cost overrun has happened under V4, V5, and V6 categories and the minor impact for the labour cost overrun has happened under V2.

5. CONCLUSION AND RECOMMENDATIONS

Use In the current construction industry project cost overrun is treated as a regular feature because all projects which were completed resulted in cost overruns. An accurate budget is a prominent requirement for all stakeholders in construction projects. To maximise the profit within contracting firms it is essential need to be aware of the budgeted cost overrun aspects. Even though there are many cost variables related to construction cost, the material and labour costs can ensure as critical cost variables that can influence the contractors' budgeted cost overrun heavily.

Basically, this research is limited to building construction projects in Sri Lanka. Further, this study was focused on two main variables, material cost and labour cost in building construction projects. The case studies were limited to three cases due to the unavailability of required data to conduct the research, confidentiality of the cost data of contractor organisations and the ethical rules that they are following.

When considered the findings, it was evident that a major impact for the contractors' budgeted cost overrun is happening due to the material cost and labour cost overruns. According to the analysis and findings of case studies, the average contribution of material cost to the cost of civil work was assessed as 60%, whereas the cost of labour was indicated as 35%. Even though the contribution of the cost of concrete work has a high contribution to the total cost of civil work, it has a lesser contribution to the contractors' budgeted cost overruns in building construction projects. Plastering work, tiling work and painting work are the major work categories that can highly influence the material cost and labour cost overruns in building construction projects. Therefore, contractors should pay special attention on the budgeted cost of plastering work, tiling work and painting work when preparing the initial budget to maximise the profit through minimising the budgeted cost overrun.

Future research can be conducted to develop a methodological framework to monitor the impact of material cost and labour cost on the construction supply chain and predetermine the financial situation of the contractors adopting Sensitivity Analysis technique.

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THE IMPACT OF PROFESSIONALS' KNOWLEDGE ON INNOVATION ADOPTION IN THE CONSTRUCTION INDUSTRY: A CRITICAL LITERATURE REVIEW

Umesha Weerapperuma[1], Suranga Jayasena[2], Akila Rathnasinghe[3] and Niraj Thurairajah[4]

ABSTRACT

The construction industry is one of the leading economic sectors in any country yet is renowned for its reluctance to adopt novel innovations. Meanwhile, research has found that the decision of any industry on the adoption or rejection of innovations depends on its positive or negative perception, which is stipulated by industry professionals' knowledge. Therefore, this research aims to disclose how the professionals' knowledge affects successful innovation adoption specific to the construction industry. A qualitatively based extensive literature synthesis has been conducted concerning three concepts to provide a holistic view of innovation decisions. Namely, the Technology Acceptance Model (TAM), Technology-Organisation-Environment framework (TOE), and Diffusion of Innovation theory (DOI). The findings revealed that the "existing knowledge" of professionals was a key factor in innovation decisions. Accordingly, five main perceived attributes (relative advantage, compatibility, complexity, trialability and observability) have been identified through Roger's innovation-decision model, and decisively common measurement items have been documented under each perceived attribute that comprehensively endorses the "existing knowledge" of construction professionals. Furthermore, this contemporary study found that all the recognised measurement items extensively affect innovation-decision. In the absence of a pragmatic decision framework, this article provides a clear impression for both technology developers and their users/stakeholders on crucial elements of innovation adoption that have been concerned via decision makers' technological perception.

Keywords: *Diffusion of Innovation (DOI); Innovation Adoption; Innovation Decision; Technology Acceptance Model (TAM)*

1. INTRODUCTION

The construction industry contributes greatly to economic growth and social development while operating in a hyper-competitive environment (Boadu, Wang and Sunindijo, 2020). It is common knowledge that constant growth in the construction industry is critical for

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the national economy to fulfil a nation's rising needs. The effective and dynamic development of the construction industry depends on the formation of modern innovations that satisfy its technical and scientific development on a commercial basis (Timchuk, Nikityuk and Bakhtairova, 2021). Accordingly, various tactics are used by construction organisations to monitor their quality and productivity. Some organisations are focused on cost management, while others are concerned with design strategies, and yet others regulate their productivity by modifying the quality of their services. Although these practices have improved productivity so far, most of these strategies will not be able to survive the forthcoming market competition due to digitalisation (Odubiyi, Aigbavboa and Thwala, 2021). Because market competition in the 21st century's construction industry is highly dependent on new technologies, such as drones, machine learning, artificial intelligence (AI), offsite construction, and BIM, that promote productivity (Odubiyi, Aigbavboa and Thwala, 2021). This compels construction firms to invest in new technologies and technical skill development to leverage the innovations. The trend of digitisation, automation, information and communication technology (ICT) has been anticipated to be the soul of the Fourth industrial revolution (Industry 4.0) (Timchuk, Nikityuk and Bakhtairova, 2021). Moreover, different technologies as a part of Industry 4.0 are permissible to address productivity issues in construction projects.

For example, the internet of things (IoT) has already been used in the construction industry for smart homes, environmental monitoring, and energy management, yet there is a significant lack of willingness to incorporate IoT applications (Chen, et al., 2020). Qin, et al. (2020) stated that BIM technology has brought remarkable innovations in terms of productivity to the construction industry. Subsequently, the author stated BIM has intended and successfully proven to improve productivity through waste minimisation but there is a lack of adoption without much details of benefits. However, the authors further stated that poor compatibility in the application, a shortage of professionals, resistance to changes, the weak willingness of corporations among project stakeholders, and difficulty in coordination as barriers to BIM adoption. Furthermore, McNamara and Sepasgozar (2021) emphasised that the main reasons for resistance to change for innovation adoption are an aversion to new challenges and an unwillingness to change one's current working pattern.

In addition, McNamara and Sepasgozar (2021) have discovered that despite technical, organisational, financial, and environmental assistance being given, construction industry practitioners are hesitant to embrace new technologies owing to behavioural aspects influenced by technology perception. As emphasised by Li, et al. (2019), in the current knowledge economy era, the construction industry has highly depended on intangible assets such as knowledge, human creativity and innovations. Further, the authors stated that existing knowledge would be replicated and exploited in perceptions in innovation decisions. Hence, knowledge impacts innovation decisions either positively or negatively. As a result, the purpose of this paper is to identify how knowledge interacts with professionals' innovation decisions and knowledge constructs for innovation adoption.

2. RESEARCH METHODOLOGY

The qualitative research approach has been adopted for its potential to achieve an in-depth analysis of theoretically based concepts, models, and frameworks (McNamara and Sepasgozar, 2020). Accordingly, this paper aims to answer the research problem of "how professionals' knowledge affects successful innovation adoption specific to the construction industry" through a qualitatively based extensive literature synthesis.

Hence, to achieve the aim, this paper presented the literature synthesis and arguments on the following themes: current construction industry behaviour in innovation decisions; the Technology Acceptance Model (TAM); the Technology-Organization-Environment Framework (TOE); Diffusion of Innovation Theory (DOI); and Knowledge Impact in Innovation Decisions Concerning Perceived Attributes and Measurement Items. By following the process with inductive reasoning, the basis was drawn from existing literature on the topic (Azungah, 2018). An in-depth study of the models, frameworks, and concepts was carried out with a cross-reference to the sources that have been used to describe innovation adoption with respective technologies. Accordingly, TAM (refer to section 4.1) was connected to TOE (refer to section 4.2) through external variables. Afterwards, with the main focus on technological variables, the perceived attributes were connected to the TOE framework. Following that, the existing knowledge via perceived attributes was recognised as the heart of the research topic by a comprehensive study using DOI theory (refer to section 4.3). The study's available knowledge was gathered from a variety of sources, including journal articles, conference papers, e-books, and other publications. Finally, a conceptual framework was developed by compiling pertinent literature findings to have a better understanding of how professionals opted to adopt innovations based on their behavioural factors, which originated from "existing knowledge".

3. CURRENT CONSTRUCTION INDUSTRY BEHAVIOUR IN INNOVATION ADOPTION

Technology adoption in the construction industry is accelerating at a slower rate compared to other industries (Timchuk, Nikityuk and Bakhtairova, 2021). However, industries like manufacturing and automobiles keep exploring innovations as a way of maintaining industry productivity (Belle, 2017). Hence, individuals and organisations in the construction industry have a huge responsibility towards the industry's digitalisation. Table 1 presents reasons for the lack of adoption of innovations in the construction industry from individuals' perspectives.

Table 1: Reasons for lack of adoption for innovations in the construction industry - individuals' perspective

Reasons for lack of adoption for innovations in the construction industry – individuals' perspectives	[1]	[2]	[3]	[4]	[5]	[6]
Resistance to change behaviour	✓	✓	✓	✓	✓	✓
Lack of knowledge and competencies	✓	✓	✓	✓	✓	✓
Negative prior experiences	-	✓	-	✓		-
Social factor and networking	✓	✓	-	-	✓	✓
Fear of failure	✓	-	✓	✓	-	-
Lack of trust	-	-	-	-	-	✓
Perception of unusefulness	✓	✓	✓	-	✓	-
Perception of difficulty of use	✓	✓	✓	-	✓	-

Sources:[1] Kassem,Brogden and Dawood, 2012; [2] Eadie, et al., 2013; [3] Yusof, et al., 2014; [4] Lines, et al., 2015; [5] Borhani, 2016; [6] Alizadehsalehi and Yitmen, 2019)

As illustrated in Table 1, "resistance to change behaviour" is a prudent reason for the lack of adoption of innovations. Consequently, "lack of knowledge and competencies" is having a direct effect on "resistance to change behaviour". Further, individuals' roles are significant if the construction organisations are ready for digitalisation (Lin and Chen, 2012). Accordingly, the perception of either "usefulness" or "ease of use" derives from an individual's knowledge. Therefore, the black and red arrows in Table 1 indicate that "knowledge" has a significant effect on innovation adoption as a whole. To identify the way of overcoming "resistance to change", the individuals' technological acceptance behaviour that is saturated with "knowledge" should be sequentially analysed, and the origin of the problem should be identified. Therefore, the theories related to innovation adoption were discussed in the below sections to provide a theoretical background for the research problem with the use of existing literature.

4. THEORIES ON TECHNOLOGY ADOPTION

The acceptance, adoption, and use of technologies at an individual level have become ripe topics in the construction industry due to the high resistance to change among construction industry stakeholders (Hong and Yu, 2018). After introducing new technology, various factors influence their decision on how and when to use it (Woosley, 2011). Figure 1 illustrates the evolution of theories about technology acceptance. Accordingly, the reason for the selection of TAM for this study has been justified under section 4.1.

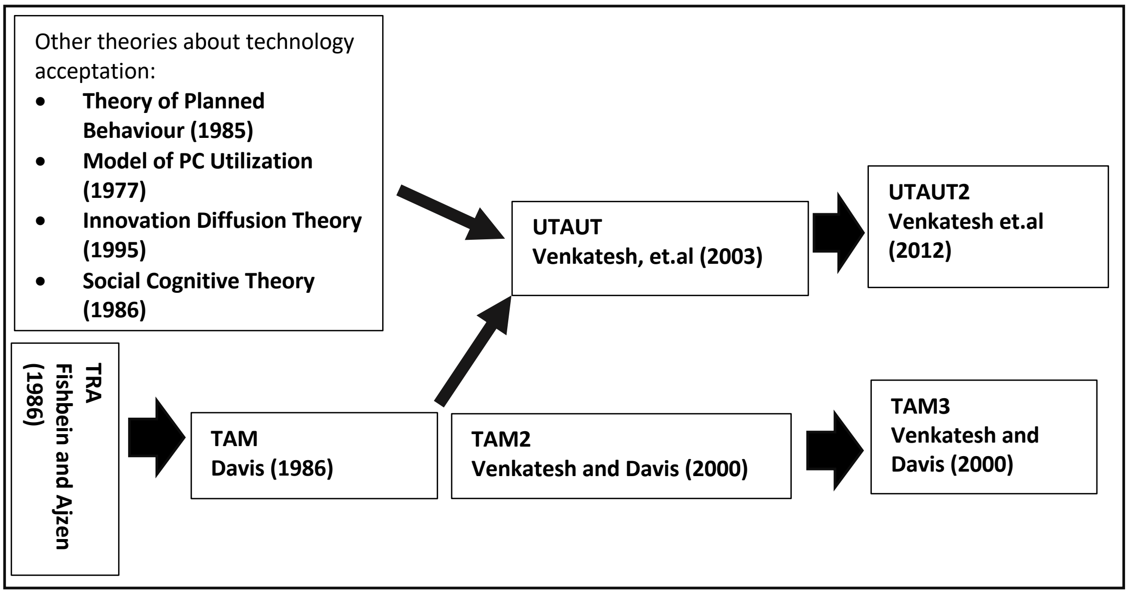

Figure 1: Evolution of theories about technology acceptance

Source: Rondan-Cataluña, Arenas-Gaitán and Ramírez-Correa (2015)

TAM was introduced by Davis (1986), which was an adopted theory from the Theory of Reasoned Action (TRA) and Theory of Planned Behaviour (TPB) (Rondan-Cataluña, Arenas-Gaitán and Ramírez-Correa, 2015). All other models were built upon the basis provided by TAM.

4.1 TECHNOLOGY ACCEPTANCE MODEL

Since the TAM is the most widely applied and most influential model to investigate individuals' behaviour on technology adoption and it provides more flexibility for researchers to select external variables relevant to the study area other than the TAM2, Unified Theory of Acceptance and Use of Technology (UTAUT), and TAM3, this study is also partially based on the TAM to study individuals' perception of innovation adoption. Several scholars have used the TAM to assess individuals' behaviour in innovative technology adoption for the construction industry, such as BIM applications for mobile devices (Hong and Yu, 2018), big data (Soon, Lee and Boursier, 2016), smart contracts (Badi, et al., 2021) and IoT (Chen, et al., 2020). Figure 2 demonstrates the TAM proposed by Davis (1986).

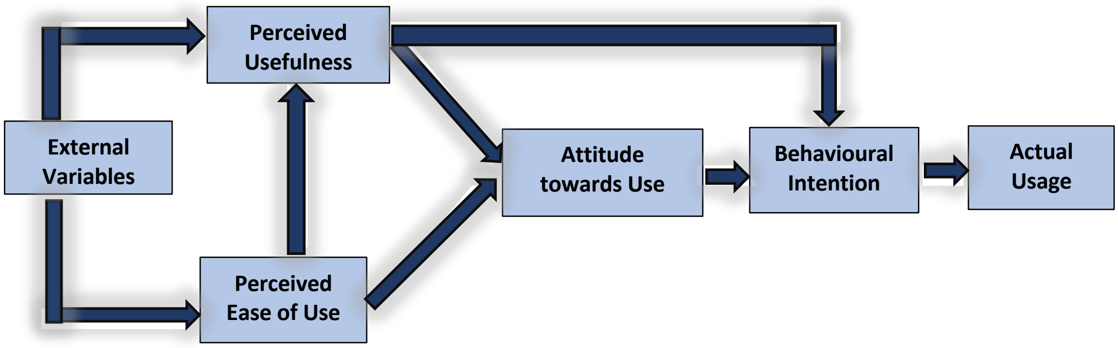

Figure 2: Technology acceptance model

(Source: Davis, 1986)

In the TAM, "perceived usefulness" (PU) and "perceived ease of use" (PEOU) are primary constructs concerning the acceptance of technology by an end-user. Further, those two primary concepts are influenced by the "external variables". As described by Davis (1986), PEOU is "the degree to which a person believes that using a particular technology would be free from effort" (p. 320) and PU is "the degree to which a person believes that using a particular system would enhance his or her job performance" (p. 320). The other two constructs in TAM are "attitude towards use" (ATU) and "behavioural intention to use" (BIU). The actual usage of the technology will depend on those two constructs. According to Woosley (2011), ATU means the user's desirability of using the system. BIU defines it as the measure of the likelihood that a person will use an application. Actual system usage is the dependent variable of TAM. As shown by Figure 2, all these constructs are influenced by the "external variables".

4.2 TECHNOLOGY-ORGANISATION-ENVIRONMENT FRAMEWORK

As an extension of the TAM, the TOE framework has been used in this study. The Technology-Organisation-Environment framework (TOE framework) was introduced by DePietro, Wiarda, and Fleischer in 1990 (Tornatzky and Fleischer, 1990) as an application-level framework to investigate from the perspective of both an organisational and an individual level (Chiu, Chen and Chen, 2017). TOE mainly illustrates the three facets of research into the factors that affect the acceptance of innovative technology by organisations (Baker, 2012). Figure 3 illustrates the TOE framework.

Moreover, the technological context comprises the characteristics and usefulness of the technology; the organisational context includes the organisation's nature, such as internal management, communication processes, size, and slack; and the environmental context consists of factors that affect the related business field, like competitors, partners, regulations, and market structure (Tornatzky and Fleischer, 1990; Baker, 2012).

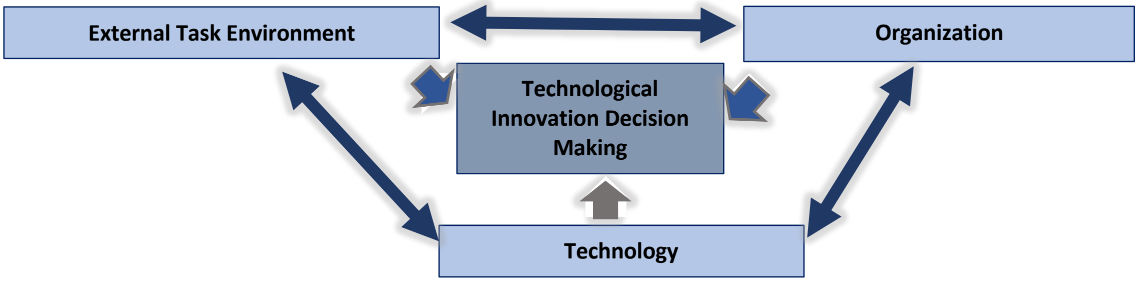

Figure 3: Technology-Environment-Organization framework

Source: Tornatzky and Fleischer (1990)

Accordingly, this study was mainly focused on the "technological perspective" with the incorporation of TAM to maintain the coherence of the in-depth literature findings.

4.3 DIFFUSION OF INNOVATION THEORY

The Diffusion of Innovation theory was developed by E.M. Rogers in 1962 (Chiu, Chen and Chen, 2017). As elaborated by Roger, innovation is "any idea, practice, or object that is perceived as new by an individual or another unit of adoption." Diffusion is defined as "the process by which an innovation is communicated through certain channels over time among the members of a social system" (Rogers, 1962, p.192). According to the DOI theory, "knowledge is an individual's initial exposure to the innovation's existence and understanding of how the innovation works" (Vejlgaard, 2018, p.6). Therefore, the requirement for knowledge on innovation adoption has been connected to integrated TAM-TOE through perceived attributes. Accordingly, the next section discussed the impact of knowledge on the decision-making process of any innovation.

