SYMPOSIUM PROCEEDINGS

The 9th World Construction Symposium

Reshaping Construction: Strategic, Structural & Cultural Transformations towards the 'Next Normal'

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DEPARTMENT OF BUILDING ECONOMICS
UNIVERSITY OF MORATUWA

PROCEEDINGS

of

THE 9TH WORLD CONSTRUCTION SYMPOSIUM 2021

ON

RESHAPING CONSTRUCTION: STRATEGIC, STRUCTURAL & CULTURAL TRANSFORMATIONS TOWARDS THE 'NEXT NORMAL'

EDITORS

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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 the 9th World Construction Symposium (WCS) on the pertinent theme, "Reshaping Construction: Strategic, Structural & Cultural Transformations towards the Next Normal". Since, the inception of this WCS series back in 2012, this is the first time the symposium was held as a mainly digital event due to the COVID-19 pandemic. 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 Liverpool John Moores University, United Kingdom; Centre for Innovation in Construction and Infrastructure Development (CICID); The University of Hong Kong, Hong Kong; 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 9th 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 9th World Construction Symposium 2021 a success.

Editors

The 9th World Construction Symposium
Colombo, Sri Lanka
July 2021

PREFACE

The 9th World Construction Symposium (WCS 2021) 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 09-10 July 2021. The symposium was held in partnership with Liverpool John Moores University, United Kingdom; Centre for Innovation in Construction and Infrastructure Development (CICID); The University of Hong Kong, Hong Kong; 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 9th milestone of this symposium series, which has been held annually since 2012. Throughout these past years, WCS has continued to provide 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. This year's symposium was unique in that it was held as a mainly digital event due to the COVID-19 pandemic. The pandemic has brought to light the significance of construction and efficient and healthy built environments more so than ever. So, it is in this light, that we focused on 'Reshaping construction: Strategic, Structural & Cultural Transformations towards the Next Normal' as the theme of this year's symposium.

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, 49 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, Hong Kong, Sri Lanka, United Kingdom, Dubai, India and New Zealand. The papers cover a wide spectrum of areas such as energy efficiency in the built environment, project governance and procurement, ICT applications in construction, enhancing value and sustainability in construction, environmentally and socially sustainable infrastructure, climate change adaptation and disaster resilience, cost and scope management in construction, stakeholder engagement and management, operation and maintenance of built environment for sustainability, waste management and circular economy, occupational health and safety in built environment, and sustainable construction methods and process improvement.

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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Professor Steve Rowlinson is Emeritus Professor attached to the Department of Real Estate and Construction, Faculty of Architecture, the University of Hong Kong. He also serves as a Visiting Professor at Chongqing University, China, and an Honorary Adjunct Professor at Bond University, Australia. Prof. Rowlinson has over forty years of international experience in teaching and consultancy in construction project management. His research areas include occupational health, safety and wellbeing in construction, digital construction, construction innovation, procurement systems and integrated project delivery. With over 250 publications and 50 PhD graduates to date, Prof. Rowlinson is a world-renowned academic in construction project management.

KEYNOTE SPEAKERS

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Dr. Ioannis Brilakis is a Laing O'Rourke Reader in Construction Engineering and the Director of the Construction Information Technology Laboratory at the Division of Civil Engineering of the Department of Engineering at the University of Cambridge. He completed his PhD in Civil Engineering at the University of Illinois, Urbana Champaign in 2005. He then worked as an Assistant Professor at the Departments of Civil and Environmental Engineering, University of Michigan, Ann Arbor (2005-2008) and Georgia Institute of Technology, Atlanta (2008-2012) before moving to Cambridge in 2012 as a Laing O'Rourke Lecturer. He was promoted to University Reader in October 2017. He has also held visiting posts at the Department of Computer Science, Stanford University as a Visiting Associate Professor of Computer Vision (2014) and at the Technical University of Munich as a Visiting Professor, Leverhulme International Fellow (2018-2019), and Hans Fischer Senior Fellow (2019-2021). He is a recipient of the NSF CAREER award, the 2019 ASCE J. James R. Croes Medal, the 2018 ASCE John O. Bickel Award, the 2013 ASCE Collingwood Prize, the 2012 Georgia Tech Outreach Award and the 2009 ASCE Associate Editor Award. Dr. Brilakis is an author of over 200 papers in peer-reviewed journals and conference proceedings, an Associate Editor of the ASCE Computing in Civil Engineering, ASCE Construction Engineering and Management, Elsevier Automation in Construction, and Elsevier Advanced Engineering Informatics Journals, and the past chair of the Board of Directors of the European Council on Computing in Construction.

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A FRAMEWORK TO MEASURE COLLABORATION IN A CONSTRUCTION PROJECT

Deepjyoti Nath[1], Varun Kumar Reja[2] and Koshy Varghese[3]

ABSTRACT

Collaboration amongst stakeholders in a construction project plays a significant role in managing and completing a project successfully. It specifically helps in interface management amongst the stakeholders. Among the various aspects of collaboration, there are two key factors that predominant. Firstly, the psychological factors that define a person as a natural collaborator, and secondly, the project-level enablers that determine a collaborative project. Therefore, in this study, two inductive theories are developed- one for psychological factors and another for project-level enablers of collaboration. This study aims to identify the key psychological factors and project enablers associated with collaboration and develop a conceptual framework to measure collaboration in a construction project. The workflow of the conceptual framework is developed in the first part of the research, and the input requirements are quantified. Robust hypothesis testing methodology is adopted to identify the key psychological factors and project enablers. Hypotheses testing yields three specific psychological factors for defining a person as a natural collaborator, and six enablers are essential for facilitating project collaboration. These results are used as input parameters in the derived conceptual framework to measure the level of collaboration in a construction project.

Keywords: *Collaboration in construction; Enablers of collaboration; Measuring collaboration; Psychological factors; Stakeholder management.*

1. INTRODUCTION

Construction activities are unique in terms of trade flow. It requires several stakeholders to come together to deliver a specific service or product. The successful completion of construction projects depends on stakeholder management based on the size and complexity of construction projects. The interface management of the stakeholder is significantly impacted by the level of coordination amongst the involving stakeholders (Wang, 2000). The cited reasons for the lack of coordination are ineffective communication, poor collaboration, unbalanced risk allocation, etc. (Narayanan *et al.*, 2019).

Moreover, for an economy like India, collaboration in construction projects is crucial as it addresses some of the inherent and common issues with project management. However, quantifying the extent of collaboration in a construction project can be a proper

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perspective of collaboration, as it will unveil critical concepts of collaborative working within construction projects. Additionally, limited research has been conducted on measuring collaboration in the Indian construction industry.

Therefore, this paper attempts to:

- Identify the key psychological factors and project level enablers associated with collaboration in the construction industry, and
- Derive a conceptual framework to measure the level of collaboration in a construction project.

To fulfil the objectives, a detailed methodology was proposed and is presented in Figure 1. Data collection included a questionnaire survey performed with Indian construction professionals. Appropriate hypothesis testing methodology was adopted to analyse the collected data in the questionnaire survey. The scope of this study is limited to the following stakeholders of a construction project: clients, project management consultants, designers, main contractors, and subcontractors. However, the study can be extended to any number of stakeholders as per the use case by following the same methodology.

This paper is divided into six sections. In the first section, the research problem is introduced, and the objectives for this study are presented. Section 2 presents the review of existing literature on construction collaboration. The result of the keyword search is also presented in this section. Section 3 presents the methodology adopted for the present study. The inductive theories (i.e., hypotheses H1 and H2) are also presented in this section. Section 4 presents the results of hypothesis testing and introduces the conceptual framework to measure collaboration. Discussion on the findings of the hypotheses testing and potential future work are presented in section 5. Finally, section 6 concludes the study by showing the contribution of this research to the field of construction collaboration.

2. LITERATURE REVIEW

Among the several challenges of managing construction projects, interface management has always been a concern. Hence, the success of construction projects can be attributed to stakeholder management (Wu *et al.*, 2008). On the other hand, the client expects quicker delivery of projects in contracts, thereby ensuring that the contractor will adopt the latest technologies to execute the task. In this process, the contractor involves several specialized contractors to perform the specific functions (Shelbourn *et al.*, 2007).

In addition, the construction industry's landscape is changing rapidly with frequent changes in technology and the complexity of the project itself. This new landscape matrix of construction projects emphasizes partnering, joint ventures, Public-Private Partnerships, and strategic alliances (Rahman *et al.*, 2014). On the contrary, the construction industry has always been characterized by uncertainty, suspicion, and adversarial attitudes for a long time (Wu *et al.*, 2008). Therefore, collaboration amongst project participants increases the value and predictability of work, creates an enabling environment for innovation and technical development, and encourages continuous development. In this context, studies have pointed out several benefits of collaboration in construction project management, including stakeholder management (Akintan and Morledge, 2013; Rahman *et al.*, 2014).

Prevalent research in collaboration demonstrates that collaboration between customers and suppliers reduces the cost of controlling, decreases the probability of failure, and creates a potential for innovation and learning. In the long run, it creates a culture of trust and reliability (Dietrich *et al.*, 2008). Eriksson and Nilsson (2008) have reasoned that partnering, a form of collaborative working, aims to increase cooperation and integration between project participants by building trust and commitment.

Since Egan's (John, 1998) and Latham's (Latham, 1994) works, a boost in research is observed in the area of construction collaboration (Hughes *et al.*, 2012). This boost in research has diversified the understanding of the term 'collaboration' to different researchers. For example, Hibbert *et al.* (2008) described collaboration as "all forms of situation where different parties work together." In addition, some researchers have argued that partnering and alliancing are also some forms of collaboration (M. Bresnen and Marshall, 2000a; Wu *et al.*, 2008). According to Hughes *et al.* (2012) often in literature, collaboration is referred to as an umbrella term for alliancing, joint ventures, networking, and partnering.

Among the several aspects of collaboration, two critical aspects are psychological factors and project level enablers (Wu *et al.*, 2008; Chakkol *et al.*, 2017; Panahifar *et al.*, 2018; Deep *et al.*, 2019). Psychological factors essentially denote a person as collaborative, whereas project-level enablers play a crucial role in enabling a collaborative working environment amongst the project participants. In this context, Wu *et al.* (2008) have identified a spectrum of collaborative working attributes and felt that these attributes are necessary to develop a basic understanding of collaborative working in the construction industry (Wu *et al.*, 2008). Similarly, a study has identified six important factors that will lead to a willingness to collaborate amongst the contractors (Panahifar *et al.*, 2018). Moreover, another similar study has produced a list of aspects and developed a questionnaire to rank them to produce a definition of collaboration (Hughes *et al.*, 2012). A study conducted by Hudnurkar *et al.* (2014) found 28 factors affecting collaboration in the supply chain by conducting a detailed literature review. Similarly, another group researcher has argued that real-time communication between all stakeholders is essential for achieving effective coordination and collaboration.

Earlier, Eriksson and Nilsson (2008) have presented a case study on construction collaboration. They studied the benefits of partnering in each stage of a construction project in a pharmaceutical plant in Sweden. Their key conclusion was that implementation of collaborative working requires a long-term perspective and continuous improvement. Additionally, Chan *et al.* (2003) reviewed partnering in general and tried to find out how partnering can help construction projects in Hong Kong. They found that improved communication and relationship are two significant benefits derived from partnering in a construction project.

However, literature does not have a robust methodology to execute a project collaboratively (Akintan and Morledge, 2013). As each construction project is unique, developing a standard set of rules to implement collaborative work is impossible. In addition, research papers do not provide an exhaustive list of enablers of collaboration, which leads to confusion amongst the stakeholders when they often try to collaborate. Therefore, in this research, a list of enablers discussed in the literature is prepared, along with their frequency of appearance in literature.

The project level enablers, along with their frequencies are presented in Table 1.

Table 1: Project level enablers of collaboration and their frequency of discussion

Sl No	Project Level Enablers	Frequency	Studies that discussed the enablers
1	Commitment Towards Work	15	(M. Bresnen and Marshall, 2000b; M. Bresnen and Marshall, 2000a; Girard and Robin, 2006; Neeraj Jha and Misra, 2007; Dietrich *et al.*, 2008; Eriksson and Nilsson, 2008; Löfgren and Eriksson, 2009; Eriksson, 2010; Hughes *et al.*, 2012; Akintan and Morledge, 2013; Abdirad and Pishdad-Bozorgi, 2014; Rahman *et al.*, 2014; Hudnurkar *et al.*, 2014; Chakkol *et al.*, 2017; Deep *et al.*, 2019)
2	Trust	14	(M. Bresnen and Marshall, 2000a; Shelbourn *et al.*, 2007; Wu *et al.*, 2008; Dietrich *et al.*, 2008; Löfgren and Eriksson, 2009; Eriksson, 2010; Hughes *et al.*, 2012; Akintan and Morledge, 2013; Abdirad and Pishdad-Bozorgi, 2014; Rahman *et al.*, 2014; Hudnurkar *et al.*, 2014; Panahifar *et al.*, 2018; Deep *et al.*, 2019; Hamzeh *et al.*, 2019)
3	Communication	13	(M. Bresnen and Marshall, 2000a; Girard and Robin, 2006; Shelbourn *et al.*, 2007; Shen *et al.*, 2008; Wu *et al.*, 2008; Eriksson and Nilsson, 2008; Eriksson, 2010; Hughes *et al.*, 2012; Abdirad and Pishdad-Bozorgi, 2014; Rahman *et al.*, 2014; Chakkol *et al.*, 2017; Deep *et al.*, 2019; Hamzeh *et al.*, 2019)
4	Real-Time Information Sharing	13	(M. Bresnen and Marshall, 2000a; Shelbourn *et al.*, 2007; Shen *et al.*, 2008; Eriksson and Nilsson, 2008; Hunter and Leahey, 2008; Ahuja *et al.*, 2009; Hughes *et al.*, 2012; Akintan and Morledge, 2013; Abdirad and Pishdad-Bozorgi, 2014; Rahman *et al.,* 2014; Hudnurkar *et al.*, 2014; Panahifar *et al.,* 2018; Hamzeh *et al.,* 2019)
5	Shared Vision	10	(M. Bresnen and Marshall, 2000a; Shelbourn *et al.,* 2007; Dietrich *et al.*, 2008; Hunter and Leahey, 2008; Ahuja *et al.*, 2009; Löfgren and Eriksson, 2009; Hughes *et al.*, 2012; Rico, 2015; Chakkol *et al.*, 2017; Deep *et al.*, 2019)
6	Readiness to Share Information	10	(M. Bresnen and Marshall, 2000b; Girard and Robin, 2006; Neeraj Jha and Misra, 2007; Eriksson and Nilsson, 2008; Shen *et al.,* 2008; Wu *et al.*, 2008; Ahuja *et al.*, 2009; Hudnurkar *et al.*, 2014; Panahifar *et al.,* 2018; Hamzeh *et al.*, 2019)
7	Adaption of Information Technology	9	(Girard and Robin, 2006; Eriksson and Nilsson, 2008; Hunter and Leahey, 2008; Ahuja *et al.*, 2009; Eriksson, 2010; Abdirad and Pishdad-Bozorgi, 2014; Hudnurkar *et al.*, 2014; Deep *et al.*, 2019; Hamzeh *et al.*, 2019)
8	Process Design	7	(Hughes *et al.*, 2012; Hamzeh *et al.*, 2019)
9	Engagement of Stakeholders	6	(M. Bresnen and Marshall, 2000b; Neeraj Jha and Misra, 2007; Shelbourn *et al.*, 2007; Dietrich *et al.*, 2008; Chakkol *et al.*, 2017; Hamzeh *et al.*, 2019)
10	Reliability	5	(Dietrich *et al.*, 2008; Eriksson, 2010; Hudnurkar *et al.*, 2014; Chakkol *et al.*, 2017; Deep *et al.*, 2019)

These ten enablers are sorted based on the frequencies of discussion, and in this study, all ten enablers are used. In addition, it has been observed that 'commitment towards work,' 'trust,' and 'communication' are discussed the most in prevalent literature.

Similarly, psychological factors are presented in Table 2.

Table 2: Psychological factors of collaboration and their frequency of discussion

Sl No	Psychological Factors	Frequency	Studies that discussed the enablers
1	Building Relationships	10	(M. Bresnen and Marshall, 2000b; Shelbourn *et al.,* 2007; Wu *et al.,* 2008; Löfgren and Eriksson, 2009; Eriksson, 2010; Hughes *et al*., 2012; Rahman *et al*., 2014; Rico, 2015; Chakkol *et al*., 2017; Hamzeh *et al*., 2019)
2	Self-Motivation	8	(M. Bresnen and Marshall, 2000b; M. Bresnen and Marshall, 2000a; Shelbourn *et al*., 2007; Dietrich *et al*., 2008; Wu *et al*., 2008; Hughes *et al*., 2012; Rahman *et al*., 2014; Rico, 2015)
3	Transparency	6	(Eriksson, 2010; Hughes *et al*., 2012; Hudnurkar *et al*., 2014; Chakkol *et al*., 2017; Panahifar *et al*., 2018; Hamzeh *et al*., 2019)
4	Being Respectful	6	(Girard and Robin, 2006; Shelbourn *et al*., 2007; Wu *et al*., 2008; Hughes *et al*., 2012; Chakkol *et al*., 2017; Hamzeh *et al*., 2019)
5	Being Appreciative	2	(M. Bresnen and Marshall, 2000a; Girard and Robin, 2006)
6	Discipline	2	(Neeraj Jha and Misra, 2007; Eriksson, 2010)
7	Curiosity	2	(Rico, 2015; Chakkol *et al*., 2017)
8	Generosity	1	(Rico, 2015)

From Table 2, we see that 'building relationships' is discussed the most in literature followed by 'self-motivation'. Further, pfrevailing literature does not have any intuitive framework to measure the collaboration in a construction project. This research has identified these gaps, and a framework to measure the level of collaboration in construction is developed. The following section presents the methodology used to create this framework.

3. METHODOLOGY

The methodology used for this research is presented in Figure 1. Both inductive and deductive research approaches were used in this research. First, a basic literature review was done, as illustrated in the previous section. In addition, to understand the current practices in the Indian construction industry, a round comprising of four unstructured interviews was conducted with richly experienced construction professionals of India.

The data collected were analysed conceptually, and based on the gaps found, the problem statement was defined. In addition, the workflow of a conceptual framework was also developed. Finally, the input requirements for the conceptual framework were quantified to measure the extent of collaboration in a construction project.

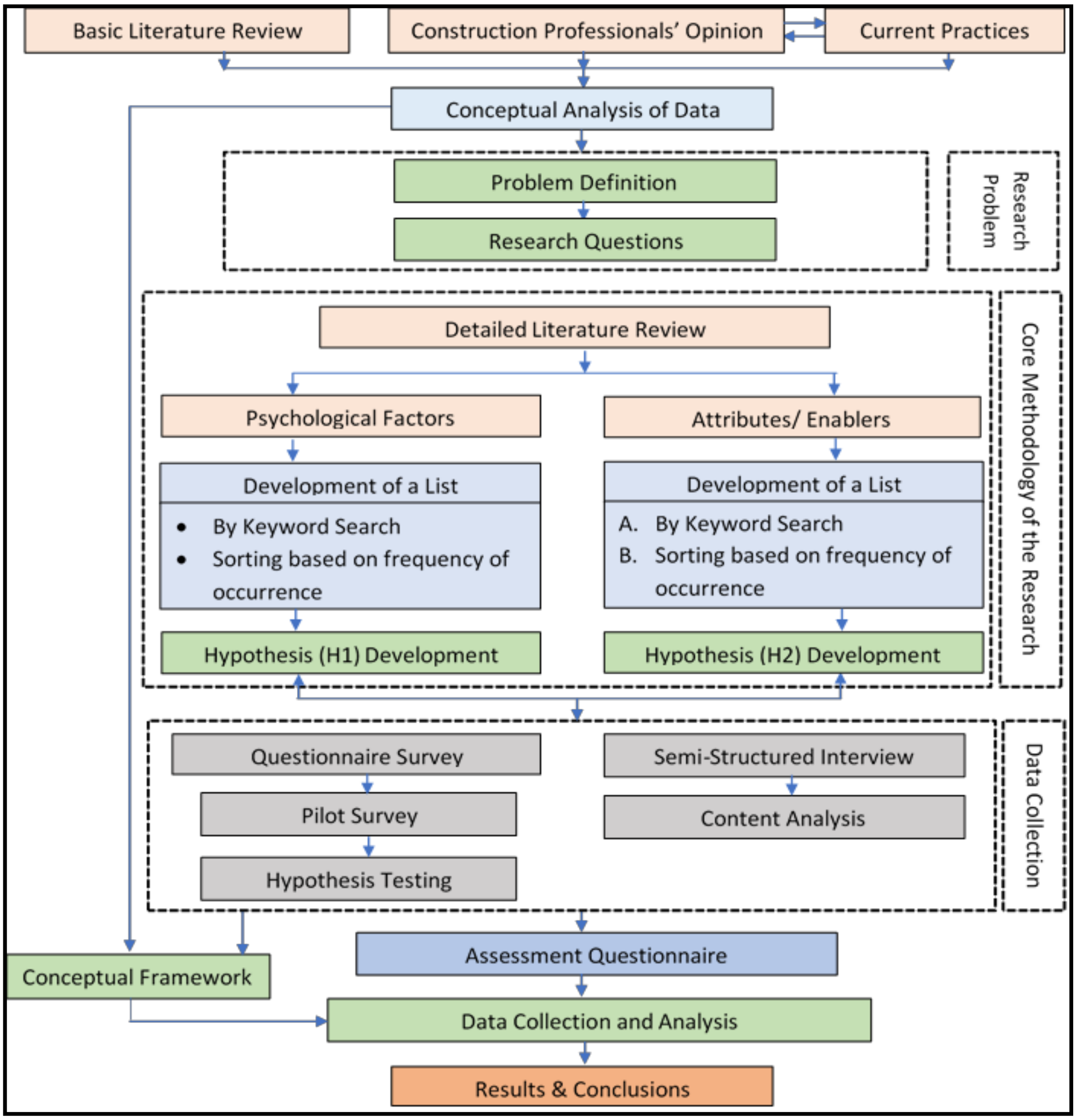


Figure 1: Research methodology for the present study

A keyword search was conducted on the existing literature published on construction collaboration. The keywords used were 'collaboration in construction,' 'interface management,' 'measurement of collaboration,' and 'aspect of collaboration.' In addition, a list of project-level enablers and psychological factors was made after selecting the relevant literature from the keyword search. Based on Tables 1 and 2, two hypotheses were developed as inductive theories. These are presented below:

Hypothesis 1 (H1): A person is said to be collaborative if they express the following psychological features through their work in a construction project setting.

The psychological factors are: Curiosity, Generosity, Appreciative, Building relationships, Transparency, Discipline, Self-motivation, Respectfulness.

Hypothesis 2 (H2): A particular project's hierarchy is collaborative if the person/teams responsible for the assigned work at that level show experience or perform with the following enablers at the place.

These project-level enablers of collaboration are: Trust, Good communication, Shared vision, Process design, Engagement of stakeholders, Adoption of information technology, Real-time information sharing, Reliability on work assigned, Commitment towards work, Readiness to share information.

It can be noted that the project level enablers in Table 1 and psychological factors in Table 2 were from different research papers across several countries. This conceptual framework was explicitly intended to be used for Indian construction projects; therefore, understanding the relevance of these enablers in the Indian context was required. Thus, to capture the perspective of construction professionals across India, a detailed and specific questionnaire was designed. The questionnaire aimed to sort the most critical enablers for the Indian construction industry by collecting data from construction professionals. The data were collected using a five-point Likert scale: 1 denoting 'Not Important' to 5 denoting 'Very Important'.

A pilot survey was done to ensure that the questions were understood clearly and there was no ambiguity in word selection. Next, the questionnaire was shared with experienced construction professionals across various projects and companies. They were requested to follow the instructions while answering the questionnaire and respond based on their understanding of construction management.

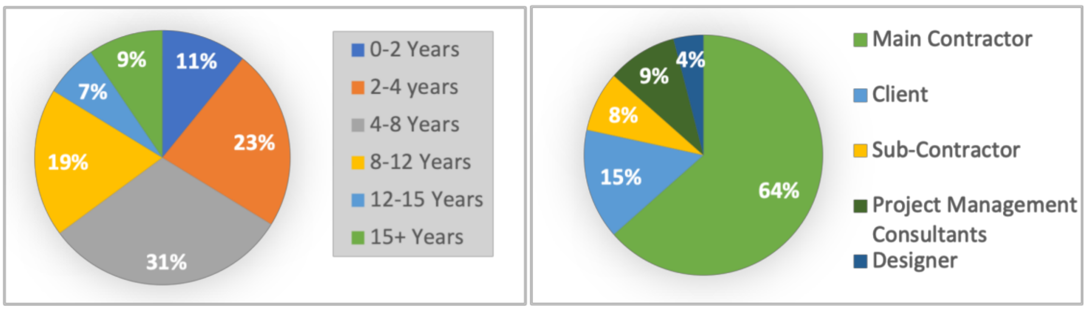
An appropriate statistical hypothesis testing model that includes 't-test' and 'Mann-Whitney Rank Sum test' was proposed, and the data collected using the questionnaire was statistically analysed. The statistical hypothesis testing model resulted in developing the 'stakeholder- project level enablers' matrix. In the deductive research approach of this study, this 'stakeholder- project level enabler' matrix was the basis for the conceptual framework.

In the next section, the results of the questionnaire survey are presented. The results were used to derive the conceptual framework.

4. RESULTS AND FRAMEWORK DERIVATION

The questionnaire was sent to 130 participants, and 74 responses were received. This yielded an adequate response rate of 56.92%.

Figure 2 represents the demographics of the respondents. Figure 2(a) shows respondents' affiliation concerning Client, Project Management Consultants, Designers, Main Contractors, and Subcontractors. It can be observed that 64% of the respondents are main contractors. Similarly, the experience of the respondents is shown in Figure 2(b). It is observed that 73% of the respondents have work experience between 2-12 years.



2(a) 2(b)

Figure 2: (a) Demographics of respondents - experience; (b) Demographics of respondents - affiliations

Table 3: Results of statistical hypothesis testing

Sl. No	Psychological Factors	Main Cont.	Client	PMC	Sub-Contractor	Designer
1	Curiosity	X	X	X	X	X
2	Generosity	▲	▲	▲	▲	▲
3	Being Appreciative	▲	▲	▲	▲	▲
4	Building Relationships	X	X	X	X	X
5	Transparency	▲	▲	▲	▲	▲
6	Discipline	X	X	X	X	X
7	Self-Motivation	X	X	X	X	X
8	Being Respectful	X	X	X	X	X
	Project Level Enablers					
9	Good Communication	▲	▲	▲	▲	▲
10	Trust	X	X	X	X	X
11	Shared Vision	X	X	X	X	X
12	Process Design	▲	▲	▲	▲	▲
13	Engagement of Stakeholders	▲	▲	▲	▲	▲
14	Adoption of Information Technology	▲	▲	▲	▲	▲
15	Real-Time Information Sharing	▲	▲	▲	▲	▲
16	Reliability of Work	▲	▲	▲	▲	▲
17	Commitment Towards Work	X	X	X	X	X
18	Readiness to Share Information	X	X	X	X	X

Codes: ▲- Important, X- Not Important, Main Cont.- Main Contractor

As per the responses obtained from main contractors, it is observed that “generosity,” “being appreciative,” and “transparency” are three crucial intrapersonal psychological factors for collaboration.

Similarly, “good communication,” “process design,” “engagement of stakeholders,” “adoption of information technology,” “real-time information sharing,” “reliability towards work” are project-level enablers, which are essential for defining a project as a collaborative project.

In addition, no significant difference is observed in the pattern of responses of the main contractors and other stakeholders within the scope of this research. This statement was derived after testing the data using Mann-Whitney Rank Sum Test. Therefore, the conclusion drawn in the previous paragraph about main contractors will hold for other stakeholders, viz. clients, project management consultants, subcontractors, and designers.

The conceptual framework for measuring the collaboration in a construction project was derived and is presented in Figure 3. The results of hypotheses testing presented in Table 3 are the primary input data for this conceptual framework. From Table 1, a list of ten enablers along with their frequency was obtained. The results of the hypothesis testing methodology yielded the six most important enablers of collaboration of the Indian construction industry. The psychological factors are not used in the conceptual framework.

For each of these six project level enablers, a set of statements were derived so that these statements together define each of the project level enablers. These statements were developed intuitively and based on the authors' understanding, supplemented by the literature review. These statements are to be used for measuring collaboration in a construction project.

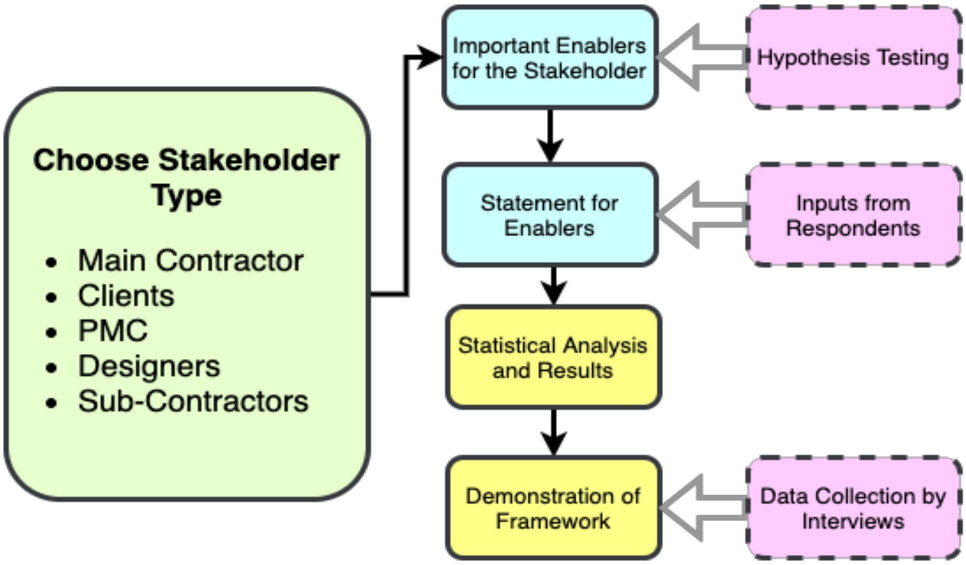


Figure 3: Conceptual framework to measure the level of collaboration in a construction project

The statements are assessed by the project participants of a construction project in a 5-point Likert scale. The average score of the statements under each project level enabler is taken and overall Likert score is the algebraic sum of all project level enablers.