4.3.1 Innovation Decision Model

Later, Rogers (1983) proposed a more improved model for identifying the stages of adoption called the "innovation-decision model." According to Roger, this is the process that individuals (or any other decision-makers on innovation adoption) follow to implement a new idea. The "innovation-decision model" is shown in Figure 4. As per the model (refer to Figure 4), the knowledge stage is the first step of an innovation-decision process. Then it is connected with the persuasion stage. Therefore, the persuasion stage follows the knowledge stage. Accordingly, an individual forms a favourable or unfavourable attitude toward innovation within the persuasion stage by further exploring knowledge under perceived attributes (refer to Table 3). The persuasion stage is more latent and depends on the individuals' perceptions, while the knowledge stage remains cognitive and well known (Wani and Ali, 2015). After that, Rogers (1983) described four outcomes via the knowledge stage and persuasion stage for technology adoption or rejection. Since this study is limited to technology adoption, only the knowledge stage to persuasion stage has been studied towards technology adoption.

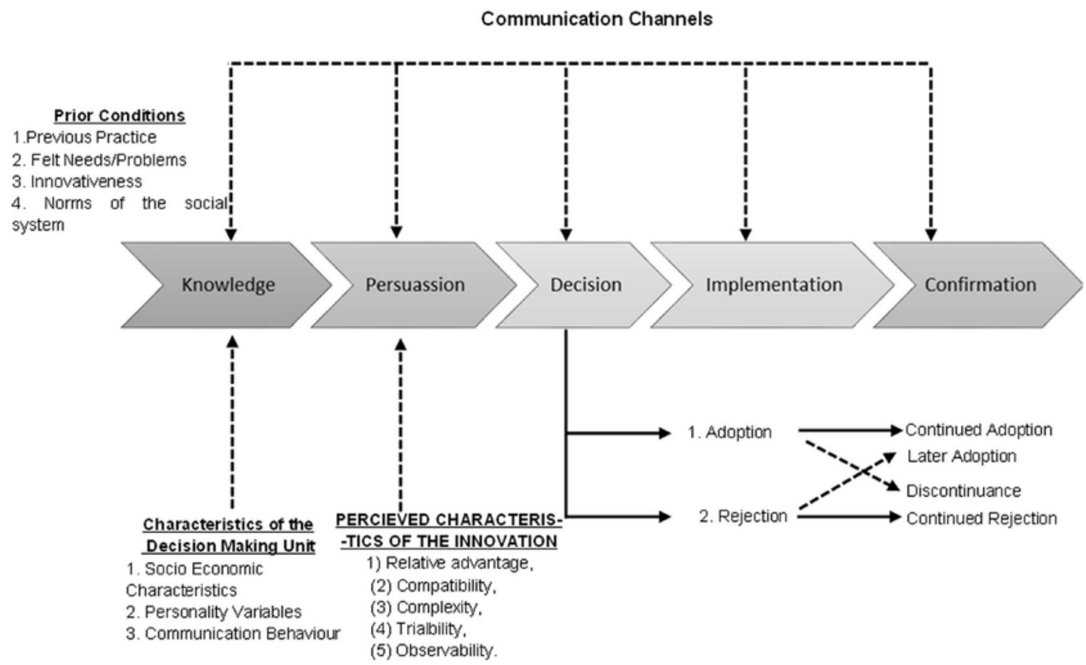

Figure 4: Model of five stages in the innovative-decision process

Source: Rogers (1983)

5. IMPACT OF KNOWLEDGE ON INNOVATION-DECISION

Howells (2002) prompted knowledge as a personal belief rather than the attribute of truth, which was justified by traditional epistemology. Moreover, Howells (2002) instigated "existing knowledge" to involve innovating, inventing, and discovering new knowledge while supporting the acceptance of new knowledge. Further, knowledge is primarily conceptualised as individual property as information (of a special quality) and located in a person's mind or memory. Thus, once the new knowledge arrives, it will be assessed with existing knowledge that is stored in an individual's mind (Howells, 2002). As per the DOI, once the knowledge is acquired on the knowledge stage, it is further discovered and justified through perceived attributes (relative advantage, compatibility, complexity, trialability, and observability) in the persuasion stage.

Even if the knowledge (in the innovation-decision model) has been given, the individuals may not be ready to adopt new technology. The persuasion stage occurs when individuals have a negative or positive attitude toward the innovation, but "the formation of a favourable or unfavourable attitude toward an innovation does not always lead directly or indirectly to an adoption or rejection" (Rogers, 2003, p. 176). Therefore, individuals' attitudes are shaped when they know about the innovation. Furthermore, Rogers (2003) declared that the knowledge stage is more cognitive (or knowing) centred, while the persuasion stage is more effective (or feeling) centred. Thus, individuals are persuaded more sensitively about the innovation at the persuasion stage. Rogers (2003) described the innovation diffusion process as "an uncertainty reduction process" (p.232), and the author stated that attributes of innovations (perceived characteristics or attributes) are facilitated to reduce the uncertainty about the innovation. The attributes of innovation include five characteristics. Rogers (2003) stated that "individuals' perceptions of these characteristics predict the rate of adoption of innovations" (p. 219). The knowledge that is directly related to those perceived attributes would be beneficial in increasing relevancy and productivity during the knowledge acquisition stage. Accordingly, those attributes were elaborated as follows:

- Perceived attributes and measurement items

Accordingly, Rogers (2003) explained that innovation proceeds through five stages of the adoption process: knowledge, persuasion, decision, implementation, and confirmation. Potential adopters will be more involved and seek out information about technology in the persuasion stage other than in the knowledge stage (Meyer, 2010). Thus, Roger has identified five perceptual characteristics of innovation (perceived attributes): perceived relative advantage, compatibility, non-complexity, trialability, and observability. Table 2 illustrates the definitions originally made by Rogers.

Table 2: Definitions for perceived attributes

Perceived Attributes	Definitions
Relative advantage	"The degree to which an innovation is perceived as being better than the idea it supersedes" (Rogers, 2003, pp.229).
Compatibility	"The degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters" (Rogers, 2003, pp.240).
Complexity	"The degree to which an innovation is perceived as relatively difficult to understand and use" (Rogers, 2003, pp.257).
Trialability	"The degree to which an innovation may be experimented with on a limited basis" (Rogers, 2003, pp.258).
Observability	"The degree to which the results of an innovation are visible to others" (Rogers, 2003, pp.258)

Further, the measurement items that determine the perception via identified attributes were discussed by several researchers. Table 3 illustrates those measurement items with their respective perceived attributes.

Table 3: Perceived attributes

Construct	Measurement items	References
Perceived relative advantage		
PR1	It increases the efficiency and effectiveness	[R1], [R2], [R3], [R4], [R5], [R6]
PR2	It aids in economic gains	
PR3	It increases social prestige	
Perceived compatibility		
PC1	It is compatible with the organisation's existing values, experiences, work practices and norms	[R1], [R2], [R3], [R4], [R5], [R6]
PC2	It is compatible with the existing operating environment including hardware and software	
PC3	It is compatible with organisational needs	

Construct	Measurement items	References
Perceived non-complexity		
PNC1	It does not need greater technical skills	[R3], [R4], [R5], [R6]
PNC2	It does not require a lot of thinking an extra effort	
PNC3	It does not hard to understand and easy to reach up consensus	
Perceived trialability		
PT1	A trial period allows for checking whether the proposed technology is suited to the individuals' existing knowledge level	[R3], [R4], [R5], [R6]
PT2	A trial period reduces the perceived risks	
PT3	Being able to try out the innovative technology is important to adopt it in future	
Perceived observability		
PO1	Other industries using the same technology	[R3], [R4], [R5], [R6]
PO2	Other industries have positive consequences	
PO3	Understanding the positive effects of the proposed technology	

Sources: [R1] (Slyke, et al., 2008), [R2] (Mason, 2017), [R3] (Lin and Chen, 2012), [R4] (Pankratz, Hallfors and Cho, 2002), [R5] (Badi, et al., 2021), [R6] (Chiu, Chen and Chen, 2017)

Numerous scholars have identified that the previously mentioned perceived attributes (relative advantage, compatibility, non-complexity, trialability, and observability) are positively related to technology adaptation through hypothesis testing (Pankratz, Hallfors and Cho, 2002; Chiu, Chen and Chen, 2017). By using hypothesis analysis within the UK construction industry context, Badi, et al. (2021) recognised those perceived attributes are positively related to smart contract adoption. Therefore, those measurement items can be designed for respective innovation scenarios.

6. THE CONCEPTUAL FRAMEWORK-INTEGRATED TAM-TOE-DOI FOR INNOVATION ADOPTION

The developed conceptual framework of this study as an outcome of the integration of TAM, TOE, and DOI theories is shown in Figure 5. There were several pieces of literature exploring the adaptability of innovative technologies that combined the TAM with the TOE framework. Qin, et al. (2020) applied the TAM-TOE model to explore the factors of BIM adoption. Gangwar, Date and Ramaswamy (2015) used the TAM-TOE model to identify the determinants of cloud computing adoption. Further, as reported by Chiu, Chen and Chen (2017), DOI theory has been combined with the TOE framework to give a theoretical framework for assessing the adaptability of broadband mobile applications by enterprises.

Many research studies have been undertaken to integrate more than one model to provide a holistic evaluation of the determinants of technology adoption in terms of different technologies; for example, the integrated TAM-TOE-DOI framework for cloud computing adoption (Singh and Mansotra, 2019) and blockchain technology adoption in supply chains (Bhardwaj, Garg and Gajpal, 2021).

Accordingly, this conceptual framework (refer to Figure 5) promotes an in-depth investigation into the root cause of resistance to innovation adoption using well-established theories, which is an extension of existing studies.

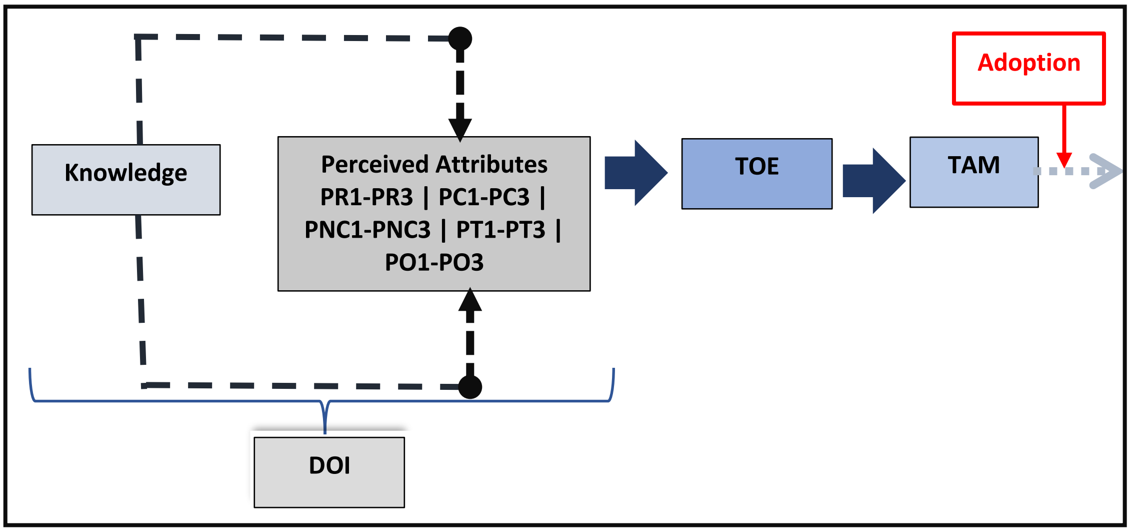

Figure 5: Conceptual framework-integrated TAM-TOE-DOI for innovation adoption

7. CONCLUSION AND THE WAY FORWARD

This extensive review of the literature was intended to understand how industry professionals make decisions on innovation adoption. It is beneficial to identify the way that either the adoption or rejection decision comes. Therefore, it is important to understand the relevant knowledge that is required to make the correct decision at a stipulated time. Accordingly, in the first part of this study, "innovation adoption" was discussed with the background findings under the section, "reasons for the lack of innovation adoption in the construction industry" and then TAM, TOE, and DOI theories. As per the TAM, individuals' "behavioural intentions to use," which are derived from "perceived usefulness" and "perceived ease of use," were identified. At the end of the model, TOE was connected through an external variable that is common for both TAM and TOE. According to the pre-defined scope of this study, the technological variables were mainly focused on, disregarding organisational and environmental variables. Thereafter, technological variables were further elaborated through perceived attributes (relative advantage, compatibility, non-complexity, trialability, and observability), which were identified through the innovation-decision model. Then, the second part of the study, "impact of knowledge in innovation decisions," was discussed concerning the identified perceived attributes and their measurement items, respectively. Those anticipated measurement items were presented as PR1-PR3, PC1-PC3, PNC1-PNC3, PT1-PT3 and PO1-PO3. Simultaneously, the integrated TAM-TOE-DOI conceptual framework was presented as a way of emphasising how the problem of this study has been identified. Further, that framework can be moderated by organisational, environmental, or any other external variable. Accordingly, the knowledge requirement can be identified through existing (already defined from the innovation-decision model) or separate perceived attributes and measurement items. Additionally, a separate model such as TAM2, TAM3, or UATUT (Unified Theory of Acceptance and Use of Technology) can be replaced with one relevant to the scope of the study.

Although this study has been given a holistic view of innovation adoption decisions from the technology perspective, the outcome of the study would be beneficial for construction industry practitioners, innovators, and decision-makers to have a clear image of the sequence of innovation adoption decisions related to their general parameters during the initial stage. Because this knowledge framework has targeted exact perceived attributes that are straightforwardly considered by the decision-makers. Furthermore, this paper is an initial conceptualisation of the impact of knowledge on innovation-decision. Therefore, perceived and measurement items can be identified for several technologies and prepared as knowledge frameworks concerning their innovation adoption as a way forward in this study.

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THE IMPACT OF PROCUREMENT METHOD ON CONSTRUCTION TIME WASTE

Kavishka Hewamulla[1], Himal Suranga Jayasena[2] and Kavini Guruge[3]

ABSTRACT

Selection of the most appropriate procurement method for a proposed project is challenging because there are many factors to be evaluated in deciding. This study focuses on the impact of procurement method on construction time waste, and it was conducted to find how the time wastage varies according to the selected procurement route. Such knowledge is important in making better decisions when selecting a procurement method. Accordingly, the research aim was set to find the significant differences of time waste between traditional and design and build procurement methods. this research was conducted from a quantitative approach, deductive theory data collected through an online survey, and for data analysis using descriptive statistics. Twenty-two (22) number of time waste factors were identified through literature review. survey respondents weighted the significance of each factor between traditional and design and build procurement methods. Ten (10) factors caused significantly higher time waste in traditional method and none of the factors caused higher time waste in design and build method. Accordingly, the study concludes that time waste in traditional procurement is generally higher in traditional procurement method compared to design and build procurement method.

Keywords: *Design and Build Method; Procurement; Time Waste; Traditional Method.*

1. INTRODUCTION

Construction is the industry of constructing built facilities such as buildings and roads. The construction process differs from that of manufacturing (Eve, 2007). Construction of a building or an infrastructure project is a complex process which requires careful attention from overall process to finer details in it. In order to fulfil the whole process, there are several factors needed to be concerned on, and a major part of this is addressed at the procurement method selection (Myren and Hellers, n.d.).

The definition of the procurement in construction has been developed from time to time (Rahmani, et al., 2017). One commonly used definition is that construction procurement is the process of design, build, management, finance and operation construction projects (Hughes, et al., 2006). It also can be understood that a procurement system defines scope or responsibilities of each party of the construction contract. Furthermore, procurement methods can be classified into four key categories, viz, (a) Traditional Method, (b) Design and Build, (c) Management Oriented, and (d) Collaborative; PPP, PFI (Hamma-adama

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and Ahmad, 2021). Each procurement method has different advantages and disadvantages over other methods. These are accounted in selecting appropriate procurement method (Rahmani, et al., 2017). Considering the Sri Lankan context, traditional procurement method, and design and build method take priority (Nikmehr, et al., 2016).

Even though, how perfectly selected the procurement method, construction waste is an unavoidable issue many researchers have attempted to address (Faniran and Caban, 2007; Nagapan, et al., 2012). Under construction waste there are several types, where time waste is considered as one (Ali and Arun, 2014). It is already accepted that design and build procurement method delivers projects in shorter time compared to Traditional procurement method. However, whether there is a difference in time waste in each procurement method is unknown. The gap in knowledge limits the procurement method selection as the inefficiencies due to time waste is unaccounted in that decision. To address this research problem, the aim was set to find the significant differences of time waste between traditional and design and build procurement methods. To reach the aim, three objectives were developed as below:

1. to find the modes of time waste in construction projects,
2. to identify the level of each mode in between two procurement methods, and,
3. to identify the significant differences in level of each mode in between two procurement methods.

2. LITEREATURE REVIEW

Construction industry, which plays a major role in Sri Lankan economy can be divided into three parts: firstly buildings, secondly infrastructure and thirdly, specialty trades (Myren and Hellers, n.d.).

In relation to construction process we can identify two separate stages as pre-contract stage and post-contract stage. According to the Royal Institute of British Architects (RIBA) plan it is a must to figure out the most suitable procurement method for each project particularly (Royal Institute of British Architects, 2020). As per the point, perfect procurement method is also able to manage the whole project, adding customer satisfaction and business performance are key factors (Hughes, et al., 2006).

Essentially, procurement is the cycle used to acquire development in businesses. It involves the determination of a legal binding system that clearly identifies the bonds for members within the structure cycle and the structure of specialists (Naoum and Egbu, 2015). In general, there are four main procurement methods: (a) traditional method, (b) design and build, (c) management oriented and (d) collaborative; PPP, PFI (Hamma-Adama and Ahmad, 2021). In this study, it mainly focuses on the traditional procurement method and design and build procurement method which are mostly used procurement methods in Sri Lankan construction industry.

2.1 TRADITIONAL PROCUREMENT METHOD

Traditional procurement method which is known as separated procurement method remains the most used method of procuring building works (Rahmani, et al., 2017). It consists of a three-party agreement between the customer, consultants, and contractor. Traditionally, design and construction are separated in the procurement process (Davis, et al., 2008). There are certain advantages and disadvantaged of this method such as, since clients have direct contractual connections with the design team, they could influence the evolution of the design; therefore, assuming no changes are made, construction costs may be estimated with reasonable certainty before construction begins. However, if any attempt is made to choose a contractor for the work before the design is complete, the plan may fail to some extent due to the potential of several post-contract revisions, which will cause a delay in the progress of the work and an increase in the expenses (O'shea, et al., 2019).

2.2 DESIGN AND BUILD PROCUREMENT METHOD

Design and build which also known as integrated procurement method ~~is~~ slightly differs from the traditional method. On a lump sum fixed price basis, an integrated procurement technique can be described as using a single contractor to operate as the only point of responsibility (Hendrickson, et al., 1989). The appointed contractor is in charge of designing, managing, and completing a construction project on schedule, on budget including whole-life expenses, and in line with a pre-determined output specification. The contractor is expected to have reasonable skill and expertise in order to meet the client's expectations (Zuber, et al., 2019). Apart from that there are several number of variants which are considered as small deviations on the general procedure, some of them are; turnkey, novated design and build and package deals (Rahmani, et al., 2017).

2.3 CONSTRUCTION WASTE

Stakeholders of a construction project pay their attention to select the most suitable procurement method cautiously since it can affect the whole process of construction in both good and bad manner (Rosado, et al., 2019). Even though, construction industry has massive progresses in every aspect but still construction waste has been a concern of researchers for decades (Malik, et al., 2019). The construction industry accounts for 25% of solid waste generated around the globe (Benachio, et al., 2020). As shown in Figure 1, which was identified by Ramaswamy and Satyanarayana (2009), construction waste is classified mainly into four categories.

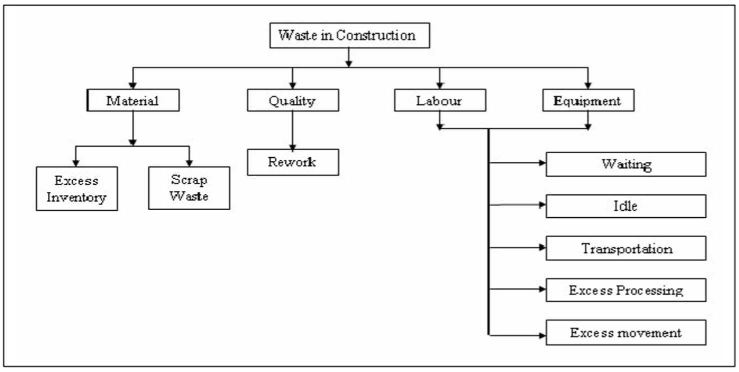

Figure 1: Waste in construction

Source: Ramaswamy and Satyanarayana (2009)

Apart from the findings of Ramaswamy and Satyanarayana (2009) regarding the main types of construction waste, Ali and Arun (2014) have figured out another three classifications of construction waste in 2014. In their study they have separated waste into three categories to make it easier to quantify waste in construction.

1. Money waste/Economic waste
2. Time waste
3. Material waste

During a past study conducted by Alwi, et al. (2002), they have ranked and grouped waste variables. Group 1 of waste variables which contains the variables repair on finishing works, waiting for materials, delays to schedule, tradesmen slow/ineffective, waste of raw materials on-site and lack of supervision/poor quality is ranked as the most important group of variables (Sugiharto, et al., 2002). Those variables were further classified by Ali and Arun (2014) as follows,

1. Repair on finishing work - Responsible for time waste, money waste and to an extend material waste depending on type of work
2. Waiting for materials - Time waste
3. Delays to schedule - Time waste
4. Slow tradesmen - Time Waste and money waste.
5. Waste of raw materials onsite - Material waste
6. Lack of supervision - All wastes can be incorporated as a result of lack of proper supervision,

where most of the variables are classified under time waste (Ali and Arun, 2014).

2.4 CONSTRUCTION TIME WASTE

During their study, Alwi, et al. (2002) stated that experts have figured that there are several inefficient activities during the planning and development process, mostly in construction industry as well. The majority of these activities consume time without providing extra benefits to the process (Sugiharto, et al., 2002).

Although time waste is linked to the overall delay of building projects, a full analysis of time wastes is not a common topic of research. But during their studies some past researchers have identified certain time waste factors in construction industry, which are summarized in Table 1.

Table 1: Causes of time waste

Source	Causes for Time Waste
Design	Interaction between various specialists
	Rework due to design changes and revisions
	Lack of information about types and sizes of materials on design documents
	Error in information about types and sizes of materials on design documents
	Contradictions in design documents
	Delay in approval of drawings
Procurement	Delay in material supply
	Receiving materials that do not fulfil project requirements defined on design documents, and waiting for replacement
	Delay in transportation and/or installation of equipment
Operation	Scarcity of crews
	Unrealistic master schedule

Source	Causes for Time Waste
Other	Rework due to workers' mistakes Scarcity of equipment Waiting for design documents and drawings Lack of coordination among crews Choice of wrong construction method Accidents due to lack of safety Irregular cash flow Severe weather conditions Bureaucracy and red tape Unpredictable local conditions Acts of God

(Source: Polat and Ballard, 2004; Ali and Arun, 2014).

Reviewing the sources of waste in detail, Design is one of the main causes of waste and under this, there are other various types which cause waste in construction (Islam, et al., 2016). Basically, there can be a waste due to inexperience designers, lack of design information, poor design quality, last-minute client requirements, design errors due to frequent design changes as well (Meghani, et al., 2011). In spite of that related to time waste in constriction, Polat and Ballard (2004) identified aforementioned six causes for time waste.

Another main source of waste is procurement. In related to procurement there are several methods of waste such as ordering errors, wrong material delivery, item not in compliance with specification, different methods used for estimation, supplier errors, waiting for a replacement, error in shipping. Above mentioned types can consider as main factors which cause waste (Daniels, et al., 2005). In related to time waste there are specifically three causes identified under source of procurement (Polat and Ballard, 2004). Where delay in material supply is a major issue, which is a direct cause for time waste. Receiving materials that do not fulfil project requirements defined on design documents and waiting for replacement also time wasting (Rosado, et al., 2019). Delay in transportation and installing of equipment obviously take time and due to the errors of the procedure it will cost time hence causes a time waste (Arif, et al., 2012).

In regard to the sources of waste operation takes part, where eight causes were identified by Polat and Ballard (2004). There can be a waste due to operation errors of the project. Errors and mistakes can happen regarding supervision, controlling, planning, site management and communication problems (Viana, et al., 2012). Apart from mentioned causes, scarcity of crew, rework, accidents due to lack of safety can be considered (Vitharana, et al., 2015).

With the exception of design, procurement and operation still there are some factors which cause construction waste, such as; irregular cash flow, severe weather conditions, bureaucracy and red tape, unpredictable local conditions which occur unexpectedly, for example pandemics and finally, acts of god, as an example floods or tremor where legally binding language alluding to demonstrations of god are known as power majeure conditions, which are regularly utilized by insurance agencies (Katz and Baum, 2011).

The literature review consists of a basic knowledge in addressing the research question in hand, primarily with a list of causes of time waste. Following this, in order to fulfil the aim of this study, what was left to Identify is the level of each mode in each of two procurement methods and then to Identify the significant differences in level in between two procurement methods.

3. METHODOLOGY

Being a complex topic, 'Procurement system on Construction Time Waste' held a complex set of areas to be considered as productivity measurements significantly vary. The key aspects to be concerned were, research design approach, theoretical approach, strategy of inquiry and research method (Pandey and Pandey, 2015). A quantitative approach was utilized in this research because it was with the aim of identifying the differences in a manner that can contribute to an analytical decision (Pandey and Pandey, 2015). As the time waste causes are already known, the necessity was to find if causes were having significant difference in effects from a hypothesized equal point. Therefore, the theoretical approach of the study was deductive.

The strategy of enquiry comprised of a quantitative questionnaire survey, where the respondents were given the opportunity to scale the time-wasting factors comparatively on a ratio scale. A questionnaire survey with a 9-point scale which was formed adhering to the Analytic Hierarchy Process (AHP) was utilized. The 9-point scale was adopted mainly because it helps in analysing data through a comparison between each factor identified. The nine-point scale structure is given below (Mu and Preyra-Rojas, 2017).

Table 2: 1 to 9 scale table

Intensity of Level (1-9 Scale)	Definition
1	Equal Level
2	Weak
3	Moderate Level
4	Moderate Plus
5	Strong level
6	Strong Plus
7	Very Strong or Demonstrated Level
8	Very, Very Strong
9	Extreme Level

(Source: Mu and Preyra-Rojas, 2017)

Data was collected through a questionnaire survey which was directed to the industry professionals. Factors such as field of engagement, period of experience and academic and professional qualifications were taken into consideration when selecting the respondents. 28 respondents completed the questionnaire. The questionnaire listed 22 time-waste factors under which the respondent had to select if design and build or traditional procurement had higher level of wastage first, then next to it mark intensity of higher against the lower based on 9-point scale (in Table 2). Equal importance could be marked as one in scale.

For analysing purposes, collected data were initially transformed to have negative or positive direction based on Design and Build and Traditional Method respectively, with Zero as the neutral point (Eq. 01).

$$S_{ji} = K_{ji}\left(R_{ji} - 1\right) \qquad \textit{(Eq. 01)}$$

Where, S = transformed Severity Score value that ranged from –8 to +8, K = –1 if Design and Build selected to be with higher level of wastage, +1 if Traditional was selected. R = 9-point scale response for each factor j by i^{th} respondent. Accordingly, if Design build had extreme level of time waste for a factor, the S would become –8. The transformed scores were analysed using descriptive statistical techniques with Box Plots being the primary method. In addition, statistical mean, standard deviation, median and quartiles were used in interpretation.

4. ANALYSIS AND FINDINGS

Severity Scores (S) were first visually analysed on a colour-scaled matrix shown in Figure 2 for a generalized understanding of distribution of scores.

	Response / Time waste factors	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	Interaction begiven various specialists	-1	-2	2	4	2	-3	6	2	1	6	2	2	-4	8	7	-2	5	8	-2	0	-5	7	6	2	4	-2	-3	-2
2	Rework due to design changes and revisions	0	-2	-1	-4	2	-4	6	2	-6	-8	3	3	-5	2	7	-2	-3	7	0	7	5	7	8	7	8	8	7	-3
3	Lack of information about types and sizes of materials on design documents	2	-3	-4	-3	2	3	4	2	6	-7	3	4	-4	-5	0	-3	-5	5	4	6	5	0	4	6	5	-5	-4	3
4	Error in information about types and sizes of materials on design documents	-1	-2	-1	-8	2	3	5	0	4	-8	4	-5	-2	-7	5	4	-4	5	2	7	-5	5	3	6	4	5	5	-3
5	Contradictions in design documents	1	-3	-4	-5	2	2	4	3	6	7	3	2	1	-8	3	-2	-5	4	0	4	5	3	5	7	7	7	8	4
6	Delay in approval of drawings	0	-3	2	-6	2	-3	2	2	-7	-7	2	3	-4	-3	6	-2	-4	7	-8	7	5	6	8	7	6	8	8	4
7	Delay in material supply	-1	-3	3	0	2	1	2	1	-5	-7	0	4	-7	1	0	-3	-5	0	5	0	5	0	0	0	0	-1	2	-6
8	Receiving materials that do not fulfil project requirements defined on design documents, and waiting for replacement	0	-2	-2	7	2	-2	1	2	4	4	-5	5	-6	-7	0	-2	5	0	8	2	5	0	0	3	0	0	-2	3
9	Delay in transportation and/or installation of equipment	0	-3	2	-3	2	0	0	2	2	7	0	2	-1	-2	-4	-2	-4	0	8	0	5	-4	0	0	0	0	0	-5
10	Scarcity of crews	1	-3	-1	3	2	0	-2	2	8	-7	0	3	-4	8	0	-2	5	1	8	0	5	0	0	0	0	0	-4	-6
11	Unrealistic master schedule	0	-3	2	8	3	-1	-2	3	-7	8	0	4	-5	-8	1	-2	-5	0	4	1	5	1	0	3	0	0	1	-3
12	Rework due to workers' mistakes	0	-2	3	4	2	0	3	5	-4	5	-3	5	-5	-3	2	-2	4	-3	4	0	-5	2	4	3	4	7	6	3
13	Scarcity of equipment	-1	-3	-2	1	2	0	0	2	1	6	2	2	-4	-2	0	-2	-3	-3	4	-2	5	0	-2	0	0	-1	-2	-5
14	Waiting for design documents and drawings	0	-4	3	8	1	2	3	3	-4	7	2	3	-3	-4	6	-2	4	6	-8	7	-5	6	6	4	5	7	7	3
15	Lack of coordination among crews	0	-4	2	3	2	-2	5	3	6	-7	0	4	-4	-8	-2	-2	-4	0	3	-2	5	-2	4	3	-3	-2	-3	2
16	Choice of wrong construction method	0	-3	1	4	2	2	8	4	-5	-6	5	5	-6	-8	5	-2	4	1	8	-1	-5	4	4	4	-2	-3	2	3
17	Accidents due to lack of safety	0	-3	-4	0	2	0	4	3	0	6	0	-2	-3	-7	0	-2	-4	0	8	0	-5	0	0	0	0	0	3	4
18	Irregular cash flow	-1	-3	-4	-5	3	-2	6	3	-3	5	0	-3	-2	-4	0	-2	4	0	5	0	5	0	0	0	1	0	0	-5
19	Severe weather conditions	0	-2	4	-3	3	0	5	2	-2	-6	0	4	-4	-4	0	-2	4	0	0	0	5	0	0	3	0	0	0	-6
20	Bureaucracy and red tape	0	-4	3	7	2	0	6	2	5	6	6	5	-4	-2	3	-2	-4	-1	2	3	5	3	3	6	4	4	3	-6
21	Unpredictable local conditions	0	-5	-5	-5	0	0	5	2	2	7	-4	2	-3	-2	1	-2	4	0	3	0	5	1	0	4	0	-3	-2	-6
22	Acts of God	-2	-4	-4	-7	3	1	6	2	-4	0	0	-3	-3	-4	0	-2	4	0	0	0	-5	0	0	0	0	0	0	8

Figure 2: Severity score of time waste factors

The visual observations showed significant variability in scores among the respondents for large majority of factors. Therefore, it was decided to use the median score as the indicative basic value for the judgement. However, consideration was also given to include the level of variability to make in finding the interpretations. Figure 3 shows the median score (or the second quartile) for the factors.

The median value of scores can be interpreted as the score of the average respondent for each factor. This score is not affected by the extreme scores that would have been given by any other respondent. Thus, it represents a more reliable centre value given the fact that there is a wide variability in most factor scores.

	Time waste factors	Median = Q2
1	Interaction begiven various specialists	2.00
2	Rework due to design changes and revisions	2.00
3	Lack of information about types and sizes of materials on design documents	2.00
4	Error in information about types and sizes of materials on design documents	2.50
5	Contradictions in design documents	3.00
6	Delay in approval of drawings	2.00
7	Delay in material supply	0.00
8	Receiving materials that do not fulfil project requirements defined on design documents, and waiting for replacement	0.00
9	Delay in transportation and/or installation of equipment	0.00
10	Scarcity of crews	0.00
11	Unrealistic master schedule	0.00
12	Rework due to workers' mistakes	2.50
13	Scarcity of equipment	0.00
14	Waiting for design documents and drawings	3.00
15	Lack of coordination among crews	0.00
16	Choice of wrong construction method	2.00
17	Accidents due to lack of safety	0.00
18	Irregular cash flow	0.00
19	Severe weather conditions	0.00
20	Bureaucracy and red tape	3.00
21	Unpredictable local conditions	0.00
22	Acts of God	0.00

Figure 3: Median of each time waste factor

Figure 3 shows that there are ten factors showing level differences between the two procurement methods.

1. Interaction begiven various specialists
2. Rework due to design changes and revisions
3. Lack of information about types and sizes of materials on design documents
4. Error in information about types and sizes of materials on design documents
5. Contradictions in design documents
6. Delay in approval of drawings
7. Rework due to workers' mistakes
8. Waiting for design documents and drawings
9. Choice of wrong construction method
10. Bureaucracy and red tape

It is interesting to find that all 10 factors show higher level of time waste in the tradition procurement method as the scores indicate the positive sign. Balance 12 factors showed equal level of time waste in both procurement methods indicated by the neutral value zero. For all factors, 50% or more respondents had scored at or above Zero. From these results, it could be generalized that time waste is always higher in traditional procurement method, and those waste occur through 10 factors above. However, this interpretation has its limitations since it disregards the variability of scores.

Box Plots shown in Figure 4 were used to identify the nature of variability and to expand the interpretation above.

The factors were reordered from the highest to the lowest based on following statistics in order to support better visualization.