The level of collaboration of a construction project is defined into three categories- ‘collaboration visible to great extent,’ ‘collaboration visible to some extent,’ and ‘no visible collaboration.’ This classification is based on the overall Likert scale value of the six sorted project level enablers of collaboration, which is presented in Table 4. The overall Likert score (Column 3, Table 4) is calculated from the inputs collected from the construction professionals of the project.

Table 4: Basis of measuring the level of collaboration based on Likert scale

Sl No	Collaboration Extent or Level of Collaboration	Overall Likert Score
1	Collaboration Visible to Great Extent	30-21
2	Collaboration Visible to Some Extent	15-21
3	No Visible Collaboration	< 15

5. DISCUSSION

Hypotheses testing resulted that three out of the eight psychological factors are important for defining a person as a natural collaborator. These are “generosity,” “being appreciative,” and “transparency.” In addition, six out of ten project-level enablers are important for defining project-level collaboration. These are “good communication,” "process design," "engagement of stakeholders," "adoption of information technology," "real-time information sharing," and "reliability towards work." Hence, by identifying these aspects, the first objective of the study was achieved.

These findings can be related to the project management practices in the Indian construction industry. Construction projects involving multiple stakeholders should have a system enabling and promoting collaborative activities within construction projects. It is synonymous with process design, engagement of stakeholders, and adoption of information technology to facilitate collaboration. In addition, construction projects often face problems due to a lack of friendliness and readiness to share information. This argument supports the findings that good communication and willingness to share information enhances collaboration within construction projects.

In line with the findings of this study, existing literature has also discussed many aspects for successful collaboration within construction projects. For example, researchers have illustrated the importance of good communication as an enabler of collaboration (Eriksson, 2010; Panahifar *et al.*, 2018). Further, readiness to share information is also denoted as a key enabler of collaboration Hughes *et al.*, 2012). Moreover, management should ensure its role in embracing and enhancing a culture of collaboration in construction projects and enabling it. In this context, the participants should have a shared vision, and the construction activities are to be designed accordingly (Wu *et al.*, 2008; Narayanan *et al.*, 2019).

In addition, the adoption of information technology such as BIM can provide a platform for all project participants to collaborate effectively (Wu *et al.*, 2008; Hughes *et al.*, 2012). The BIM integration in project management requires all the stakeholders to participate in the collaboration process.

However, literature does not have an explicit framework to measure the collaboration of construction projects that includes the soft issues of collaboration. Therefore, in this research, a framework is developed using the key soft issues for the construction industry to measure collaboration in a construction project. This adds value to the existing literature on construction collaboration.

However, many researchers have argued the importance of trust as a project-level enabler of collaboration. On the contrary, the hypothesis testing results from this study contradicted these arguments. It was unexpected to note that trust is not important as per the hypotheses testing methodology. Similar observations were recorded for commitment towards work.

Future work may include validating the collaboration measurement framework by performing few case studies to continue this research. In this process, the construction professionals will understand the importance of collaboration and get acquainted with the concepts of collaboration. Furthermore, this value addition to the conceptual framework can be enhanced by incorporating the feedback received from the construction professionals.

6. CONCLUSIONS

The research presented in this paper tries to find the key psychological factors and project enablers of collaboration for a construction project. The key contribution of this paper is two-folded. Firstly, a list of psychological factors and project enablers are developed from the literature obtained from a keyword search on construction collaboration. Appropriate hypotheses testing methodology is used to sort the important psychological factors and project level enablers for the Indian construction industry. This resulted in three psychological factors and six project enablers amongst the sorted, which are important for the Indian construction industry. Secondly, a conceptual framework is derived that includes these six project enablers to measure the collaboration of a construction project. However, the psychological factors were not used in the conceptual framework.

The findings of the hypothesis testing methodology are in line with the discussions presented in the existing literature. However, this research adds value to the current literature as it develops a framework to measure collaboration in a construction project. The future scope of this research may be to develop a methodology to validate the framework and perform some case studies.

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A MODEL FOR HUMAN CAPACITY BUILDING OF LARGE-SCALE CONTRACTORS TO FOSTER LEAN CONSTRUCTION IN SRI LANKA

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ABSTRACT

People are at the core of lean implementation more than a set of tools and techniques. Several studies reflect that implementing lean to the construction industry heavily relies on the knowledge and skills of the people and how they respond to changes. Several studies have reflected that building human capacities as one of the most prominent considerations to foster lean concept in construction industry. However, there is a lack of empirical investigation on human capacities and strategies to build human capacities for successful lean construction implementation of large-scale contractors. Therefore, the purpose of this paper is to investigate the human capacities to be built in order to implement lean concept and propose organisational level strategies to build those capacities in large-scale contractors of Sri Lanka to foster lean construction. A qualitative approach was adopted as the research approach and case study was the selected research strategy. Fifteen respondents from three cases were interviewed to gather in-depth input to the study and collected data were analysed using code-based content analysis with NVivo 12 Software. The study identified positive attitudes, values, commitment, trust, adopt to cultural change, physical fitness, technical skills, and team building as human capacities necessary for unskilled and craft level workers. Positive attitudes, managerial and technical skills, team building, communication skills, knowledge, commitment, social skills and interest in new concepts were recognised as human capacities of administrative and professional and managerial levels. Several strategies that can be used by the contractors to build the above capacities have been summarised into a model. The final model presents the unskilled, craft, administrative, and professional & managerial level human capacities to be built by large scale contractors and strategies to be used for building those capacities to foster lean in construction industry.

Keywords: *Human capacity building; Large scale contractors; Lean construction; Strategies.*

1. INTRODUCTION

Lean Construction (LC) is one of the best construction project management approaches, that enhances the successful delivery of construction projects through continuous improvement, reduction of wastage, and value maximisation of client's money (Mano *et al.*, 2021). Major benefits of using LC include reduction of construction cost,

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improvement of the quality of construction, increase of the productivity and customer satisfaction (Demirkesen *et al.,* 2020). However, the implementation of lean in construction industry is not free from barriers. Among the barriers, most of the studies have highlighted lack of lean awareness and understanding, lack of top management commitment, time and commercial pressure, culture and human attitudinal issues, unwillingness to provide training and resources to adopt new systems, and insufficient finances as major barriers for lean implementation in both global and local context (Mano *et al.,* 2021; Ranadewa *et al.,* 2018). When considering the above barriers, it is clear that most commonly identified lean implementation barriers are related to the human aspects. In this context, Bhasin (2012) emphasised that lean is not just a set of tools and techniques, but its heart is the people. According to Koskela *et al.* (2002), LC requires changes in individual behaviour and thus, building individual capacities will accelerate the lean implementation.

In Sri Lankan context, Ranadewa *et al.* (2019) highlighted that human capacity building has the key potential towards the successful lean implementation in small and medium contractors (SMCs) in Sri Lanka. Lack of focus on human capacities has further slowdown lean implementation. Thus, an investigation on human capacity building for successful lean implementation is a paramount research focus in construction industry. Ranadewa *et al.* (2019) have investigated the importance of human capacity building in SMCs to enable lean in Sri Lankan construction industry. However, their study was limited to construction SMCs, that have unique difficulties and way of operations. Further, the difficulties and capabilities of large construction organisations are different from construction SMCs in lean implementation. This has been proven by UN-HABITAT (1996) as the convenience of evaluating the workers and employees of the project, planning of human resources, and better understanding of top management on the skills of human resources of SMCs rather large-scale contractors. Further, the large-scale contractors have the higher organisational conditions including human, material and financial resources rather SMCs (Melo and Machado, 2013). Hence, this paper aims to investigate the human capacities to be built in order to implement lean concept and propose organisational level strategies to build those capacities in large scale contractors of Sri Lanka to foster lean construction.

2. HUMAN ENABLING CAPACITIES AND STRATEGIES IN PRACTICE TO FOSTER LEAN CONSTRUCTION

In order to implement the right tools and strategies to create customer value, understanding capacity building concepts is significantly important (Linné and Ekhall, 2012). Howell *et al.* (2017) explained LC as a value seeking process that maximises value and continually redefines perfection construction whereas, UNESCO (2011) defined the term capacity as the ability of individuals, organisations and systems to perform functions efficiently, effectively and sustainably. Further, Groot and Molen (2001) described human capacities as the knowledge, skills and attitudes of human resources in design, development, management and maintenance of institutional, operational infrastructures and organisational process.

Previous literature has emphasized the links between lean implementation and human resources management, capacities, and policies, which provide evidence on the possibility of fostering lean concept through human capacity building (Olivella *et al.* 2008). Hence, it is essential to identify the lean enabling human capacities.

The human capacities to be developed by individuals for successful lean implementation in construction industry are summarised in Table 1.

Table 1: Human capacities required for lean construction implementation

Human Capacities	**References**														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1.Knowledge	X	X	X	X	X	X	X	X	X			X	X	X	X
2.Education level					X						X	X	X	X	X
3.Technical skills	X	X					X		X						
4.Managerial skills	X	X				X	X	X				X	X		
5.Social skills							X								
6.Attitudes	X	X			X	X	X			X		X	X		X
7.Values/ ethics					X							X	X		X
8.Desires to organisational improvement			X	X	X										
9.Trust	X				X		X								
10.Commitment					X	X	X							X	
11.Experience		X			X	X		X					X		X
12.Training					X	X		X			X	X	X		X
13.Capacity to change				X		X	X	X					X		
14.Adaptation to culture						X		X		X				X	
15.Self-confidence			X				X							X	
16.Continual professional development									X				X		X

References: [1] Groot and Molen (2001); [2] Enemark and Ahene (2003); [3] Bhasin (2012); [4] Alves *et al.* (2016); [5] Alves *et al.* (2016); [6] Aziz and Hafez (2013); [7] Pavez and Alarcón (2006); [8] Ranadewa *et al.* (2019); [9] Kululanga (2012); [10] Maidi (2020); [11] Rashidi and Ibrahim (2017); [12] Jin and Ling (2005); [13] Achanga *et al.* (2006); [14] Ankomah *et al.* (2017); [15] Antosz and Stadnicka (2017)

Considering the human capacities highlighted in the above table, most of the researchers have stressed that knowledge, managerial skills, attitudes, and training are essential to sustain the lean concept in construction industry. Further, some other human capacities emphasised in the table such as educational capacities, desires to organisational improvements, self-commitment, previous experiences, individual's capacity to change and adaptation to the cultural deviations within the organisations seem comparatively important factors for successful lean implementation. Hence, building human capacities can be presumed as an important consideration to foster lean construction. However, majority of local construction organisations in developing countries lack human capacities to implement lean. Therefore, an investigation on lean enabling human capacities and strategies that can be taken by the construction organisations to build those capacities are inevitable for a successful lean journey.

The strategic actions to be taken for building human capacities to foster lean construction can be explained under the individual, organisational, industrial, and governmental levels as shown in Table 2.

Table 2: Strategies for building human capacities to foster lean construction

Strategies for Building Human Capacities to Foster Lean Construction			
Individual Level	**Organisational Level**	**Industry Level**	**Government Level**
1.Continuous urge on learning lean concepts [1] 2.Individual commitment on training lean practices [1] 3.Develop self-confidence and commitment [2] 4. Enhance individual knowledge by self-learning process [3] 5.Enhance the self-awareness of lean practices throughout process [1] 6.Improving individual morale by themselves [4] 7.Self-development of soft skills [2]	1.Support individuals to obtain required lean knowledge [5] 2.Encourage mentoring and enhance individual awareness on lean benefits [5] 3.Promote training and learning within organisation [6] 4.Adopt lean culture within the organisation [7] 5.Persuade individuals in partnership to work with others [8] 6.Promote new developments within an organisation [5] 7.Have a reward scheme to motivate lean implementors [9]	1.Encourage academic-industry partnership in lean research [5] 2.Enhance collaborative practices among parties in construction industry [2] 3.Conduct seminars and workshops on LC [10] 4.Build the innovative models for individuals and organisations [2] 5.Organise lean conference by relevant authorities and institutions [11] 6.Produce lean trainers by lean institutes [11] 7.Pubilsh research on LC by construction industry authorities and institutions [12]	1.Introduce new laws and regulations to support lean implementation [13] 2.Provide loan facilities at concessional interest rates for lean implementing project [11] 3.Provide tax concessions for lean projects [14] 4.Establish stable economic & political environment within the country [14]

References: [1] Ong and Sui Pheng , 2021; [2] Green and May, 2005; [3] Bakas *et al.,* 2011; [4] Howell, *et al.,* 2017; [5] Mohamed, 2021; [6] Alves *et al.,* 2016; [7] Bortolotti *et al.,* 2015; [8] Srinivasan *et al.,* 2020; [9] Dave, 2013; [10] Bygballe *et al.,* 2018; [11] Ranadewa *et al.,* 2019; [12] Kulatunga *et al.,* 2007; [13] Kululanga, 2012; [14] Sarhan and Fox, 2013.

According to Table 2, the individual employees must be committed to lifelong learning in lean environments and self-develop individual capacities. Support, encourage and mentor employees to enhance knowledge on LC, and promote training and learning on LC within organisation are highlighted as strategies to be adopted in organisational level. Conducting training programme, publishing research, organising conferences, and produce trainers on LC are the industry level strategies summarised in Table 2. Considering the governmental level strategies, providing loan facilities, tax concessions and stable political environment within the country for lean implementers are identified as encouragements for the lean implementation within organisation. Having considered above review, it is important to investigate the human capacities to be built in order to implement lean concept and propose organisational level strategies to build those capacities by large scale contactors in Sri Lanka to foster lean construction.

3. RESEARCH METHODOLOGY

The nature of the research problem, which is to identify the human capacities necessary for successful lean implementation in Sri Lankan construction industry necessitates an in-depth investigation. Moreover, the opinions of respondents regarding the human capacities were also required to be collected. Hence, a qualitative approach was selected as the suitable research stance for this study (Naoum, 2007).

Within the qualitative research approach, case study research strategy was adopted to proceed with the study considering several reasons. Case study strategy could facilitate to accomplish the aim of this study since this strategy enables the in-depth investigation in the context (Yin, 2011). Further, the study investigated a real-life phenomenon, which was human capacity building of employees, using the experiences of top management level employees of a construction projects. Considering the aforementioned reasons, the case study strategy was adopted to the study. The boundary of the case studies was identified as the lean implemented construction projects by large contractors in Sri Lankan construction industry. Hence, three (03) cases were selected for the study, from large contractors (C2 or above) in Sri Lankan construction industry, those who have implemented LC practices. Human capacities necessary for successful LC implementation have been considered as the unit of analysis.

According to Yin (2011), several data collection techniques can be included in case study strategy such as interviews, document reviews and observations. Data was collected using an open-ended interview guideline by allowing respondents to answer independently in this study. The collected data was analysed with code-based content analysis using NVivo software. Five top management respondents from each project were interviewed using an interview guideline. The profile of the respondents has been elaborated in Table 3.

Table 3: Respondent profile

Project	Respondent	Description
Project A	AR1	Project Manager with 20 years of experience
	AR2	Deputy Project Manager with 15 years of experience
	AR3	Planning Engineer with 5 years of experience
	AR4	Site Engineer with 3 years of experience
	AR5	Quantity Surveyor with 12 years of experience
Project B	BR1	Project Manager with 25 years of experience
	BR2	Construction Manager with 18 years of experience
	BR3	Resident Engineer with 20 years of experience
	BR4	Site Engineer 6 years of experience
	BR5	Quantity Surveyor 16 years of experience
Project C	CR1	Project Manager with 23 years of experience
	CR2	Deputy Project Manager with 20 years of experience
	CR3	Planning Engineer with 10 years of experience
	CR4	Site Engineer with 5 years of experience
	CR5	Quantity Surveyor with 8 years of experience

The scope of the study was narrowed to identify human capacities necessary for unskilled, craft level, administrative, and professional & managerial level employees to successfully implement lean concept in large scale contractors and propose strategies to build the human capacities. Moreover, the proposed strategies to build the human capacities necessary in fostering lean construction have been limited to organisational level strategies.

4. RESEARCH FINDINGS

4.1 HUMAN CAPACITIES NECESSARY FOR FOSTERING LEAN CONSTRUCTION IN LARGE SCALE CONTRACTORS IN SRI LANKA

The respondents were questioned regarding the human capacities necessary to foster LC in unskilled, craft, administrative, and professional & managerial level employees as described below.

4.1.1 Human Capacities Necessary for Unskilled Level Employees

Several respondents of all selected projects highlighted that the way of people thinking and practicing within the working environment needs to be changed in a positive manner. Hence, *"positive attitudes"* and *"values or ethical behaviour"* have been identified as two of the critical human capacities that need to be developed. According to AR1 and AR3, due to several lean practices are being adopting in the working environment, the existing culture is changing and hence, the unskilled workers need to be *"adopt to cultural changes"*. Further, to be compatible with the working patterns within the lean environment, the necessity of *"commitment"* and *"trust"* between workers have been emphasised by AR1, BR2 and CR4. Considering the above capacities need to be developed, the respondents have further stressed that unskilled workers should have the *"capacity to change"* with the cultural and working process changes within the working environment. Additionally, BR3 have emphasised that having a higher level of *"physical fitness"* will enhance the labour productivity and higher quality of work, which is essential in fostering LC. Moreover, BR1 highlighted that *"higher level of understanding"* of unskilled labours about their responsibilities and achievable individual benefits within the lean environment is another essential human capacity. CR1 has also emphasised that the unskilled level workers need to develop their ability to work with the co-workers as a team to achieve the ultimate objective of enhancing the value of project. Hence, *"team building"* has identified as another human capacity, which is necessary to be developed in unskilled level workers. In addition to all other opinions, CR5 highlighted that the desire to achieve organisational development must be developed not only within the top management, but the lower-level workers must also have the same sense. Hence, *"desire to organisational development"* has been emphasised by CR5.

4.1.2 Human Capacities Necessary for Craft Level Employees

The human capacities identified for the unskilled level workers namely *"positive attitudes"*, *"values or ethical behaviour"*, *"adopt to cultural changes"*, *"trust"*, *"commitment"* and *"capacity to change"* have also been highlighted for the craft level workers by majority of respondents in all three projects. Additionally, AR1 stated that the *"technical skills"* needs to be inculcated in the craft level workers to work with the machinery, lean tools, and techniques. Further, *"team building"* is also highlighted by AR4, since craft level workers are working in a team environment by co-operating with the other co-workers. Further, BR1 has highlighted that *"self-confidence and personal integrity"* is essential to develop within the craft level workers in fostering LC. Moreover, CR5 stressed the idea of having the *"desire to organisational development"* within the craft level workers same as in the unskilled workers.

4.1.3 Human Capacities Necessary for Administrative Level Employees

The respondents from all three projects have highlighted the importance of having *"positive attitudes"* and *"values/ethical behaviour"* in the administrative level staff same as in the unskilled and craft levels. More comprehensively BR1 stressed that administrative level staff is an important category, who should necessarily avoid the attitudinal issues towards the lower-level workers, colleagues and senior staff. Further, the several respondents from all three projects have identified the necessity of having lean knowledge and the technical know-how of administrative level staff in lean implementation. Having *"sound knowledge"* of LC is important to be built in administrative staff to recruit the employees for the project. Moreover, the respondents have highlighted the necessity of *"higher educational level"* since it will ensure the required level of knowledge to execute the lean practices. Moreover, the respondents have highlighted the importance of having *"managerial skills"* to build the collaborative working environment between the workers. Additionally, AR2, AR3 and CR5 have highlighted "technical skills" and having the sound "experience" of LC. Further, BR1 and CR1 have highlighted the importance of *"team building"* and *"communication skills"* in the administrative level staff to encourage co-workers to adhere to the lean environment while establishing the proper interpersonal relationship and networking within the team members. The *"adaptation to culture"* is another important human capacity stressed by AR3. According to AR3, all the human resources within the working environment need to be adhered to the lean culture irrespective of the level. At the same time AR3 highlighted *"commitment"* as another important human capacity of the administrative staff to enhance the effective performance of the workers. According to BR1, *"having interest in implementing new concepts"* is another important capacity, which the administrative staff need to be build up. Further, CR3 has suggested the necessity of having *"social skills"* as it is comparatively important to create the culture to make the subordinates work within the project. According to the respondents, having social skills is significantly important for administrative level staff rather professional and management level.

4.1.4 Human Capacities Necessary for Professional and Managerial Level Employees

When considering the human capacities essential in professional and managerial level employees, several respondents have highlighted the same human capacities as suggested for the administrative level employees. More comprehensively, the *"managerial skills"* in professional and managerial staff will contribute to continue better relationship with the subordinate workers to obtain their full capacity towards the lean practices within the working environment. Further, having managerial skills would lead the managers to achieve the higher productivity of human resources. CR5 has further expressed that having the experience in lean implementation would facilitate the top management to adopt lean practices within the project to achieve the goal of cost effectiveness and higher quality. Further, BR1 and CR1 have highlighted the importance of *"team building"* in professional and management level since they need to lay the foundation of team building in order to adopt the co-workers to the lean culture. According to BR1, *"having interest in implementing new concepts"* will lead the top management to take initial step to implement lean within the organisation and project environment. Anyhow, the respondent has specifically stated that *"social skills"* are not significantly important human capacities to be built in professional and managerial level staff.

4.2 STRATEGIES TO BUILD HUMAN CAPACITIES FOR FOSTERING LEAN CONSTRUCTION IN LARGE SCALE CONTRACTORS IN SRI LANKA

Strategies to build human capacities in the construction industry have been identified in four respective levels namely individual, organisational, industrial, and governmental as highlighted in the literature findings. However, this paper focus is limited to organisational level strategies. Hence, the following section provides the strategies that were proposed at the organisational level to develop human capacities necessary to foster LC for unskilled, craft, administrative and professional & managerial levels.

4.2.1 Strategies to Build Human Capacities of Unskilled Level

To enhance the level of understanding, individual responsibilities and to develop positive attitudes within the lean environment, AR1 proposed to conduct *"on-the-job training"* programmes for unskilled workers. This strategy would support to motivate the unskilled workers to provide their maximum productivity in practising LC within the project. BR2 suggested to *"provide reasonable welfare facilities"* to unskilled workers. According to BR2, this strategy would enhance the productivity and capacity of the unskilled workers and allow the top management to promote practices of LC within the lower-level workers. To adopt unskilled workers to the lean culture, suitable culture for the unskilled level workers needs to be built and maintain within the working environment. Accordingly, *"build and maintain suitable culture"* can be proposed as an important strategy. CR4 proposed to *"conduct daily meetings"* with unskilled levels workers to inject the idea on practicing LC and maintaining quality of the work as another important strategy. This will enable the top management to build the suitable interpersonal relationship with lower-level workers. Further, this strategy would contribute to enhance the team building capacity of the unskilled workers and also the desire to organisational development. BR1 suggested another strategy of *"having strong administrative team"*, so that negative attitudes on lean construction practices within project and negative ethical values of unskilled workers could be eliminated through proper administration of workers. According to AR3, *"introducing a flow of inspection"* can be proposed as another strategy to build human capacity of commitment to the work. Further, this strategy would support to avoid the unnecessary wastages of defective works, overproduction and overprocessing by unskilled workers. Further, some respondents highlighted the importance of *"introducing new rules"* to the unskilled workers rather the policies in LC implementation.

4.2.2 Strategies to Build Human Capacities of Craft Level

Similar strategies suggested for the unskilled workers have been proposed by several respondents since the human capacities are also similar in nature for both unskilled and craft level workers. In addition to the aforementioned strategies in unskilled level, BR1 highlighted to *"conduct trade test"* for craft level workers within the project to identify the talents of the workers. This would support to enhance the technical skills of the workers essential in supporting LC implementation and ensure the self-confidence of the workers. Further, AR3 proposed to *"introduce a suitable reward scheme"* to encourage the craft level workers who are contributing to the LC practices implemented within the construction project.

4.2.3 Strategies to Build Human Capacities of Administrative Level

According to majority of the respondents from all the projects, *"conducting training programs"* has been proposed by AR1, BR2, CR5 as an important strategy to be implemented in the administrative level. Provide a suitable training program regarding the LC practices, tools and techniques would be contributing the administrative level staff to develop the implementation of LC. This strategy would be contributing to enhance the knowledge on administrative level staff essential in lean construction implementation. *"Provide promotions"* to the administrative level staff who are actively participating in establishing LC practices within the project would be significantly important in building the human capacities such as attitudes, commitment and adaptation to culture as suggested by BR1. *"Conducting Continual Professional Development (CPD)"* programmes were suggested by BR2 and CR1 as an important strategy to build human capacities of interpersonal skills and interest in new concepts. CPD on LC practices, tools and techniques can be conducted in the organisational level to make aware the administrative level staff about LC. Further, as proposed in previous section for craft level workers, *"allocating an allowance"* to employees who are implementing LC practices within the projects can be proposed for administrative level staff as well. In addition to that, BR1 emphasised the *"introduction of new rules and policies"* is significantly important in supporting the successful lean implementation within the organisation. Further, CR2 identified *"conduct weekly meetings"* and *"provide welfare facilities"* to administrative level staff would encourage to involve more in LC practices.

Additionally, some of the respondents highlighted the necessity of governmental involvement in building human capacities in this level. Accordingly, CR2 stated that government must take the initiative to provide tax concessions and other monetary benefits such as loan facilities to the lean implementing construction organisations. Hence, this will enhance the interest of administrative level workers in the implementation of new concepts such as LC as evidenced in literature findings by Green and May (2005).

4.2.4 Strategies to Build Human Capacities of Professional and Managerial Level

According to the respondents, the same strategies as proposed in the previous section for administrative level have been highlighted for the professional and managerial level as well. More comprehensively AR4 proposed that *"allocating an allowance"* for the lean implementors within the organisation would encourage the professional and managerial level staff to move for lean initiatives. Although, the aforementioned strategies have been proposed in organisational level for professional and managerial staff, some of the respondents have stressed that suitable strategies need to be deployed in the industry level as well. Accordingly, AR1 suggested that the construction industry should take necessary steps to provide training programmes, conducting seminars, workshops, CPDs' and conferences on LC practices as evidenced in the literature findings by Green and May (2005) and Bygballe *et al.* (2018).

4.3 MODEL OF ORGANISATIONAL LEVEL STRATEGIES FOR BUILDING LEAN ENABLING HUMAN CAPACITIES

This study mapped human capacities for fostering lean construction with the strategies required for building those capacities into a model as presented in Figure 1.

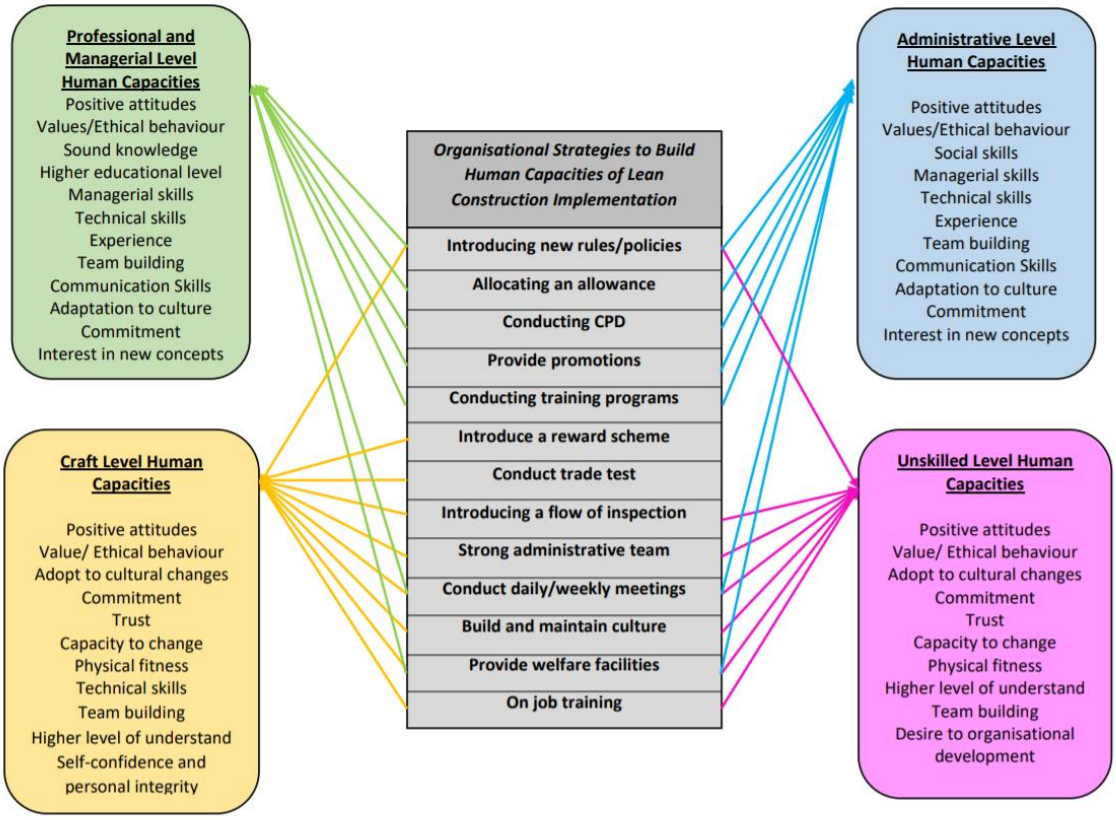

Figure 1: Model of organisational level strategies for building lean enabling human capacities

According to Figure 1, the study has identified several human capacities to be built by unskilled, craft, administrative, and professional & managerial level employees to foster lean construction in large scale contractors. Organisational level strategies that can be proposed to develop human capacities have been illustrated separately for unskilled, craft, administrative, and professional and managerial levels in the model. According to Figure 1, human capacities such as level of understand, positive attitudes can be improved by conducting on job training for unskilled and craft level workers and attending to the training programs conducting by the organisations. Moreover, several human capacities such as communications skills, technical skills, and team building can also be improved by attending the training programs. The impact of promote training and learning within the organisation have also been proven in literature by Alves *et al.* (2016). Further, the importance of introducing a reward scheme to motivate the employees who are involve in the lean implementation within the organisation was highlighted in the literature by Dave (2013). The same strategy has been identified by the respondents to foster the lean construction through building the necessary human capacities such as commitment and interest in new concepts. Except the identified strategies in the literature, several strategies to foster lean construction through human capacity building have been illustrated in Figure 1 such as introducing new rules and policies, conducting CPD for administrative and professional and managerial level employees, trade tests for craft level workers, conducting daily or weekly meetings and provide welfare facilities, introducing a flow of inspection and introducing a strong administrative team within the project structure. According to the findings summarised in Figure 1, the proposed strategies for human capacity building is similar in nature for both administrative, and professional & managerial levels. Further, the strategies identified for unskilled and craft level workers are similar in nature as categorised in Figure 1, while introducing new rules and reward scheme is significantly important for capacity building of craft level workers.