1. Median or the second quartile (Q2) - 50th percentile
2. First quartile (Q1) - 25th percentile
3. Third quartile (Q3) - 75th percentile

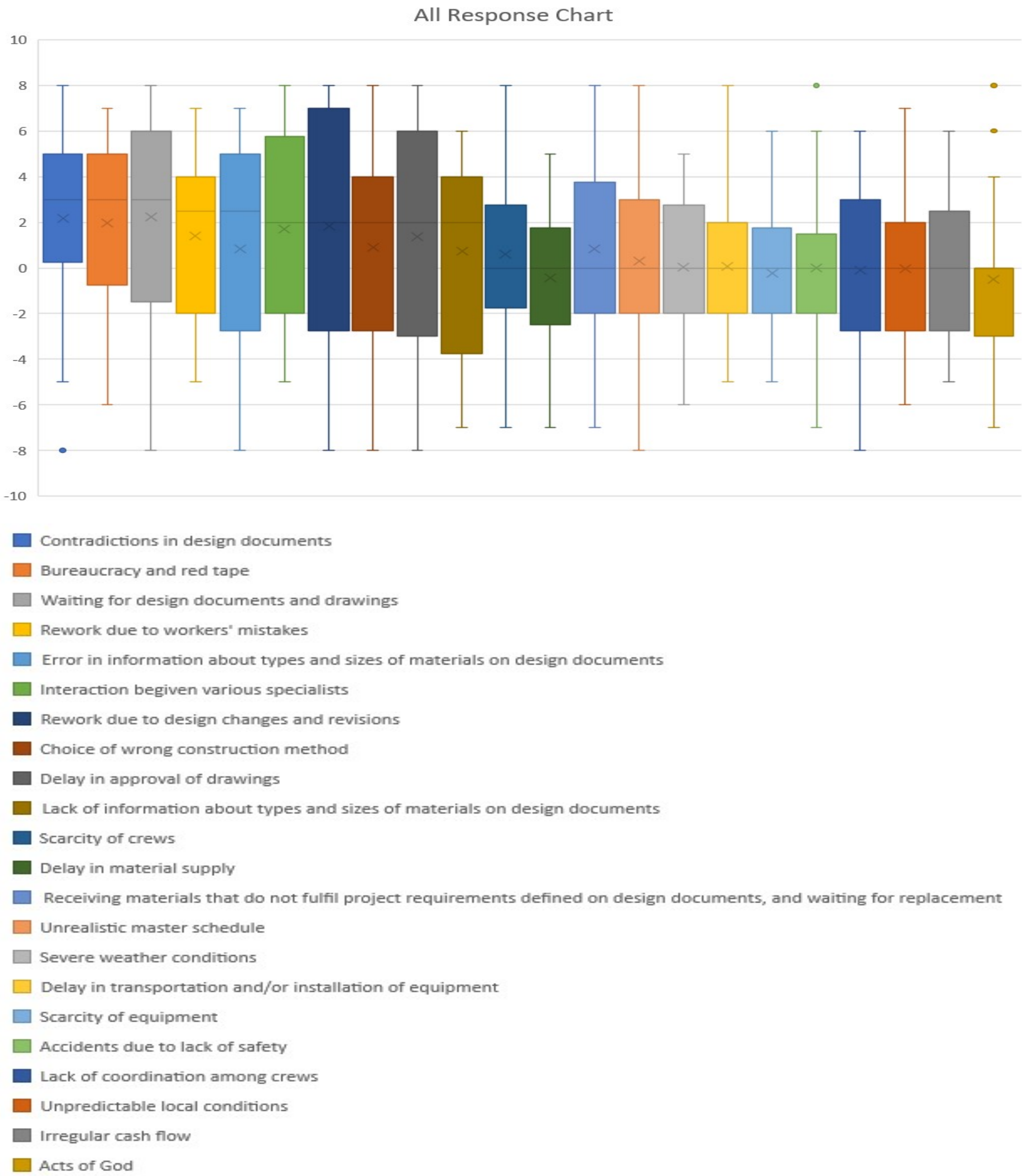

Figure 4: Summary of all respondents

Larger boxes show higher level of variability. The Q2 line always being at or above zero re-iterates the previous interpretation. However, there are some peculiar observations.

Only one factor: "contradictions in design documents" had the middle majority safely above zero. This means, even for the nine factors which had higher level of a score for Traditional procurement method, at least a little portion of middle majority had paradoxical experience or opinion. For the complex context in this, this fact shall not be disregarded. Two other factors have median staying at 3, but one of them (waiting for design documents) has the middle 50% going lower than negative one. Twelve factors having their median at zero do have relatively a narrower inter quartile range indicating a comparatively a higher-level consistency. This also indicates that half of the respondents ranked equal or higher level of time waste for those 12 factors for design and build procurement method. Interestingly, time waste by Acts of God had been ranked equal of higher for design and build at least by 75% of the respondents. The middle majority of scores ranged from zero to negative three, while the median is still at zero indicating a significant skewness towards design and build.

5. CONCLUSIONS

The study was focused on the impact of procurement methods on construction time waste in the perspective of traditional procurement method and design and build method. Table 3 summarizes the generalized conclusion from the study where 22 time waste factors identified through literature are now identified along with the procurement method having higher level of time waste.

Table 3: Time waste factors how effect to the procurement

Source	Time waste factor	Procurement method with higher level of time waste
Design	Interaction begiven various specialists	Traditional
	Rework due to design changes and revisions	Traditional
	Lack of information about types and sizes of materials on design documents	Traditional
	Error in information about types and sizes of materials on design documents	Traditional
	Contradictions in design documents	Traditional
	Delay in approval of drawings	Traditional
Procurement	Delay in material supply	No difference
	Receiving materials that do not fulfil project requirements defined on design documents and waiting for replacement.	No difference
	Delay in transportation and/or installation of equipment	No difference
Operation	Scarcity of crews	No difference
	Unrealistic master schedule	No difference
	Rework due to workers' mistakes	Traditional
	Scarcity of equipment	No difference
	Waiting for design documents and drawings	Traditional
	Lack of coordination among crews	No difference
	Choice of wrong construction method	Traditional
	Accidents due to lack of safety	No difference
Other	Irregular cash flow	No difference
	Severe weather conditions	No difference
	Bureaucracy and red tape	Traditional

Source	Time waste factor	Procurement method with higher level of time waste
	Unpredictable local conditions	No difference
	Acts of God	No difference

According to the findings of the study, it can be concluded as time waste in traditional procurement in general is higher than design and build method. Factors related to procurement source are unlikely to cause higher level of time waste in either method while all design related factors have higher level of time waste in traditional method in general. A few operations related and other factors would also cause higher level of time waste in traditional procurement method. Design and build method in general would not incur higher level of time waste through any source identified. While acknowledging that this is the generalized conclusion, study identified that there was a large minority who found comparatively a higher level of time waste in design and build method almost under all factors.

On a final remark, from time waste point of view, the choice of procurement method is design and build method. That is, a client who choses design and build method by considering other factors, does not require to be concerned about time waste levels against traditional method. On the other hand, a client who choses traditional method must focus on the above identified sources to judge how much of cost they would bring compared to the benefits identified against the design and build method. Nevertheless, possibility of paradoxical reality should not be disregarded as observed in findings. Such outcomes are not rare due to the complex nature of construction projects procurement.

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THE ROLE OF QUANTITY SURVEYORS FOR THE SUCCESS OF SMALL-SCALE CONSTRUCTION PROJECTS IN SRI LANKA

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ABSTRACT

Several small-scale construction projects are being implemented around the country being a part of development process in Sri Lanka. Most of the Quantity Surveying related areas has become major problem making subjects in those projects and there is lack of involvement of the Quantity Surveyors in those projects when comparing with other professionals in the industry. This research was conducted to highlight the importance of involvement of Quantity Surveyors for success of such projects in Sri Lankan construction industry. Mixed-method approach was used in this research. Most important Quantity Surveying roles that directly impact for the success of small-scale construction projects were determined and categorized under the different stages of construction projects by using semi-structured interviews and questionnaire survey as primary data collection methods. These data were analyzed by using Correlation analysis and Relative Importance Index (RII) analysis as statistical analysis methods. Identified Quantity Surveying roles were ranked based on the impact on the success of those small-scale projects using RII values. Further Correlation analysis was performed to show the relationship between Quantity Surveyor's involvement and success of small-scale construction projects. Barriers for satisfactory involvement of Quantity Surveyors in small-scale construction projects and strategies to increase the involvement of Quantity Surveyors were identified by analyzing data from semi-structured interviews using manual content analysis. Among those barriers most of the interviewees stated that obtaining the service from non-professionals at lower cost was the major barrier and introducing service packages to the client in early stages of project was considered as the main strategy to increase the Quantity Surveyor's involvement to small-scale construction projects. However, the research was concluded that the involvement of client and contractor Quantity Surveyors to the pre-construction and post-construction phases are critical to the success of small-scale construction projects in Sri Lanka.

Keywords: *Construction Industry; Quantity Surveyor; Small-Scale Construction Projects.*

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1. INTRODUCTION

The construction industry is a key component and more significant industry of a country's economy (Lewis, 2004). The construction industry is considered to be one of the major contributors to the national economy (Ngai, et al., 2002). The construction industry plays a major role in producing wealth and improving the living standards of the people of a country (Illangakoon, 2017). Yogeshwaran, et al. (2018) emphasized that in the construction industry, the role of Quantity Surveyor has become one of the key professions. Furthermore, Olanrewaju and Anahve (2015) stated that in a construction project, Quantity Surveyor has become one of the leading profession in cost management, procurement process and the contractual matters throughout the project. According to Dada and Jagboro (2012), Quantity Surveyors should involve in construction projects in pre-construction, construction and post construction stages.

Nkado and Meyer (2001) emphasized that Quantity Surveyors are contributing to the overall performance of the construction projects. According to Perera, et al. (2007), Quantity Surveyor needs to engage in construction industry as a profession who’s scope is more than taking off the quantities. Hwang, Zhao and Toh (2014) emphasized that there is a lack of consensus on the definition of the small-scale construction projects. Further it stated that identification of small scale construction projects was done based on the schedule and project cost. Illangakoon (2017) defined the small-scale construction projects which are undergone according to the Construction Industry Development Authority/Standard Bidding Document/03 (CIDA/SBD/03) guideline. Most of the time the clients of the small scale construction projects inaccurately presumed that the Quantity Surveyor's services are limited to the large scale construction projects and that Quantity Surveyor's services are not called when constructing or developing small scale projects (Visser, 2009).

Bremer, et al. (2019) emphasized that clients of residential construction projects have not proper idea about the role of the Quantity Surveyor. According to the Dasanayaka (2019), small scale construction projects need to identify their cash flow issues and suggest some strategies to stabilize them. Poor Quantity Surveying practices in small-scale construction projects is one of the main reasons to reduce their improvements (Weerakoon, et al., 2020). As per the existing literature, the proper Quantity Surveying practices are lacking in the small-scale construction projects in Sri Lanka. Therefore, for the success of those projects Quantity Surveyors needs to be involved in small scale construction projects. Therefore, this study aims to increase the involvement of the Quantity Surveyors to success of small-scale construction projects in Sri Lanka. Accordingly research has four objectives such as defining Quantity Surveyor’s role in small scale construction projects in Sri Lanka, investigating relationship between the involvement of Quantity Surveyors and success of small-scale construction projects in Sri Lanka, identifying barriers for satisfactory involvement of Quantity Surveyors in small-scale construction projects in Sri Lanka and strategies to increase the involvement of Quantity Surveyors in small scale construction projects in Sri Lanka.

2. LITERATURE SYNTHESIS

The construction industry is a highly reactive and dynamic industry (Lewis, 2004). The worldwide construction industry has several common features and some specific features may be similar among developing countries (Olawale and Sun, 2010). Yogeshwaran, et al. (2018) mentioned, Sri Lanka's current construction industry is seriously affecting the country's Gross Domestic Product (GDP) with the development of expressways, high-rise commercial buildings and real estate developments. Due to current practices of construction industry and industrial complexes, many difficulties arise in the construction industry and require advanced management practices and skills (Koutsikouri, et al., 2008). Moreover, small scale construction projects face serious financial and management issues, which can lead to failures of such projects (Dasanayaka, 2019). The performance of Quantity Surveyors in small scale construction projects in Sri Lanka has not yet reached up to the standards due to various circumstances (Weerakoon, et al., 2020). Therefore, there are lot of poor QS practices in the small-scale projects in the construction industry in Sri Lanka.

2.1 QUANTITY SURVEYOR'S ROLE IN THE CONSTRUCTION INDUSTRY

Quantity Surveyor is one of the key profession in the construction industry and Quantity Surveyor is considered as the construction economist or cost manager who is trained to manage construction cost of projects (Shafiei and Said, 2008). According to Badu and Amoah (2004), Quantity Surveyor is considered to be a person who has the knowledge to successfully analyze both construction work and cost components of a project, as well as to apply his experience to the cost related matters in contruction projects. In Sri Lanka, the Institute of Quantity Surveyors of Sri Lanka (IQSSL) is the main institute governing the Quantity Surveying profession (Yogeshwaran, et al., 2014). According to Yogeshwaran, et al. (2018) in Sri Lankan context, IQSSL, Australian Institute of Quantity Surveyors (AIQS), Royal Institution of Chartered Surveyors (RICS) and Pacific Association of Quantity Surveyors (PAQS) are the governing, interacting and influential professional bodies for Quantity Surveyors professions. Commonly in the construction industry, Quantity Surveyors are working for the client or contractor (Shafiei and Said, 2008). Moreover, Towey (2012) also categorized the Quantity Surveyor profession into the contractor's Quantity Surveyor and client's Quantity Surveyors and identified their different roles and responsibilities. Table 1 represents the identified roles of client's Quantity Surveyor from existing literature.

Table 1: Roles of Client's Quantity Surveyor

Roles for Client's Quantity Surveyor	References			
	E	F	G	H
Feasibility studies, estimating and Preliminary cost advising	✓	✓		✓
Evaluation of tenders	✓	✓		
Guidance for contractual matters	✓	✓		✓
Preparation of Bill of Quantities (BOQ)	✓	✓		
Advising on selection of contractors	✓	✓		
Contract Administration		✓	✓	
Attending to the join measurements		✓		
Assist to construction works	✓		✓	
Preparation of statements for taxes and other expenses	✓			
Preparation of cash flow forecasting and financial reports	✓	✓		✓

Roles for Client's Quantity Surveyor	References			
	E	F	G	H
Evaluate the payment applications	✓	✓		✓
Evaluate the sub contractor's payments	✓		✓	
Provide expert advice on industrial conflicts using the process of arbitration, adjudication and legal dispute process (Dispute resolution)	✓		✓	
Evaluating or arguing with contractual claims	✓	✓	✓	✓
Evaluate the final payments	✓			

Sources: A: Said, et al. (2010), B: Visser (2009), C: Chandramohan, et al. (2020), D: Bremer, et al. (2019).

Table 2 represents the identified roles of contractor's Quantity Surveyor from existing literature.

Table 2: Roles for Contractor's Quantity Surveyor

Roles for Contractor's Quantity Surveyor	References			
	A	B	C	D
Preparation of tender documents	✓	✓	✓	
Advising for procurement	✓	✓	✓	✓
Pricing the BOQ	✓	✓	✓	
Payment application preparations	✓	✓	✓	
Evaluating the required preliminaries	✓		✓	
Determining the variance of change from designer or client	✓		✓	✓
Assisting in the selection of Subcontractors	✓		✓	✓
Valuing the payment to subcontractors	✓		✓	✓
Preparation of cash flow forecasts and financial reports	✓		✓	✓
Preparing and updating the usage of company plant and material	✓		✓	✓
Evaluation of labour cost	✓		✓	
Project programming and planning		✓	✓	✓
Attending to the joint measurement process	✓	✓		
Preparing the claims according to contract	✓	✓	✓	✓
Dispute Resolution			✓	✓
Contract Administration			✓	✓
Building Information Management			✓	✓
Cost Advising			✓	✓
Final payment application preparation	✓		✓	
Risk Management	✓			
Taxation advice				✓

Sources: E: Cornick and Osbon (1994), F: Ashworth, et al. (2013), G: Weerakoon, et al. (2020), H: Chandramohan, et al. (2020)

2.2 SMALL-SCALE CONSTRUCTION PROJECTS

In the literature, there is no solidarity definition for the small-scale projects. The project duration is less than or equal to 14 months are known as small scale construction projects (Liang, 2005). Illangakoon (2017) emphasized that, the small-scale construction project can be defined as the construction projects carried out in accordance with CIDA/SBD/03 guideline. However Hwang, et al. (2014) emphasized that definition for the small-scale construction projects can be discussed by referring to the project cost and time. Therefore, it would be a good definition if there is any definition that covers the project size, project duration as well as the contract price. With reference to the existing literature, if a project has one or more characteristics such as carried out in accordance with CIDA/SBD/03 guideline, initial contract value up to 10 million Sri Lankan Rupee (LKR) and project duration is less than or equal to 14 months will be considered as small-scale construction projects in Sri Lanka.

2.3 SUCCESS OF THE CONSTRUCTION PROJECTS

Dasanayaka (2019) emphasized that there are different definitions and meanings for success of the projects and generally success means the measurements of achievement of targets and expectations. When considering the success of a construction project, it can be identified as a goal which is associated with time, quality and cost as the main three pillars (Chan, et al., 2002). Moreover, if the project is not completed in terms of time, cost and quality it can be identified as an unsuccessful project (Larsen, et al., 2016). Further Silva, Warnakulasooriya and Arachchige (2015) highlighted time, cost and quality as three efficiency dimensions for the success of the construction projects.

2.4 BARRIERS FOR QUANTITY SURVEYORS TO INVOLVE IN SMALL-SCALE CONSTRUCTION PROJECTS

Bremer, et al. (2019) stated that there are several reasons for the drop of Quantity Surveyor intervention for small-scale projects specially in small residential and housing projects. Accordingly, authors noted that the clients of those projects are completely unaware about the service and fees of the Quantity Surveyors. Furthermore, the authors pointed out that, those project clients have misunderstood about the fact that QS scope can be cover-up by other professionals or by themselves. According to Visser (2009), clients are erroneously assuming that Quantity Surveyor fees, which are considered too high and also believed that QS services are only needed for large projects. Therefore, clients of small-scale construction projects have not clear idea of the Quantity Surveyor's role, services and their fees. According to Weerakoon, et al. (2020), if the clients make timely payments to the contractors without any delays, contractors can maintain a stable cash flows and then they can hire competent Quantity Surveyors for the construction projects. Moreover, authors stated that lack of project conditions on the recruitment of qualified individuals to small scale projects, which could impair the performance of the Quantity Surveyors. Bremer, et al. (2019) emphasized that, Quantity Surveyors have capable skills and competencies to manage time, cost, and quality. According to Rensburg and Albertus (2010), construction projects require a professional person with the ability to manage cost, time and quality parameters. Moreover, authors highlighted that to manage the cost overruns and ensure the work quality of projects, Quantity Surveyors are the most appropriate professionals. Furthermore, authors elaborated the above statement in their research with refer to the other professions such as Project Managers, Architects, and Engineers by using following bar chart represented in Figure 1.

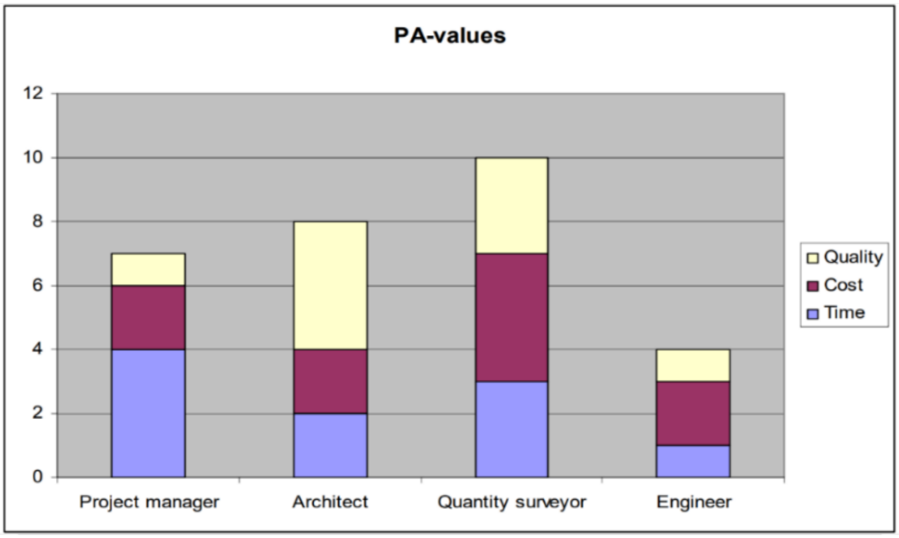

Figure 1: Principal agent values for each profession

Source: Rensburg and Albertus (2010)

Visser (2009) stated that, a Quantity Surveyor can make required guidance and professional assistance specially in cost management of small-scale construction projects. However, Weerakoon, et al. (2020) mentioned that in Sri Lankan construction industry, performance of small-scale construction projects are not in a satisfactory level. Bremer, et al. (2019) proved that, there will be an increase of the performance of cost, quality and time of small-scale construction projects once after involvement of Quantity Surveyors as a principal agent. Therefore, there is a requirement to increase the involvement of Quantity Surveyors in small scale construction projects in Sri Lanka. Further findings of this research will open up some job opportunities for Quantity Surveyors in small-scale construction projects in Sri Lanka.

3. RESEARCH METHODOLOGY

3.1 RESEARCH APPROACH

Mixed approach is a systematic integration of quantitative and qualitative methods in a single study for the purposes of obtaining a complete picture and deeper understanding of the phenomenon (Johnson, et al., 2007). Amaratunga, et al. (2002) emphasized that experimental accuracy, reliability and quality of research are often improved and that potential risks can be avoided when using the mixed method instead of a qualitative and quantitative methods. Quantitative method was used to investigate the relationship between the involvement of QSs and success of small-scale construction projects and qualitative method was used to identify the barriers and strategies for satisfactory involvement of QSs in small-scale construction projects. Thus, in order to collect both quantitative and qualitative data, mixed approach was used for this research.

3.2 DATA COLLECTION

A comprehensive literature synthesis was carried out to collect secondary data to identify the Quantity Surveyor's role in construction projects as listed in above table 1 and 2.

Thereafter Quantity Surveyor's role was defined to the small-scale construction projects in Sri Lankan context through semi structured interviews as primary data collection. Further, those semi-structured interviews were conducted to identify barriers for satisfactory involvement of Quantity Surveyors in small-scale construction projects in Sri Lanka and strategies to increase the involvement of Quantity Surveyors in small scale construction projects in Sri Lanka. Interviews were conducted as online face to face meetings through zoom and Google meet applications with duration of 30-45 minutes. The sample was selected grounded on the population of graduate Quantity Surveyors with more than 10 years of experience and 10 interviewees were selected as the sample by using purposive sampling technique. Table 3 is representing the details of interviewee sample.

Table 3: Summary of interviewee sample

Respondent Code	Service Type	Industry Experience (Years)	Profession
P1	Client/ Contractor	18	Chartered QS
P2	Client	16	Chartered QS
P3	Contractor	15	Chartered QS
P4	Contractor	12	Senior QS
P5	Contractor	13	Senior QS
P6	Client/ Contractor	17	Senior QS
P7	Client	12	Senior QS
P8	Client/ Contractor	18	Chartered QS
P9	Client/ Contractor	11	Senior QS
P10	Contractor	11	Senior QS

Then questionnaire survey was conducted as the other secondary data collection method to investigate the relationship between the involvement of Quantity Surveyors and success of small-scale construction projects in Sri Lanka. Thus, considering the time limitations, this was designed as a web-based questionnaire survey through Google forms and delivered the link through the email platforms. For this questionnaire survey, 50 respondents were selected as the sample by using simple random sampling. Table 4 emphasizes the summary of primary data collection methods for this study.

Table 4: Summary of population and sample for primary data collection

Data Collection Method	Population	Sample	Sample Technique	Covered Objectives
Semi Structured Interviews	Graduate Quantity Surveyors in Sri Lanka	10	Purposive Sampling	Objective 01, 03 and 04
Questionnaire Survey	Quantity Surveyors, Civil Engineers and Architects	50	Simple Random Sampling	Objective 02

3.3 DATA ANALYSIS

Secondary data collected from semi structured interviews were subjected to comprehensive manual content analysis (frequency analysis). Questionnaire survey data was analyzed through RII analysis and Correlation analysis by using SPSS software. Correlation analysis was used to identify the relationship between the involvement of

Quantity Surveyors and success of small-scale construction projects in Sri Lanka as dependent variable and the independent variable. Lim and Ting (2013) emphasized that the respondent's rated factors could be graded accurately using RII. Accordingly, based on the RII, Quantity Surveying roles have been identified that have the greatest impact on the success of small-scale construction projects in Sri Lanka. In here 1-5 likert scale was used in questionnaire survey where 1-very unimportant, 2-unimportant, 3-neutral, 4-important and 5-very important. Following Eq. 01 is the RII equation (Gunduz et al., 2013) which was used for analysis.

$$\text{RII} = \frac{\sum_{i=1}^{n} wi\ xi}{A * \sum_{i=1}^{n} xi} \qquad \textit{(Eq. 01)}$$

Where, wi = Allocated weight for factors (for this study i = 1, 2, 3, 4, 5); xi = Number of respondents in each scale; and A = Highest weight (for this study i = 5)

4. RESEARCH FINDINGS AND DISCUSSION

4.1 RESPONDENT PROFILE

Table 5 represents the number and percentages of respondents of questionnaire survey and overall respond rate was around 90%. Out of all respondents, 47% are Quantity Surveyors, 38% are Civil Engineers and 15% are Architects. This is represented by Figure 2.

Table 5: Percentage of respondents in questionnaire survey

Profession	No of Respondents	Percentage
Quantity Surveyors	21	47%
Civil Engineers	17	38%
Architect	7	15%

Figure 3 is representing the respondent work experience. The highest number of responses were collected from the professionals who have 5-10 years of experience and the percentage is 40%.

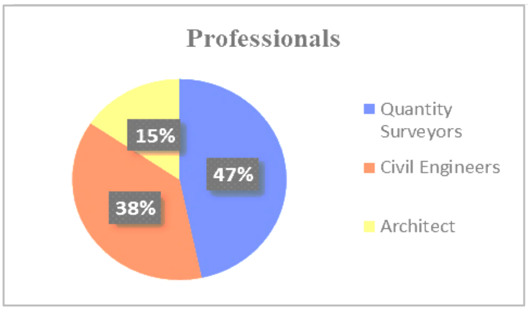

Figure 2: Percentage of respondents

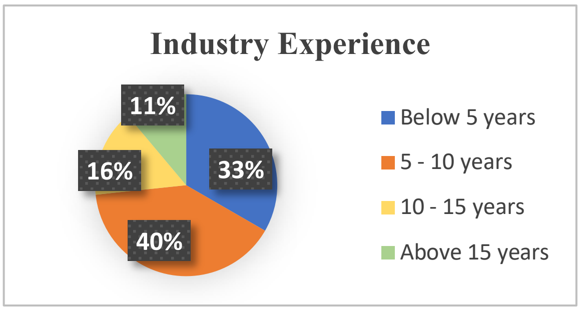

Figure 3: Respondents work experience

4.2 QUANTITY SURVEYOR'S ROLE IN SMALL-SCALE CONSTRUCTION PROJECTS IN SRI LANKA

Based on the existing literature, roles of client's Quantity Surveyors and contractor Quantity Surveyors were defined in the literature synthesis as listed in Tables 1 and 2. Table 6 shows the identified roles of client's Quantity Surveyors and contractor's

Quantity Surveyors which are the most important roles for small-scale construction projects in Sri Lanka with their frequencies. Frequency means the number of interviewees who identified each role as important for success of small-scale construction projects. These roles were further divided to stages of construction projects as given in Table 6.

Table 6: Most important roles for Client's and Contractor's Quantity Surveyors in small-scale construction projects in Sri Lanka

Stage	Role for Client's Quantity Surveyor	Frequency	Role for Contractor's Quantity Surveyor	Frequency
Pre-construction stage	Preparation of BOQ for client	8	Preparation of tender documents	6
	Advising on selection of a contractor	7	Pricing the BOQ	8
	Contract Administration	6	Assisting in the selection of Subcontractors	7
			Contract Administration	8
Construction stage	Evaluate the payment applications	9	Payment application preparations	9
	Preparation of cash flow forecasting and financial reports	8	Valuing the payment to subcontractors	7
	Attending to the join measurements	8	Preparation of cash flow forecasts and financial reports	7
	Evaluate the sub contractor's payments	7	Attending to the joint measurement process	8
	Dispute resolutions in construction stage	6	Project programming and planning	7
			Dispute Resolution in construction stage	6
Post construction stage	Evaluate the final payment applications	8	Final payment application preparations	9
	Evaluating or arguing with contractual claims	7	Preparing the claims according to contract	7
	Dispute resolutions in post construction stage	7	Dispute Resolution in post construction stage	7
			Valuing the payment to subcontractors	6

4.3 RELATIONSHIP BETWEEN THE INVOLVEMENT OF QUANTITY SURVEYORS AND SUCCESS OF SMALL-SCALE CONSTRUCTION PROJECT IN SRI LANKA

The most important roles of Quantity Surveyors that will highly influence for the success of small-scale construction projects in Sri Lanka were determined through the questionnaire survey. Table 7 shows the most important QS roles of contractor and client Quantity Surveyors for success of small-scale construction project in Sri Lanka with their RII values and rankings. Accordingly, contract administration, preparation of BOQ, payment application preparations, evaluate payment applications, final payment application preparations and evaluate final payment applications were identified as the most important contractor and client QS roles respectively in pre-construction stage, construction stage and post construction stage.

Table 7: Most important roles which influence to the success of small-scale construction projects

Stage	Contractor's QS Role			Client's QS Role		
	Role	RII	Rank	Role	RII	Rank
Pre-Construction stage	Contract Administration	0.9111	1	Preparation of BOQ for client	0.8933	1
	Pricing the BOQ	0.8889	2	Contract Administration	0.8889	2
	Assisting in the selection of subcontractors	0.8844	3	Advising on selection of a contractor	0.8844	3
	Preparation of tender documents	0.8711	4			
Construction stage	Payment application preparations	0.8978	1	Evaluate the payment applications	0.8933	1
	Attending to the joint measurement process	0.8933	2	Preparation of cash flow forecasting and financial reports	0.8889	2
	Preparation of cash flow forecasts and financial reports	0.8889	3	Attending to the join measurements	0.8844	3
	Valuing the payment to subcontractors	0.8800	4	Dispute resolutions in construction stage	0.8800	4
	Project programming and planning	0.8756	5	Evaluate the sub contractor's payments	0.8756	5
	Dispute Resolution in construction stage	0.8711	6			
Post construction stage	Final Payment application preparations	0.8978	1	Evaluate the final payment applications	0.8933	1
	Valuing the payment to subcontractors	0.8933	2	Evaluating or arguing with contractual claims	0.8889	2
	Preparing the claims according to contract	0.8844	3	Dispute Resolutions in post construction stage	0.8756	3
	Dispute Resolution in post construction stage	0.8800	4			

Further, as per Table 8, all the independent variables (IV) have strong relationships with the success of the small-scale construction projects (dependent variable). Among those independent variables IV1, IV4 and IV5 obtained strong Correlation with the dependent variable and Correlation values are 0.517, 0.612 and 0.575. Thus, the contractor's Quantity Surveyor involvement in the pre-construction and the post construction stages have a strong relationship with the success of the small-scale construction project in Sri Lanka. Moreover, the client's Quantity Surveyor involvement in the construction stage has a strong relationship with the success of the small-scale construction project in Sri Lanka.

Table 8: Results of correlations analysis

Independent Variables	Sig. Value	Pearson Correlation
Contractor's Quantity Surveyor involvement in the pre-construction stage (IV1)	0.000	0.517
Client's Quantity Surveyor involvement in the pre-construction stage (IV2)	0.030	0.324

Independent Variables	Sig. Value	Pearson Correlation
Contractor's Quantity Surveyor involvement in the construction stage (IV3)	0.020	0.345
Client's Quantity Surveyor involvement in the construction stage (IV4)	0.000	0.612
Contractor's Quantity Surveyor involvement in the post construction stage (IV5)	0.000	0.575
Client's Quantity Surveyor involvement in the post construction stage (IV6)	0.040	0.308

4.4 BARRIERS FOR SATISFACTORY INVOLVEMENT OF QUANTITY SURVEYORS IN SMALL-SCALE CONSTRUCTION PROJECTS IN SRI LANKA

Table 9 shows the identified barriers for satisfactory involvement of Quantity Surveyors in small-scale construction projects in Sri Lanka which were identified through semi structured interviews.

Table 9: Barriers for satisfactory involvement of QSs in small scale construction projects

Barriers	Interviewee Code										Frequency
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	
Client's less awareness about the Quantity Surveyor's roles in the construction projects	✓	✓	✓	✓		✓		✓		✓	7
Client's less awareness about the Quantity Surveyor's fees		✓		✓	✓	✓		✓	✓	✓	7
Contractor's cash flow issues	✓	✓		✓	✓	✓	✓		✓	✓	8
Obtaining services from non-professionals at low cost	✓	✓	✓	✓	✓	✓	✓		✓	✓	9
Lack of legal influence to obtain services from non-professionals	✓	✓	✓		✓		✓	✓	✓		7

Out of 10 interviewees 9 interviewees stated that, most of the time in the industry there are non-professionals who having lack of knowledge about the construction industry and do some Quantity Surveying related works at low charge. Interviewee P_1 stated that, some person in the industry are preparing and pricing the BOQ but they haven't any qualifications at least certificate levels or diplomas. Furthermore, P_1 pointed out, as a result most of the time clients cannot manage the project cost when using such kind of erroneous estimates. P_2 emphasized that, most of the time clients of small-scale projects need to prepare the BOQ only to get approve their bank loans and they haven't any idea about the purpose of the BOQ and other contract documentation. Interviewees P_4 and P_6 stated that many of the clients in small-scale construction projects are known only to Civil Engineers and Architects as professionals in the industry. P_{10} stated that small-scale construction projects have some fear of hiring professionals with their fluctuating cash flows.

4.5 STRATEGIES TO INCREASE THE INVOLVEMENT OF QUANTITY SURVEYORS IN SMALL-SCALE CONSTRUCTION PROJECTS IN SRI LANKA

Table 10 shows the strategies to increase the involvement of the Quantity Surveyors for small scale construction projects in Sri Lanka which were identified through semi structured interviews.

Table 10: Strategies to increase the Involvement of QSs in small scale construction projects

Strategies	Interviewee Code										Frequency
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	
Introduce service packages to the client in early stages of the projects	✓	✓	✓	✓		✓	✓	✓	✓	✓	9
Working as a freelance Quantity Surveyor		✓		✓	✓	✓		✓	✓	✓	7
Charge according to the percentage of the contract as a contractor's QS	✓	✓		✓	✓	✓	✓		✓	✓	8
Influencing professional bodies and the government to introduce legal backgrounds for professions		✓	✓	✓	✓		✓		✓	✓	7

Out of 10 interviewees, 9 stated that the Quantity Surveyors should introduce a service packages for small scale construction projects. In this service packages, client/lead consultant will request required QS services for the project and payment will be done as per the scope of services and totally for the project. (E.g.: 1 lakh or 1.5 lakh for total project). Interviewee P_1 emphasized that Quantity Surveyors should act as a client agent to manage designer and contractor selection for small scale construction projects. Interviewee P_3 stated that if the Quantity Surveyor could introduce himself to the project before other professionals, the Quantity Surveyor could find the management role in such projects. P_{10} emphasized that if contractors maintain good quality in the industry in recruiting professionals, they have more opportunities to get more projects. Seven interviewees emphasized the need for a proper legal background for small-scale projects in Sri Lanka and P_4 suggested that certain legal requirements should be introduced from professional bodies and government for such projects. Further interviewees P_8 and P_9 emphasized that Quantity Surveyors can introduce their service through modern digital platforms such as Fiverr, Freelancer and Houzz. Moreover, the interviewees highlighted and recommended to use software such as planswift, iTWO costX, Cubicost, Autodesk Revit, Sweet home 3D and SketchUp to offer QS services through digital platforms as new diversified area of the modern Quantity Surveying.

4.6 DISCUSSION

Based on the above results of the study, 14 roles were identified for contractor's Quantity Surveyors and 11 roles for client's Quantity Surveyor in the small-scale construction projects in Sri Lanka. Therefore, the most important roles are available for the contractor's party. Further, the significance levels of IV1, IV2, IV3, IV4, IV5 and IV6 were under 0.050. Thus, there are strong Correlations between each independent variable and dependent variable which can be concluded that, QS role directly affects to the success of small scale projects in Sri Lanka. Further, Weerakoon, et al. (2020) noted that the contractor's cash flow issue led to a reduction in the Quantity Surveyor's involvement in small-scale construction projects which was mentioned by 9 interviewees out of 10 in this study. Introducing service packages to the clients in the early stages of the projects is the most common strategy obtained at the higher frequency level (9 responses) to increase the involvement of the Quantity Surveyor in small scale construction projects in Sri Lanka. Bremer, et al. (2019) also argued that if the Quantity Surveyor could be involved in the early stages of the project, it would be a strong basis for engaging in small-scale projects such as housing projects. Moreover, Quantity Surveyors can offer their services in the digital platforms using software such as planswift, iTWO costX, Cubiccost, Sweet home 3D and SketchUp which is good sign for future of Quantity Surveying with few additional competencies.