5. CONCLUSIONS

There has been a notable growth in lean implementation in the construction industry. Hence, there is a need to investigate the human capacities that are necessary in implementing lean in large scale contractors in Sri Lankan construction industry and suitable strategies to build the respective human capacities. The human capacities have been identified with respect to the unskilled, craft, administrative, and professional & managerial levels. Positive attitudes, values, or ethical behaviour, adopt to cultural changes, commitment, trust, capacity to change, physical fitness, higher level of understanding, team building, and desire to organisational development have been identified as human capacities necessary for unskilled level. In addition to the aforementioned capacities, technical skills and self-confidence, and personal integrity are the human capacities identified for the craft level. Considering the administrative and professional & managerial levels, some of the major human capacities have been identified as sound knowledge, educational level, managerial skills, social skills, experience, team building, capacity to change and adaptation to culture. Anyhow, comparative to the professional and managerial level, the study has identified that social skills are highly important human capacity to be built for administrative level. Further, the strategies have been identified to build the human capacities in unskilled, craft, administrative, and professional & managerial levels to successfully implement LC. The model developed in this study will guide the large-scale contractors to identify the organisational level strategies to build human capacities in unskilled, craft, administrative and professional & managerial levels to foster lean construction in large scale contractors in Sri Lankan construction industry.

6. ACKNOWLEDGEMENTS

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A MODEL TO ASSESS THE MAINTENANCE LEANNESS OF APPAREL INDUSTRY BUILDINGS IN SRI LANKA

P.A.L.P. Perera[1] and Nayanthara De Silva[2]

ABSTRACT

Escalating needs of availability in built environments have pursued maintenance to be recognized with the strategic importance notwithstanding the conventional belief of necessary evil. Nevertheless, it absorbs the three-quarters of whole building lifecycle cost. Studies proved that proportion significantly contributed by inefficiencies owing to poor maintenance, lack of reliability focus, poor management commitment, technical and human resources-related issues. Consequently, Sri Lankan buildings opted to adopt numerous strategic management approaches such as Lean, Six-Sigma to acquire the higher status of efficiency and effectiveness in their operations. Simultaneously, adherence to lean concepts was apparent in Sri Lankan manufacturing context, relatively fewer attempts were made on establishing assessment procedures to distinguish the degree of leanness. Hence, research was focused on developing an assessment model to address the leanness levels in maintenance operations. Lean quantification metric "Leanness" in maintenance is defined through identified parameters in literature and those were narrowed down into seven (7) leanness criteria and further expanded into forty-two (42) leanness attributes paving a pathway to the formation of a theoretical assessment model. For the investigation, nine semi-structured interviews were conducted from three identical cases. The derived data were analysed using the manual content analysis technique. Empirical findings revealed satisfactory adherence scoring the thirty-eight (38) attributes accomplishment as the highest and twenty-five (25) as the least. Findings point out significant gaps in lack incorporation of planned maintenance programs with maintenance inventory-related aspects, lack of undertakings on extensive reliability analysis efforts for maintenance activities. The outcomes will mark valuable insights for building practitioners to engage in maintenance operations in a versatile manner to acquire a waste-free, quality, stakeholder-driven maintenance environment.

Keywords: *Built environment; Lean maintenance (LM); Leanness; Leanness assessment; Sri Lanka.*

1. INTRODUCTION

In recent decades, building maintenance was given the utmost importance worldwide due to the increasing complexities of built environments. Henceforth, it is a disciplinary, closely related to essential routines that ensure the desired performance outcomes of the building, safety, and the quality of the occupants' lives (Chan *et al*., 2009). It touches the broad scope and is associated with a costly process in terms of both financial and

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environmental dimensions (Puķīte and Geipele, 2017). Quantitatively, the operating cost of the buildings is contributed by to 75-80% of built-asset operation and the maintenance cost (Madureira *et al*., 2017). Moreover, 30% of additional energy consumed by building equipment and components that are not adequately maintained and operated and leading to frequent equipment downtime (Kim and Katipamula, 2018). Thus, high expenses occurred due to the insufficient reliability of systems and created many declines in the service delivery (Salata *et al*., 2014). Lack of management commitment, technical and human resources-related issues, lack of integration with organizational objectives, lack of spare parts, incapability to cope up with the modern technology increased inefficiencies generating the "waste" in the building maintenance function (Ali *et al*., 2016; Lateef *et al*., 2010). To curtail those deadly wastes and effectively assist the operations of the organization while diluting the pressure put on maintenance, a systematic approach has gained a significant focus (Lahiri *et al*., 2008). Driven by that intention, most of the organizations embraced the concept of lean, the multi-dimensional approach that aims at eliminating "waste", (Muda in Japanese) while enhancing the value of the operations (Womack and Jones, 2003). Researchers interpreted it as a journey, which requires continuous monitoring to assess the existing levels of leanness and direct into the potential improvements (Narayanamurthy and Gurumurthy, 2016). Among the main components of the lean implementation cycle: Lean training, Value Stream Mapping (VSM), and Lean Assessment, Lean Assessment generate more information (Wan and Chen, 2009) recognizing the problematic areas to be improved (Alemi and Akram, 2013; Urban, 2015). Notwithstanding the fact, few researchers have attempted on investigating the "leanness" aspects of maintenance environments (Narayanamurthy and Gurumurthy, 2016). Gupta *et al.* (2019) derived the Lean Maintenance Index (LMI) via the incident matrix approach focusing on the key features of LM. Moving to the Sri Lankan manufacturing environment, adherence to the lean application, Total Productive Maintenance (TPM), evident, but its effect has not adequately assessed by researchers (Wickramasinghe and Perera,2016). Fulfilling that gap, the study aims at formulating a leanness assessment model to assess the degree of "leanness" that prevails in the building maintenance domain. Concurrently, the study will extract the potentials of embedding the "fine-tuned" TPM practices: i.e., Lean Maintenance (LM) theories providing valuable insights for building practitioners to achieve a waste-free, quality, stakeholder-driven maintenance environment (Wan and Chen, 2009).

2. LITERATURE REVIEW

Following subsections denotes the key literature findings regarding research focus which ultimately leads to the formulation of the model to assess the leanness in building maintenance.

2.1 THE CONCEPT OF LEAN AND LEAN MAINTENANCE

The versatile concept, "Lean" was first coined in the book "The machine that changed the world: story of lean production" resulting in the massive production environments that are highly responsive to the changes in customer demand (Poppendieck, 2002). Lean thinking can be defined as a capability to provide the exact product output that the customer requires at a reasonable price and minimal time consumption while optimally conserving the system inputs (transformed resources and transforming resources) (Shou *et al*., 2019 ; Thürer *et al*., 2016). The concept of "waste" which is highly termed with

Lean has been evolved from the cost and waste reduction perception to enhance customer satisfaction. Recent literature added the eight-waste component: underutilized employee creativity to the "classical seven wastes" of "overproduction, waiting, transportation, process waste, inventory, waste motion, and defects" (Mostafa *et al*., 2015; Liker , 2003). Followed by the hypothesis developed by Womack and Jones (2003) on its universal application, many researchers have attempted to integrate the lean principles to maintenance comprehensively mapping the aforesaid wastage and overseeing it as a pathway to obtain the reliable, cost-effective maintenance status (Abreu *et al*., 2016 ;Verma and Ghadmode , 2004). Accordingly, the concept of LM practices took its lead injecting the new principles to TPM constructing the clear structural pathway with long-term strategic perspective away from the business dynamics (Baluch *et al*., 2012; Clarke *et al*., 2010). Smith and Hawkins (2004) broadly defined the LM as a "Proactive maintenance operation employing the planned and scheduled maintenance activities through TPM practices, using maintenance strategies developed through application of RCM decision logic and practiced by empowered (self-directed) using the 5S process, weekly kaizen improvements autonomous maintenance (AM) using the maintenance work order system, Computerized Maintenance Management System (CMMS), Enterprise Asset Management system (EAS)" (p. 257).

2.2 LEANNESS ASSESSMENT METHODS

Leanness is a useful metric that is used to quantify the level of lean implementation and its progress, or the potential achievements in the future (Alemi and Akram, 2013). According to Hallam (2003) "Lean quantification" or the "Leanness Assessment" defined as a procedure which supports to evaluate the level of "leanness" accomplished either qualitative or quantitative terms and inherent with certain key characteristics: quantifiable and adheres to the strategic objectives of the organization and customer values, capability to dominate and evaluate the performance, supports to realize the current state and potential opportunities for further improvements and contemporary (repetitive evaluation) and realistic. Assessments based on performance and the adoption of practices are the widely used main approaches of leanness assessment (Cocca *et al*., 2019; Singh *et al*., 2010). Practice-based assessments act as a tool to guide the success of their implementations, track the potential improvements whereas a performance-based approach focus on improving the level of achievement in the performance outcomes caused by lean adoption (Urban, 2015). Moreover, existing literature needs conducting more research on lean assessment frameworks or instruments due to the lack of presence in literature and its flexibility to extend for the different sectors to fit with the dynamic changes (Narayanamurthy and Gurumurthy, 2016). Fulfilling that gap of relatively fewer efforts in this context, the study aims at developing the practice-based lean assessment model which has the flexibility of extending for numerous sectors. Accordingly, the relevant literature derived through digital keyword search "Lean Maintenance", "Lean Thinking Maintenance" during the period of 2001-2020 were synthesized and parameters for the assessment were identified accordingly. Thus, Maintenance Leanness can be defined as follows.

The measure that aims to integrate Lean tools and techniques, to enhance the maintenance effectiveness, maintenance cost utilization, and maintenance quality through the optimized maintenance planning and scheduling, resource utilization, equipment management, Maintenance automation, effective problem diagnosis, effective utilization of the maintenance data, continuous improvement efforts while managing the workforce to cater the business needs under involvement of positive management which ensures the secured workplace and smooth informational flow.

All parameters were presented under the seven "leanness criteria" and those were expanded into 42 "leanness attributes" (Table 1).

Table 1: Leanness attributes

Leanness attributes	Leanness Attributes
LC1- Organization structure	**LC1.1** -Team involvement for decision making **LC1.2** - Smooth informational flow via a powerful communication network **LC1.3** -Visual displays of safety, quality, cost, delivery, and productivity data to the employees
LC2 -Nature of the Management	**L2.1** - Supportive management role **L2.2**- Self- motivated visionary personality **L2.3** - Use of informal controls to manage employees **L2.4** - Educate on Lean concepts
LC3- Management Involvement	**L3.1** - Development of standard work in collaboration with their teams and establish the baseline for their continuous improvement **L3.2**- Organizational value focus **L3.3** - Focusing on effective capability development efforts of their team **L3.4** - Evaluating the performance of the current state of processes with rapid and frequent feedback loopholes with next level management **L3.5** - Managerial versatility through working on extended assignments rather than coordinating the resources and rotating the work
LC4-Effective and efficient Maintenance practices	**LC4.1** - Establish Autonomous Maintenance standards. **LC4.2** - Machine operators were given an overview of the machine, how to perform the inspections of the basic operations of the machines **LC4.3**.-Visual standards regarding cleaning, lubrication, tightening and loosening and tightening through immediate feedback about the current standards of affairs **LC4.4** - PM activities are taken place to prevent the occurrence of the breakdowns **LC4.5**.- PM aligned with the provision of work procedures, documents, or tools including the detailed information regarding the safety requirements **LC4.6** - Data utilization to come up with effective decision making **LC4.7**-Systematic diagnosis of losses and failures and track and address the equipment problems and root causes setting 3M (Material, Man, and machine) conditions **LC4.8** - Development Management via continual evaluation and improvement of the maintenance process in terms of the quality, time, and resources **LC4.9** - Safety initiatives and designs and ensure the safe work environment **LC4.10** - Office TPM practices established via strong interdepartmental relationships **LC4.11**- Extensive reliability analysis for the maintenance considering the economic levels and techniques of preventive and Predictive Maintenance (PdM) activities and equipment reliability **LC4.12** - Application of information systems to enhance the maintenance operations

Leanness attributes	**Leanness Attributes**
LC5- Utilization of inventory of spares and materials	**L5.1** - Standardized practices for the issuing, staging, reordering, and reporting of the departments and materials
	L5.2 - IT-based communication
	L5.3 - Distributed MRO storerooms placed in a centralized location
	L5.4 - Encourage usage of standardized materials for common applications
	L5.5 - Pull system Focus: Demand - driven inventory management
	L5.6 - Extend the preventive maintenance program to specific spares which need specific attention in defined intervals
	L5.7 - Constantly update the plants' inventory lists purging of the removed items
	L5.8 - Tracked premature failures of equipment using store inventory or stock-outs
	L5.9 - Designate the minimum and maximum levels for each spare part
	L5.10 - Generated part usage data through the CMMS can be used to organize the storeroom
LC6- Employee Status	**L6.1** - Multi-skilled employees are formed through facilitating multiple skills training programs for employees
	L6.2.- Self – directed, task-oriented action teams are formed through the multi-department membership for maintenance activities
	L6.3.- Encourages the Job rotation system
	L6.4.- Flexible workforce formation adopts the new technologies
LC7-Employee involvement	**L7.1**.- Self-directed employees pursuing continuous improvements and performed work with the value focus thinking
	L7.2.- Strong and cooperation was established via top-down communication (feedback charts improvement measurements)
	L7.3.- Employee morale is uplifted through Provision of remuneration based on their significant performance
	L7.4 - Employees were given the decision-making power and increased the level of autonomy

Eventually, the leanness assessment model was formulated concentrating the expanded "leanness criteria" into 4 main "leanness enablers" (Figure 1).

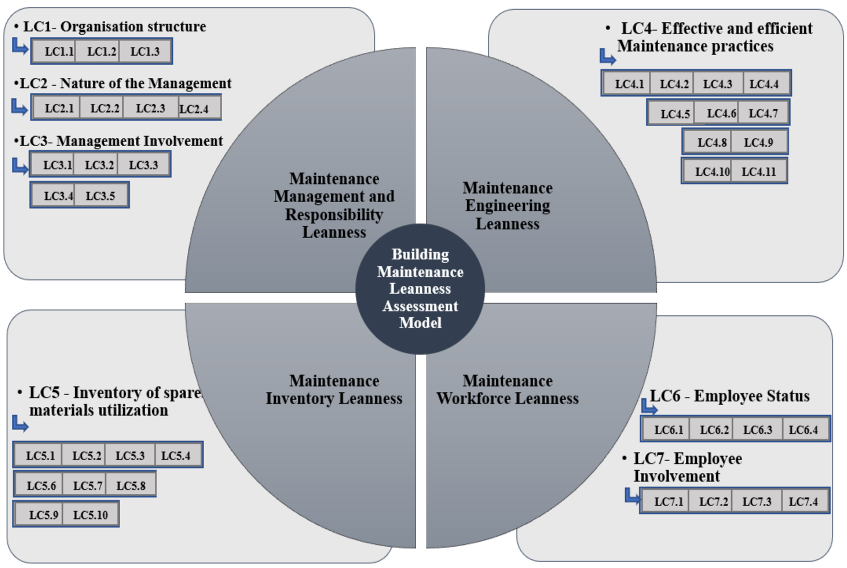

Figure 1: Leanness assessment model

3. RESEARCH METHODOLOGY

The research design provides a clear and solid pathway or framework to answer the identified research problem (Saunders *et al*., 2009). Accordingly, the qualitative research approach deployed considering the nature of the research problem in which the focus is to assess the current maintenance practices by answering the "How" and "Why" type questions (Yin, 2018). Furthermore, it supported the researcher's intention of deriving valuable insights on research outcomes from in-depth discussions with the professionals who are actively involved in that field (Creswell , 2003). Driven by that intention, adopted case study research strategy can be justified as the study investigates the real-life phenomenon, a quality of leanness exists within the building maintenance practices occurred in the operation stage in which lack of leanness aspects account for increasing maintenance inefficiencies and risen maintenance-related expenses (Yin, 2018). As it facilitates the competitive advantage over the random sampling technique (Patton and Appelbaum, 2003), research deploys a non-probability sampling technique: snowball sampling where initial respondents were selected on probability and then the network of respondents was formed via information obtained from initial respondents (Acharya *et al*., 2013). Accordingly, three identical cases from the apparel industry buildings from the Sri Lankan context were selected expecting the literal replication logic (Yin, 2018). Further researcher purposefully considered the building units from apparel manufacturing industry as a case boundary, since the lean culture is rooted to a certain extent in the manufacturing domain (Wickramasinghe and Perera, 2016) and research outcome will be an aid to achieve the competitive edge in their operations. A total of 9 semi-structured interviews were conducted with managerial level respondents considering their involvement in maintenance-related decision-making and engagement in the maintenance workforce management. Detailed profiles of the interviews from selected cases were tabulated in Table 2.

Table 2: Profile of the interviewees

Case	Code	Designation	Role	Experience
Case 01	C1R1	Engineering Manager	Undertakes informed decisions to maintain the assigned plants with sustainable operation	7 Years
	C1R2	Premises Engineer	Responsible for the smooth operation of the building services in the facility.	5 Years
	C1R3	General Manager	Liable for making informed decisions on the maintenance of utility services and machinery	14 Years
Case 02	C2R1	Factory Engineer	Responsible for the smooth operation of the Hard FM services	4 Years
	C2R2	Factory Engineer	Responsible for the smooth operation of the Hard FM services.	8 Years
	C2R3	Maintenance Engineer	Responsible for the maintenance of utility services	2 Years
Case 03	C3R1	Senior Executive - Engineering	Responsible for handling maintenance projects, energy, and sustainability projects.	6 Years
	C3R2	Senior Executive - Engineering	Responsible for handling the maintenance projects and the maintenance of the utility supply section.	4 Years
	C3R3	Assistant Manager - Engineering	Responsible for the labour allocation in the PM Program	8 Years

Derived data were analysed using the code-based content analysis technique, which is a reflective process, that involves continuous actions of identifying, condensing meaning units, coding, and categorizing while revisiting the raw data to achieve the comprehensive analysis (Erlingsson and Brysiewicz, 2017). The marked similarities and dissimilarities of selected cases were interpreted using the cross-case synthesis and it facilitated the reader to assess the levels of leanness in building maintenance via argumentative interpretations.

4. FINDINGS

Based on empirical findings, the accomplishment of thirty-eight (38) attributes out of forty-two (42) leanness attributes were recorded as the highest score whereas accomplishment of twenty-five (25) leanness attributes was recorded as the lowest. Accordingly, highlights of case findings were presented in a detailed manner under the following key themes.

4.1 MANAGEMENT AND RESPONSIBILITY LEANNESS

Under this dimension, the highest number of attributes (12) were fulfilled by case 2, and the least number (10) was achieved by case 3. Under "LC1- organization structure", the existing organizational structures of selected cases were established in a manner that supports minimizing the wastage commonly found in conventional vertical structures. As per respondent notion, the formation of teams within the existing structure and active collaboration of team members for decision making via "*brainstorming sessions"* has smoothened business operations. In case 2, "*cross-functional teams*" formulated including various levels of employees from various departments. Furthermore, respondents stressed the importance of information technology (IT) -based systems over manual operations to obtain a smooth informational flow while eliminating the potential time delays in communication. However, cases 1 and 3 have paid considerably less attention to visual displays of safety, quality, cost, delivery, and productivity data to the employees as a mechanism to easily trigger potential wastage.

Under "LC2- Nature of the Management" all the respondents oversee the manager as a supportive, responsible, and reactive figure away from his conventional role of directing. CIR3 emphasized the importance stating, "*performance of the plant heavily lies on the nature of the manager*". Furthermore, as highlighted in LC2.2, in all cases, the manager appeared as a self-motivated visionary personality that constantly motivates their team members via regular morning meetings, interacting with their employees and collecting their ideas for the betterment. In case 1, C2R1 stressed the three vital aspects of management: *"leadership, process and people management".* Further, he elaborated, *"leadership will set up the vision and the mission, the process will set up the required guidelines to be followed(audits) and training we are giving required awareness to the employees*". In LC2.4, compared to other cases, only case 2 equipped the management and employees with lean practices. Thus, from the researcher's point of view, management awareness on lean seemed to be a critical success factor for implementation in which ultimately highlighted through the highest leanness score.

Under "LC3- Management Involvement" management is actively involved with the development of standard work in collaboration with their teams based on employee feedback, "Gemba walks", Kaizen programs. Moreover, the horizontal flow of the value of the entire value stream is highly considered the belief, that different divisions (technical, quality, production) are highly interconnected. When it comes to the LC3.3, cases 1 and 2 are highly concerned with the development capability of their employees. C1R1 mentioned organization attempts on equipping the mechanics with mainly with technical skills whereas management with human skills, conceptual (Analytical skills) skills. Comparatively, case 2 deploys the specific lean application "*Skill matrix"* to address the skill gaps of the employees.C2R1 mentioned the employees are given a different type of training based on their employee level namely "*technical training and management basis training*". He further elaborated *"technical training opportunities will be arranged based on the qualitative (Personal opinions, upcoming trends, and technological advances) and quantitative factors (MTTR, downtime), etc".* Apart from that, case 2 set a strong focus on giving knowledge of lean for all levels of employees. Furthermore, in cases 1 and 2 adherence to the lean tools: Root cause analysis, Pareto tools, Gemba walks have been used to enhance the versatility of the decisions. It is clearly highlighted in the C2R3's statement "*... if we found strong deviations from the set target or goals, we go ahead with the five day - Kaizen events to share knowledge with the high performing units in the group and come up with the feasible solutions for the deviations.*"

4.2 MAINTENANCE ENGINEERING LEANNESS

Under this dimension, the highest number of attributes (11) were achieved by case 2 and the least number (6) was by case 3. Under "LC4-Effective and efficient maintenance practices" Cases 1 and 2 adhered with the lean maintenance tool, TPM whereas case 3 abide by combined practices of preventive and predictive maintenance strategies. Under TPM they followed the two branches: Planned Maintenance (PM) and AM. Under PM, all cases concerned heavily on preventive maintenance aspects rather than going for advanced PdM strategies. Moving on to AM aspects, case 1 practices mainly for sewing machine operations compared to the building asset maintenance. Simultaneously, case 2 deploys a comprehensive AM program along with the yearly basis training and audits programs to assess the success. C2R3 stated, "*operators were given with two time periods to the AM per day, and engineering team will collect those tags and put the data into a database (through excel) check the details on issues, who maintained likewise*". However, all three cases were unable to address the "LC4.11- Extensive reliability analysis for the maintenance considering the economic levels and techniques of preventive and predictive maintenance activities, and equipment reliability". Moreover, all three cases deploy information systems to accelerate maintenance operations. In case 1, BMS, a software-based daily preventive monitoring system and work order management systems are established. Gathered data through the aforesaid systems, are effectively utilized for the informed maintenance decision-making. With the aid of data management guides the employees to undertake the PDCA, RCA to come up with the actual causes for problems.

Accordingly, C1R1 mentioned, *"reducing the maintenance services that they have contracted with suppliers and enhance the skills of the in-house teams undertake the maintenance activities as a result, they were able to achieve 80% of in-house maintenance PM data has been contributed a lot*". Moreover, case 3 paid less for the initiation of comprehensive and detailed analysis to systematically trigger the problems. It was highlighted those Lean tools such as 5 WHYs, RCA, Gemba walks, honour cycles, five-day kaizen programs are used by the case 1 and 2 in comparison to case 3 where the excel-based data sheet facilitated to come up with the informed decisions. Apart from that, all the cases are set to focus on continual evaluation and improvement of the maintenance activities in terms of quality, time, and resources. Both cases 1 and 2 deployed the PDCA process as a continual evaluation tool for maintenance activities while case 3 deployed the separate continuous monitoring and evaluation team for maintenance improvements.

4.3 MAINTENANCE INVENTORY LEANNESS

Under this dimension, the highest number of attributes (8) were fulfilled by case 2 and the least number (6) was by case 3. Under the "LC5- Utilization of inventory of spares and materials", demand driven inventory management systems were maintained by all the cases. They have paid significant attention to the impact on business operations. C1R2 stated, "*we have categorized (A, B, C, D) the based on their risk and criticality"*. Further, he elaborated*," high risk high critical items are maintained through reorder level, compared to its high-risk low critical items are maintained when the requirement emerged*". Apart from that, few of the best practices that organizations followed are derived: centralization of all the spare parts within the factory units in the cluster, procure the similar models that consume the similar spare parts and local spare parts usage. Yet, strong deviations were identified within the existing practices concerning the leanness attributes (LC5.8 and LC5.9). The constant update of the plants' inventory lists purging of the removed items, tracked the premature failures of equipment using inventory consumption are identified as untouched areas, and has the potential of curtailing the wastage. However, lack of adherence can be observed in all cases except case 1, where the maintenance storerooms are utilized using the data generated through CMMS.

4.4 MAINTENANCE WORKFORCE LEANNESS

Under this dimension, all the attributes (08) were fulfilled via case 2 and the least number (3) was by case 3. Comparatively, case 2 contributed significantly to employee development, considering the "non- utilized employee skill" as a waste to the organization. Under "LC6- Employee status" case 1 and 2 have paid concern on forming the multi-skilled workforce. In case 1, C1R3 mentioned, "*it is done through the comprehensive plan which maps the employee actual potential, company expectations from the employee, provision of both theory and practical gaps*." Furthermore, strategies like "Job rotation" were highlighted in which a good opportunity for case 3 enhances their existing practices. In case 1 CIR1, CIR2 highlighted "*succession planning*" as a strategy of employee development.

Under "LC7- Employee involvement", in all cases, employees are encouraged to pursue continuous improvement efforts and performed the work with value focus thinking. More often management encourages the continuous improvement culture. As stated by C1R2 "*kaizen ideas were linked with employees, KPI (innovation per year) and employees enthusiastically engage in that event*". Moreover, C2R1 mentioned, "*regular meeting, quiz, competitions, auditing were organized to boost their skills as a well as the morale*". Comparatively, case 3 has taken fewer efforts on forming the self-directed employees as there is a lack of organized events to grab their active cooperation. Furthermore, in cases 1 and 2 a higher employee involvement was observable compared to case 3 due to the reward-based performance evaluation system where employees were induced by monetary incentives. C3R2 mentioned, "*we already developed the evaluations sheets forms, but has not seemed to be much strong motivate as it lacks the parts of giving them awards or incentives*" which can be identified as a lagging factor of motivating their employees for better performance. However, all three organizations focused on establishing strong top-down communication mostly via regular morning meetings. Apart from that, both cases 2 and 3 highlighted the feedback sessions as an improvement measurement. Furthermore, in all cases, employees were given autonomy to perform their duties mainly based on their skill levels under the direct supervision of immediate management.

5. DISCUSSION

Findings disclosed in all cases, team-based flatter structures enhanced better communication, induced empowerment, less bureaucracy new development opportunities (Powell, 2002). Yet, findings raised the lagging point in terms of enhancing the communication via charts that depicts safety, quality, cost, delivery, and productivity data to the employees. As a favourable solution to it, storyboarding which is a simple graphical panel that enhances information access can be recommended (Davies and Greenough, 2001). Empirical findings further pointed out the emerging need of promoting the lean concepts via training sessions among managerial level workers as they are the driving force in achieving the higher degree of leanness (Smith and Hawkins, 2004). When it comes to the maintenance engineering leanness dimension, the importance of engaging with RCM concepts and tools was raised to effectively address the reliability aspect of maintenance in the local context (Johannesson *et al*., 2013). Furthermore, identified lagging points in adherence to AM can be addressed by enhancing the operators' skill, giving operators ownership to perform the machine cleaning, simple minor routine adjustments, and maintenance (Yile *et al*., 2008). Away from the positive efforts taken by practitioners to enhance the maintenance workforce leanness, the "cross-functional team set up" derived through case 2 appeared to curtail potential information wastage while allowing room for potential improvements in line with the horizontal value stream. It is formed the self-directed, task-oriented action teams via through the multi-department membership for maintenance activities that are significantly contributed to develop the employees set up. Yet, from the researcher's point of view, it can be a real eye-opener for the industry to adhere in to. Furthermore, the empirical investigation proved the provision of adequate information, skills and motivation, and power that enable favourable obtaining of employee involvement (Benson *et al*., 2004). Following that fact, findings encouraged for the reward-based performance evaluation system where employees induced by monetary incentives (Zatzick and Iverson, 2006). Moreover, quizzes, competitions to enhance the employee's performance also act as the motivating factors to induce their active engagement in local context.