5. CONCLUSIONS AND RECOMMENDATIONS

There were 14 number of important contractor's Quantity Surveyor's roles and 11 number of client's Quantity Surveyor's roles identified for small scale construction projects in Sri Lanka. The Correlation analysis result stated that all the variables has a direct relationship with the success of the small-scale construction projects and among that, involvement of contractor's Quantity Surveyor in the pre-construction stage and post construction stage has a strong relationship with success of the small-scale construction projects in Sri Lanka. Contract administration, payment application preparations and final payment application preparation have been identified as the highest RII value roles for the contractor's Quantity Surveyor during the pre-construction stage, construction stage and post-construction stage respectively. Moreover, preparation of BOQs, evaluating payment applications and evaluating final payments have been identified as the highest RII value roles for client's Quantity Surveyor. Further, obtaining services from non-professionals at low cost and contractor's cash flow issues were identified as the main barriers for satisfactory involvement of Quantity Surveyors in a small-scale construction projects. Introducing service packages to the client in early stages of the projects and charging according to the percentage of the contract sum as contractor's QSs can be emphasized as strategies to increase the involvement of the Quantity Surveyors in small scale construction projects in Sri Lanka. Furthermore, interviewees further highlighted that Quantity Surveyor can be involved in small-scale construction projects as a freelance Quantity Surveyors using digital platforms and modern software. The involvement as a contractor's Quantity Surveyor to the pre-construction and post-construction stages are critical to the success of small-scale construction projects. From the contractor's point of view, the contract percentage-based fee system is a better strategy to get the services of a Quantity Surveyors than by recruiting for permanent jobs.

This study was focused only the small-scale building construction projects in Sri Lankan context as the limitation. Furthermore, the definition used for small-scale construction projects may vary depending on price fluctuations and the economy of the country. For future studies, identifying additional competencies required to perform as a Quantity Surveyors for the success of small-scale construction projects can be recommended.

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THE ROLE OF THE QUANTITY SURVEYOR IN ACHIEVING CIRCULAR BUILT ENVIRONMENT AT THE DESIGN STAGE

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ABSTRACT

The construction industry is becoming more circular by reducing waste, reusing building materials, and embracing regenerative solutions for energy generation and biodiversity conservation. The ramifications of circularity on building operations are complicated, necessitating a comprehensive assessment of the consequences before deciding on the best course of action. In addition, professionals need to perform diversified services in achieving Circular Built Environment (CBE). Thus, the investigation of the involvement of Quantity Surveyors (QSs) with the CBE is important in achieving the CBE during the Design stage. Hence, the study aimed at investigating the role of QSs in achieving a CBE. The research apprehends a qualitative approach inclusive of two expert interview rounds adhering to the Delphi technique and manual content analysis for data analysis. The research findings revealed the important roles of QS in achieving CBE at the Design stage. Accordingly, cost control, cost planning, feasibility studies, measurement and quantification, risk management, value engineering and innovations and technologies were highly agreed upon by the majority of interviewees as important roles of QS during the Design stage.

Keywords: *Circular Built Environment (CBE); Design Stage; Important Roles; Quantity Surveyor (QS).*

1. INTRODUCTION

The Circular Economy (CE) is a philosophy that aims to alter current consumption and output trends that are putting a tremendous strain on the earth and its environmental capability (Spreafico and Landi, 2022). It has been extensively reviewed throughout the world as an alternative to the old economic model, namely, "purchase, consumption and dispose", as well as a solution to the complication of efficient use of resources and environmental pollution (Adi and Wibowo, 2020). The CBE is considered a key sector in CE where its strategies can be implemented (Egemose, et al., 2022).

CE in the built environment is easier to achieve (Stephan and Athanassiadis, 2018) by involving professionals to develop the incentive to create circular construction goods (Chang and Hsieh, 2019). Professionals in the built environment are now confronted with

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the difficult task of comprehending and transforming strategic sustainability goals into sound project-specific actions (Adams, et al., 2017). In addition, Buren et al. (2016) stated that professionals play a significant role in the CBE. Olanrewaju and Anahve (2015) have found architects, structural engineers, civil engineers, service engineers and quantity surveyors as the key professionals in construction projects. Professional Quantity Surveyor (QS) is a key domain of managing the cost of a project (Thayaparan, et al., 2011). Chamikara, et al. (2020) have defined a QS as a person who plays an expert role in the construction industry to uplift the sustainable approach. QS contributes greatly to adapting to those changes in CBE. Hence, it is important to investigate the QS's role in the sustainable development of the built environment (Yogeshwaran, et al., 2018). Among the seven stages of a building's life cycle (Foster, 2020), Design stage and Building Material Sourcing stage are considered the most crucial stages of the lifecycle of a building. The effectiveness and efficiency of the Design stage can significantly impact processes such as manufacturing that occur downstream in the product development process (Wijewansha, et al., 2021). Hence, this study aims to investigate the role of QS in achieving a CBE at the Design stage.

2. LITERATURE REVIEW

2.1 CIRCULAR BUILT ENVIRONMENT

CE is a way of replacing the end-of-life concept with an economic system that promotes resource reuse, alternately minimising, recovering, and recycling in construction distribution, production, and consuming processes (Kirchherr, et al., 2017). The popularisation of the concept of CE, along with the sustainability trend in the construction industry, motivate conducting studies on recycling and reusing waste streams included in the reprocessed aggregate (Geissdoerfer, et al., 2017). Furthermore, when building materials and components are no longer needed for the intended use, they are deemed as waste, hastening destructions to the ecosystem, increasing environmental costs, and generating resource scarcity. The construction industry is linked to demolition and end-of-life activities and operations. According to Nuñez-Cacho, et al. (2018), due to the high environmental impact of construction waste and demolitions, the construction industry needs to pay more attention towards optimising its resource consumption. The concept of CE can help mitigate the environmental impact of construction (Ghisellini, et al., 2018).

Construction professionals are the people who contribute to addressing the issue related to sustainable construction by designing, building, and operating facilities to create a sustainable built environment (Kibert, 2007). Thus, construction professionals play a pivotal role in achieving CBE. Among the many professionals, QSs play a significant role in making construction projects more feasible by utilising cost-effective ways while improving the worth of the final product (Chamikara, et al., 2020).

2.2 ROLES OF PROFESSIONAL QUANTITY SURVEYOR

Quantity surveying is a synthesis of several disciplines, including construction technology, computer technology, economics, law, and management, and many others (Panojan, et al., 2019). According to Dada and Jagboro (2015), the quantity surveying profession is no longer in its infancy. Several investigations and professional associations have explored the roles of QS in various ways. Table 1 illustrates the QS's roles which were identified from past studies.

Table 1: Roles of Quantity Surveyor identified by past studies

Roles of Quantity Surveyor	Researchers															
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Measurement and quantification	✓	✓	✓		✓	✓		✓	✓		✓	✓	✓			✓
Cost control	✓	✓	✓	✓		✓			✓	✓		✓		✓	✓	✓
Cost planning	✓	✓	✓	✓	✓		✓		✓				✓	✓		
Preparation of Bills of Quantities (BOQ)	✓	✓	✓	✓	✓			✓		✓		✓	✓	✓		
Final account preparation	✓	✓		✓	✓		✓	✓			✓	✓	✓		✓	
Feasibility studies		✓		✓			✓	✓		✓	✓	✓			✓	✓
Risk management	✓			✓			✓	✓	✓	✓			✓			
Arbitration	✓		✓			✓				✓				✓		
Value engineering	✓		✓		✓	✓	✓			✓			✓		✓	✓
Interim valuations and payments	✓	✓	✓		✓	✓		✓		✓		✓			✓	
Cost estimation	✓		✓			✓			✓			✓			✓	
Preliminary estimation	✓	✓	✓	✓				✓		✓				✓		
Tender process	✓		✓	✓				✓		✓		✓		✓		✓
Procurement advice		✓	✓			✓			✓		✓		✓		✓	
Settlement of contractual claims	✓	✓				✓	✓		✓				✓			✓
Contract documentation	✓			✓		✓		✓			✓				✓	
Contract administration	✓	✓		✓			✓	✓		✓	✓				✓	
Value management					✓			✓	✓	✓			✓	✓	✓	
Facility management					✓	✓	✓									✓
Building information services	✓		✓			✓				✓			✓			✓
Specification preparation		✓	✓			✓			✓		✓					✓
Project management		✓			✓	✓			✓							✓
Construction planning		✓	✓	✓	✓	✓			✓					✓		
Variation analysis	✓		✓		✓		✓		✓							
Negotiations on financial issues			✓				✓						✓			
Quantity management	✓	✓				✓				✓						
Adjudication	✓		✓		✓					✓		✓		✓		✓
Subcontract administration	✓	✓						✓			✓				✓	
Technical auditing			✓		✓		✓					✓		✓		✓
Building surveying		✓		✓		✓			✓				✓			
Examine priced BOQs				✓		✓		✓			✓			✓		
Financial reporting	✓		✓				✓					✓				
Administration's maintenance	✓		✓						✓				✓		✓	
Meditation	✓			✓			✓				✓			✓		✓
Insurance evaluation		✓				✓				✓			✓			✓
Life cost analysis	✓		✓			✓			✓						✓	
Insurance valuation		✓		✓				✓			✓				✓	

Roles of Quantity Surveyor	Researchers															
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Investment appraisal	✓			✓				✓			✓					✓
Programming		✓				✓				✓		✓				
Taxation advice			✓					✓					✓			
Due diligence reports		✓					✓		✓							✓
Premises audits				✓				✓				✓				
Insolvency services		✓					✓							✓		
Cost benefit analysis						✓					✓					✓
Private Finance Initiative (PFI) consultancy			✓										✓			
Cost modelling										✓			✓			
Post occupancy evaluation					✓	✓										
Planning and supervision			✓							✓				✓		
Sustainability advisor		✓						✓							✓	
Expert witness						✓										
Cost engineering services			✓				✓						✓			

A: Chandramohan, et al. (2018), B: Chamikara, et al. (2020), C: Yogeshwaran, et al. (2018), D: Salleh, et al. (2020), E: Olatunji, et al. (2010), F: Moyanga (2017), G: Wao and Flood (2016), H: Panojan, et al. (2019), I: Perera, et al. (2011), J: Thayaparan, et al. (2011), K: Pyung and Sungho (2018), L: Dada and Jagboro (2015), M: Oladotun and Edosa (2017), N: Olanrewaju and Anahve (2015), O: Shafiei and Said (2013), N: Sonson (2014), P: Xia, et al. (2016)

Due to the lack of literature findings specific to the roles of QS in CBE, literature findings related to the roles of QS in the built environment were extracted from the literature. According to Table 1, *'Measurement and quantification'*, *'Cost control'*, *'Cost planning'*, *'Bills of Quantities (BOQ)'*, *'Final account preparation'*, *'Feasibility studies'*, *'Risk management'*, are the roles of QS that were identified by the majority of the authors. Chamikara, et al. (2020) expressed that cost planning advises the client on how much the project cost will be. Also, cost planning will advise when the expected expenses will most possibly occur. Hence, it is important to get the required project finance and determine possible project profit. Therefore, the cost planning process is essential to the success of the project during the Design stage of the building. Furthermore, Yogeshwaran, et al. (2018) identified, '*Arbitration'*, *'Life cost analysis'*, *'Insurance valuation'*, *'Value engineering'*, *'Interim valuations and payments'*, *'Cost estimation'*, *'Preliminary estimation'*, *'Tender process'*, and *'Procurement advice'* as the key professional roles of a QS. According to Chamikara, et al. (2020), procurement advice is a key contractual role, and it helps enhance profitability by reducing superfluous expenses and minimise delays and speeding up the supply chain. Similarly, Rahla, et al. (2021) expressed that professionals and policymakers involved in the current practices related to the concept rarely take an innovative approach to ensure resource efficiency. The use of recycled products or forecasting recycling to the existing building stock does not comprehensively promote CE. The findings from the literature are in a generic form. However, the concept of CBE is far more different from the old linear growth model or linear economy of take, make, and discard of materials (Schroeder, et al., 2019). Thus, it is paramount to investigate the roles a QS have to achieve CBE, specially during the Design stage, as the Design stage will lay the foundation for other stages of a building's life to evolve.

2.3 IMPORTANCE OF INVESTIGATING ROLES REQUIRED BY THE QUANTITY SURVEYOR IN ACHIEVING CIRCULAR BUILT ENVIRONMENT AT THE DESIGN STAGE

The global population is rapidly increasing, creating challenges to the entire natural system and human existence (Ortiz, et al., 2009). As a result, demand for residential buildings, commercial buildings, civil structures, and infrastructure will rapidly start to rise. According to Ahmed, et al. (2009), buildings use more than 15% of global materials. Also, the Design stage is arguably the most important in the CBE because the employer wants to ensure that every decision being made will maximise the employer's investment. Janssens, et al. (2021) further ascertained that, in the CBE, many professionals are expected to provide a diversified service. QS plays a significant role in sustainability (Chamikara, et al., 2020) and waste handling. Thus, the investigation of the flexibility of QS's role and adaptation in the presence of dynamic changes in the CBE is critical to the survival of the CBE and its resistance to threats. Unless QSs are not qualified to detect the future direction and be aware of impending changes as the CBE emerges, they will face more challenges than opportunities. Although the current diversified roles of QS has been widely discussed in the literature (Thayapaan, et al., 2011; Dada and Jagboro, 2015; Jaafar, et al., 2016; Moyanga 2017; Chandramohan, et al., 2018; Yogeshwaran, et al., 2018; Panojan, et al., 2019; Chamikara, et al., 2020), attention on QS's role in achieving CBE is rarely seen. Thus, conducting research regarding the role of the quantity surveyor in achieving a CBE at the Design stage is an absolute necessity.

3. METHODOLOGY

The Delphi technique is well-received method of getting expert opinions on a certain knowledge area (Mansour, et al., 2020). It aims to obtain a consensus among a panel of experts on real-world issues that are often intangible (Gad and Shane, 2012). The Delphi qualitative method was chosen as the research approach for this study. Experienced QSs were selected in two rounds of the Delphi survey using purposive sampling. Purposive sampling allows the selection of knowledgeable and interested interviewees in the selected area of study (Etikan, 2016). Chartered QSs with extensive expertise in the construction sector, especially connected to CBE practices, were regarded to have the necessary capability to make a judgment on the application CE concept. Therefore, experienced professionals representing construction organisations were invited for the study. In addition, PhD candidates with a primary focus on the circular built environment research domain were invited as respondents for the study. As an outcome, the type of sample plugs in the research gap with viral data and experience-based solutions. Therefore, the Delphi qualitative method can benchmark the roles of QSs (Avella, 2016). Table 2 provides the profiles of the participants for both Delphi rounds.

When selecting the purposive sample, as per the criteria given in above Table 2, every expert must fulfil the above compulsory qualifications, and at least two additional qualifications must be fulfilled. A total of twelve (12) experts participated for the first Delphi round, while ten (10) experts provided their contributions to the second Delphi round. Expert panels with panel size ranging from six to twelve are considered best for

Delphi studies (Habibi, et al., 2014); thus, the selected panel sizes during both rounds were considered appropriate.

Table 2: Expert profiles

Coding	**Delphi Round 1**	**Delphi Round 2**	**Designation**	**Criteria**						
				Compulsory Qualification				**Additional Qualifications** (Satisfy at least three)		
				C1	**C2**	**Professional Experience** (Satisfy at least one)		**A1**	**A2**	**A3**
						C3	**C4**			
I.01	✓	✓	Senior Lecturer	✓	✓	✓		✓	✓	✓
I.02	✓	✓	PhD Candidate	✓	✓		✓			✓
I.03	✓	✓	Chief QS	✓	✓	✓	✓		✓	✓
I.04	✓	✓	PhD Candidate	✓	✓		✓			✓
I.05	✓	✓	Managing Director	✓	✓	✓		✓	✓	✓
I.06	✓	✓	Senior Lecturer	✓	✓	✓		✓		✓
I.07	✓	✓	Senior Lecturer	✓	✓	✓		✓		✓
I.08	✓	✓	Managing Director	✓	✓	✓		✓	✓	✓
I.09	✓	✓	Chief QS	✓	✓	✓			✓	✓
I.10	✓	✓	Director	✓	✓	✓		✓	✓	✓
I.11	✓		Chief QS	✓	✓	✓		✓	✓	✓
I.12	✓		Managing Director	✓	✓	✓		✓	✓	✓

Compulsory Qualification: C1 - Graduate in Quantity Surveying Discipline, C2 - Knowledge and Better Understanding of CBE, C3 - More than 10 years in the Construction Industry, C4 - PhD Candidate in a related area.

Additional Qualifications: A1 - A Postgraduate degree related to Construction Management, A2 - Corporate Member of a Quantity Surveying Professional Institution, A3 - Practical Experience/ Research Experience in CBE

4. RESEARCH FINDINGS

4.1 DELPHI ROUND 1 - QUANTITY SURVEYOR'S IMPORTANT ROLES IN CIRCULAR BUILT ENVIRONMENT

The main objective of the expert interviews was to evaluate the applicability of literature findings related to the roles of QS that can be used to achieve CBE. Initially, through the literature review, fifty-two (52) QS roles in the built environment were identified. During the Delphi Round 1, the respondents were requested to validate the identified roles QS for CBE. QS roles with an agreement percentage exceeding 80% were considered as important roles. At the end of Delphi Round 1, twenty-nine (29) important roles were identified out of 52 QS roles. In addition, three (3) important new roles were identified and are indicated in bold letters. Hence, thirty-two (32) important roles in achieving the CBE were identified as illustrated in Figure 1 and carried forward to the Delphi Round 2.

During the Delphi Round 2, the same question was iterated by the respondents to build up a consensus.