6. CONCLUSIONS

At a time when Lean Maintenance is still a relatively new concept in Sri Lanka, the study will draw the readers' attention to embedding those principles to enhance maintenance operations. The overall study portraits the application of the information template to assess the degree of leanness that exists within the building maintenance. Based on the extensive literature analysis on "Lean Maintenance" and "Lean Thinking maintenance", forty-two (42) leanness attributes were derived and tested with three identical cases in the apparel industry. Empirical findings showcased the favourable adherence to lean practices in the local context, stressing the potential rooms for improvements. Accordingly, the importance of extensive reliability analysis for the maintenance considering the economic levels and techniques of preventive and predictive maintenance activities and equipment reliability, lack of incorporation of the planned maintenance program with inventory management aspects outcome with existing gaps in selected all cases. It is recommended to implement those actions on extending the planned maintenance programs touching the reliability aspects and interlink inventory management with PM programs of the facility. Furthermore, it will be a versatile effort to conduct the lean awareness sessions, promote multi-skill training programs to all levels to grab their active involvement in maintenance operations. Value focus mindset of the employees can be distinguished as a dominant factor that drives to acquire a higher degree of leanness in maintenance environments in Sri Lankan context.

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A NEW SAFETY CLIMATE ASSESSMENT TOOL FOR GULF CONSTRUCTION

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ABSTRACT

One of the methods which could improve the safety performance of construction organizations is the safety climate approach which is helpful to know the existing maturity level of the safety climate and to develop plans to achieve the required level of maturity. Most of the existing safety climate tools were developed considering different industries in developed countries while construction was based only on few tools. Construction projects in the Gulf Cooperation Council (GCC) member countries are at a peak. This article, therefore, attempts to develop a safety climate assessment tool for the Gulf Cooperation Council (GCC) construction industry. A mixed research method consisting of a systematic review (N = 32), structured questionnaire (N = 102) and email interview (N = 19) was adopted in this research. A new assessment tool that has seven factors including (i) Aligning and Integrating Safety As Value (ii) Training At All Level (iii) Improving Site Safety Leadership (iv) Management Commitment (v) Empowering And Involving Workers (vi) Ensuring Accountability At All Level and (vii) Improving Communication has been finally developed. Each factor is supported by a number of simple questions that the participants have to answer on a Likert scale of 1 to 5 is finally developed. Although, the newly developed tool is validated through email interviews held with the construction industry professionals, however, longitudinal studies are recommended to gauge to the effectiveness of the tool.

Keywords: *Construction industry; Health and safety; Knowledge management; Management; Safety climate.*

1. INTRODUCTION

Statistics from several sources reveal that construction is regarded as one of the most hazardous industry. For instance, the International Labour Organization (ILO) data for the year 2015 reveals that every year, more than 100,000 workers die on construction sites due to different occupational safety and health conditions. This means that the number of deaths on construction sites is roughly equal to 274 deaths per day. This number is nearly 30% of all occupational deadly injuries (ILO, 2015). The situation in the GCC countries is particularly alarming due to a number of reasons discussed in detail by Umar *et al*. (2019). The construction projects are at a peak as the region is in the stage of developing its major infrastructures. Recently, the deaths of construction workers in the construction of a stadium for the football world cup 2022 have attracted the attention of media and international organizations. Some of these reports show the number of

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construction workers that died in the project has already reached 1,200. Some of the reports estimate that the number of deaths in this project will reach 4,000 by the end of 2020 when it is completed (Safety Media, 2018; International Trade Union Confederation (ITUC), 2014; Ganji, 2016). The Human Rights Watch report (2018) indicates that the total workforce in Qatar is approximately two million, with 95% of this workforce being expatriates. A total of 800,000 expatriates (40% are employed by the construction sector (Human Rights Watch, 2018). The report further shows that in only 2012, a total of 520 workers from India, Bangladesh, and Nepal died due to different work-related accidents and conditions in Qatar. Different reports indicate most of the construction workforce (= 90%) in these GCC countries are from Asian countries (Middle East Annual Conference (MEAC), 2014; General Organization for Social Insurance (GOSI), 2018; Oman Society of Contractors (OSC), 2016; Labour Market Regulatory Authority (LMRA), 2018; Gulf Research Centre (GRC), 2018; General Retirement & Social Insurance Authority (GRSIA), 2017; Ministry of Human Resources and Emiratizations (MHRE), 2018). There are a number of ways to improve the safety performance of construction organization and one of them is using the safety climate approach (Clarke, 2006a; Oah *et al*., 2018). The main goal of this research was to develop a safety climate assessment tool for construction organizations in Oman. Since the construction workers demography in the GCC construction is somehow the same, there is a possibility that this tool can be used in other GCC countries.

Different authors recognized that a mature safety climate and a rich safety culture contribute to achieving a safe workplace (Clarke, 2006b, Clarke, 2010; Neal and Griffin, 2006; Wallace *et al*., 2006; Nielsen and Lyngby Mikkelsen, 2007; Pousette *et al*., 2008; Kuenzi and Schminke, 2009; Kines *et al*., 2011; Umar and Egbu, 2018). The safety culture represents the overall culture of an organization reflecting how the safety is considered or treated. Likewise, safety climate may be classified as a subgroup of organizational climate which provides a direction to safety management, complementing the frequent predominant engineering path. The literature review suggests that although there are differences between the two terms i.e., safety climate and safety culture, however these concepts for improved safety performance have attracted more concentration across a broad number of industrial businesses including construction (Flin *et al*., 2000).

One the reason behind this suggested by Bergh *et al*. (2013) is that rich safety culture and a mature safety climate are considered among the most important elements in attaining a safer workplace. To enhance the level of safety culture and safety climate, it is crucial to, first gauge the existing level of safety culture and safety climate, then agree with what level of safety culture and safety climate is required, obtainable and desired, and then to make strategies to accomplish the safety culture and safety climate, which is desired (American Institute of Chemical Engineers (AIChE), 2012). A similar concept of safety climate approach was also explained by Umar and Wamuziri (2017) and described relevant safety climate factors or dimensions can be measured among different categories of staff working in a construction organization or in a project undertaken by the construction organization. The results will reflect the safety climate of the organization or the safety climate of the specific project. After the assessment of safety climate factors, construction organizations will be able to identify and prioritize the weak area for improvement. They further suggested that safety climate leading factors can be reviewed on a five-level scoring scale to assess what level of safety culture for that factor is achieved by construction organization. The main question is what could be the safety climate factors that need to be included in a safety climate assessment tool. This was partially investigated by Umar and Eggu (2018) through a semi-structured interview held with the construction profession in the GCC region. They, however, recommended that such factors should be derived considering the view of the members in a construction team. Similarly, the literature review of the existing safety climate assessment tools reflects that most of them were developed considering the industries in some advanced countries (Zohar, 2010). Apart from that, construction was the base for only a few assessment tools. The perceptions of the safety climate could be different among different industries and regions (Barbaranelli *et al*., 2015).

This article, therefore, aims to investigate the safety climate factors in Oman construction considering the whole team members. The outcome of this research, on one hand, provides a tool for the construction organization in GCC to assess their safety climate but also contributes to the existing knowledge of body in relation to the extent of safety climate factors that are considered significant in Oman construction industry context. A research approach considering both quantitative and qualitative methods were adopted to achieve this. Based on the finding, a safety climate assessment tool is proposed for the GCC construction industry. The research methodology is further explained in the next section.

2. RESEARCH METHODOLOGY

Both qualitative and quantitative research methods were employed to achieve the aim of this research. Since there has been several studies and tools for the safety climate assessment are develop in different regions and countries, there, it was considered important to consider those studies, and factors used in those studies. In the first stage, the most prevailing safety climate factors were extracted from the existing safety climate tools used in construction through a systematic review (Martins *et al*., 2019). This was done using specific keywords in several databases. PRISMA guidelines were followed in this search (Moher *et al*., 2009). Briefly, the safety climate factors used in this research are shown in Table 1. In the second stage, a quantitative research strategy was employed. Briefly, the quantitative research method integrates the norms and practices of the natural scientific model and positivism. It views the social phenomenon as an outer objective truth (Cooper *et al*., 2006). The factors included in this questionnaire were based on data collected in the first stage. Although research conducted by Umar and Egbu (2018) also aimed to determine the key factors which highly influence the safety climate in Oman, however, there were some limitations in their study related to the data collection. They collected the data in two parts. The data collected in the first part was from the existing literature in which the most common safety climate factors were identified. The data collected in the second part of the research was from a specific group of construction professionals. Since the construction team of an organization or construction project consists of Managers, Engineers, Site Supervisor Foreman, and Workers, therefore their view of different safety climate factors derived from the semi-structured interview was considered to be important. This research, therefore, attempts to collect the data from the whole construction which was done using a structured questionnaire administrated among different respondents. This part considers the safety climate factors derived from the systematic literature review done in the first stage of research.

A simple questionnaire was adopted for recording the response of the respondents using a Likert scale. Part I of the questionnaire is related to the personal/background information of the respondents. In Part II of the questionnaire, the respondents were asked to rate their responses related to management commitment on a scale of 1 to 5. (1= strongly disagree, 5 = strongly agree). In part II there is a total of 10 questions. These questions are related to “management commitment”. Part III is related to the “alignment and integration of safety as value” and there is a set of 11 different questions. In Part IV, there are 10 questions that are related to “accountability at all levels”. In part V, which is related to “improvement of site safety leadership”, has a set of 8 questions. There are 7 questions in part VI entitle as “empowering and involving workers”. Part VII of this questionnaire is related to “improvement of communication” and it has 9 questions. There are 7 questions in part VIII (training at all levels). Part IX is related to “encouragement and involvement of owner/client” and it has 10 questions. In part X of the questionnaire, the respondents were requested to rate the relevancy of different safety climate factors. The last section of the questionnaire (part XI) is provided for the comments of the participants. The questionnaire was developed in the English language and the necessary assistance was provided to the respondents who were not able to read and write in English. The construction industry workforce as reported by the Oman Society of Contractors is consists of 92% of foreign workers and there are only 8% of the Omani working in this industry (Umar, 2017).

Data was collected from a variety of respondents that includes managers, engineers, site supervisors, foreman, and workers. Considering the scope of this research project, it was aimed to have at least 100 responses from the selected respondents. A construction organization registered as an excellent grade with the Tender Board of Oman was considered to be the best place to have the appropriate number of the required respondents in each group (Tender Board of Oman [TBO], 2018). The normality of the data was checked through the ratio between skewness and its standard error, and the ratio between kurtosis and its standard error (Yeo and Johnson, 2000). The data was considered normal if the ratio was between – 1.96 to $\pm$ 1.96 (Thode, 2002). Briefly, Skewness is a measure of symmetry, or more precisely, the lack of symmetry (Das and Imon, 2016). A distribution, or data set, is symmetric if it looks the same to the left and right of the centre point. Similarly, Kurtosis is a measure of whether the data are heavy-tailed or light-tailed relative to a normal distribution.

The questionnaires received with signed in informed consent were used in the analysis and results. The raw data obtained from the questionnaires were processed using SPSS, data analysis software. To calculate means scores for each factor or dimension of safety climate and individual, the raw data from different items were used. As a rule, for data analysis, only the answered items of the questionnaire were used. If in a specific dimension or factor, a respondent has answered less than 50% of the items, thus all answers were excluded for that dimension. This was done based on the fact that a mean score based on less than 50% of items is not considered as valid. For the calculation of the mean score of each dimension and group, the mean score of different dimensions or factors and individuals were used. In further analysis, the mean scores for all the dimensions were utilized.

Table 1: Parameters of the review protocol for safety climate factors

Keywords	**Period**	**Inclusion Criteria**	**Exclusion Criteria**	**Database**	**Total Downloaded Articles/ Reports**	**Total Articles/ Reports/ Tools After Criteria**	**Derived Safety Climate Factors**
Safety Climate Factors, Safety Climate Assessment Tool Safety Climate Dimension	January, 1980 - April, 2019	Publications/ Reports/ Tools on Safety climate in Construction Publications / reports that resulted into a new safety climate assessment tool Publications / reports on safety climate focusing GCC region	Publications/ Reports /tools articles where the keywords are not in the title, abstract or in the keywords Publications / reports that do not resulted in to a new safety climate assessment tool (this condition is not applicable on the study related to GCC region) Articles/ Reports/ news articles in non-English language	Web of Science PRO QUEST SCOPUS Science Direct Google Chrome	32	18 Zohar (1980); Dedobbeleer and Beland (1991); Health and Safety Executive (HSE) (1997); Neal *et al*. (2000); Seo *et al*. (2004); Zohar and Luria (2005); Parker *et al*. (2006); Pousette *et al*. (2008); Construction Industry Safety Climate Index Software (CISCIS) (2008); Gittleman *et al*. (2010); DeArmond *et al*. (2011); Kines, *et al*. (2011); Umar and Wamuziri (2016); Umar *et al*. (2017); Umar and Wamuziri (2017); Centre to Protect Workers' Rights (CPWR) (2017); Umar and Egbu (2018)	1. Commitment from Management to Enhance Safety 2. Alignment and Integration of Safety as Value 3. Enforcing Accountability At All Level 4. Enhancing Workplace Safety Leadership 5. Empowerment and Involvement of Workers 6. Enhancing Communication 7. Ensuring Training for all staff 8. Encouragement of Owner and Client Participation

An independent sample T-test (two-tailed) was conducted to see if there is any notable variation among two independent groups. A probability value (p-value) less than 0.05 from a two-tailed T-test was treated statistically powerful for all tests. Cronbach's alpha coefficient which is also known as the coefficient of reliability was calculated to check the internal consistency of the different safety climate factors. The mean values of each item in different safety climate factors were used to rank items in the same factor. Item ranked as 1; means that the item in a safety climate factor was considered important by the respondents to enhance the maturity level of that factor. The content analysis technique was adopted to examine comments written in the last section of the questionnaire. Graneheim and Lundman (2004) guidelines were used for content analysis. The assessment tool developed in this research was validated using a qualitative research method in which the views of construction industry professionals were sought through email interviewing.

3. RESULTS AND ANALYSIS

A total of 290 questionnaires were distributed to four main construction organizations which were executing major construction project in Oman. One hundred and two (102) duly filled questionnaires were returned representing a response rate of 37.17%. Four questionnaires (3.92%) out of 102 were rejected due to several reasons. The most common reason for rejecting the questionnaires was that more than 50% of the questions were not answered. The sample size was validated using equation 1 which is

$$N = \left(\frac{Z\sigma}{d}\right)^2 \quad (1)$$

Where, Z = 1.96; Standard deviation (σ) = 7.10 (calculated from age of respondents using SPSS program); Error (d) = 1.71 (5% of the mean value of the age)

Based on these parameters, the above equation gives the value of acceptable sample size (N) as 66.25 (~ 67), which is far less than the sample size used in this research (= 102). The number of responses from organization 1, 2, 3 and 4 were 28 (25.57%), 23 (23.46%), 26 (26.53%) and 21 (21.42%) respectively. All of the respondents who participated in this survey were expatriate males belong to different nationalities (refer Figure 1).

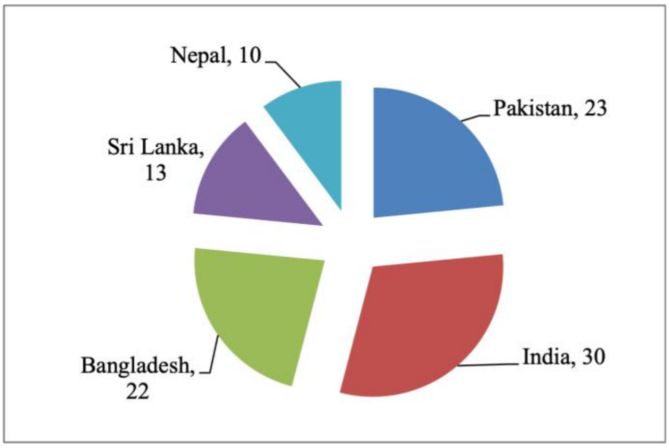

Figure 1: Distribution of respondent based on their nationalities

The respondents were in different occupations including managers, engineers, supervisors, foremen and general workers. Similarly, the respondents were from different age groups and were having different educational qualifications and experience. The ratio between skewness and its standards error for age was 0.59. Similarly, the ratio between kurtosis and its standard error for age was 1.24. Both the ratios were found to be less than +1.96 and reflect the normality of data. The correlation between age and qualification of the respondents was found to be significant at the 0.05 level (2 tailed). The internal reliability of all the Likert items along with qualification, position, and country of respondents was checked by calculating Cronbach's Alpha (α) using SPSS and was found to be 0.630.

The Spearman's Correlation Coefficient was also calculated to measure the strength and direction of the association between different variables. The elements considered for this analysis were age, position, qualification, experience, age group, country and all the eight safety climate factors used in the questionnaire. The results show the correlations among some elements are significant at 0.01 and 0.05 (two-tailed). Overall, the relationships do exist in these elements, however in some cases, it is stronger and positive or negative, and in some cases, it is weaker and either positive or negative. For instance, there is a strong positive (Spearman's Correlation Coefficient = 0.933) relationship of the respondent's ages and experience which is significant at 0.01 (two-tailed). A negative relationship was however observed between respondents' positions with safety climate factors number 3 (- 0.24) and 4 (- 0.199) at a significance level of 0.01 (two-tailed).

Similarly, one way ANOVA test was also conducted to measure the significance of all factors used in the safety climate questionnaire. The factors considered for this analysis were age, age group, position, experience, qualification, and country. The p-value 0.05 or lower was considered as significant. The results show that item No. 9 and item No. 10 of the factor "aligning and integrating safety as a value" was significant (p = 0.03 and 0.017) when positions of the respondents were considered. Similarly, item No. 2 and item No. 3 in the "ensuring accountability" factor was significant at a p-value equal to 0.06 and 0.049 respectively when compared with the positions of the respondents. Item No. 5 in the "empowerment and involvement of the workers" factor was found to be significant with a p-value of 0.034. The p-value of item No. 6 in "improving communication" was 0.017 and thus considered as significant. The results show that there is no item significant in "owner and client involvement" as the p-value of all the items was more than 0.05. Since there was a relationship among the considered elements considering Spearman's Correlation Coefficient that was either stronger or weaker and positive or negative, and the significance of the items is established through the results of one-way ANOVA test, the ranking of the different safety climate factors was done through their mean scores. The mean values of each safety climate factor which respondents rated on a Likert scale of 1 to 5 are given in Table 2.

Two safety climate factors "Alignment and Integration of Safety as a Value" and "Training at All Level" got the highest mean score of 4.15 followed by "Improved Safety Leadership" and "Management Commitment" which got the mean score of 4.12 and 4.08 respectively. Overall, five safety climate factors achieved a mean score of more than 4. The mean score of two safety climate factors was near to 4 (3.80 and 3.87 respectively). One safety climate factor 'encouraging owner/client involvement' secured a mean score of 2.78.

Table 2: Mean score of different safety climate factors

Safety Climate Factors	N	Minimum	Maximum	Mean	Std. Deviation	Rank
Management commitment	98	1	5	4.08	0.94	III
Aligning and integrating safety as value	98	1	5	4.15	0.89	I
Ensuring accountability at all levels	98	1	5	4.07	0.83	V
Improving site safety leadership	98	1	5	4.12	0.80	II
Empowering and involving workers	98	1	5	3.80	0.97	IV
Improving communication	98	1	5	3.87	0.82	VI
Training at all levels	98	1	5	4.15	0.87	I
Encouraging owner/client involvement	98	1	5	2.78	0.96	VII

The mean score of different safety climate factors calculated from different occupational groups is given in Figure 6. The mean score of all the safety climate factors, except owner/ client involvement was considered significant. As mentioned in Table 2, the mean score of “owner/client involvement” was 2.78, based on total respondents (N = 98) and was thus ranked as VII. Similarly, the same factor “owner/client involvement” mean score is 3.25 by an occupational group of “Managers”, (N = 12); by “Engineers”, (N = 18) it is 2.444; by “Supervisors” where N = 16, it is 2.625; by “Foremen”, where N = 14, it is 3.071; by “General Workers” (N = 20), it is 2.6 and by “other” where N = 18, it is 2.889. Overall, considering both the aggregate mean score (2.78) where N = 98, and the mean score of the safety climate factor “owner/client involvement” it is lower than 3. Only the mean score by “foremen” is 3.071, however, the N = 14. The newly developed safety climate assessment tool was circulated through email to a total of 50 managers working in different construction organizations. A total of 19 responses representing a response rate of 38% were received. All the feedback received from the construction managers were positive and reflected that the proposed safety climate assessment tool could be suitable for their organizations.

4. DISCUSSION

The new safety climate assessment tool is a continuation of the existing tools however differs from the existing tools not only based on the number of factors/questions but also the ranking of the factors used. Many similar studies rank the “management commitment” as the top leading factor in safety climate, however, the results of this study rank the “management commitment” as the third important factor that highly influence the safety climate in Oman (Zohar, 1980; Dedobbeleer and Beland, 1991; HSE (UK), (1997); Neal *et al*., 2000; Seo *et al*., 2004; Pousette *et al*., 2008; Kines *et al*., 2011; CPWR, 2017). Similarly, based on the mean score, in this study “aligning and integrating safety as value” is ranked first, however, in most previous studies; this factor was not used directly. For instance, Neal *et al*. (2000) refers to this as management value. Zohar (1980) used two different factors in his study namely “effects of safe conduct on promotion and “effect of safe conduct on social status" placed in his tool at the third and fourth position. Both of these factors adopted by Zohar (1980) in his safety climate tool, however, indicate the safety needs to be valued for the promotion of workers and the positive impact of social factors of safe acts needs to be acknowledged. In construction organizations, safety can, however, be valued by a number of means which should not be limited to workers' promotions or the social factors. The views of the respondents in this study at one side consider the "aligning and integrating safety as value" as one of the most important factors which are ranked as first, but on the other side, it reflects that this factor is currently not properly considered and there could be a huge positive impact on the construction organization safety climate. One of the possible reasons that why safety is not considered as a value in construction organizations in Oman is that most of the workers in the industry are expatriate and do not have the full rights of local citizens. This reason, however, needs to be further investigated. Safety communication in this study is ranked as six. The review of the previous studies as mentioned in table 1 shows that safety communication was used in a total of four safety climate tools (Neal *et al*., 2000; Pousette *et al*., 2008; Kines *et al*., 2011; CPWR, 2017). The study conducted by Neal *et al*. (2000), placed safety communication at second in their eight factored safety climate assessment tool.

The results and analysis of the data collected from the survey questionnaire show that different safety climate factors could be used to assess the current maturity level of the organization or project safety climate. The existing maturity level could be further used to select the items in each safety climate factor and develop different types of plans to improve the maturity of these items. The results show that out of total eight safety climate factors, seven were considered relevant, while one factor "Encouraging Owner/Client Involvement" did not attract much attention of the respondents. Although, the mean score of this factor in more than 2.5, however, as 3 refers to neutral in the questionnaire, therefore this trigger that the respondents do not consider 'owner or client involvement' as much important that could improve safety performance. The score of remaining safety climate factors was in a significant range and therefore considered important factors to improve safety performance. Based on the individual mean score, all safety climate factors were ranked from 1 to 8 as shown in Table 3. Two safety climate factors (aligning and integrating safety as a value, and Training at All Level) achieved the highest and similar score; therefore, both of them are raked as first. Similarly, each safety climate is factored in different items that could be implemented by the decision-maker to enhance the maturity level of the concerned safety climate dimension. Construction organizations can select all the items in a safety climate factor or may choose some of the items depending on their capabilities and available resources. It is, however, recommended that if a construction organization could not consider all the items in a safety climate factor, they may choose the top raked items in acceding order. For instance, if the maturity level (mean score) of the safety climate factor "Management Commitment" is 2, and the construction organization wishes to achieve a maturity level of 4.5, then that construction organization may consider all the items in "Management Commitment". Since the ranking of the safety climate factors and its items presented in this research are based on the data collected from a variety of respondents from a limited number of construction organizations, it is therefore, appropriate that construction organizations consider all the items in a particular factor. Although the newly developed tool was appraised from the selected group managers working in different construction organizations, it is still important to monitor the effectiveness of the tool on a long-term basis.

Table 3: Ranking of safety climate factors

Safety Climate Factors	Rank
Aligning and Integrating Safety as Value	I
Training at All Level	I
Improving Site Safety Leadership	II
Management Commitment	III
Empowering and Involving Workers	IV
Ensuring Accountability at All Level	V
Improving Communication	VI
Encouraging Owner/Client Involvement	VII

5. CONCLUSIONS

Based on the result and analysis of the collected data, a safety climate assessment tool with a total of seven factors is prosed for construction organizations working in Oman. The safety climate factor "Encouraging Owner/Client Involvement" has been excluded from the tool due to a low mean score. Overall, there are nine main items in the proposed tool. The part I which has seven sub-items is related to 'Personal/Background Information'. Part II of the tool is 'Aligning and Integrating Safety as Value' which has a total of 11 sub-items. Similarly, Part III of the proposed safety climate assessment tool is 'Training At all Level' which has a total of seven sub-items. Part IV of the tool is 'Improving Site Safety Leadership' which has a total of eight sub-items. Management commitment as a safety climate factor is included in part V and it has ten sub-items. Part VI of the safety climate assessment tool covers 'Empowering and Involving Workers' which is supported by seven sub-items. Ensuring Accountability at all Levels is covered in Part VII of the tool and has a total of 10 sub-items. Similarly, Part VIII covers 'Improving Communication' factors which have further nine sub-items. There is also Part IX in the proposed safety climate tool which can be used if the participants have any additional comments or feedback. Items in part II to part VIII have the option to record the response of the participant on a Likert scale of 1 to 5 (1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree). Although the newly developed tool was appraised from the selected group managers working in different construction organizations, it is still important to monitor the effectiveness of the tool on a long-term basis. It is expected that the status and maturity of Oman and GCC construction will be enhancing in the near future, therefore the safety climate factors which are significant now may not be significant in the future. A review cycle for the current tool after each five is recommended. It is still not clear how small and medium construction organizations limited resources could be benefited from this tool. Since most of the construction organizations in Oman and the GCC region can be classified as small and medium enterprises, therefore further research in this area is therefore recommended to see how the safety climate approach will benefit such organizations.

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ACCURACY OF TRADITIONAL CONTINGENCY ESTIMATION IN THE CONSTRUCTION INDUSTRY

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ABSTRACT

Contingency amounts are allocated in the construction projects to deal with uncertainties arising during the projects. Contingency amounts are usually estimated traditionally by simply adding a percentage of the estimated contract amount. However, the traditional system of contingency estimation is heavily criticised as ineffective due to several reasons. Therefore, this research focuses on evaluating the level of accuracy of current contingency estimation techniques in the Sri Lankan context. This study adopted a mixed-method research approach. Empirical data were collected using expert interviews and questionnaire survey. Data collected from the expert interviews were analysed using manual content analysis. Descriptive statistics and inferential statistics were used to analyse the questionnaire survey data. Findings revealed that inexpensiveness is the highly motivating factor for the rigid usage of the traditional method to estimate contingency in the Sri Lankan context. Estimated contract amount, procurement method, payment method, and type of client were identified as highly influencing factors in contingency estimation. Finally, the hypothesis test of this study revealed that the traditional contingency estimation is ineffective. Since the traditional contingency estimation proved ineffective and highly inaccurate, experts in the industry should consider a flexible alternative approach in contingency estimation to improve the accuracy of the contingency amount.

Keywords: *Alternative method; Contingency; Estimation techniques; Traditional method.*

1. INTRODUCTION

Contingency is the percentage of a construction budget set aside to accommodate unknown factors and uncertainties connected to the construction projects (Lam and Siwingwa, 2017). Accordingly, a project's total financial commitment can be expressed by adding contingencies within an estimated budget which provides the basis for cost control and measurement of cost performances (Baccarini, 2005). The excess contingency allowance ensures that design and construction will be finished smoothly within the budget and schedule. However, the funds tied up as contingency prevent the parties from undertaking other activities such as contractors bidding for other projects and owners investing in new projects (Günhan and Arditi, 2007). Insufficient contingency leads to the additional financial commitment that allows seeking unexpected financial arrangements (Amade *et al.*, 2014). Hence, it is vital that a sufficient contingency amount

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must be allocated to a project to enable the parties to deal with uncertainties; and, at the same time, not tie up valuable funds (Nawar *et al.*, 2018).

Experts usually depend on traditional methods to specify the contingency amount based on subjectivity, experience, gut feeling, and instinct - they do not rely on a mathematical approach to support that decision (Touran, 2003). The public sector is a better example of the adaptation of the traditional method for contingency estimation. Government is a major investor in the construction industry at all levels and has a responsibility to act as industry regulator and legislator (Keith and Peter, 2004). In Sri Lanka NPA guidelines, in total cost estimation, the maximum allocation for physical contingencies is up to 10%. It further suggests that allowance for variations incur during the project are allocated within this limit. If the limit exceeds, approval should be taken from the appropriate level of authority mentioned in the manual. However, the uniqueness of each construction project and other factors induces several issues in this traditional contingency estimation (Karlsen and Lereim, 2005). Hence, researchers identified and analysed advanced mathematics and probabilistic methods used for estimating contingency to overcome this problem.

A recent study by Moselhi and Roghabadi (2020) shows that researchers developed models and identified tools and techniques globally to improve efficiency in contingencies estimation. However, in Sri Lanka, the contingency estimation technique is still an under-researched topic. Therefore, this research envisages evaluating the current rigid practice in contingency estimation in Sri Lanka to identify its effectiveness. The research aim here is to analyse the accuracy of the contingency estimation in the Sri Lankan context. The research aim was developed by reviewing the concept of contingency estimation in construction projects, identifying the significant factors considered for contingency estimation, analysing the different techniques used in contingency estimation in the world and Sri Lanka, and evaluating the accuracy level of contingency estimation in Sri Lanka.

2. LITERATURE REVIEW

2.1 SIGNIFICANCE OF CONTINGENCY IN CONSTRUCTION PROJECTS

Contingency is the additional amount allocated above the base estimate as a reserve of money in a construction project (Lam and Siwingwa, 2017). There is no standard definition for contingency in the literature, but in general, it is defined as the source of funding for unexpected events occurring during construction projects (Günhan and Arditi, 2007). Therefore, contingency provides flexibility to the project. It also allows value addition to a project by implementing design changes and scope changes within the budget (Ford, 2002). The generally accepted contingency amount in a construction project is identified as design contingency, construction contingency, and client contingency (Patrascu, 1988). Design and construction contingencies are used to cover the additional costs during the pre-construction and construction phases, respectively (Günhan and Arditi, 2007). The client contingency is the risks brought up by the employer, mainly due to some change in taste or scope of the project. Furthermore, client contingency can be experienced during both the construction and design phases, from inception to completion (Lam and Siwingwa, 2017).

Contingency is also regarded as one of the best strategies to deal with numerous construction risks (Elbarkouky *et al.,* 2016). Therefore, contingency is used in conjunction with other construction risk reduction techniques. Accordingly, various methods are proposed in the literature to use contingency sum to use as a management tool (Lam and Siwingwa, 2017). Proper constancy estimation and identifying a suitable content estimation method are crucial because an improper contingency estimation method can lead to overestimating and underestimating the contingency amount. In the overestimated scenario, the funds tied up as 'contingency' prevent the parties from undertaking other activities such as contractors bidding for other projects and owners investing in new projects (Günhan and Arditi, 2007).

On the other hand, underestimating contingency amounts creates issues such as cost overrun, time overrun, payment delay, and the need for sudden financial loans (Amade *et al*., 2014). However, underestimation of the contingency amount is a significant concern in the researchers' view. Lam and Siwingwa (2017) conducted a hypothesis test. They showed that the allocated contingency amounts are insufficient to cover the actual contingency amount, which is the sum of the actual amount spent at the end of the project as a contingency.

2.2 FACTORS CONSIDERED FOR CONTINGENCY ESTIMATION

Construction industry projects are subject to larger amounts of risks due to their unique features such as long period, a large number of stakeholders and labours, complicated process, financial intensity, and dynamic environment (Bahamid and Doh, 2017). However, all the risk factors are not considered for the contingency estimation because variables or factors considered for contingency estimation must be simple, and hence, unnecessary parameters should be avoided (Baccarini, 2006). Lam and Siwingwa (2017) identified the project's complexity and estimated that project cost at a detailed design stage as critical factors considered for determining contingency sum - a larger and more complex project has a higher chance of having an inadequate estimated cost. In addition, duration, location and type of work (new build or refurbishment) influence the contingency estimation (Jimoh and Adama, 2014), while design completeness and scope changes are identified as other leading contributors to the contingency amount deviations (Buertey *et al*., 2013).

McLain *et al*. (2014) recognised geotechnical conditions as another factor that needs to be considered for contingency estimation. Ahiaga-Dagbui and Smith (2005) study validate these arguments by identifying inclement weather, unsuitable ground conditions, scope changes, and client's cash flow problems as factors affecting contingency amount. Economic factors such as tax rate, exchange rate, and price fluctuations also influence determining contingency in construction projects (El-Karim *et al*., 2015).

2.3 CONTINGENCY ESTIMATION METHODS

Contingency estimating methods are categorised into three groups: deterministic, probabilistic, and modern methods (Bakhshi and Touran, 2014). Table 1 presents the detailed breakdown of these methods and their comparison in various criteria to summarise several literature findings.

The traditional method is the most common and simplest method used in contingency estimation (Baccarini, 2005). In this method, a percentage of the estimated contract amount is added as a contingency amount. This percentage is derived either from expert opinions or a fixed percentage set by the institution (Baccarini and Love, 2014). The traditional method has been used for a long time even though alternative methods are proposed with better benefits (Bello and Odusami, 2008). This traditional method is also referred to as the 'deterministic method' and highly criticised in the literature (Baccarini and Love, 2014). The traditional method expresses a single figure of the amount rather than the range, as the term deterministic implies (Bakhshi and Touran, 2014). Since this method ignores formal risk assessment, it is suitable for a project with a low budget, having less time to prepare an estimate, and when the insufficient budget is allocated for estimation. However, these methods fail to address the unique characteristics of a specific project like complexity, market condition, and location (Olumide *et al*., 2010).

Table 1: Detailed breakdown of contingency estimation methods along with the comparison

Contingency Estimation Methods	**Criteria**	**Simple to Execute**	**Specific Risk Factors in Project Considered**	**Considered Subjective Uncertainty (Experts' Opinion)**	**Cost Consuming**	**Time Consuming**	**Need of Estimator Knowledge on Selected Field**	**Reliance on Past Data**
Deterministic Methods	Predefined Percentages	✓						
	Expert Judgment	✓		✓				
Probabilistic Methods	Expected value		✓					✓
	Regression							✓
	Monte Carlo Simulation		✓		✓			✓
Modern Mathematical Methods	Fuzzy Techniques		✓	✓	✓	✓	✓	
	Artificial Neural Network		✓	✓	✓	✓	✓	

3. METHODOLOGY

The study used the mixed approach because it helps in-depth exploration of a research problem (McCusker and Gunaydin, 2015) by integrating quantitative and qualitative data (Uprichard and Dawney, 2019). The first part of the study used a qualitative approach to identify the different types of contingencies estimation methods and factors considered during contingency estimation (McCusker and Gunaydin, 2015). The second part of the study used a quantitative approach to identify the significant factors considered for contingency estimation and the effectiveness of the traditional contingency estimation (Creswell, 2017). The required qualitative data were collected by interviewing experts based on their experience (Fellows and Liu, 2015). Accordingly, face-to-face semi-structured interviews were held with experts who had more than ten years of working experience in construction projects in Sri Lanka to validate the literature findings and assess new facts. Table 2 lists the interviewees' profiles. The empirical results of the interviews were analysed using manual content analysis.

Table 2: Details of Delphi round 1 respondents

Nr.	Designation	Experience in Construction Industry
1	Senior Quantity Surveyor	15 Years
2	Project manager	10 Years
3	Quantity Surveyor	11 Years
4	Project manager	17 Years
5	Engineer	10 Years
6	Senior Quantity Surveyor	19 Years
7	Quantity Surveyor	10 Years
8	Engineer	10 Years
9	Senior Quantity Surveyor	11 Years
10	Project manager	11 Years

The significance level factors considered for the contingency estimation were identified using a questionnaire survey. The questionnaires were distributed among 40 respondents working on construction projects. Among the 33 returned questionnaires, 30 were duly filled. The survey respondents, who had to have more than five years of working experience in construction projects in the profession of quantity surveying, engineering and project management, were selected using purposive sampling based on their professional qualifications, experience, knowledge, and willingness to participate in the survey. Table 3 presents the details of the respondents. The survey findings were analysed using the relative importance index (RII) and were calculated using Equation 01:

$$RII = \frac{\Sigma(Wn)}{N\ x\ A} \qquad (01)$$

Where W = rating given to a factor by each of the respondents; n = frequency of the responses; N = total number of responses; A = highest weight.

Table 3: Details of Delphi round 2 respondents

Profession	Experience in Construction Industry (Years)					
	1-5	**6-10**	**11-15**	**16-20**	**21-25**	**Total**
QS	3	5	2	1	1	**12**
Engineer	7	4	4	1	-	**16**
Project Manager	1	-	1	-	-	**2**
Total	**11**	**9**	**7**	**2**	**1**	**30**

Quantitative data, such as the contract amount and the contingency amount of 34 projects, were collected and analysed using a hypothesis test to achieve the overall aim of the study. The hypothesis test was identified as the most suitable method, as it was used in a similar survey of Lam and Siwingwa (2017), which concluded that contingency amount is insufficient in Zambia.

4. FINDINGS AND ANALYSIS

4.1 DIFFERENT CONTINGENCY ESTIMATION METHODS

The interviewees validated all six (06) contingency estimation methods identified from the literature review as applicable to the Sri Lankan context. The traditional method, regression, expected value, Monte Carlo Simulation, Artificial neural network, and fuzzy logic techniques are the contingency estimation methods identified from the literature review and expert interviewees. In order to determine the awareness of contingency estimation methods and their usage in the local construction industry, the questionnaire survey respondents were asked to respond about their involvement in the construction projects with traditional contingency estimation methods vs alternative contingency estimation methods. Accordingly, 94% of the respondents were involved in the projects that used the traditional method, while the remaining 6% of the respondents were involved in the projects with alternative contingency estimation methods.

Except for the respondents' personal involvement, their general awareness of these contingency estimation methods were also identified from the questionnaire survey as interpreted in Figure 1.

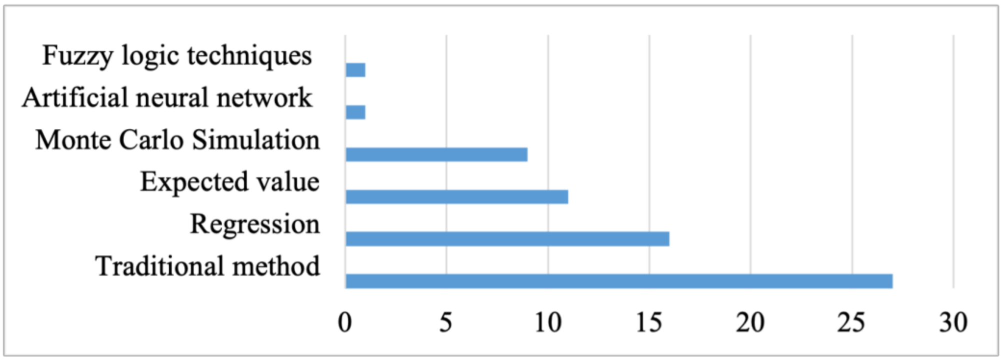

Figure 1: Awareness of contingency estimation methods

As per Figure 1, a considerable gap exists between the traditional methods and other methods. The regression method stands at the second position with 50% awareness of the respondents; a 34% difference occurs between the first two methods. Almost all the respondents were unaware of the last two methods, i.e., fuzzy logic and Artificial Neural network. However, the main criticism regarding contingency estimation is the rigid use of the traditional method without experimenting with other techniques. Many (84%) questionnaire respondents agreed that traditional methods are overwhelmingly used in projects without seeking alternative methods for contingency estimation.

The literature review identified cost, time, easiness, and simplicity as reasons for this higher tendency towards traditional methods. Besides, three factors were identified through interviews, i.e., lack of knowledge about the alternative methods, uncertain or not proven benefits about using the alternative methods, and lack of critical need for change. Questionnaire survey respondents were asked to priorities these findings, and Table 4 provides the results.

Table 4: Motives for the use of traditional contingency estimation method

Factors	RII value	Significance	Rank
Low cost	0.952	High	1
lack of knowledge about the alternative methods	0.841	High	2
Uncertain benefits about using the alternative methods	0.828	High	3
No critical need for change	0.817	High	4
Time saving	0.800	High	5
Simple and easy method	0.648	Medium	6

Low cost was the most significant motivating factor for the rigid use of the traditional contingency estimation method and ranked 1st with the RII of 0.952, whereas a simple and easy method was identified in the 6th rank with the RII of 0.648. However, it was not identified as the least significant factor but at medium level significance. All other factors were identified in the range of highly significant, according to the RII value.

4.2 Factors Considered for Contingency Estimation

Table 5 presents the factors considered during the contingency estimation calculation, including 11 literature findings and three additional factors identified from the expert interview. Interviewees validated that all 11 factors identified from the literature review are applicable to the Sri Lankan context. The procurement method, payment method, and conditions of the contract are the additional factors identified by the interviewees, as indicated by the red coloured text in Table 5, which also presents the RII value, significance level, and the ranking of each factor.

Table 5: Significance of factors affecting contingency estimation

Factors	RII value	Significant level	Rank
Estimated Contract amount	0.975	High	1
Procurement method	0.855	High	2
Payment method	0.848	High	3
Type of client	0.813	High	4
Contract period	0.772	High -Medium	5
price fluctuation	0.761	High-Medium	6
Complexity	0.752	High-Medium	7
Location	0.662	Medium	8
Type of wok (new/refurbishment/maintenance)	0.637	Medium	9
Geo technical condition	0.628	Medium	10
Exchange rate	0.600	Medium	11
Completeness of design	0.586	Low	12
Conditions on contract	0.538	Low	13
Weather condition	0.497	Low	14

Among the four highly significant factors, the *estimated contract amount* identified as most significant with the RII of 0.975. The *procurement method* and *payment method*, identified as 2nd and 3rd significant factors, respectively, were not identified from the literature but the interviews. Interviewees identified the procurement method as one of the important factors considered during the contingency estimation, with an example of design discrepancies related to contingency amount. According to the interviewees, the case of design discrepancies between tender drawings and as-built drawings always resulted in additional costs. If it is a traditional procurement method, the project cost will increase. However, the risk related to the design discrepancies does not exist in the design and build procurement method. Hence procurement method is a factor determining contingency estimation.

Similarly, the interviewees identified the payment method because payment varies between fixed-price contracts and measure and pay contracts. Even though interviewees newly identified *conditions of contract* as one of the factors, it was ranked 13th with the RII of 0.538, which falls under the low significance level.

4.3 EFFECTIVENESS OF TRADITIONAL CONTINGENCY ESTIMATION

More than 75% of the respondents mentioned during the questionnaire survey that the allocated contingency amount is not sufficient to cover the actual contingency amount. However, this conclusion is based only on the survey respondents' opinion. Therefore, findings were tested with the actual data from the past project. Accordingly, a Hypothesis test was performed to check whether the contingency estimated in past projects is sufficient to cover the actual contingency amount.

- The null hypothesis, H_0 = the traditional contingency sum, is sufficient for a building project in the Sri Lankan construction industry.
- Alternative hypothesis, H_1 = the traditional contingency sum, is insufficient for a building project in the Sri Lankan construction industry.
- In the traditional method, usually, 10% of the initial contract amount is allocated as a contingency. In addition, from the questionnaire survey, respondents indicated 3% deviation could be tolerated. Hence, the 13% level is selected as a sufficiency level.
- Now H_0 and H_1 can be rewritten as: H_0; $\mu \leq 13\%$ and H_1; $\mu > 13\%$, where μ = mean of actual contingency.

The samples for this test were collected in a convenience sampling method, and data were collected from more than 30 numbers of projects, which is the minimum requirement for an appropriate hypothesis test. Table 6 presents the data collected for the hypothesis testing. Accordingly, P6 and P14 have extremes value comparing the other values; hence P6 and P14 are excluded from the further calculations. In addition, the estimated contract amount presented in Table 6 excluded the amount deducted as value engineering benefit. The value of the test statistic is calculated by using Equation 02.

$$Z(test) = \frac{\bar{x}-\mu_0}{\sigma/\sqrt{n}} \quad (02)$$

Where, $\bar{x}$ = mean of sample, μ_0 = mean of the population, σ = the standard deviation of the population, and n = the number of observations. Based on the collected data and using Equation 02, the test statics (Z) value is obtained as 2.73, where x ̅=17.35, μ_0=13, σ=8.70, and n=30.

Table 6: Details of hypothesis test projects

Project Name	Estimated Contract Amount	Estimated Contingency (a)	Final Contract Amount	Actual Contingency (b)	(a) – (b)
P1	848,747,593.00	10%	867,562,785.00	12.22	2.22%
P2	49,506,724.00	10%	45,411,850.77	1.73	-8.27%
P3	15,446,560.00	10%	15,142,923.60	8.03	-1.97%
P4	195,500,000.00	10%	202,166,453.00	13.41	3.41%
P5	245,000,000.00	10%	293,456,712.00	29.78	19.78%
P6	83,000,000.00	10%	143,554,901.00	82.96	72.96%
P7	333,500,000.00	10%	351,566,423.00	15.42	5.42%
P8	135,606,769.00	10%	163,009,554.44	30.21	20.21%
P9	83,129,025.00	10%	98,826,738.35	28.88	18.88%
P10	659,278,899.05	10%	701,478,007.19	16.40	6.40%
P11	215,849,580.00	10%	226,857,782.30	15.10	5.10%
P12	102,920,893.02	10%	132,648,124.06	38.88	28.88%
P13	107,595,678.75	10%	126,857,453.25	27.90	17.90%
P14	456,654,782.98	10%	632,655,323.78	48.54	38.54%
P15	78,355,623.55	10%	91,461,323.16	26.73	16.73%
P16	75213652.3	10%	81591273.58	18.48	8.48%
P17	30,684,362.22	10%	26,682,054.00	-3.04	-13.04%
P18	88,791,026.42	10%	101,065,431.90	23.82	13.82%
P19	196,257,143.45	10%	199,743,027.56	11.78	1.78%
P20	68,678,995.67	10%	72,682,932.00	15.83	5.83%
P21	330,145,764.65	10%	342,874,163.53	13.86	3.86%
P22	456,923,865.48	10%	492,865,429.34	17.87	7.87%
P23	215,674,265.00	10%	242,759,552.87	22.56	12.56%
P24	149,673,900.62	10%	147,221,886.76	8.36	-1.64%
P25	44,587,465.98	10%	46,917,836.33	15.23	5.23%
P26	127,491,731.48	10%	132,587,241.78	14.00	4.00%
P27	53,914,980.03	10%	60,826,781.46	22.82	12.82%
P28	541,826,402.62	10%	562,887,336.33	13.89	3.89%
P29	205,998,664.81	10%	200,892,965.44	7.52	-2.48%
P30	612,854,037.62	10%	653713982.6	16.67	6.67%
P31	310,642,711.11	10%	341275843.4	19.86	9.86%
P32	96,527,831.09	10%	102586391.3	16.28	6.28%
Average				**17.35%**	**7.35%**

If Z is greater than the critical value, the null hypothesis is rejected. The critical value for rejection with a 10% significance level is 1.956. The calculated value of Z is 2.73, which falls in the rejection area, and the null hypothesis is rejected. Hence, the traditional contingency sum is insufficient for a building project in the Sri Lankan construction industry. The average amount of actual contingency is 17.35% of the estimated contract sum, which is more than 7% higher than the actual estimated contingency amount. The hypothesis test also indicates that the contingency sum allocated in traditional methods is insufficient. Hence it can be concluded that the traditional contingency estimation method in Sri Lanka is ineffective.

5. CONCLUSIONS

This study focused on analysing the accuracy of the contingency estimation in the Sri Lankan context, which is rarely touched on in the literature. Similar to the literature, this study also identified six contingency estimation methods applicable to the Sri Lankan context. Among them, the traditional method of contingency estimation proved to have high awareness in the Sri Lankan perspective, whereas fuzzy logic techniques obtained very little awareness. Moreover, six factors were identified in this study as motivating factors for the rigid use of the traditional estimation method in Sri Lanka. Accordingly, low cost was the highly motivating factor for the rigid use of the traditional method. Fourteen significant factors affecting the contingency estimation were identified from this study, and the estimated contract amount was most significant. Finally, at the end of the hypothesis study, it was concluded that there is still a potential to increase the effectiveness of the tractional method of contingency estimation in Sri Lanka.

The contribution made by this study will considerably assist the industry to be aware of the importance of enhancing the effectiveness of the traditional method of contingency estimation in Sri Lanka. Furthermore, it is recommended to recognise the alternative contingency estimation methods available and adapt them to enhance the accuracy of the contingency estimation. The study makes a theoretical contribution by providing a benchmark for the accuracy of the traditional contingency method, especially for the Sri Lankan construction projects. Because, though several past studies have identified the rigid usage of this traditional method, they were not specific to the Sri Lankan situation and were not focused on analysing its accuracy. This study will be a helpful basis for further research to explore the alternative contingency estimation methods in the Sri Lankan perspective and to compare the effectiveness of them against the existing rigid method.

An investigation should address the research question, "are all increases from the estimated cost to be covered from the contingency?" This issue was not identified from this study's hypotheses. One limitation of this study was that since data were collected within the Sri Lankan context, it may influence the generalisation of the findings from a global viewpoint.

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ANALYSING THE GAP BETWEEN PREDICTED AND ACTUAL OPERATIONAL ENERGY CONSUMPTION IN BUILDINGS: A REVIEW

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ABSTRACT

Operational energy consumption in buildings has a crucial impact on global energy consumption. Nevertheless, significant energy savings can be achieved in buildings if properly designed, constructed, and operated. Building Energy Simulation (BES) plays a vital role in the design and optimisation of buildings. BES is used to compare the cost-effectiveness of energy-conservation measures in the design stage and assess various performance optimisation measures during the operational phase. However, there is a significant 'performance gap' between the predicted and the actual energy performance of buildings. This gap has reduced the trust and application of the BES. This article focused on investigating BES, reasons that lead to a performance gap between predicted and actual operational energy consumption of buildings, and the ways of minimising the gap. The article employed a comprehensive literature review as the research methodology. Findings revealed that reasons such as limited understanding of the building design, the complexity of the building design, poor commissioning, occupants' behaviour, etc., influence the energy performance gap. After that, the strategies have been identified to minimise the energy performance gap such as proper commissioning, creating general models to observe occupants' behaviour in buildings, and using the general models for energy simulation, ensuring better construction and quality through training and education, etc. Further, the findings of this study could be implemented by practitioners in the construction industry to effectively use energy simulation applications in designing energy-efficient and sustainable buildings.

Keywords: *Building Energy Simulation (BES); Building sector; Operational Energy (OE)*

1. INTRODUCTION

Buildings play an important role in consuming a large share of global energy consumption (Fan and Xiao, 2017). A building's Life Cycle Energy (LCE) comprises embodied energy (EE) and Operational Energy (OE). Energy spent for the construction of buildings, including transportation is known as embodied energy, and energy use by building services is known as OE (Praseeda *et al.,* 2016). Stephan and Stephan (2016) stated that operational energy in buildings is the core energy consumption mode throughout the total

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lifetime of buildings. The energy consumed by the building during its use phase accounts for 80%-90% of the energy consumption of the entire life cycle (Brady and Abdellatif, 2017). According to Liu and Mi (2017), the operational energy of a building is mainly consumed by air conditioning, ventilation, lighting, and water distribution systems. Furthermore, in most buildings, the energy consumption of Heating Ventilation and Air conditioning (HVAC) systems make up 52%, and lighting accounts for 25% of total operational energy consumption (Pérez-Lombard *et al.,* 2008). Further, there are other factors that contribute to the use of energy during the operation phase of a building. The occupants' careless activities have a significant impact on the energy consumption. For instance, the occupants habitually tend to keep windows and doors open waste energy by creating an additional load on the HVAC system. This may result in an increase of three and a half times more energy utility for the HVAC system when compared to its regular consumption (Lee and Yang, 2017). The aging of equipment, defects in components and systems, and ineffective practices in buildings also cause energy wastages (Fan and Xiao, 2017). Further, an increase in population, changes in lifestyle, improvement in facilities, and duration of occupation in buildings impact the energy consumption of a building. (Pérez-Lombard *et al.,* 2008). Considering the thermal comfort, increasing the comfort level of the buildings elevates energy usage by 20%, and the hours of use of air conditioning has contributed to increasing the energy usage by 42-68% in similar weather conditions (Mastrucci and Rao, 2017).

Compared to other costs, the operational energy cost of the buildings is considerably high. Reducing the cost of energy in the operation phase significantly increases net profit. Therefore, it is necessary to plan at the initial stages of a building lifecycle to reduce the energy consumption during the operation phase. Energy simulation is a perfect and essential tool to measure and predict the operational performance at the design stage of a building to eliminate possible shortcomings during its use phase. Further, BES enables facility managers to analyse buildings' energy usage whilst optimising the performance (Cong *et al.,* 2009). There are many energy simulation software such as Ecotect, eQuest, IES-VE, Design Builder, OpenStudio, ArchiCad 16, and EnergyPlus (Jarić *et al.,* 2013). BES tools have been combined with modern technology and calculated energy consumption based on the parameters of the internal environment to predict the impact of the building's urban environmental energy demand (Gobakis and Koolokotsa, 2017). According to Hong *et al*. (2017), BES is widely used to forecast future energy utilisation and reduce energy wastage by implementing the necessary modifications. BES produces sound output through receiving input of energy utility information and other required parameters on energy consumption. BES is a tool used to measure the effect of the internal environment regarding the utility of energy in the building (Gobakis and Kolokotsa, 2017). Further, BES tools could also be used to view the energy performance changes before and after modifications are done (Zoras *et al.,* 2017). BES tools help determine energy performance and find the possible advantages and mechanisms that help with energy savings and cost reductions (Ciampi *et al.,* 2015).

However, Van Dronkelaar *et al*. (2016) mentioned that simulated energy prediction varies from actual energy consumption. Further, Hong *et al*. (2018), Turner and Frankel (2008), and Soebarto and Williamson (2001) agreed that variation in predicted and measured energy is a barrier to promote BES tools. Hence, to enable the use of BES tools, the gap should be identified and minimised. Less work has been devoted to exploring the factors that cause the gap between predicted and actual operational energy consumption of buildings, and these set the research agenda for the future. In this sense, an academic gap exists in recognising and analysing factors that cause the gap between predicted and actual operational energy consumption of buildings. Therefore, this study explores the factors that cause the gap between predicted and actual operational energy consumption of buildings. The study also identifies strategies to reduce the gap between predicted energy and actual energy consumption of buildings.

2. 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 researcher to identify gaps with relevant evidence through the knowledge that is currently prevailing. Therefore, as in any research carried out, a sound literature review enriches and strengthens the research process. Hence, this study employed a comprehensive literature review to investigate the BES concept, factors that create a gap between predicted and actual operational energy consumption of buildings, and the ways of minimising the gap. The relevant literature was searched using search engines and data bases limited to 'Google Scholar', 'Scopus', 'Science direct' and 'Emerald'. When searching, 'OPERATIONAL ENERGY AND BUILDINGS', 'ENERGY SIMULATION AND BUILDING SECTOR', and 'SIMULATED ENERGY AND ACTUAL OPERATIONAL ENERGY CONSUMPTION' were used as the keywords to find the relevant publications for the research problem. Accordingly, around 55 peer-reviewed articles published between 2000-2020 were reviewed in this study. In addition, book chapters, conference proceedings, and publicly available publications were reviewed to gain a broader understanding of the area. Even though there are some steps of the systematic literature reviews integrated into this literature search, still it is identified as a conventional "comprehensive literature review". This is due to not following the formal systematic review protocols in this study to comply as a systematic literature review. In line with the review study conducted by Rathnayake *et al.* (2020), the steps shown in Figure 1 are conducted to perform the comprehensive literature review.

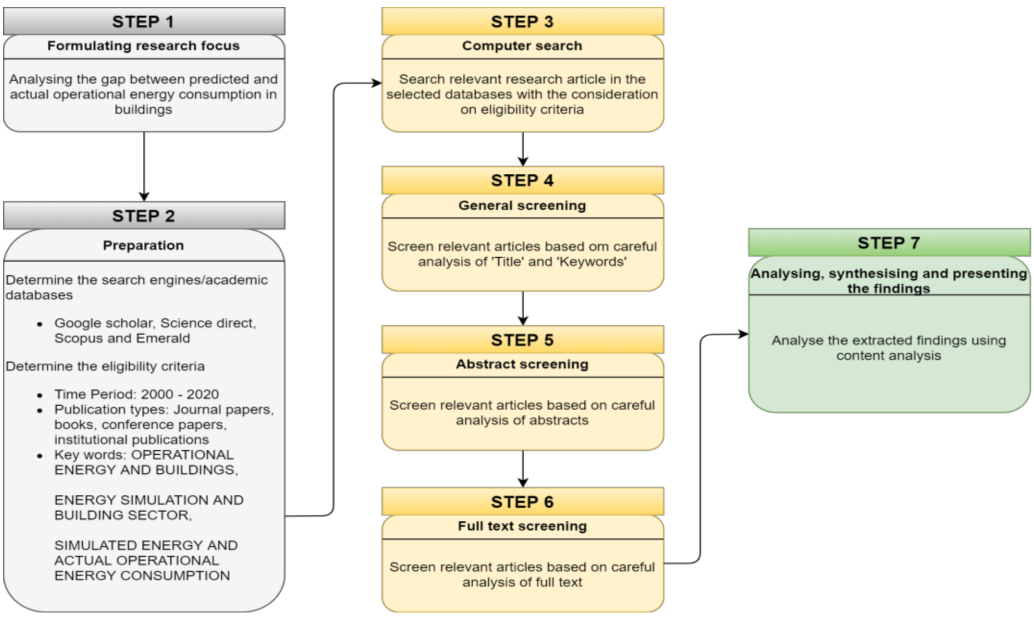

Figure 1: Research process (Adapted from: Rathnayake et al., 2020)

3. LITERATURE REVIEW

3.1 OPERATIONAL ENERGY AND BUILDINGS

According to Devi and Palaniappan (2014), OE is the energy required for building operation during its use phase. Furtherm, Rasmussen *et al*. (2018) defined operational energy as the energy needed to maintain comfortable conditions in the building through processes such as heating, ventilation, air conditioning, hot water supply, and lighting. Further, according to Giordano *et al*. (2015), OE refers to Primary Energy Demand (PED) for heating, ventilation, cooling, hot water production, and lighting. Ramesh *et al*. (2010) stated that the OE of the building accounted for 80-90% of total energy consumed by the building.

Air conditioning and illumination are the primary consumers of operational energy (Praseeda *et al*., 2016). Air conditioning uses 50% of operational energy in buildings in the developed nations (Pérez-Lombard *et al.,* 2008). Mastrucci and Rao (2017) stated that energy consumption for heating associated with the countries with cold climatic conditions accounts for around 25-36% of the OE. The illumination occupied around 6-13% of OE. China is now the world's largest consumer of energy, the largest producer and consumer in 2019. According to the statistics of Building Research Establishment (BRE) and the Institute for the Diversification and Saving of Energy (IDEA), the energy composition of end uses in buildings is compared in three countries viz, United States of America (USA), United Kingdom (UK), and Spain. The comparison has been drawn based on the building facilities such as HVAC, lightings, equipment, Domestic Hot Water (DHW), refrigeration, food preparation, and others. In all three countries, HVAC accounted for the highest percentage, whilst lighting is placed as the second. Food preparation comes as the lowest percentage of total energy consumption in offices. The statistics of BRE and IDEA are presented in Table 1.