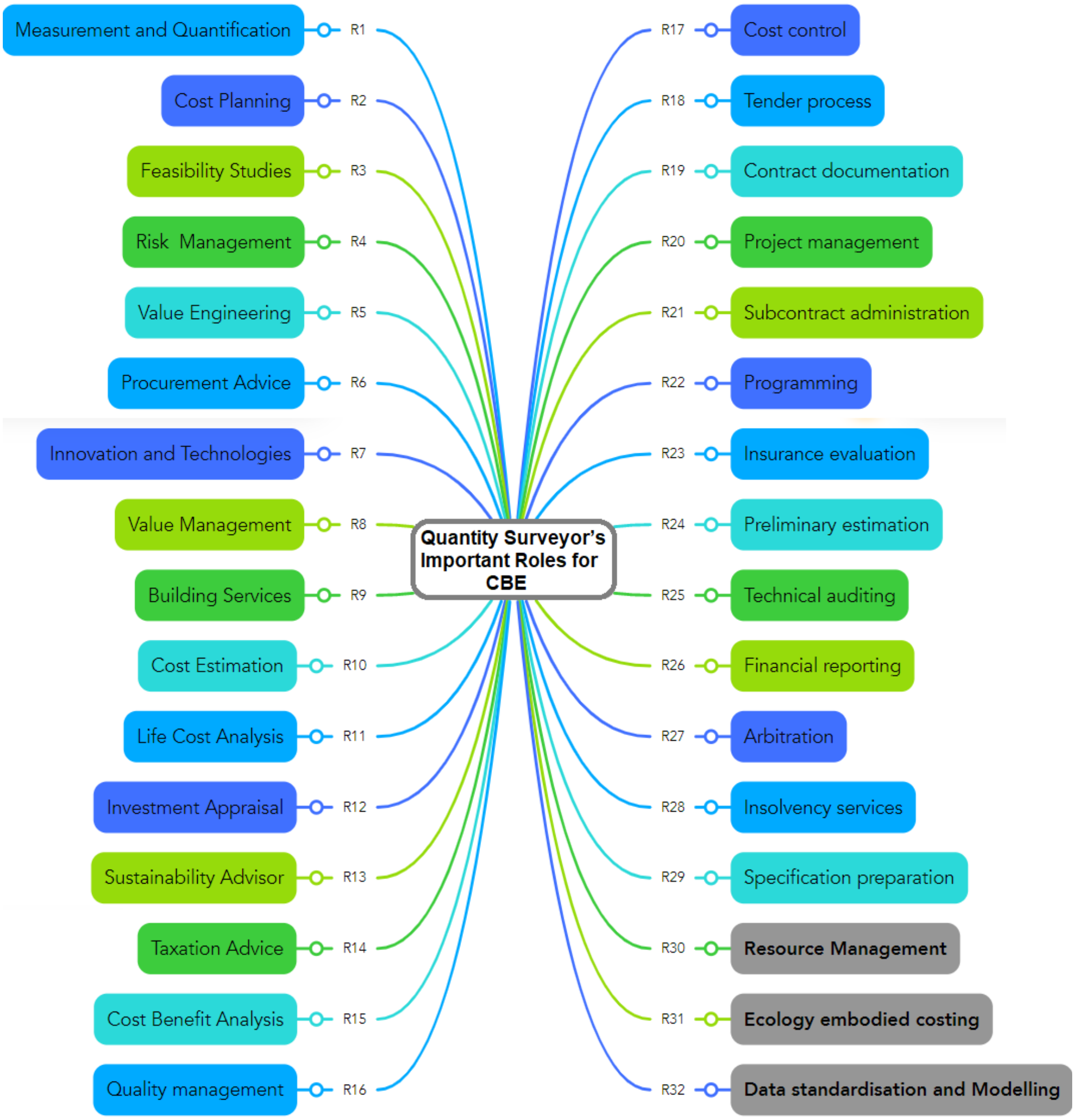

Figure 1: Quantity Surveyor's important roles for CBE

Figure 1 depicts QS's important roles that can be used in CBE as per the opinions of the respondents, and the roles are listed in descending order of their importance. The majority of respondents agreed that the QS's roles might be applied in CBE, as described in the literature. Specifically, **I.10** stated, *"The increasing rate of industrialisation has a negative influence on biodiversity all around the world."* As a result, there is an obvious and pressing need to lessen this impact by shifting away from linear consumption behaviour and toward more circular solutions, thereby minimising the footprint of the built environment. **I.10** especially highlighted, *"The construction industry and built environment have a tremendous impact on the environment since they are the greatest users of natural resources, accounting for more than a third of all energy consumed globally on an annual basis."* Moreover, **I.08** stated that *"The effects of circularity on* *building operations are complex, needing a detailed check of the consequences before deciding on the best course of action."*

All the ten (10) interviewees agreed with the first four key roles of QS's in CBE, namely, *Cost control*, *Cost planning*, *Feasibility studies*, and *Risk management*. On the Value engineering, **I.09**, who objected to the factor, stated that *"When considering the usage of locally and culturally relevant materials, value engineering cannot have a substantial influence at the design stage."* Otherwise, all the participants implied the benefits in *Value engineering*, considering strategies of CBE such as enhanced efficiency in the built environment, prioritising what is important and easy recycling, achievement of Green Building certificate (LEED, BREEAM, DGNB), cost-savings in recyclable finishes and light fixtures, helps to deliver a smart building etc. Under the *Procurement advice* role, **I.10** responded as, *"Where the comprehensive engineering work is used to obtain bids for equipment and supplies, issue purchase orders, and negotiate CBE contracts."* According to **I.10**, the value management role is the same as the duty in Value engineering. Building services carried out also another QS's role that has more positive responses with the approach of CBE strategies. **I.07,** who objected to the role, stated that *"Building services is a type of professional engineering that aims to provide a safe and comfortable indoor environment while reducing a building's environmental impact."* Most of the interviewees have given their opinion as *"Quality control is crucial during the Design stage since it is the cornerstone of the CBE project's success."* Furthermore, quality control directly affects to enhance materials durability to extend the lifespan of a construction. Although, respondents have highlighted the use of sustainable approaches in CBE.

4.2 DELPHI ROUND 2 - QUANTITY SURVEYOR'S IMPORTANT ROLES AT THE DESIGN STAGE

During the Delphi Round 1, twenty-nine (29) roles were identified. During the Delphi Round 2 interviews, experts were asked to identify applicable important and moderate roles at the Design stage in achieving CBE. QS roles with an agreement percentage exceeding 80% were considered important. Thus, at the end of Delphi Round 2, twenty-two (22) important roles were identified out of 29 QS roles. Figure 2 indicates important QS roles at the Design stage in achieving CBE.

All the interviewees have agreed that new roles ensure efficiency and productivity in achieving CBE strategies. **I.03** highlighted, *"At the Design stage, cost planning and control should highly impact for reduction of construction waste and materials where the management of actual and forecast costs against that budget."* Also, all the interviewees strongly agreed about cost planning and cost control. According to **I.04**, *"Risk management is an effective QS's role at the Design stage when it is implemented systematically through reduction principle of CBE."* Since QS necessitated the use of a substantial amount of material resources as well as the participation of a number of professionals and institutions in the decision-making process throughout the life cycle of built buildings. **I.06** highlighted, *"Measurement and Quantification role is required by all reduction of construction waste and material usage involved in either the generation or utilisation of construction cost information during the Design stage."*

Measurement and quantification *role is well-established in the CBE at the Design stage, and their applications are well known, where the majority of respondents agreed with* *this role.* ***I.03*** *highlighted,* "For these systems to work effectively, QS involved in measurement and quantification have to have special characteristics because accuracy can be one of the most important aspects to ensuring that a construction project runs smoothly." *At the Design stage, construction resource management is a complete process that comprises pre-emptive planned, scheduling, and controlling of enterprise-wide resources. It helps to accomplish every task with precision and meet the project objectives within time.* ***I.01*** *highlighted,* "Appropriate resource management keeps projects on schedule by satisfying management and resource expectations and maximizing resource utilisation from contract to contract." *Furthermore, all interviewees highly agreed that embodied energy and cost of construction of any building depend upon the consumption of resources, more specifically construction materials at the Design stage. Thus, an efficient design may lead to reuse in built environment cost and ecology embodied costing. Therefore, QS plays a significant role in CBE at the Design stage.*

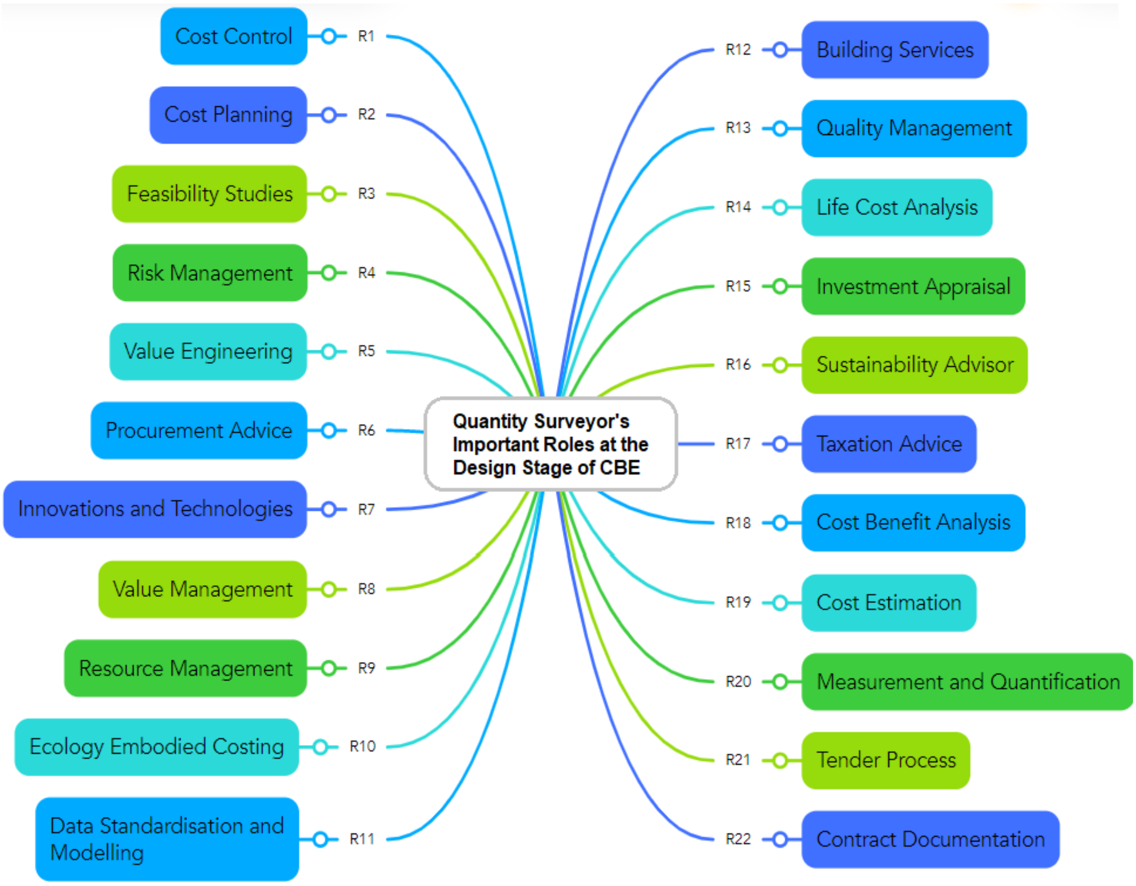

Figure 2: QS's important roles at the design stage of CBE

4.3 DISCUSSION

There are very few past research studies that discussed the use of CEB for a better future in the built environment. Among roles of a QS identified from the literature, most roles can be applied for in achieving CBE in the built environment. The most important roles are *'Cost control'* and *'Cost planning'*. Furthermore, **I.03** highlighted, *"At the Design stage, cost planning and control should highly impact to reduction of construction waste and materials where the management of actual and forecast costs against that budget."*

Hence, it is clear that cost control and cost planning roles cause more impact during the Design stage of CBE. Emphasising the impact of *'Cost control'* and *'Cost planning'*, Chandramohan, et al. (2020) had ranked these roles for QS context and highlighted that the cost control process involves ensuring that the budget does not exceed without prior client approval. Similarly, Chamikara, et al. (2020) expressed that cost planning gives advice to the client on how much the project cost will be. Also, cost planning will advise when the expected expenses will most possibly occur. Hence, it is important to get the required project finance and determine possible project profit. Therefore, the cost planning process is essential to the success of the project during the Design stage of the building.

Additionally, Panojan, et al. (2019) opined that risk management make construction projects more efficient and practical such that uncertainties should be identified before occurring and changing into crisis, and a balance should be made between threats and opportunities at the Design stage of building. Similarly, in this study risk management was identified as an important role a QS should play during the Design stage. Other than the above roles, Chamikara, et al. (2020) expressed that there are important roles such as *'Procurement advice'*, *'Value management'*, *'Sustainability advisor'*. Similarly, through this study, those roles were identified to be significant roles of QS in achieving CBE during the Design stage. According to Chamikara, et al. (2020), procurement advice is a key contractual role, and it helps enhance profitability by reducing superfluous expenses and minimising delays and speeding up the supply chain. Perera, et al. (2011) identified that the construction sector has contributed a lot towards the destruction of our ecosystem, with 32% of landfill waste are generated from the construction and demolition of buildings. 13% of construction waste is sent directly to the landfill without being used. Therefore, the sustainability advisor plays a vital role to provide consistency to the contract during the Design stage. When considering the literature findings, most of the previous research findings were based collectively on sustainability and QS job roles. Moreover, all the roles identified by the literature survey have been agreed upon by the respondents. Findings suggest that only the important roles have a certain degree of significance in CBE during the implementation at the Design stage of a building. In line with the research findings, many authors have stressed that the scope and design of the project may have a massive impact on the anticipated risk.

Furthermore, Chandramohan, et al. (2020) had ranked job diversity in quantity surveying in Sri Lanka, and the findings show a considerable similarity, where twenty-two of the important roles recorded in that study are recorded as diversified roles in this study as well. Conversely to this study, the authors have suggested the entrepreneur, PFI consultancy, and academics as important roles. Roles such as *'Resource management'*, *'Ecology embodied costing'*, and *'Data standardisation and modelling'* have not been addressed in previous studies related to QS's roles in the built environment. Nevertheless, with the research findings, **I.05** stated that *'Resource management'*, *'Ecology embodied costing'* and *'Data standardisation and modelling'* have a significant effect on the successful completion of CBE during the Design stage of building. Moreover, the impact of this study and probability values may vary with the project conditions and project nature.

5. CONCLUSIONS AND RECOMMENDATIONS

The aim of the study was achieved through a cumulative process consisting of a literature review and a two-round Delphi survey. The study was a cumulative process fulfilled through the literature review Delphi Rounds 1 and 2 of the expert interviews. The study was a cumulative process fulfilled through the literature review Delphi Rounds 1 and 2 of the expert interviews. 'Cost control,' 'Cost planning', 'Feasibility studies', 'Sustainability advisor', 'Risk management' and 'Value engineering', were strongly agreed QS's roles by interviewees in the Design stage of building in CBE. Furthermore, *'Cost modelling'*, and *'Innovations and technologies'* are also considered important roles that impact the QS role during the Design stage.

Among the recommendations advanced from this study, it is highly recommended to provide a clear and explicit scope definition during the Design stage of building. The newly identified QS's role, resource management, ecology embodied costing, and data standardization and modelling are recommended as new roles that QS should play to achieve circular CBE during the Design stage. Implementing the new technologies creates a need to prepare and implement proper regulations. For proper identification, monitoring and management of roles in the pre-construction stage of building, QS should understand the CE concept and an experienced project team are required.

This study will contribute to research by categorising QS's roles in achieving CBE, especially during the Design Sourcing stage of a building's life. Thus, this study can be used as a benchmark for future research when conducting further studies on different aspects of QS roles in CBE. The research finding help to upgrade the role of QSs to align with new trends in construction and can even be used as a curriculum for developing the QS related degree and diploma level programmes. Moreover, this research can be used as a formal guideline to achieve sustainable CE strategies to achieve CBE with the use of QSs. Lack of awareness of built environment professionals on the concept of CBE limits the number of participants for the study. Furthermore, with the COVID-19 pandemic situation, there were many difficulties contacting face to face potential participants for the study.

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VALUE ENGINEERING FOR THE SELECTION OF A SUITABLE TYPE OF FOUNDATION IN METRO RAIL PROJECTS: A CASE STUDY FROM INDIA

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ABSTRACT

The design and construction of foundation systems for metro rail projects require effective planning and performing analysis over various alternatives in achieving a suitable cost-effective solution. Often the foundation system is selected based on the Soil Bearing Capacity (SBC) and other onsite constraints are left unconsidered. This results in costly design changes during the execution stages and incurs severe delays in the project. This demands the application of advanced managerial techniques to select cost-effective solutions during the design stages of metro rail projects. Value Engineering is one such function-oriented approach used in analyzing the functions of a product or a process and selecting a suitable solution that achieves all the required functions at the lowest possible cost. The application of the value engineering concept in metro rail projects would enable identifying suitable solutions while considering different alternatives over several criteria. Hence, this paper applies value engineering technique for selecting the suitable foundation type for the construction of metro rail projects. A case study of an ongoing metro rail project was considered and three foundation alternative types and nine significant selection criteria were identified. The foundation alternatives were quantitatively analyzed using the weighted evaluation technique. The results indicate that for limited availability of Right of Way (ROW), the foundation with Controlled Low Strength Mortar (CLSM) is highly suitable. In scenarios of limited ROW with less SBC use of pile foundation is identified as a suitable cost-effective foundation type.

Keywords: *Foundation Type; Metrorail Projects; Value Engineering; Weighted Evaluation Technique.*

1. INTRODUCTION

Metro rail projects comprise massive structures that necessitate immense amounts of expenditure, materials, skilled laborers, engineers, and heavy machinery for the construction. Unlike conventional railway systems, metro rail projects are unique, and grade-separated from traffic and other existing urban transportation systems (Sharma, et al., 2013). They are mostly constructed in the middle of the Right of Way (ROW) of the

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roads as elevated structures and partly as underground structures depending on the site conditions. Several considerations are made during the planning and design stages of the metro projects. They include consideration of the type of structure (underground or elevated), impact over the surrounding environment, passenger traffic, land acquisition, issues in construction and maintenance of the structures (Sharma, et al., 2013). Over the number of considerations, the selection over the type of foundation is often less emphasized in current practice.

The foundation of metro rail projects plays a crucial role in confirming the stability of the entire structure. In practice, the selection of the type of foundation is made based on the nature of the soil, type of loads, and the type of proposed structure. However, other critical factors like the surrounding environment, the existence of sub-surface utilities, and the availability of land for construction are not considered during the planning and designing stages of metro rail projects. Often design changes were made during the execution phases of metro projects due to unfavorable site constraints and resulting in cost and schedule overruns in the project.

Value Engineering is a systematic procedure that employs various techniques over a product or a facility to analyze its existing functions, aiming to propose the best suitable alternative at the lowest possible cost without sacrificing the function or quality (Assaf, et al., 1996; Yanita and Mochtar, 2021). They are used in various manufacturing and construction industries in maximizing the value aiming at a lower lifecycle cost of the product or the project (Liu and Shen, 2005). However, in the Architecture Engineering Construction (AEC) industry, their applications are fairly limited to buildings (Lee, 2018; Berawi, et al., 2021), highway infrastructure projects (Kim, et al., 2016; Mousakhani, et al., 2017), and their application on other infrastructural projects such as metro rail projects are left unattended. The application of systematic value engineering can provide a cost and time-effective solution for the construction of a foundation in metro rail projects that can improve the value of the project without reducing its intended function. Hence, the paper aims to fulfill this gap through the application of the Value Engineering (VE) process in metro rail projects and develop a solution for the selection of a suitable type of foundation.