Table1: Operational energy composition of buildings in the USA, UK, and Spain

Energy end uses	USA (%)	UK (%)	Spain (%)
HVAC	48	55	52
Lighting	22	17	33
Equipment (appliances)	13	5	10
DHW	4	10	0
Food preparation	1	5	0
Refrigeration	3	5	0
Others	10	4	5

(Sources: Pérez-Lombard *et al*., 2008)

The OE in buildings is seen to have escalated with an increase in population, changes in lifestyle, improvement in facilities, and duration of occupation (Pérez-Lombard *et al.,* 2008). Further, operational energy varies to a great extent with the level of comfort required, climatic conditions, and operating schedules (Ramesh *et al.,* 2010). A 20% increase in energy usage together with increasing hours of air conditioning usage to maximise the comfort level of the built environment has contributed to increasing the energy usage by 42-68% in similar weather conditions (Mastrucci and Rao, 2017). According to Kong *et al*. (2012), during the last 10 years, the energy use of the built environment has rapidly risen in China contributing to 30% of the total energy consumption of the country. Further, the energy consumption of the built environment in 2010 was twice as in 1996 due to the increase of the average annual rate by 10%.

Overall, compared to other costs of buildings, the OE cost is a considerable amount. This reduction of the OE cost can greatly increase the net profit of the organisations. Therefore, it is necessary to control OE consumption. This can be planned from the early stages of the building's lifecycle. Considering such early interventions to reduce the OE, energy simulation can be identified as one of the best tools to evaluate changes in the built environment to meet varying requirements (Garwood *et al.,* 2018). Further, the Building Energy Simulation (BES) is not only limited to the early phases of the building's lifecycle, there is room for energy efficiency improvements in the operation phase as well. The next section explains more details about BES.

3.2 BUILDING ENERGY SIMULATION (BES)

BES is also known as Building Energy Modelling (BEM) (Pang *et al.,* 2016), Building Performance Simulation (BPS) (Kim and Park, 2016), or Building Energy Performance Simulation (BEPS) (Egan *et al.,* 2018). BES applications for predicting building performance have been growing rapidly since the 1980s (Wright *et al.,* 2013). BES provides several benefits for the users including prediction of the energy consumption of the buildings through the ever-increasing knowledge of information technology (Doukas *et al.,* 2009; Mondrup *et al*., 2014), integrating standards to buildings (Doukas *et al.,* 2009; Rallapalli, 2010), forecasting energy performance to facilitate decision-making (Garwood *et al.,* 2018), estimation of the energy usage considering prevailing external conditions (Wang *et al.,* 2018), verifying the accuracy of energy-related modifications in buildings (Murray *et al.,* 2014) and supporting buildings designers such as architects and engineers to reduce energy consumption and cost (Abdullah *et al.,* 2014).

BES software collects inputs from various sources and performs predictions at different phases of the building lifecycle (Abdullah *et al.,* 2014). Energy simulation software plays a key role in reducing the cost of energy in buildings (Sousa, 2012). There are several energy simulation software such as DesignBuilder, EnergyPlus, eQuest, Green Building Studio, Integrated Environmental Solutions (IES), Sefaira, etc. (Sousa, 2012) with various interfaces for users by applying a variety of simulation engines (Abdullah *et al.,* 2014). The software forecasts of the energy consumption include various parameters relating to energy in buildings such as the thermal condition, effect of air circulation and the use of natural ventilation, the energy consumption of equipment, and impact of the behaviour of occupants (Rallapalli, 2010). Further, according to Yi (2016), BES software also helps in using daylight in various places within the building that will help to minimise energy usage, improve the comfort of the workplace, and increase efficiency. For example, the use of current practices on illumination planning and power density are compared using energy simulation with standards, which can identify potential changes. Such changes in buildings reduce energy consumption, which leads to minimising operational costs (Delgoshaei *et al.,* 2017). With the application of BES software, the HVAC load can be predicted throughout various seasons (Florentin *et al.,* 2017). Consideration of climatic information using weather predictions has enabled us to weigh the effects of the external environment that contributes to the energy utilisation of the building (Gobakis and Kolokotsa, 2017).

EnergyPlus is a freely available software, created by the United States Department of Energy to examine the performance of building services. EnergyPlus, simulation software comprehensively estimates energy loads of built environment such as heating and cooling and predicts energy consumption by providing the required parameters, which are necessary to verify predicted and real consumption. eQUEST was also created by the United States Department of Energy which has a less complex and user-friendly interface for energy evaluation to eliminate issues in Graphical User Interface (GUI). Sefaira is another commercial modelling software that supports the customers in creating a 3-dimensional analysis of the model to examine the consumption of energy for HVAC. Further, the Sefaira application supports all architectural, engineering, or construction tools like Sketchup and Autodesk Revit. In addition, DesignBuilder is also a software that helps to produce 3-dimensional effective energy designs and operation models for buildings designed in a manner that can extract the required information from Building Information Modelling (BIM).

Van Dronkelaar *et al*. (2016) state that there is a difference between modeled energy prediction and the measured actual energy use in buildings. Further, Hong *et al*. (2018), Turner and Frankel (2008), and Soebarto and Williamson (2001) agree that variation in predicted and measured energy is a barrier to the acceptance of the BES tools for buildings. The next section explains the reasons identified in the literature for the gap in simulated energy and actual operational energy consumption in buildings.

3.3 Reasons for the Gap in Simulated and Actual Operational Energy Consumption of Buildings

According to Bordass *et al*. (2004), various causes lead to creating a gap in the predicted energy consumption using the BES and the actual energy consumption. A detailed review of the root causes for the energy performance gap is listed below which identified ten causes for the energy performance gap as given in the literature.

1. Lack of understanding about the building design

A lack of understanding with the professionals who do the BES regarding the design of the building, building orientation, materials used in construction, renewable energy sources used in building, etc. This would lead to errors in the energy simulation due to a lack of information or wrong information input to the BES software (Bucking *et al.,* 2014).

2. The complexity of the building design

It has been identified a relationship of the complex building designs to increase the inaccuracies of the BES. The complex building designs seem to have more gaps in the predicted and actual energy performance than the more simple building designs (Bunn and Burman, 2015).

3. Uncertainties in building energy modeling

According to Kim and Augenbroe (2013), there are uncertainties in specifications and modelling such as numerical uncertainty, scenario uncertainty, the uncertainty of the assumptions, uncertainty of the building details, variations of materials, etc which lead to the gaps of the predicted and actual results.

4. Inter-model variability

Raslan and Davies (2010) stated that there is 13 software that has been recognised for creating significantly wrong predictions for energy performance. Further, the modelling tools that are created by many countries for various purposes might not applicable for other situations. This results in varied predictions of the performance of a building in different countries.

5. Poor on-site workmanship

On-site workmanship needs to be adapted and training carried out to increase levels of complex building construction (Williamson, 2012). Installation of the drainage system, ducts for ventilation, and electrical conduit work will provide a means for gaps that negatively influence air tightness and also enable thermal loss (Morant, 2012). Such issues in the actual construction works create energy wastages that are not counted in the BES.

6. Changes after design

Morant (2012) reports poor compatibility between design specified and installed, which caused a significant effect on the divergence between predicted and actual data.

7. Poor commissioning

Buildings are handed over to clients after construction. There is a process of commissioning, a separate stage that ensures the building services such as HVAC, lighting, water supply systems, and other energy-using building systems meet with the owner's performance requirements and perform and operate as intended and at maximum energy efficiency (Wagner *et al.,* 2007). Poor commissioning leads to create gaps in the predicted and actual energy consumption.

8. Poor practice and malfunctioning equipment

Assumptions made about temperature set points, control schedules, and the overall performance of the HVAC system, the actual operation of the building can be idealised from the design stage. However, in reality, many assumptions tend to deviate and directly affect the energy use of buildings during the operation phase.

9. Occupants' behaviour

Another dynamic factor during building operation is occupants. They have a substantial influence on the energy performance of a building by handling controls, such as those connected to lighting, sun shading, windows, set points, and office equipment, and also through their presence, and these controls may deviate from the predetermined schedule. BES might not be able to capture the impact of this complex behaviour of the occupants for energy consumption.

10. Measurement system limitations

Like the use of the building energy model to predict energy usage, the usage of metered energy through the measurement system should be verified to ensure the accuracy of the data. The limitations of the measurement system make the assessment of actual energy use inaccurate (Maile, 2010).

11. Longitudinal variability in operation

The energy performance gap is generally assessed for a year of measured data. However, longitudinal performance is affected by factors such as building occupancy, deterioration of physical elements, climatic conditions, and building maintenance processes and policies (De Wilde *et al.,* 2011).

As identified above, there is a considerable likelihood for the existence of gaps in the predicted and actual energy consumption due to such causes. The BES communities usually focus to mitigate or eliminate the causes of such gaps. The strategies to reduce the aforementioned gas are explained in the following section.

3.4 STRATEGIES TO REDUCE THE GAP BETWEEN SIMULATION RESULTS AND ACTUAL ENERGY CONSUMPTION

Literature has identified various strategies to reduce the gap between simulated and actual energy consumption. Ensuring proper hypothesis of prediction, perfect tuning of building services, and functioning of the facility as designed are important factors to monitor the simulation of the building. This has resulted, in the narrowing of the gap between actual energy consumption and estimated energy consumption (Vázquez *et al*., 2011). Further, Vázquez *et al*., 2011 mentioned that investigating and creating general models to observe the behaviour of tenants in buildings and using them in energy consumption prediction can reduce variations. Simple observation, obtaining readings, and generating a model to predict energy more absolutely, with the use of basic monitoring results will help to input the energy model with accuracy and predict the actual performance of the building (van den Brom *et al*., 2018; Gram-Hanssen and Georg, 2018). Furthermore, training and education are necessary to improve the skills of personnel in the construction industry by ensuring quality construction (Gram-Hanssen and Georg, 2018). Similarly, to strictly implement the maintenance and operation practices in the building, training, and education of facility managers should be strengthened. Whereas, in the design phase, energy modelers need to understand differences in energy performance, whilst promoting skills, innovation, and technological development to respond more appropriately in creating reliable designs. Post-occupancy evaluation can be properly conducted and it is resultant to minimise fine-tuning during operation and helps to reduce the gap between simulation results and actual energy consumption (Kimpian *et al.,* 2014). In addition, Proper commissioning exercises can help maximise the efficiency of building services to avoid unnecessary energy use (Morant, 2012; Gram-Hanssen and Georg, 2018). Therefore, continuous monitoring of performance during operation is vital to ensure that the design goals are achieved under normal operating conditions (Torcellini *et al.,* 2006). Further, continuous feedback can improve the design process and more accurately predict actual usage of energy performance (Hopfe and Hensen, 2011). Furthermore, model calibration aims to compensate for errors that may mask modelling errors at the entire building level (Clarke, 2001). Raftery *et al*. (2011) stressed that the calibration methods can improve the quality of future models by identifying common false assumptions and developing best-practice modelling methods. The reliability and accuracy of the calibration model depend on the quality of the measurement data used to create the model, as well as the accuracy and limitations of the tools used to simulate the building and its systems (Coakley *et al.,* 2012). A summary of sections 3.3 and 3.4 is depicted in Figure 2.

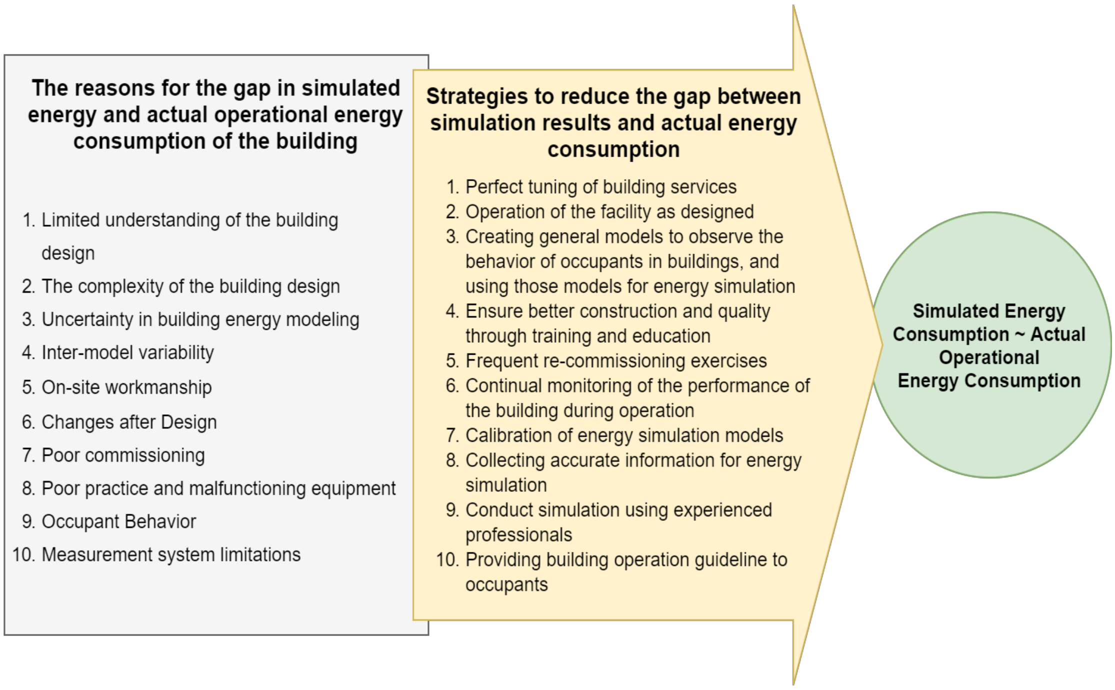

Figure 2: Summary of reasons for the energy performance gaps and strategies

4. CONCLUSIONS AND THE WAY FORWARD

This study provided an overview of the BES concept with respect to the gaps and strategies of the actual and predicted OE consumption. The building sector has been identified as one of the major contributors to the global environmental impact due to its high OE consumption. BES tools are important for building designers to reduce energy consumption and energy cost. The energy simulation software supports designers to take accurate decisions based on the simulation data. Therefore, the paper discusses the BES concept and its importance to the building sector and different types of BES tools. The literature highlighted that there is a significant gap between the predicted energy performance of buildings and the actual energy performance of buildings. Hence, reasons that created a gap between simulated energy and actual operational energy consumption of the building are discussed. Findings revealed that reasons such as limited understanding of the building design, the complexity of the building design, uncertainty in building energy modelling, poor commissioning, occupant behaviour, etc. negatively influence energy simulation. Thereafter, strategies such as proper commissioning, creating general models to observe the behaviour of tenants in buildings, and using those models for energy simulation, ensure better construction and quality through training and education, etc. are proposed to minimise the performance gap. Further, the findings of this study could be utilised by practitioners in the construction industry to use BES applications effectively for designing energy-efficient and sustainable buildings while minimising the predicted and actual energy performance gap. Further research can be carried out to determine the critical reasons which contribute to the gap between predicted and actual energy consumption.

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ANALYSIS OF FEASIBILITY OF BLOCKCHAIN TECHNOLOGY FOR INTERNATIONAL TRADE RELATED TO SRI LANKAN CONSTRUCTION INDUSTRY

H.D. Weerakoon[1] and H. Chandanie[2]

ABSTRACT

Sri Lankan (SL) construction industry has been trading with overseas suppliers to fulfil the need for material and technology. This process faces many issues due to the poor digitalisation of the industry. The financial flow of international trade is dominated by financial institutions (i.e., banks) and the industry faces many issues e.g., delays, additional charges, complexity, lack of information sharing, and requiring legal assistance. Blockchain Technology (BCT) has emerged as a revolutionary digital technology in the past decade. Key features of BCT i.e., immutability, decentralisation, distributed ledgers, enhanced security, consensus, and speed have been identified to provide solutions for issues in the various industries including the supply chain. Hence this paper aims to investigate the feasibility of using BCT to solve existing issues in financial flow with special reference to the barriers to adopt it in the international trade of the Sri Lankan construction industry. As the data collection method, an expert opinion forum was carried out by involving both international trade experts and blockchain specialists in the Sri Lankan construction industry. Key findings present that BCT can solve issues such as transparency issues and poor information sharing between parties, excessive documentation and complexities, payment delays, and financial costs in the international trade of the SL construction industry. Further, findings revealed that the government's approval, legal requirements, lack of knowledge and technology, and reluctance to change the industry can act as barriers to adopt BCT in Sri Lanka.

Keywords: *Blockchain; Construction international trade; Expert interviews; Financial flow.*

1. INTRODUCTION

The involvement of a large number of stakeholders and the uniqueness of each output may describe the complexity and risk level of the construction industry (Belle, 2018). Being more complex construction has come a long way to a level to trade internationally with foreign stakeholders such as suppliers and contractors (Belle, 2018). Procuring materials and equipment for construction is one of the challenging areas because it governs the time for construction, cost, and quality factors of the construction output (Hewavitharana *et al.,* 2019). Exporting and importing commodities in and out of countries are common in construction because of the availability of limited resources and

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varied technology advancements in different regions (Schumacher, 2013). As a developing Asian country, Sri Lanka is showing interest in foreign supplies for fulfilling requirements of construction material and equipment. However, construction supply chains face many problems such as lack of coordination and trust between suppliers and customers in the supply chain, design problems, less transparency, misinformation, and poor quality of materials and equipment (Nanayakkara *et al.,* 2013).

In 2008, Satoshi Nakamoto invents blockchain as a public transaction ledger of the cryptocurrency (Abeyratne and Monfared, 2016). Due to the mainstream focus on bitcoin, blockchain was originally seen as a way to create new digital currencies that people can use anonymously in trade between untrusted participants beyond geographic boundaries (Wang *et al.,* 2017). Gradually, professionals have identified the significance of blockchain systems. Moreover, blockchain critically challenges conventional systems by improving in many areas such as transparency, accountability, security, trust, cost minimisation, and efficiency (Kshetri, 2018). Hence, this paper discusses the financial flow-related issues since they are considered more critical in the international trade of the SL construction industry and reviews the feasibility of adopting BCT as a solution to overcome such issues.

2. LITERATURE REVIEW

2.1 ISSUES IN THE FINANCIAL FLOW OF CURRENT PRACTICES OF INTERNATIONAL TRADE IN CONSTRUCTION SUPPLY CHAIN

In the Sri Lankan context, Wedikkara and Devapriya (2000) describe that price determination for projects, designing process, forecasting, and operation of the construction firm also depend on the supply side of the construction industry. Further, considering the environment of the Sri Lankan construction industry it depends more on foreign suppliers due to the scarcity of construction material and technology. According to the Board of Investment Sri Lanka (2013), the imported components used in major infrastructure in Sri Lanka vary from 45-63% of the total cost. Therefore, international trade is a vital component in the Sri Lankan construction industry.

Power (2005) identified that three types of supply chains in construction; i.e. (i) The primary supply chain: Supplies the material required for the final construction output, (ii) The support chain: Offers construction facilitating materials and equipment, and (iii) The human resource supply chain: Includes labour supply. The primary supply chain and support chain mentioned above can be identified very often in the history of the construction sector in Sri Lanka. Such flows are largely formalised, regulated, and managed by stakeholders in the construction supply chain such as clients, contractors, manufacturers, and subcontractors. Figure 1 illustrates that the generic supply chains are comprising of three flows; i.e. (i) Financial flow, (ii) Material flow and (iii) Information flow.

Financial flow is the process of optimising the working capital of the party to get the expected outcome within successful boundaries (Phong, 2018). Traditionally, financial flow is heavily relied on centralised financial authorities to reduce financial risks (Chang *et al.,* 2019). Moreover, the author states that in terms of reducing potential risks among trading parties, certain types of payment methods such as; payment by delivery, telegraphic transfer, open account, and Letter of Credit (LC) are introduced and adopted in different contexts.

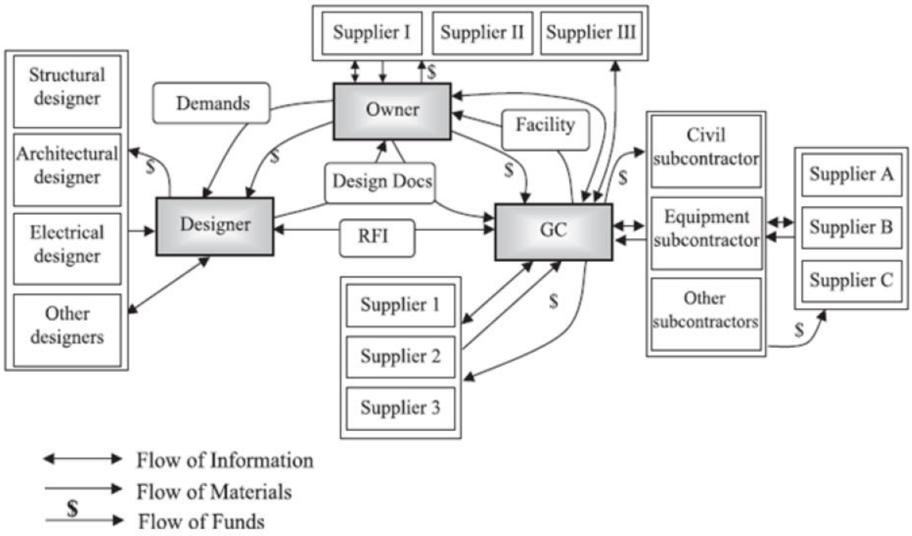

Figure 1: Model of global construction supply chain (Source: Phong, 2018)

Focusing on international trades in the construction supply chain, greater emphasis is given to LC (Rodrigo *et al.*, 2018) that involves two banks (customer's bank and supplier's) to ascertain the financial credibility (Mann, 2000). To understand issues in the traditional process required attention must be given to the sequence of financial activities in the LC process. Figure 2 illustrates the steps of international trade related to the LC process.

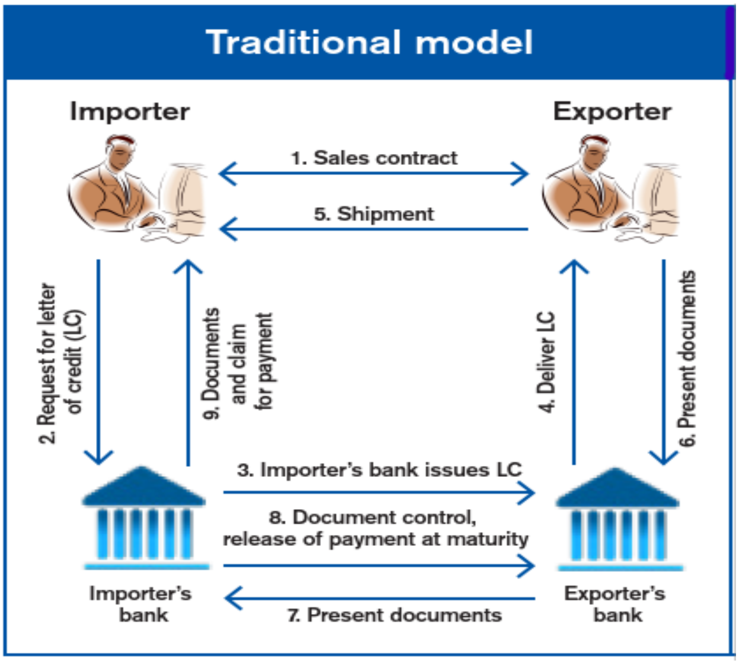

Figure 2: Traditional method of trading using LC (Source: Ganne, 2018)

As Figure 2 illustrates Seller (exporter) and Buyer (importer) agree to the contract first then the buyer request LC from his bank and the bank issues the LC including the specified amount to the seller's bank. Later, the seller receives the LC from his bank and it works as a guarantee for his commitment and the supplier can ship the product by contacting the shipping service. Shipping service issues the document called Bill of Lading (BL) to the supplier confirming the supplier has deployed the shipment which presented as the proof to the seller's bank. Those documents are issued to the buyer's bank by the seller's bank and the buyer claims them from his bank by making the payment. The buyer can release the products delivered to his port by presenting the documents to port authorities (Faber and Butler, 1992). This process has been able to provide excellent risk reduction in trading over the decades (Chang *et al.,* 2019). Due to the benefits of LC, the Sri Lankan construction industry also relied on the LC procedure for international trading while there are other methods such as on-account wire transfer and telegraphic transfer methods being less used. However, dependence on third-party centralised financial authorities has created several issues eventually due to increased demand in production (Bai and Sarkis, 2020).

Table 1 provides the issues related to the financial flow of construction international trade that has been identified through literature study.

Table 1: Issues in the financial flow of Sri Lankan construction international trade

Issue	Reference	Explanation
Payment delays	[1], [2], [3], [4], [5]	LCs can be amended or rejected due to several reasons and the buyer has to await the payments longer.
Lengthy payment cycle	[4], [5], [6]	Payments should be circled through two banks to receive by the seller.
Time-consuming	[1], [2], [3], [4], [5]	Documentation practices are time-consuming because of the involvement of more parties.
Complexity and coordination problems	[1], [5], [6]	More parties incorporated in the process other than the seller and the buyer. Documentation practices are time-consuming.
Increased cost due to bank financial charges	[1], [5]	Third-party financial agents impose financial charges resulting in an additional cost to trade parties.
Require legal assistance	[5]	Current payment terms are based on complex documentation practices, and they will require legal assistance.

(Sources: [1] Perera *et al.,* 2020; [2] Vrijhoef and Koskela, 2000; [3] Lu *et al.,* 2021; [4] Wibowo and Sholeh, 2015; [5] Le *et al.,* 2018)

The issues above stated do require a modern solution and the intent of this research is to answer those issues using blockchain technology. Therefore, the next sub-topics are concerned about BCT, its benefits, and its usage.

2.2 BLOCKCHAIN

Blockchain is considered a potential disrupter of the status quo in the commercial sector innovating in transactions, revolutionising industries and driving economic change on a global scale (Perera *et al.*, 2020). Kinnaird *et al.* (2017) comprehensively describe the blockchain as a distributed ledger. But instead of being centrally oriented and managed as today's most databases, it is decentralised and not under the control of any single person, group, or organisation.

Many of today's experts claim that BCT is a greater and important invention and it will become outstanding than the World Wide Web (WWW) (Kinnaird *et al.,* 2017). Cryptocurrency Ethereum's white paper states that the blockchain technology's range of potential applications is infinite from digital currency to blockchain empowered legal contracts with the most striving applications yet to be created (Buterin, 2015).

The elements of BCT architecture and important features of BCT are described hereon.

Distributed Ledger (DL)

Blockchain processes the transactions in a database similar to actual ledger entries but electronically assembled roughly into groups called "blocks" and ensures that already entered data can never be modified or deleted hence it is difficult to hack (Kinnaird *et al.,* 2017).

Nodes

A node can be represented by an active electronic device (e.g. a computer or smartphone) connected to the blockchain network using the internet (Binance Academy, 2020).

Asymmetric encryption/digital signature

Used in many IT systems, email, and the internet which allows people to encrypt the data without sharing confidential data. A pair of keys are introduced "private" and "public". Any person or machine can use the public key to encrypt the data and only the owner of the specific private key is authorised to decrypt the data (Kinnaird *et al.,* 2017).

Block

In a distributed ledger, each valid transaction is recorded in a "block" which is cryptographically linked into another (Bogart and Rice, 2015). Mining is the mechanism of transactions that are clustered into a block and added to the end of the current blockchain (Sarmah, 2018).

Consensus mechanisms

In the blockchain, consensus refers to a series of procedures related to approving and confirming a transaction or set of transactions by using consensus algorithms (Perera *et al.*, 2020). In Bitcoin blockchain, this achieved by generating a mathematical puzzle (referred to as "Proof of Work") and entering a transaction into the ledger can only be achieved by solving this mathematical puzzle (Crosby *et al.*, 2016).

Hashing

Hashing concept will allow BCT to remain un-hackable. Hashing can be described as a process of a string of characters and turns it into a usually shorter fixed-length value or key which serves as a representation of the original string which is widely used in cryptographic algorithms (Gervais *et al.*, 2016; Tavares, 2018).

2.3 BLOCKCHAIN FOR CONSTRUCTION SUPPLY CHAIN MANAGEMENT

The construction industry shows little adoption of the information technology revolution compared to financial and manufacturing industries which partake the greater outcomes through information technology (Agarwal *et al.,* 2018). Implementation of an ICT solution in a project-based industry is challenging when compared to the process-based industry (Nanayakkara *et al.,* 2019). But, the uses of blockchain seem to provide solutions to dozens of issues related to various industries. Especially researchers show that blockchain has great potential to overcome supply chain issues (Ganne, 2018; Chang *et al.,* 2019). Following benefits can be ascertained by blockchain technology.

Quality assurance

Products can be purchased and tracked in the supply chain using blockchain technology and it reduces the risk. In this manner insuring costs and bank charges can be eliminated (Kinnaird *et al.,* 2017).

Security of transactions and time saving

Compared to the traditional LC method blockchain can provide more security and guarantee the funds (Ganne, 2018). Also, the P2P network is certainly fast compared to the traditional LC process and it is important to tally up the increased construction demand. Figure 3 illustrates the differences between LC and blockchain approaches.

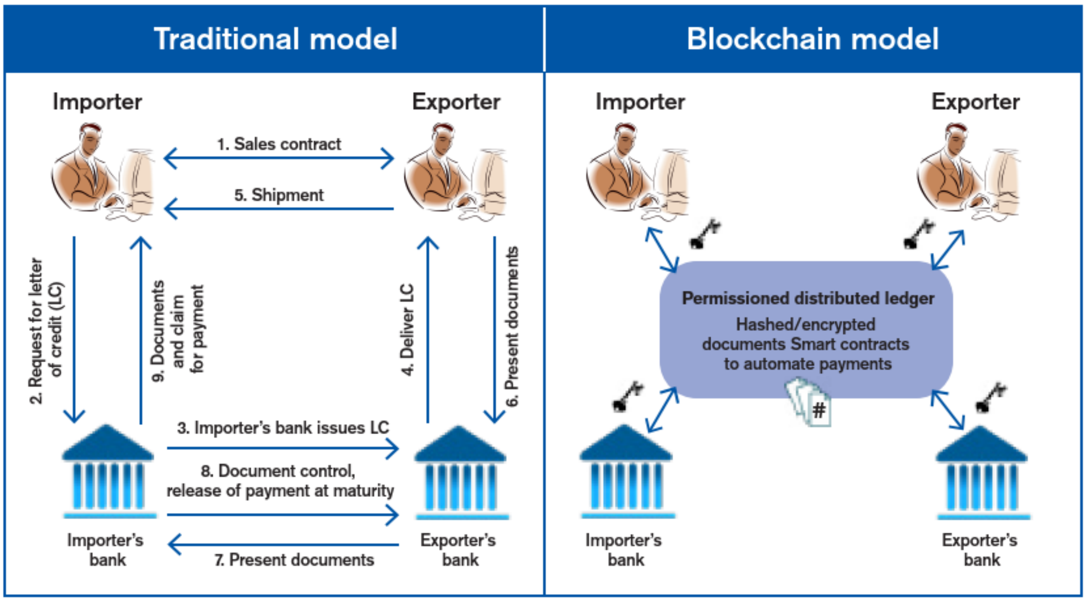

Figure 3: Differences between LC and blockchain approaches (Source: Ganne, 2018)

Better coordination and communication

The un-involvement of third parties makes the coordination and communication process much easier (Chang *et al.,* 2019). In this case, blockchain is a smart solution with a distributed database by creating time-stamped blocks via cryptography (Chang *et al.,* 2019) which means secured information with much less transmission time compared to all traditional methods.

Reliable information/records

The buyer can make sure of the product's quality and history of transactions (if any) by referring to the immutable distributed ledger (Ganne, 2018). It solves the trust and reliability issues that have had for years in business.

3. METHODOLOGY

This research attempted to investigate the feasibility of BCT as a solution to address financial flow issues in SL construction international trade. Awareness of BCT within the Sri Lankan construction industry was found to be minimal at present because it is not yet adopted in the country resulting a qualitative approach is favourable rather than a quantitative approach. Therefore, to obtain data a qualitative approach was chosen by conducting an expert forum. Semi-structured interviews carried out in two phases involving the experts in the practices of construction international trade, and blockchain experts practising related to the construction industry.

3.1 PHASE I OF THE EXPERT FORUM

To get a better knowledge of the current practices, different perspectives from the different stakeholders in the study area were helpful. Therefore, three experts (E1, E2, E3) have been selected who work relating to international trading under Client, Consultant, and Contractor organisations. Semi-structured interviews were conducted to identify current practices and issues in the financial flow of international trade.

3.2 PHASE II OF THE EXPERT FORUM

Five experts (E4, E5, E6, E7, E8) including four experts involved in the construction sector who know BCT were selected for Phase II of the expert forum. An expert from the Information Technology (IT) industry is selected to collect precise technical knowledge. BCT's capacity to solve identified issues, challenges in implementation were discussed.

Hsieh and Shannon (2005) stated that the content analysis method is the most used to interpret qualitative text data through systematic coding and patterns. Content analysis has been selected as the most suitable analysis method for this research.

4. FINDINGS

4.1 FEASIBILITY OF BLOCKCHAIN TO OVERCOME FINANCIAL FLOW RELATED ISSUES

Issues identified from Phase I of the expert forum are summarised in Table 2.

Table 2: Summary of issues related to the financial flow of current practices

Issue	Expert		
	E1	E2	E3
Time-consuming/possible delays		x	x
Excessive documentation	x	x	x
Lengthier payment path	x	x	x
Complexity and coordination problems	x	x	
Financial charges	x	x	x
Require legal assistance	x		

Table 3 demonstrates the issues identified through the expert forum and the strength of BCT to overcome the issues in the financial flow of the construction supply chain according to the experts' opinions.

Table 3: Strength of BCT to overcome the issues in the financial flow

Issue	Strengths of BCT to overcome
Time-consuming/possible delays	Peer to Peer transactions (Reduce time)
	Possibility of transaction automation
Excessive documentation	BCT does not incorporate complex documentation
	Smart contracts (Reduce the possibility of human errors)
Lengthier payment path	Eliminate banks (Uses P2P transactions)
Complexity and coordination problems	BCT does not incorporate complex documentation
	Process and conditions are defined initially (Smart Contract)
Financial charges	Eliminate bank-related financial costs
	Only occur small transaction cost depending on the consensus mechanism
Require legal assistance	BCT does not incorporate complex documentation

Findings of the data collection are discussed hereon under each issue identified.

Time-consuming/possible delays, and complexity and coordination problems

All the experts stated that if BCT is used to make payments it will save time because the transaction will happen buyer to the supplier directly. Further, the speed of money transfer through BCT will be very high compared to wire transfer through banks. E5 expressed a brilliant idea "*Think of an example like we can attach a GPS tracker in the product shipment, and we can programme smart contract to make payments when the product arrives at the customers port, of course, it can be tracked by the GPS tracker and payment can be automated likewise*". This will help to reduce the time consumption of transactions and reduce delays. E7 stated, "*By eliminating the third-party financial institutions such as banks the supplier and importer can achieve a better and shorter path for money flow*".

Excessive documentation / Require legal assistance

Phase I of the expert forum raised an issue regarding complex documentation in the LC payment method. E4, E6, and E7 stated that lengthy documentation in conventional practice can be eliminated by using BCT backed system, because it runs on a smart contract that reacts based on logic. E8 further stated that by the use of smart contracts, human errors can be reduced because it is automated. Possible errors in conventional bank payments such as arithmetic errors can also be eliminated. This will be a solution to the issue "requirement of legal assistance on the documents" that emerged in Phase I of the expert forum.

Financial charges

All the experts claimed that by using blockchain finance costs can be reduced. E4 said "*Current LC payment procedure incurs many associated costs such as postage, courier services, bank-to-bank reimbursement charges, and LC amendment charges. Using a blockchain-based system can discard all these additional costs*". E4, E7, and E8 discussed the gas fees for transactions of cryptocurrency. E8 elaborated the matter by stating "*Due to the rewarding phase, there would be a small transaction cost because we know there are people inside the network who verify the transactions and make a block into the blockchain, and they are compensated by the blockchain. But considering the* *current financial cost that we have to incur it will be a huge saving for both supplier and the importer parties*".

Guarantee of funds

Assurance of the funds is the most important factor from the supplier's perspective. In conventional practise, banks are assuring the funds. E5 and E7 claimed that the same assurance can be generated through a network backed by blockchain. E7 elaborated the subject "*By using blockchain we can allocate the required amount of money in our wallet and give authority to the supplier to check whether we have an adequate amount of money to do business or not. Like in the bank, the guarantee of money is achievable*".

E6 stated "*if we implement blockchain transactions we have to think about the currency that we are going to use because Bitcoin is becoming more like an asset rather than a currency and its volatility is higher. Therefore, it can result in huge profits or losses for both parties. Then we have to use other stable coins like USDT, CUSD to make payments*".

Grounds to adopt BCT in Sri Lanka

E5 stated, "*Adopting blockchain-based payment system in the construction supply chain is possible compared to the other aspects that blockchain can do*". Experts stated that due to the prevailing condition of the construction sector the use of BCT to assure the material quality and history of plants is almost impossible. There is a technological gap to be filled before the adoption of BCT.

4.2 BARRIERS FOR IMPLEMENTING BCT

E5 explained that according to the focus of the research to apply BCT to international trading the central bank's acceptance will be vital because money will be sent overseas, and the central bank will surely want to monitor the transactions. Originally, blockchain's P2P transaction method will restrict the observation to such authorities. Therefore, the Central bank will have to develop a platform to do the cryptocurrency international trade where they can monitor the process. E5 further explained "*It is not just material cost that we have to pay. Sri Lanka has been collecting taxes and duties for importing products. Therefore, we have to consider the taxes, duties and levies, and other related costs when we import materials equipment from foreign suppliers. Therefore, the government should be able to develop a platform backed by BCT to collect duties and taxes".*

The anonymity of the blockchain user can pursue criminals to make deals without leaving proof and that is the reason why bitcoin is involved in illegal black-market deals globally. E4 stated that the implementation of blockchain will need relating laws to prevent such activities.

E4, E7, and E8 claim that there will be a technology barrier to adopt blockchain in the construction sector. E4 elaborated "*There is a report by McKinsey where they have identified that the construction industry is second least digitalised industry, and we are only better than agriculture. Being the second least digitalised industry, of course, it would be difficult to get it implemented*".

All experts agreed that knowledge of new technologies is minimum with construction practitioners. E4 stated that even the practitioners use smartphones and new technologies in their social life they are quite reluctant to use technology even in developed countries such as Australia. E8 stated that industry practitioners' trust in the blockchain system will be a considerable factor to implement blockchain. E6 added "*Almost every organisation keeps their funds in banks, and it is a difficult task to change their attitude into something that neglects the use of banks. I'm not saying that is impossible, but it will take a big effort*". Moreover, it will affect the decision of each parties' willingness to do business on a BCT-based platform.

Identified barriers are listed below:

- Approval of the Central Bank of Sri Lanka is required.
- A BCT based platform is required to impose taxes and to monitor transactions.
- Enacting new legal protocols to prevent misconduct is needed.
- Technological incapacity of industry practitioners.
- Trust about BCT will be a challenge due to the lack of awareness.
- Industry practitioners' natural reluctance to change.

5. CONCLUSIONS

This paper provides evidence that the current practices in the financial flow of international trading in the Sri Lankan construction industry comprised of many difficulties. The study proved that the application of blockchain technology to address such issues will be an effective solution hence the features of blockchain such as distributed ledger technology, consensus mechanism, peer-to-peer trading, and asymmetric encryption can provide the needing for an efficient supply chain. Unfortunately, the Sri Lankan construction industry is lacking behind in the adoption of new technologies. Expert forum interprets that the Central Banks' approval, a new taxation procedure, legal empowerment and lack of technology awareness will challenge the adoption of BCT in Sri Lanka. Therefore, the adoption of blockchain to the international trade process will require the government's enormous support. Most importantly the industry practitioners should be regularly updated on new technologies and their effort will eventually persuade the government to facilitate blockchain.

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APPLICABILITY OF BLOCKCHAIN TECHNOLOGY TO MANAGE FINANCIAL ISSUES IN THE SRI LANKAN CONSTRUCTION INDUSTRY

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ABSTRACT

The construction industry is one of the largest industries in any country, contributing significantly to economic growth. A range of researchers explained that the construction industry suffered from numerous issues where financial issues are more critical. Late payments, cash flow issues, and lack of security of the payment are some of them. Blockchain technology shows a potential use for managing financial activities. Therefore, this research tends to investigate the applicability of blockchain technology to manage financial issues in the Sri Lankan construction industry. A comprehensive literature survey was carried out to assess the concept of blockchain technology and identified financial issues in the construction industry. A qualitative expert opinion survey was conducted with eight construction experts who had knowledge of the blockchain technology, selected through purposive sampling to collect data in a Sri Lankan context. The collected data was analysed using the content analysis method. The findings of the expert interviews indicated that faster transactions would help to reduce late payments; removing third parties from the transaction will reduce the involvement of many parties in the transaction process; and trust, security, transparency will help to increase foreign investments. Further, the lack of knowledge in the area, legal and tax issues, low investment, and social issues will be the challenges in adopting blockchain technology to the construction industry. The research finally suggests the ways to overcome such challenges in terms of using pilot projects, government rules and regulation. Thus, the research proposes that use of blockchain technology could minimise a significant number of financial issues in the construction industry.

Keywords: *Blockchain technology; Cryptocurrencies; Distributed ledger technology; Financial issues; The construction industry.*

1. INTRODUCTION

The construction industry is one of the biggest industries in the world (Al -Momani, 2000). However, the productivity in the construction industry has not changed compared to the other industries (McKinsey, 2015). Many industries use information technology to improve their productivity (Fulford and Standing, 2014). Furthermore, the authors mention that adopting information technology can help increase productivity in the construction industry. Artificial intelligence, robotics, cloud technology, and the Internet

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of Things (IoT) are just a few technologies that can help to improve the productivity in the construction industry (Ghosh *et al*., 2018).

One of the critical factors in the efficiency of the construction industry is the successful management of financial resources (Gundes *et al*., 2019). The absence of proper financial management will lead to financial issues in projects (Mehta, 2018). Financial issues will lead to delay in construction, which would be a severe problem for all the parties to the contract (Abdul - Rahman *et al*., 2011). Late payments, cash flow issues (Hewavitharana *et al*., 2018), unstable financial background, client's poor financial and business management, difficulties in obtaining loans from financiers, inflation (Ahmed and Ahmed, 2016), difficulties in transactions from the international market are the most significant financial issues in the construction industry (Yoo, 2017). To reduce these issues, the construction industry needs a transparent and traceable payment system that has more control from the client's side and enhances the accountability for every participant (Ramachandra and Rotimi, 2015). As a solution to this need, blockchain technology has been introduced (Nordgren and Weckstrom, 2019).

Blockchain technology is used to distribute, encrypt and secure logging of digital transactions (Turk and Klinc, 2017) and it is the fundamental technology of bitcoin and other cryptocurrencies (Zheng *et al*., 2017). All transactions and digital actions that have been executed and shared among the parties increase transparency and trust while reducing scams (Watson and Hjelte, 2018). Furthermore, the author specified that it would speed up a wide variety of business processes by removing the need for intermediaries and other relevant paperwork. Blockchain technology is one of the revolutionary technologies that can change industries, business models and operating procedures such as payment settlement, accounting, administration, supply chain, customer relations, and funding systems (Igwe *et al*., 2020). Blockchain has numerous applications in different areas such as IoT, finance, business, management, health, and education (Holotescu, 2018). Therefore, the purpose of this research is to investigate the applicability of blockchain technology in the Sri Lankan construction industry to manage financial issues.

2. LITERATURE SYNTHESIS

2.1 FINANCIAL ISSUES ASSOCIATED WITH THE CONSTRUCTION INDUSTRY

According to Kubba (2010), cost overruns are regarded as a major construction issue in projects, and they are extremely common in large-scale construction projects. Azis *et al*. (2012), mentioned that major causes of cost overrun as financial difficulties faced by contractors, schedule delays, poor site management and supervision, cash flow, fluctuation of prices of materials, lack of contractor's experience, frequent design changes and incorrect time and cost estimates. Late payments are one of the issues that arise as a result of some of the key players in construction projects (Harris and McCaffer, 2003). According to Gundes *et al*. (2019), cash flow issues are caused because of poor planning and controlling cash inflow and outflow. According to Abdul - Rahman *et al*. (2011), the external factor of poor economic conditions such as currency and inflation rate would have a significant impact on the cash flow of the project, thus affecting the project's timely performance and causing financial market instability, which would result in the construction project's cash flow problems. In addition, a lack of financial resources is a major issue that affects the project's cash flow and leads to a delay in site possession, which causes delays in the project (Abdul - Rahman *et al*., 2006). According to De Silva (2020), one of the major causes of financial issues in Sri Lanka is that obtaining a loan from a bank takes a longer period of time, which affects both contractors and clients. Abdul - Rahman *et al*. (2011), mentioned changes in interest rates, inflation, and the foreign exchange rate are all causes of market issues. Table 1 illustrates the summary of financial issues and causes for the issues found in the literature.

Table 1: Main financial issues and causes

Main issue	Causes for main issue
Payment issues	Poor financial management by the employer Withhold of payment by the client Contractor's invalid claim Delay in valuation, certification of interim payment by consultant The inaccuracy of valuation for work done Insufficient documentation and information for valuation Involvement of too many parties in the process of certification The heavy workload of the consultant to evaluate variations
Cash flow issues	Too many projects handled by the contractor at the same time Contractor's unstable financial background Unqualified contractors underbidding the project cost Lack of regular cash flow forecasting Poor credit arrangement with creditors and debtors
Financial resources issues	Difficulties in getting a loan from financiers Allocation of government budget not in place
Market issues	Increment of interest rate in repayment of the loan Increment of the foreign exchange rate and inflation

2.2 BLOCKCHAIN TECHNOLOGY

2.2.1 Nature of the Blockchain Technology

In 2008, Nakamoto introduced blockchain technology to the industry. This technology is a continuously expandable list of data records, called "block", which are linked together using cryptographic methods (Gururaj *et al*., 2020a). Cryptography is a subset of cryptology that describes the creation of methods for encrypting information so it cannot be understood by unauthorised parties (Hellwig *et al*., 2020a). The blockchain information records can take any form, representing a money transfer, ownership, a transaction, someone's identity, or an agreement between two parties (Nakamoto, 2009). Blockchain technology disrupts the existing status quo through the elimination of traditional intermediary agents (Lall, 2020). Cryptographic hashing, digital signatures, document time stamping, mining, consensus algorithms, commitment protocols, and smart contracts are all important components of blockchain technology (Persis, 2020). To store digital transactions, it uses a decentralised, distributed, and immutable ledger (Xu *et al*., 2019). A peer-to-peer network is used to manage databases, where all the nodes in a network are identical and major concerns in the types of network architecture (Nakamoto, 2009). Figure 1 demonstrates the process of the blockchain system.

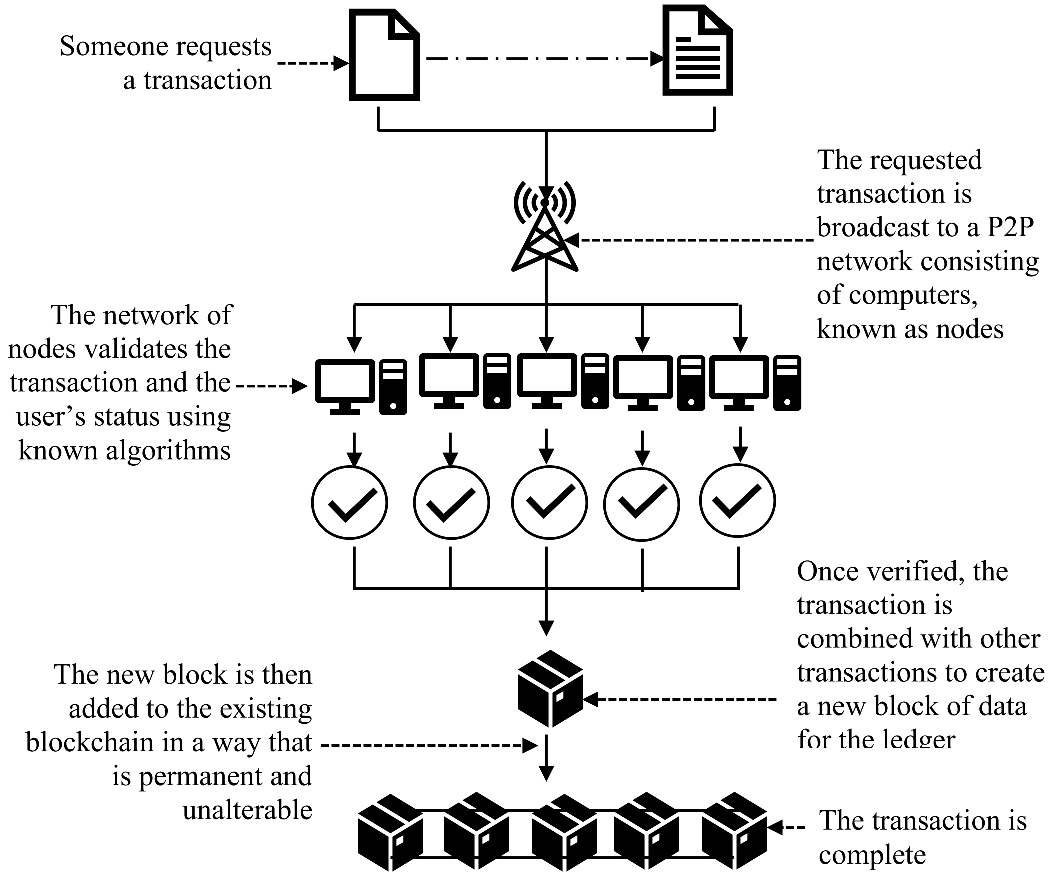

Figure 1: Process of the blockchain system (Source: Watson and Hjelte, 2018)

According to Figure 1, when one party requests a transaction, the information is broadcasted through a peer-to-peer network comprised of computers. These computers are referred to as nodes. The information in the transaction will then be verified by those nodes. Miners will create a block once that information has been verified. This block contains the transaction's hash, previous hash, and data. The request transaction will be completed once that new block is added to the chain.

2.2.2 Cryptocurrencies

When the world moves towards digital payments, and quick-payment transaction methods, information can easily be stored in a blockchain network (Gururaj *et al*., 2020b). Cryptocurrencies are used in peer-to-peer marketing to pay for and buy content in a secure manner (Nakamoto, 2009). Entries of units in a shared consensus-database called tokens or crypto-tokens make up the cryptocurrency fabric (Hellwig *et al*., 2020b). Because blockchain technology offers promising benefits such as transparency, accountability, integrity, immutability, and security, it has been linked to bitcoin, one of the most popular cryptocurrencies, and as a result, various fields are exploring and utilizing the benefits of blockchain technology (Persis, 2020). Bitcoin is the world's first virtual currency, which was introduced in 2008 (Nakamoto, 2009). Bitcoins are not real or tangible assets, and each bitcoin transaction is time-stamped by hashing it against the chain of existing blocks created using hash-based proof-of-work (Panda *et al*., 2020).

2.2.3 Distributed Ledger Technology

Distributed Ledger Technology (DLT) is one of the most essential information technology innovations that can change organisations and associations in the economy, society, and industry (Sunyaev, 2020). The distributed network is a network architecture that distributes data, software, and computer programming across multiple nodes (computers), each of which is interdependent (Nakamoto, 2009). DLT is a broad term for technologies that use replicated, shared, and synchronised digital data between users of private or public distributed computer networks spread across multiple locations, geographies, or institutions (Ghaffari *et al*., 2020). The structure of blockchain is DLT, which provides the foundation for cryptocurrencies and a variety of other applications (Kuhn *et al*., 2019). One of the critical objectives of DLTs is to allow users who do not generally trust each other to communicate without having a trusted third party (Ioini and Pahl, 2018a). Furthermore, the authors mentioned that it provided a level of transparency, traceability, and security to the transaction. However, all DLTs are based on three well-known technologies: public-key cryptography, distributed peer-to-peer networks, and consensus mechanisms, which have been combined in a unique and novel way (Ioini and Pahl, 2018b).

3. METHODOLOGY

The aim of this study was to investigate the applicability of blockchain technology to manage financial issues in the Sri Lankan construction industry. A comprehensive literature review was conducted by referring to journals, books, conference proceedings, and other reliable sources to assess the concept of blockchain technology and identify financial issues in the construction industry. Then, the current study adopts a qualitative research approach to investigate more financial issues in the industry as well as blockchain technology's applicability, benefits, challenges, and solutions for challenges in the Sri Lankan construction industry. Because there was a literature gap between the applicability, benefits, challenges, and solutions for challenges of blockchain technology in the Sri Lankan context.

A total of eight (08) experts are involved in the data collection using semi-structured interviews. The interviewees were chosen using a purposive sampling method from a pool of professionals with construction experience and knowledge of the blockchain concept. Among the eight participants, 50% are from the educational sector, 25% are from contractor organisations and the rest are from consultant organisations. In terms of experience, 80% of them have more than 10 years of experience in the construction industry. Amongst, four of them have vast knowledge in the construction industry and also have knowledge about new technologies. Also, all the educational sector interviewees have vast knowledge about blockchain technology. Because of that, the collected data from the experts was more reliable. To analyse the collected data, a content analysis was performed using NVivo 12 Pro. A summary profile of participants is presented in Table 2.

Table 2: Profile of the participants

Interviewee	Type of organisation	Designation	Years of experience	Key expertise areas
IP1	Consultant	Director	15 Years	Experience in different financial issues, Knowledge about new technologies
IP2	Consultant	Director	15 Years	Experience in different financial issues, Knowledge about new technologies
IP3	Contractor	Contract Manager	14 Years	Experience in different financial issues, blockchain technology
IP4	Contractor	AGM	14 Years	Experience in different financial issues, Knowledge about new technologies
IP5	Educational	PhD Scholar	5 Years	Blockchain technology, Carbon emission, Cost management
IP6	Educational	Doctoral researcher	13 Years	Blockchain technology, Software engineering, Information system
IP7	Educational	Professor	30 Years	Blockchain technology, Artificial intelligence, Carbon emission, BIM
IP8	Educational	PhD Scholar	5 Years	Knowledge about blockchain technology, Offsite construction

4. DATA ANALYSIS AND FINDINGS

Since there is a lack of literature on proper investigations on blockchain applicability, benefits, challenges, and solutions for challenges in the Sri Lankan construction industry, expert interviews were conducted in order to identify additional financial issues as well as blockchain applicability, benefits, challenges, and solutions for challenges in the Sri Lankan context. As a result, semi-structured interviews were conducted with the goal of gathering expert opinions on the aforementioned topics. Later, using NVivo11, the opinions of interviewees were analysed, and the results of the analysis are presented in the following section.

4.1 FINANCIAL ISSUES ASSOCIATED WITH THE CONSTRUCTION INDUSTRY

In addition to Table1, the interviewees were asked to mention any financial issues and causes. IP-1 stated that non-payments and escalation issues are some of the major causes of construction projects, as well as exchange rates and bank debts for both clients and constructors. According to IP-2, some of the major causes are issues with employers' sources of funds, contractor poor performance, and material scarcity. Subcontractors' payment delays, problems obtaining bonds and guaranties from banks, lack of payment security, and bankruptcy are some of the causes of financial problems in the industry, according to IP-3 andIP-5. IP-4 stated that client financial arrangements, due to the different clauses in conditions of the contract, poor cash flow management, lack of creditability in suppliers and subcontractors, issues in payment terms, the difficulty of obtaining bank loans, and due to the economic downturn, will have major impact on financial issues. IP-6 stated that financial problems can arise as a result of quality issues and a lack of capital investment. According to IP-7, mistrust can have a significant impact on financial problems. IP-8 mentions that tax changes and interest claims impacted both the contractor's and client's financial arrangements. Figure 2 depicts the causes discovered through interviews.

Codes

Name	Files	Reference
Payment issues	7	7
Bankrupt	2	2
Contractors performance not within the requirements	1	1
Due to different clauses in the condition of the contract	1	1
Due to quality issues	2	2
Insufficient employer's source of fund	1	1
Lack of security of the payments	2	2
Mistrust	1	1
Non-payments	1	1
Not consider the escalations	1	1
Subcontractor payment delays	2	2
The contractor applies setoff to the payment	2	2
Cash flow issues	3	3
Client's financial arrangement	1	1
Issues in payment terms	2	2
Lack of creditability in suppliers and subcontractors	1	1
Low capital investment	1	1
Financial resources issues	5	5
Bank debt	1	1
Issues with obtaining Bonds and guarantees	3	3
Tax changes	2	2
Market issues	2	2
Due to the economic downturn	1	1
Material scarcity	1	1

Figure 2: Causes discovered through the interviews

4.2 BLOCKCHAIN TECHNOLOGY APPLICABILITY, BENEFITS, CHALLENGES, AND SOLUTIONS TO CHALLENGES

In the interviews, participants were asked to indicate the applicability, benefits, challenges, and solutions for blockchain technology in the Sri Lankan construction industry. All of the experts agreed that blockchain technology has potential applications in the Sri Lankan construction industry. Furthermore, they outline the benefits of blockchain technology that can be obtained in the Sri Lankan context. Also stated the potential challenges that may arise as a result of technology and finally suggested how to overcome them.

4.2.1 Benefits of Blockchain Technology

Several benefits were found in the literature review and expert interviews. Figure 3 depicts the benefits of implementing blockchain technology in the Sri Lankan construction industry.

Codes

Name	Files	References
Benefits of the blockchain technology	7	7
Accountability	6	6
Auditability	3	3
Data immutability	3	3
Data responsibility	1	1
Decentralises transactions	3	3
Faster transactions	6	6
Security	3	3
Traceability	5	5
Transparency	5	5
Trust	5	5

Figure 3: Benefits of blockchain technology

The main benefits, according to five out of eight experts, are traceability, accountability, transparency, fast transactions, and trust. Three of the five experts also mentioned that this technology can provide decentralised transactions, data immutability, security, and auditability. One out of them additionally mentioned that the responsibility of data and transaction will be provided by blockchain technology. Besides that, IP-2 stated that it will aid in the management of the industry's financial flow. According to IP-3, "*normally, the transaction of the projects are huge values, interest rates, premium charges are also higher amounts because going for blockchain is very good for the industry*". Traceability, accountability, transparency, fast transactions, decentralise transactions, digital payments, secure payments, auditability, trust, and responsibility of data and transaction are the benefits expert interviews. When compared to the Sri Lankan construction industry, experts agreed that using blockchain technology can deliver all of these benefits.

4.2.2 Applicability of Blockchain Technology to Manage Financial Issues

During the interviews, participants were asked to identify financial issues that can be resolved using blockchain technology. Respondents mentioned the following methods for resolving financial issues with blockchain technology. According to IP-1, it will help to manage cashflow activities, reduce non-payments, and payment issues in the supply chain. IP-2 stated that it will help to improve awareness of stakeholders and allow contractors to handle more projects at once. According to IP-3, it will enable cash flow automation, the removal of payment delays, transaction management, and the reduction of obtaining bonds and unnecessary bank charges. IP-4 also mentioned transparency, auditability, will help to resolve cash flow issues, and increased foreign investment. Furthermore, said that because all transactions are recorded in the ledger, it aids data management and decision-making. According to IP-5, IP-6, IP-7, and IP-8, blockchain technology can help to achieve trust, traceability, transparency, and accountability, which will help to reduce late payment issues, payment withholding, increase foreign investment, BOI activities, increase trust between the parties, and increase payment security.