The structure of the paper is organized as follows: The next section describes the literature review on VE and their applications over different phases of the construction project. Then, the research methodology adopted in the paper is discussed. In the later sections, the application of VE for selecting a suitable foundation type for the case study is discussed and the results are evaluated. Lastly, the conclusion of the paper is provided.

2. LITERATURE REVIEW

2.1 APPLICATIONS OF VALUE ENGINEERING

The VE in the construction industry has been used for various applications such as project conceptualization, site selection, feasibility of design proposal, selection of construction material, method, and facility maintenance (Atabay and Galipogullari, 2013). The application of VE in construction projects enabled cost reduction, functional enhancement, time shortening, and improvements in constructability, quality, and sustainability (Shen and Liu, 2004; Shen and Yu, 2012; Atabay and Galipogullari, 2013; Salmi, 2017; Gunarathne, et al., 2020). The VE process was found applied at various stages of the project lifecycle such as planning and analysis, schematic design, design development, construction documentation, construction and operation, and maintenance stages (Danso and Kwadwo, 2019).

2.1.1 VE during Pre-Construction Stages

During the pre-construction stages, the VE process was mainly applied for conducting feasibility analysis of road network design (Chen and Hsu, 2011) and selecting suitable project design alternatives of highway construction (Kim, et al., 2016; Mousakhani, et al., 2017) and pipeline water supply system (Shahhosseini, et al., 2018).

The application of the VE process was also used in selecting suitable material types for construction such as optimal building façade material (Lee, 2018) and drainage pipeline material for a highway construction project (Atabay and Galipogullari, 2013).

The application of VE also extends to green construction (Li, et al., 2019) and sustainability projects (Gunarathne, et al., 2020; Berawi, et al., 2021). The VE process was used in creating a green construction evaluation system and used in identifying suitable construction schemes with maximum green construction co-efficient value. This enabled maintaining the balance between the cost implications and green construction effect on the project.

2.1.2 VE during Construction Stages

The application of VE during the construction stages of the project was used in reducing project lifecycle costs and in preventing project delays. In a highway construction project, VE was applied for cost and time optimization through selecting suitable construction methods such as in-situ construction and prefabricated construction for the selected project (Atabay and Galipogullari, 2013). In a similar study, VE was applied to evaluate and identify the most suitable construction system for bridge construction projects, thereby the cost of the project was reduced and the constructability of the project was improved (Basha and Gab-Allah, 1991).

The application of VE was also used in addressing various onsite challenges and used in deciding on suitable cost-effective management approaches for the project (Tang and Bittner, 2014). Thompson, et al., (2009) applied VE, considering site complexities to select a suitable type of embankment stabilization system. VE was also applied for identifying suitable cost-effective temporary facilities such as selecting the sources of electricity supply for the mobility phases of the project (Trigunarsyah and Hamzeh, 2017).

2.1.3 VE in Post-Construction Stage

Limited research efforts were identified on applying VE for the operation and maintenance stages of construction projects. The VE methodology was mainly used in evaluating the performance of the water distribution system and used for decision-making in renewal and rehabilitation processes (Cuimei and Suiqing, 2008).

The VE practices for construction were found applied for various buildings (Lee, 2018; Berawi, et al., 2021), and infrastructure projects such as highways (Atabay and Galipogullari, 2013; Kim, et al., 2016; Mousakhani, et al., 2017), bridges (Basha and Gab-Allah, 1991; Tang and Bittner, 2014), power stations (Trigunarsyah and Hamzeh, 2017; Li, et al., 2019) and other utility projects (Cuimei and Suiqing, 2008). However, their application specific to the construction of metro rail infrastructure projects are seldom targeted. The VE practices were used for the selection of a suitable type of material (Atabay and Galipogullari, 2013), selection of design, construction methodology (Kim, et al., 2016; Mousakhani, et al., 2017), and selection of green construction schemes (Li, et al., 2019) in infrastructure projects. However, their application for the selection of a suitable type of foundation system is left unattended. To fill the above gap in the literature, this paper applies systematic VE to select the suitable type of foundation system for the construction of the metro rail projects in India.

3. RESEARCH METHODOLOGY

A case study research methodology was used for applying VE for selecting the suitable type of foundation for the construction of metro rail projects. A case study research methodology allows collecting and analyzing empirical evidence and establishing a practical understanding of the contemporary phenomenon in a real-life context (Yin, 2018). A reliable case study involves the collection of various sources of information such as interviews, observations, documents, archival records, physical artifacts, which converge to the same set of facts resulting in triangulation (Yin, 2018). In this study, data were collected through participant observation, interviews, questionnaire and referring project documents.

The applied VE study adopts the following phases: information, creative, evaluation and development phase. In the information phase, required information about the project is collected through participant observation, conducting semi-structured interviews with the project team, and referring project documents. Relevant data such as project type, technical specifications, and issues with the construction of the foundation were obtained. In the creative phase, foundation alternative types that solve the identified problems and support the required basic function were determined through brainstorming technique. A purposeful sampling of 30 professionals from the case study (comprising of owner, designers, consultants, and contractors), were selected to form a VE team. The professionals were selected based on their profound knowledge and experience (minimum of six years) in the design and construction of metro rail projects. The professionals held positions such as Chief Engineer, Project Manager, Site Engineer, Design Engineer, and Coordinator. Two brainstorming sessions were conducted with the VE team and three suitable foundation alternatives were determined. In the evaluation and development phase, individual foundation alternatives were quantitatively analyzed using the weighted evaluation technique and suitable alternative was identified. The weighted evaluation technique allows considering both the economic and functional factors of alternatives (Dell'Isola, 1997; Basha and Gab-Allah, 1991) and enables better decision-making over the best suitable foundation type for the selected site condition. The technique involves identifying evaluation criteria and determining their relative weights or degree of importance. Semi-structured interviews were conducted with the VE team to identify evaluation criteria for the considered project. Further, a questionnaire was developed and individual criteria were ranked on a scale of 1 to 5 (varying from poor to best preference) based on the degree of importance and criteria weights were determined. Also, the foundation alternatives were ranked on a similar scale of 1 to 5 against individual criteria for each possible scenario. Finally, an analysis matrix was developed by multiplying the criteria weights and obtained foundation alternatives rank for each possible scenario and a suitable foundation type was determined.

4. CASE STUDY DESCRIPTION

The construction of the Hyderabad metro rail project was considered as a case study in this paper. The project is located in Telangana, India. It was executed in Design Build Finance Operate Transfer (DBFOT) model. It consists of 3 elevated corridors with a total length of 72 Km and the stations were constructed in the middle of the road with an elevated concourse. The construction of foundation systems for the elevated structure is affected by onsite issues such as limited availability of right of way and the presence of uncharted underground utilities. During the excavation process, many underground utilities were found in the construction area and were required to be relocated. Often delays were encountered during relocation and caused significant delays to the project. In cases, where shifting or repositioning of utilities is not possible, design changes of the footing and the super-structure were made. This escalated project completion time and increased the total lifecycle cost of the project.

Based on the onsite observation, the construction site location was categorized into 3 possible scenarios depending on the availability of the area and bearing capacity of the soil. Case 1 represents the site location with sufficient load carrying capacity and sufficient ROW is available for construction of the foundation. Case 2 represents the site location with sufficient load carrying capacity and limited ROW for construction and Case 3 represents site location with limited load carrying capacity and limited ROW for construction of the foundation.

5. TYPES OF FOUNDATION SYSTEMS

Selection over a type of foundation is mainly based on the type of load and the Soil Bearing Capacity (SBC) of the soil. Pile foundations are preferred for heavy/medium loads with loose/soft soil strata, and open foundations are preferred for site locations where hard strata or rock is available nearer to the ground level. However, the consideration of the above two criteria is not sufficient for the selection of foundation types for metro rail projects. Hence, brainstorming activities were conducted and foundation alternatives were identified and categorized into three types such as A (open foundation with square footing), B (pile foundation), and C (open foundation with Controlled Low Strength Mortar (CLSM)).

6. SELECTION CRITERIA

To evaluate the different design alternatives, suitable criteria for analysis are required. Several selection criteria were used in the extant literature for the selection of design alternatives in infrastructure projects. In a roadway expansion project five factors such as safety, constructability, maintenance, environment, and cost were considered as evaluation criteria for design alternate evaluation (Kim, et al., 2016). Similarly, for construction of bridges, eight types of criteria such as construction cost, maintenance, durability, service life, resource availability, ease of construction, construction progress rate, and design efficiency were considered (Basha and Gab-Allah, 1991). The identified criteria were limited to road and bridge construction projects. Criteria for the construction of metro rail projects are not established in the literature. Though the criteria used in the studies were similar, they vary with the project type, size, and location. Hence, to identify selection criteria impacting the selection of foundation types for metro rail projects, a semi-structured interview was conducted with the VE team. Nine evaluation criteria such as construction cost, time taken for foundation, constructability, presence of utilities, design efficiency, safety, resource availability, the service life of the structure, and construction progress rate was identified and used for the evaluation of individual foundation alternatives.

7. CRITERIA WEIGHTING

The criteria weighting identifies important individual evaluation criteria and establishes ranks or relative importance. The relative weights (raw weight) of identified criteria were obtained through the questionnaire and further normalized and presented in Table 1. The normalized weight percentage was obtained by taking the average raw weight for individual criteria and multiplying it by 100. It can be observed that construction cost and safety were considered highly important on comparing with other criteria such as the presence of utilities and ease of construction.

Table 1. Evaluation criteria along with their raw and normalized weight

Criteria	Raw weight	Normalized weight (%)
Construction cost	106	12.33
Safety	106	12.33
Service life	100	11.63
Time	97	11.28
Construction progress rate	97	11.28
Design efficiency	95	10.05
Ease of construction	91	10.58
Resource availability	85	9.88
Utilities	83	9.65
Total	860	100

8. EVALUATION OF FOUNDATION ALTERNATIVES

The analysis matrix for the foundation type was developed for the considered three case scenarios as follows.

8.1 CASE 1: WHEN SUFFICIENT SOIL BEARING CAPACITY IS AVAILABLE AND NO CONSTRAIN IN RIGHT OF WAY

In Case1, the considered site location has sufficient soil bearing capacity to transfer loads of the super-structure and hard strata with a safe bearing capacity of 45 t/m^2 to 75 t/m^2, obtained at a depth of 3m and 5m respectively. Similarly, the selected site location has no constrain in the right of way and the selected site is free from existing underground utilities or any irremovable structures like the foundation of other existing structures. Through questionnaire (as discussed in research methodology) foundation alternatives were ranked on a scale of 1 to 5 against individual criteria for the considered scenario as shown in Table 2. The obtained rank in Table 2 and the corresponding criteria weight obtained (Table 1) were multiplied to obtain a total score of individual alternatives. The resulting analysis matrix is shown in Table 3 and the foundation type with the highest score was considered as the suitable alternative.

Table 2. Ranking for the type of foundation

Type of foundation	A*	B*	C*
Construction cost	4.14	2.28	4.0
Time of construction	4.3	2.2	3.5
Ease of construction	4.1	2.4	4.0
Utilities	2.5	4.2	3.9
Design efficiency	3.7	3.6	3.0
Safety	4.5	3.3	3.4
Resource availability	4.4	2.6	3.4
Service life	3.7	4.3	3.3
Construction progress rate	4.4	2.6	3.7

*Ranking performance: best = 5; very good = 4; good = 3; fair = 2; poor = 1.

Table 3. Analysis matrix when piers on the right of way

Criteria	Normalized weight	A		B		C	
		Rank	Score	Rank	Score	Rank	Score
Construction cost	12.33	4.14	51.08	2.28	28.18	4.00	49.32
Time	11.28	4.30	48.50	2.20	24.816	3.50	39.48
Ease of construction	10.58	4.10	43.38	2.40	25.392	4.00	42.32
Utilities	9.65	2.50	24.13	4.20	40.53	3.90	37.635
Design efficiency	10.05	3.70	37.18	3.60	36.18	3.00	30.15
Safety	12.33	4.50	55.48	3.30	40.689	3.40	41.922
Resource availability	9.88	4.40	43.47	2.60	25.688	3.40	33.592
Service life	11.63	3.70	43.03	4.30	50.009	3.30	38.379
Construction progress rate	11.28	4.40	49.63	2.60	29.328	3.70	41.736
Total score			**395.89**		300.814		354.534

8.2 CASE 2: WHEN SUFFICIENT SOIL BEARING CAPACITY IS AVAILABLE AND CONSTRAIN IN THE RIGHT OF WAY

In Case 2, the considered site location has sufficient soil bearing capacity to transfer loads of the super-structure and hard strata with a safe bearing capacity of 45 t/m^2 to 75 t/m^2 are obtained at a depth of 3m and 5m respectively. However, the selected site is identified with the presence of multiple utilities that are difficult to relocate. In such a case, the alignment of the metro corridor has to be modified, which is more complex and cumbersome, or an alternate solution has to be made. The alternative foundation types were ranked against each criterion and were multiplied with their corresponding normalized weight. The obtained analysis matrix for Case 2 is shown in Table 4.

Table 4. Analysis matrix when piers do not fall on right of way for case 2

Criteria	Normalized weight	A		B		C	
		Rank	Score*	Rank	Score*	Rank	Score*
Construction cost	12.33	2.9	35.757	3.9	48.087	4.3	53.019
Time	11.28	3.4	38.352	3.8	42.864	4.2	47.376
Ease of construction	10.58	3.6	38.088	3.5	37.03	4.4	46.552
Utilities	9.65	3.3	31.845	4.7	45.355	4.1	39.565
Design efficiency	10.05	3.4	34.17	4.5	45.225	3.5	35.175
Safety	12.33	3.4	41.922	4.6	56.718	3.5	43.155
Resource availability	9.88	3.8	37.544	3.4	33.592	4.2	41.496
Service life	11.63	3.6	41.868	4.1	47.683	3.9	45.357
Construction progress rate	11.28	3.8	42.864	3.2	36.096	4.3	48.504
Total score			342.41		392.65		400.2

8.3 CASE 3: WHEN BOTH SOIL BEARING CAPACITY AND RIGHT OF WAY IS NOT SUFFICIENT

In Case 3, the selected site location is not sufficient to transfer the load of the superstructure, and no hard strata are found to a depth of 5m below the ground surface. Similarly, the selected site is identified with the presence of multiple utilities, hindering the construction of the foundation. For the considered case, the alternative foundation types are ranked and scored against individual selection criteria. The obtained analysis matrix is shown in Table 5.

Table 5. Analysis matrix when piers do not fall on right of way for case 3

Criteria	Normalized weight	A		B		C	
		Rank	Score*	Rank	Score*	Rank	Score*
Construction cost	12.33	2.00	24.66	4.60	56.718	2.70	33.29
Time	11.28	3.50	39.48	3.30	37.224	4.30	48.50
Ease of construction	10.58	3.80	40.204	3.40	35.972	3.80	40.20
Utilities	9.65	2.50	24.125	4.70	45.355	3.40	32.81
Design efficiency	10.05	2.90	29.145	4.60	46.23	3.10	31.16
Safety	12.33	3.10	38.223	4.40	54.252	3.00	36.99
Resource availability	9.88	3.80	37.544	3.60	35.568	3.60	35.57
Service life	11.63	3.70	43.031	4.60	53.498	3.70	43.03

Criteria	Normalized weight	A		B		C	
		Rank	Score*	Rank	Score*	Rank	Score*
Construction progress rate	11.28	3.40	38.352	3.90	43.992	3.60	40.61
Total score			314.764		**408.809**		342.16

9. DISCUSSION

Referring to Table 3, for Case 1, foundation type A (Open - Raft foundation) obtained a higher score of 395.89 in comparison with the other type of foundations. Compared to the type A foundation, type B has 44.82% higher construction cost, 48.83% higher erection time, 41.46% more difficult for construction. Therefore, for Case 1, type (B) is not suitable. Hence foundation type A is most suitable for cases where SBC is sufficiently high and no constraint is present in occupying the right of way of the road.

Referring to Table 4, foundation type C (foundation with CLSM) obtained a higher score of 400.2 in comparison with the other type of foundations B and C. Type C is 9.3%, and 32.56% is more profitable in terms of cost than type B and type A respectively. In terms of construction time-saving type C is 9.52% and 19.05% more efficient than type B and type A respectively. The overall score shows that under this case type C is the most suitable choice for a case concerning sufficient SBC and where constraint in occupying the right of the road prevails.

Referring to Table 5, foundation type B (Pile foundation), obtained a higher score of 400.8 on comparing with other types of foundations. The foundation type B scores a high rank of 4.7 as a suitable alternative when multiple utilities are encountered at the site. On comparing with the other alternatives in terms of ease of construction and time taken for construction, foundation type B scores low by 39.3% and 23.26%. However, in terms of safety criteria, type B scores 42% more compared with the other type of alternatives, and the safety criterion is considered critical (with normalized rank 12.33) when compared with other selection criteria. Hence, in cases where sufficient SBC and the availability of the right of way of the road are limited, foundation type B provides the best suitable choice as a foundation system.

10. CONCLUSION

The design and selection of a foundation type for construction are based on the type of loading and the bearing capacity of the soil. However, during the execution stages, the preferred original design or selected foundation type may not be suitable due to existing on-site conditions such as less availability of construction space or the presence of unmovable structures or facilities. Often less consideration was given to these factors while selecting the foundation type and changes in the original design were made during the construction stages of the project. This results in overall project delays and increases the lifecycle cost of the project. Hence it is required to identify the best suitable cost-effective foundation type while ensuring its basic intended function and value are not compromised. Hence, VE concepts were applied for the selection of suitable foundation types for the construction of metro rail projects.

A practical case study was presented in this paper and VE is applied as a decision-making tool in selecting a suitable type of foundation system. Based on the analysis, it was determined that foundation type A (open foundation with square footing) provides a suitable solution when sufficient SBC and ROW are available. In scenarios of sufficient SBC with limited ROW, the foundation type C (open foundation with CLSM) was identified as suitable. In scenarios of limited SBC and limited ROW, foundation type B (Pile foundation) was identified as suitable. It was observed that, the selection over a foundation type varied with the availability of ROW even when sufficient SBC is available. This infers that the availability of ROW impacts the selection type of foundation. Thus, the application of VE in metro rail projects enabled selecting suitable foundation type for different on site scenario.

The current study has the following limitations. The findings and the conclusion presented in the paper are project-specific and the results obtained may vary with other transportation infrastructure projects as the different project uses different selection criteria with different weights and requires different VE techniques to determine the best possible alternatives. However, the methodology adopted in this paper can be applied for any metro rail project for the selection of foundation type. Also, the current study can be extended to include cost-benefit analysis in the future.

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