Furthermore, experts mention that implementing a decentralised currency system will aid in the acquisition of blockchain features such as data encryption, immutability system, data distribution, data decentralisation, and tokenisation. Table 3 illustrates the causes that can be solved by blockchain technology in the Sri Lankan construction industry.

Table 3: Financial issues covered through blockchain technology

Benefit of the blockchain	Effected financial issues
Faster transaction	Reduce late payment issues
	With smart contract reduce payment withholding
Removing third parties from the transaction	Reduce the involvement of too many parties in the process of certification
	Reduce obtaining loans
	Remove the requirement of bonds and guarantees
Trust, security, transparency, and responsibility of data and transaction	Reduce issues in foreign investment
	Reduce issues in BOI activities
	Reduce lack of trust among stakeholders
	Reduce non-payments
	Reduce lack of security of the payments
Accountability	Reduce cash flow issues
	Reduce issues when handles too many projects at the same time
Traceability	Reduce payment issues in the supply chain
	Reduce issues in stakeholder’s payments

4.2.3 Difficulties in Implementing Blockchain Technology

In the interviews, participants were asked to identify the challenges of blockchain technology when applied to the Sri Lankan construction industry. According to IP-1 and IP-2, the main impact will be legal challenges, a lack of IT knowledge, government enthusiasm, the cost of technology, and taxation issues. According to IP-3, our infrastructure is not yet ready, and the central bank is not yet providing any facilities. IP-4 stated that the main issue will be adapting to the technology, as well as changing people's attitudes toward this technology. also mentioned reluctance to use, negative attitudes toward new technology, and scalability as major challenges. According to IP-6, the industry is not yet ready due to a lack of knowledge in this area, low investment, and the need to adopt blockchain technology as a whole industry rather than as an individual. According to IP-7, the development and adoption of the technology will necessitate a great deal of expertise, as well as changing people's minds about using it as a major challenge. IP-8 said that the main issue will be many people's reluctance to change;

additionally, the construction industry lags far behind other industries. Also, mention that the construction industry lacks the capital to invest in these new technologies. Figure 4 depicts the difficulties associated with blockchain technology in the local context.

Codes

Name	Files	References
Challenges in adapting to blockchain technology	7	7
Adopting to the technology	1	1
Changing people's mindset	4	4
Cost of the technology	1	1
Government enthusiasm	1	1
Industry is not ready	3	3
Lack of knowledge in the area	3	3
Legal challenges	2	2
Low investment	1	1
Tax issues	2	2

Figure 4: Difficulties in adopting blockchain technology

4.2.4 Solutions to Difficulties Encountered when Implementing Blockchain Technology

In the Sri Lankan context, there are several challenges to overcome. Legal issues, lack of knowledge in the blockchain, government enthusiasm, cost of the technology, tax issues, low investment, and changing people's minds about blockchain technology. Experts recommend several approaches to overcoming these obstacles. According to IP-1 and IP-6, new rules and regulations can help to mitigate some of the challenges such as legal issues, government enthusiasm, and tax issues. IP-2 suggests that acquiring knowledge and expertise from developed countries, as well as purchasing technology from them, will help to reduce challenges such as a lack of blockchain knowledge, the cost of technology, and low investment. IP-3 stated that allowing cryptocurrencies in the industry for both receiving and sending, creating a good platform for doing transactions, improving organisational digital infrastructure, and all parties involved in the project needing to be in the same network to work effectively will help to overcome challenges. According to IP-4 and IP-5, increased awareness and confidence will aid in overcoming social issues as well as low technological investment. IP-7 stated that general technological advancement, more blockchain research, public sector support, and private sector investment will help to reduce social issues, government enthusiasm, and low investment.

5. DISCUSSION AND CONCLUSIONS

Simply, blockchain technology is a technology that uses distributed ledger technology, whether for transactions, ownership transfers, to make an agreement between two parties and also many usages yet to be discovered. Blockchain technology provides unique options like faster transactions, digital transactions, accountability, traceability and increases trust, security, transparency, and responsibility. Hence, it aids to reduce late payment issues, payment withholding by using faster and digital transactions, removing intermedia parties from transactions, improve security in foreign or BOI payments by providing trust and security of the payment, accountability, traceability help to manage cash flow activities, trust and transparency will help remove providing bonds and guarantees.

When applied to the local context, blockchain technology presents numerous challenges. Some of them were legal issues, a lack of knowledge in the area, government enthusiasm, the cost of technology, tax issues, low investment, and changing people's minds. The government rules and regulations can help to mitigate legal issues, tax issues, and government enthusiasm. The government can make rules and regulations for the blockchain system and allow transactions using cryptocurrencies. Buying a blockchain system from a developer will help to mitigate the lack of knowledge and cost of the technology. Low investment and changing public opinions can be managed by using pilot projects with blockchain technology. This will help to improve investment in blockchain technology. As a result, the research findings suggest that blockchain technology could help to reduce several financial issues while also allowing the Sri Lankan construction industry to digitalise its future.

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APPLICABILITY OF LEED REQUIREMENTS TO ACHIEVE WATER EFFICIENCY IN SRI LANKAN HOTEL INDUSTRY

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ABSTRACT

LEED is an universally used green ranking system in the world. Among the six evaluation factors it specifically focuses on water use reduction, water efficient landscaping and innovative wastewater technologies. LEED provides a structure or collection of metrics to determine the water efficiency level that a building can achieve. Most of the hotels worldwide are inclined towards gaining LEED certification which is prompted by the higher volumes of water consumption in the facility. LEED is a US created rating system and the most categories of LEED certification are built according to the US aspects. Being an Asian country, Sri Lankan hoteliers also attempt to obtain LEED certification to their hotels with the motive of becoming in order to be more efficient. However, some of LEED requirements under the water efficiency category does not match the Sri Lankan hotel industry requirements. Therefore, the aim of the study to identify whether the LEED requirements under the water efficiency can be applied to Sri Lankan hotel industry. To accomplish the aim, literature synthesis was conducted to explore the water efficiency practices used by LEED certified hotels in other countries. A qualitative research methodology was subsequently adopted, directing semi-structured interviews with two LEED certified hotels in Sri Lanka to identify the LEED practices used in Sri Lankan hotel industry. Thematic analysis was conducted to analyse the collected data. Finally, a framework was developed to compare and contrast the water efficiency practices used in LEED certified hotels in other countries and Sri Lanka.

Keywords: *Green Building Rating System (GBRS); Leadership in Energy and Environment (LEED); Water efficiency.*

1. INTRODUCTION

Leadership in Energy and Environmental Design (LEED) is the most broadly adopted green building ranking system in the world, depending on the number of nations with more than 79,000 programs in more than 160 countries and regions (Doan, *et al.,* 2017). LEED system was established in 2000 by the U.S. Green Building Council (USGBC) for sustainable design practices (Xuan, 2012) and it is the worldwide known sign, which evaluates the building performance including water efficiency, sustainable sites, energy and atmosphere, materials and resources, indoor environmental quality, innovation in operations and regional bonus points (US Green Building Coulcil, 2021). LEED can be added to existing construction, existing buildings, industrial interiors, houses and

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facilities, residences, residential growth, school and retail building categories (Ahmed, *et al.,* 2019). Moreover, the authors declared that it has a point system that provides a score for green building design and construction. According to the earned points, there are four type of certification levels such as LEED Certified™ (40-49 points should be earned), LEED Silver® (50-59 points should earned), LEED Gold® (60-79 points should earn) and LEED Platinum® (80+ points should earn) (US Green Building Council, 2020).

According to Abeysekara (2015), Sri Lanka has 29 LEED certified buildings including 5 hotels and resorts such as Kandalama hotel, Cinnamon Bey hotel, Ulagalla Walawwa resort, Cape Weligama resort and Rainforest Eco lodge.To achieve LEED certification through water efficiency, there are several requirements needed to be full-filled by the buildings. According to US Green Building Council (2018), it is needed to reduce outdoor water usage, indoor water usage, building level water metering, cooling tower water usage, water efficient landscaping, innovative wastewater technologies, plumbing fixtures and fitting efficiency. According to the Green Building Market Report, Watson (2011) explained that a maximum of 1.2 trillion gallons (4.54 trillion litres) of water was saved by LEED certified projects. In addition to that Brown (2018), identified that LEED certified hotel building save 40% of water, 30% of energy, 35% of carbon emission and 70% of solid waste.

However, Rodrigo and Jayarathna (2012) pinpointed that complexity of the LEED requirements may cause an additional burden on anyone who attempts to follow LEED as certain people possess the perception that the documentation and certification procedures of LEED are costly and complex. Moreover, the authors explained that when applying LEED requirements in countries other than the United States for which it was originally developed, aspects such as compatibility, infrastructure, building policy, social needs, social and economic priorities may act as limitations. The above declaration therefore argues whether LEED certification is suitable to be used for achieving water efficiency in Sri Lankan hotel industry. In order to bridge the existing knowledge gap this paper intended to investigate the suitability of LEED certification to achieve the water efficiency in Sri Lankan hotel industry.

2. LITERATURE REVIEW

2.1 LEED

According to the U.S. Green Building Council (2017), LEED or Leadership in Energy and Environmental Design is the most universally used green ranking system in the world. Moreover, LEED offers a structure for the creation of safe, highly efficient and cost-effective green buildings and is a known global symbol of sustainability accomplishment.

Binh and Nguyen (2011), mention that the American LEED standard is comparatively ideal and one of the world's most sophisticated and practical green building certification scoring technologies. LEED certification system can be categorised as LEED-NC (applies to new buildings), LEED-CS (applies to owners and tenants to develop together), LEED-CI (applies to interior decoration of commercial buildings), LEED-ND (applies to community development), LEED-EB (applies to existing building operation management), LEED-FOR SCHOOLS and many other sub evaluation systems (Liu, et al., 2019). LEED certification system has a point system that provides a score for green building design and construction (Boston University, 2018). According to the earned points, there are four types of certification levels such as LEED Certified™ (40-49 points should be earned), LEED Silver® (50-59 points should be earned), LEED Gold® (60-79 points should be earned) and LEED Platinum® (80+ points should be earned) (US Green Building Coulcil, 2021). Moreover, the authors emphasised that the LEED certification system evaluate six aspects when giving the certification for the buildings (refer Table 1).

Table 1: Requirements of LEED certification

Category	Description
Sustainable sites	Sustainable Sites (SS) strategies address effects by enhancing environmental choices around the construction and highlighting the essential interactions between structures, ecosystems and ecosystem services.
Water efficiency	Specialised applications and metering methods to reduce indoor use, outdoor use of water. It measures all building related water sources, including cooling towers, appliances, fittings, process water and irrigation.
Energy efficiency	Focusing on decreasing energy demand through energy use and efficiency instruction and then also give priority to use renewable energy sources, LEED increases the bar on energy and provides fresh alternatives to achieve objectives.
Material	This category is intended to take into account the entire building life cycle, from extraction and manufacturing to transport, operations and maintenance and ultimately the end of life.
Indoor Environment Quality	Provide strategies to maintain indoor air quality, thermal, visual, and acoustic comfort.
Innovations	New techniques are continuously implemented on the market and current scientific research affects the development of design strategies.

(Source: US Green Building Council, 2018)

2.2 DIFFERENT WATER EFFICIENCY REQUIREMENTS OF LEED CERTIFICATION

The water efficiency classification under the LEED certification focuses specifically on water use reduction, water efficient landscaping and innovative wastewater technologies (Gurgun, *et al.,* 2013). According to the US Green Building Council (2019), the requirements should be full filled to get the LEED certification can be described as follows.

2.2.1 Prerequisites

These requirements are necessary to end or to the carrying out of a function. Therefore, to get the LEED certification, the building should be achieved following requirements earlier (Janelle, 2018). It also adds value when calculating the credits under the LEED certification.

A. Outdoor Water Use Reduction

This requirement describes that how to build up the facility to reduce the future (operation Phase) outdoor water consumption. According to the US Green Building Council (2019), the facility should be fulfilled the reduction of outdoor water usage through one of the following options.

- Option 1: No irrigation required

Beyond a fixed establishment duration of two years, the landscape does not require a permanent irrigation system.

- Option 2: Reduced irrigation

Landscape water use for peak irrigation at the site may be reduced by at least 30% from the baseline measurement. The reduction of water must be done by plant species and the effectiveness of the irrigation system. Two additional points can be earned by reducing the prerequisite water requirement. The point allocation for additional outdoor water conservation can be shown as given in Table 2.

Table 2: Points for reducing irrigation water

Percentage reduction from baseline	Points
50%	1
100%	2

B. Indoor Water Use Reduction

The aim of this prerequisite is reducing the indoor water consumption before the operation of the facility. All recently installed washrooms, urinals, private wash faucets and showerheads should be labelled with Sense water (SLOANE Global Holdings, 2016). The basic water consumption of fixtures and fittings is given in Table 3.

Table 3: Baseline water consumption of fixtures and fittings

Commercial Fixtures, Fittings, and Appliances	Current Baseline (SI units)
Water closets (toilets)	6 liters per flush (lpf)
Urinal	3.8 liters per Flush (lpf)
Public lavatory (restroom) faucet	1.9 liters per Minute (lpm) at 415 kPa, all others except private applications
Private lavatory faucet	8.3 lpm at 415 kPa
Kitchen faucet (excluding faucets used exclusively for filling operations)	8.3 lpm at 415 kPa
Showerhead	9.5 lpm at 550 kPa per shower stall

(Source: US Green Building Council, 2019)

Moreover, the US Green Building Council emphasised that water consuming appliances, equipment, and processes must meet the requirements listed in Table 4.

C. Building Level Water Metering

As a precondition for receiving water efficiency points, LEED has introduced a building level water metering standard (Harbour, 2016). According to the US Green Building Council (2019), permanent water meter installation will calculate the maximum use of the building's potable water and associated grounds. Monthly or annual meter readings must be collected manually or automatically. It is also noted that this commitment will continue for a period of five years or until the building changes ownership or the lessor.

Table 4: Standards for appliances

Appliance	Type	Requirement (SI units)
Dishwasher	Under counter	≤ 6.0 liters/rack
	Stationary, single tank, door	≤ 5.3 liters/rack
	Single tank, conveyor	≤ 3.8 liters/rack
	Multiple tank, conveyor	≤ 3.4liters/rack
	Flight machine	≤ 680 liters/hour
Food steamer	Batch	≤ 23 liters/hour/pan
	Cook-to-order	≤ 38 liters/hour/pan
Combination oven	Countertop or stand	≤ 13 liters/hour/pan
	Roll-in	≤ 13 liters/hour/pan

(Source: US Green Building Council, 2019)

2.2.2 Additional Requisites

Once the facility has fulfilled all the preconditions, there are four places where additional LEED credit points can be received by the facility.

A. Outdoor Water Usage

Eliminating the need for an outdoor irrigation system fully or increasing the need for landscape water by at least 50 % will receive up to 2 points (SLOANE Global Holdings, 2016).

The 50 % reduction of water can be accomplished from the approximate base point for the site's peak irrigation month by selecting plant species and active irrigation systems (US Green Building Council, 2019). In addition, the article highlighted that any combination of capacity, alternative water sources and intelligent scheduling technologies could achieve additional reductions above 30%.

B. Indoor Water Usage

A building can gain up to six points for LEED certification by using high-efficiency components and alternative water resources to go beyond the precondition (Southerland, 2015). In addition, the author clarified that water recycling supports the pilot credit for sustainable wastewater management, which aims to reduce waste water use by 50% from a baseline. As stated in US Green Building Council (2019), required water reduction percentages and its credit allocation are given in Table 5.

C. Cooling Tower Water Use

The main aim is to maintain the water requirement of the cooling tower while regulating bacteria, oxidation and scale in the condenser water system (US Green Building Council, 2019). Evaporative condensers that are more energy efficient than traditional condensing systems due to evaporative systems can reduce air temperature more quickly and do not lose air humidity (Western Cooling Efficiency Center of the University of California Davis, 2011). Completing this sort of evaporative condenser would allow up to two points for a project (Southerland, 2015). For cooling towers and evaporative condensers, one-time potable water study can be undertaken to optimise cooling tower cycles. The points are allocated according to the number of cooling tower cycles and Table 6 describes that credit allocation.

Table 5: Points for reducing water use

Percentage reduction	Points (CI Hospitality Industry)
25%	2
30%	4
35%	6
40%	8
45%	10
50%	11

(Source: US Green Building Council, 2019)

Table 6: Points for cooling tower cycles

Cooling tower cycles	Points
Maximum number of cycles reached without reaching any rate of filtration or affecting condenser water system operation (up to maximum of 10 cycles)	1
Achieve a minimum of 10 cycles by increasing the level of treatment in condenser or make-up water or achieve the number of cycles for 1 point and use a minimum 20% recycled non potable water	2

(Source: US Green Building Council, 2019)

D. Water Metering

Water metering is a new LEED version 4 credit that mainly focuses on water sub metering in the building (Western Cooling Efficiency Center of the University of California Davis, 2011). As stated in US Green Building Council (2019), two or more sub-systems such as irrigation, indoor plumbing and fittings, hot water, boilers, waste water or other process water should be installed in the sub-metering system.

3. METHODOLOGY

In order to fulfil the research gap, firstly it is needed to identify the LEED requirements needed to achieve under the LEED water efficiency category. A comprehensive review of literature was carried out to explore water efficiency requirements under the LEED certification by referring journals, web sites, books, dissertations, conference papers and other publications.

Qualitative research approach was selected since the research problem is exploring how LEED requirements are applicable for Sri Lankan hotel industry. Semi-structured interviews were used as data collection method to identify the applicability of the identified LEED requirements to achieve water efficiency in Sri Lankan hotels with reference to a case study strategy. Two case studies were done in two LEED certified hotels located in Kandalama and Beruwala. and through the 6 number of respondents, it was identified that how they use LEED requirements to their hotels in order to achieve the water efficiency.

Based on the data and findings collected, a comprehensive analysis was conducted by using thematic analysis method to identify the applicability of LEED requirements to achieve water efficiency in Sri Lankan hotel industry. According to Clarke and Braun (2013), the thematic form of analysis is a dynamic data analysis strategy that can be used to evaluate case studies, phenomenology and general qualitative and narrative investigations. Finally, the results of the study were used to achieve the final objective of the research, which was establishing the benefits of LEED certification system in terms of water consumption for the hotel industry.

4. RESEARCH FINDINGS AND ANALYSIS

4.1 WATER EFFICIENCY SYSTEM IN SRI LANKAN HOTEL INDUSTRY

This Section describes the water efficiency practices, which were used by the LEED certified hotels in Sri Lanka. As per empirical data gathered and analysis, discussion can be carried out by comparing the practices used by Sri Lankan hotels and the requirements which has mentioned under the water efficiency category in LEED. Table 7 summarised the existing water efficiency practices used in selected LEED certified hotels in Sri Lanka.

Table 7: Existing water efficiency practices used in LEED certified hotels in Sri Lanka

Existing Water Efficiency Practices	Hotel 1	Hotel 2
Use alternative water resources	x	x
Awareness Programme	x	x
Water aerators	x	
Sensor taps	x	
Dual flushing system	x	
Sewerage water treatment plant		x
Sub-metering	x	x
Sprinkler system for irrigation	x	
Sustainability team	x	
Rainwater harvesting system	x	
Use dishwashing machine	x	x
Use native plants	x	
Training programmes	x	
Water management plan	x	
Foreign visits	x	
BMS for monitoring	x	
Air cool chillers	x	x
7R principal	x	
Water management policies	x	
Knowledge sharing sessions	x	x
New management		x
Set targets		x
Innovative technologies	x	

Existing Water Efficiency Practices	Hotel 1	Hotel 2
Induction programmes	x	
Reuse of condensed steam water	x	x
Use atomizer for boilers to reduce the hardness of the water	x	

As per Table 7, it was summarised the water efficiency practices used in selected LEED certified hotels in Sri Lanka and it can be divided to two aspects such as water efficient fixtures and equipment and water efficiency mechanisms and technologies. Accordingly, it can be summarised as shown in Figure 1.

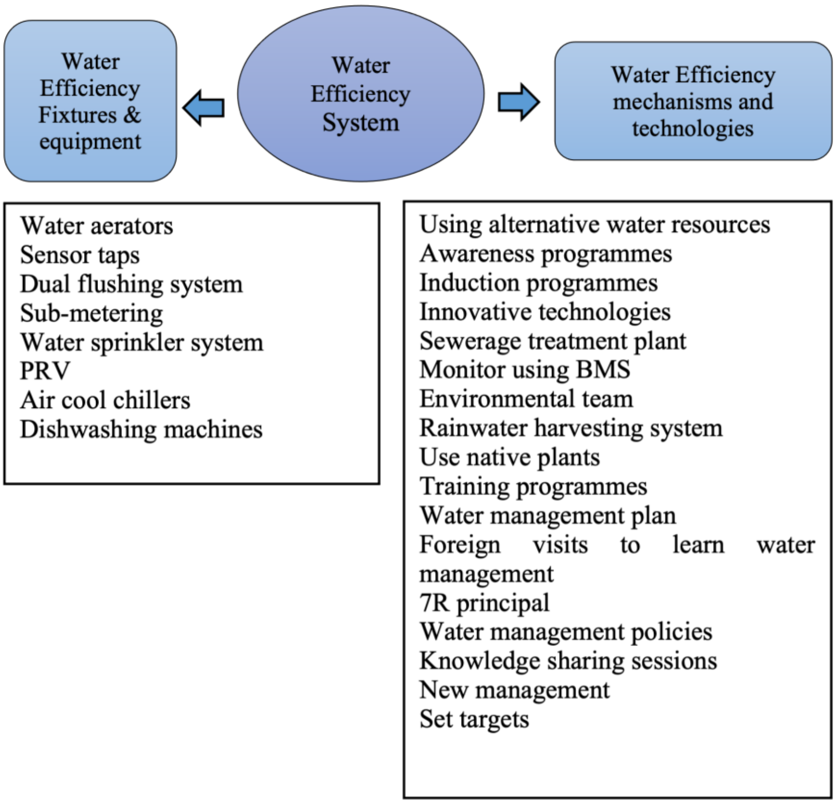

Figure 1: Water efficiency practices

As per the above analysis, most of the LEED hotels has focussed to reduce outdoor water usage, indoor water usage through the water efficiency mechanisms and technologies. Furthermore, they have tended to use innovative water management technologies such as 7R principal, water management policies, knowledge sharing session organizing with other hoteliers, water management plan, water saving method training, native plants used to reduce outdoor water consumption and they have used air cool chillers instead of using water cool chillers.

Table 8 shows the water efficiency practices used in Sri Lankan hotels as per the categories under the LEED certification. The empirical findings demonstrated that Sri Lankan LEED certified hotels are also following the water efficiency mechanisms similar to other countries. Sri Lankan hoteliers also use outdoor water reduction methods, indoor water reduction methods, cooling tower water reduction methods and water metering with new innovative technologies. Furthermore, they have use alternative water resources like tube well water, treated wastewater and harvested rain water in order to fulfil the water requirement. In addition to that, they have used native plants which is suited for the Sri Lankan environment, since those plants do not require watering.

Table 8: Water efficiency practices

LEED Requirement	Water Efficiency Practices
Outdoor Water Use Reduction	Use native plants
	Reduced the artificial irrigation systems
	100% rainwater and treated waste water used for irrigation
	Use water sprinklers to spray water
	Use low water consuming plants
Indoor Water Use Reduction	Sensor taps
	Dual flushing systems
	Aerators
	PRV
	Dishwashing machines
	Low flow shower heads
Cooling Tower Water Usage Reduction	Use air cool chillers instead of using water cool chillers
Water Metering	Sub-metering the all the Section
	Install BMS to monitor the system

When it comes to indoor water use reduction, Sri Lankan LEED hotels have used sensor taps, dual flushing system, water aerators, pressure reducing valves, dishwashing machines and low flow shower heads as water efficient fixtures.

In order to reduce the cooling tower water usage, they have used air cool chillers instead of using water cool chillers. Further, they have always encouraged their staff and guests to use natural ventilation methods instead of using air conditioners. They have arranged several knowledge sharing sessions, leaflets, meetings for their guests and staff.

Moreover, all LEED certified hoteliers have installed sub meters and BMS to identify the water consumption and water wastages. By installing BMS to the water distribution system, they can check water consumption, daily water usage any time and they can get clear idea about water usage pattern and it helps to identify any wastages easily.

5. DISCUSSION

LEED certification was developed by the US, but using worldwide and the requirements under the LEED are environmentally compatible even in the Sri Lankan context (Rodrigo and Jayarathna, 2012). It also emphasised that Sri Lanka has knowledge skills and equipment to fulfil LEED certification credit requirements. As stated by Jayasinghe and De Silva (2011), most of the credit under LEED certification can be achieved without incurring significant initial incremental costs. Green Building Information Gateway (2019) stated that 51 buildings are achieved the LEED certification and there are only 2 hotels and 5 resorts in Sri Lanka.

As per the literature review, there are four requirements such as outdoor water usage reduction, indoor water usage reduction, cooling tower water usage reduction and water metering needed to be fulfilled by under the water efficiency category. According to the data analysis which was done by using the collected information in Sri Lankan LEED certified hotels, it proved that they have also following the water efficiency practices as per the LEED requirements.

ITC Grand Chola Hotel in Chennai is a LEED platinum rated hotel and it is the world's largest LEED Platinum rated Green Hotel (Tuppen, 2012). As stated in the article, the hotel is adapting several water conservation methods such as water harvesting structures using to collect storm water, using water efficient fixtures, fittings and appliances, it can be reduced water usage by 35% compared with conventional usage, choose plants that consume low water, while trees plant to reduce the loss of evaporation and thus reduce water consumption, use drip irrigation and timer-based controls to operate the irrigation valves and prevent wastage of water, the water from the last wash is used in the laundry to pre-wash the second cycle and the use of environmentally friendly low acidic washing fluids helps to reduce running time and saves water. The Hyatt hotel, which has become the first LEED-certified hotel in Seattle by receiving the LEED Silver certification, achieved a 32% reduction in water use by installing low-flow showerheads, washstands and water closets, along with dual-flow toilets and other water-saving innovations (Chikushi, 2009).

According to the case study results, all Sri Lankan LEED-certified hotels have same practices with regard to water efficiency practices in other countries. The majority of respondents in both LEED and non-LEED certified hotels highlighted the importance of water efficiency to reduce water consumption costs, align with company environmental policies, long term conservation, avoid unbalanced water distribution throughout the year and is used as a marketing tool, increase consumer satisfaction and maintain certifications. As per the case study findings, LEED-certified hotels and non-LEED-certified hotels have similar water saving practices, while there are several differences such as; no air-cooled chillers, appropriate meters, BMS systems to monitor water usage, and local plants to reduce outdoor water use, training programs to understand employees, water management plans, 7R principles, water management policies, knowledge sharing sessions. According to the above findings the framework given in Figure 2 has been developed to show how LEED requirements are suited for Sri Lankan hotel industry.

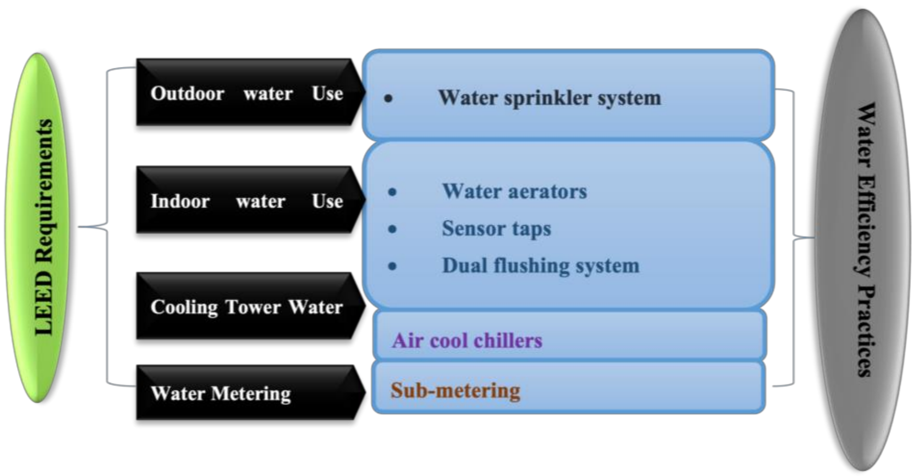

Figure 2: Framework

As per the framework, which is shown in Figure 2, black colour boxes show the water efficiency requirements under the LEED certification and blue colour boxes shows the water efficiency practices used by Sri Lankan LEED certified hotels as per the LEED requirement. This framework is useful to hotel industry people and students, who are following research regarding the water efficiency practices.

6. CONCLUSIONS

As outlined in introduction section, this review investigated the applicability of LEED certification requirements under water efficiency category in terms of achieving water efficiency in the hotel industry in Sri Lanka. At the very first, it was the identified the water efficiency requirements under the LEED certification system, which was achieved through a literature review of the study. According to the literature findings, in order to achieve the water efficiency hoteliers, need to reduce outdoor water consumption, indoor water consumption, cooling tower water consumption and sub metering with innovative water efficient technologies. Secondly, it was focused to identify the water efficiency practices used by Sri Lankan hotels through semi-structured interviews carried out during the case study exploratory process. According to that, they have used water efficiency practices as per the LEED requirements. Through these findings research aim was achieved and finally, it can be deduced that water efficiency practices under the LEDD certification are suitable to Sri Lankan hoteliers and they can easily achieve water efficiency by following LEED certification. In the case study and literature review, the final goal of identifying the applicability of LEED water efficiency practices in Sri Lankan hotel industry is achieved through the data analysis. The results of this research will be provided benefits to hotel industry professionals to identify and improve the water efficiency in Sri Lankan hotel industry.

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APPLICABILITY OF POLYMER BUILDING MATERIALS FOR PRODUCTIVITY ENHANCEMENT AND COST REDUCTION IN SRI LANKAN BUILDING INDUSTRY

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ABSTRACT

Building construction contributes to a substantial consumption of raw materials compared to other sectors in Sri Lanka. Despite the excessive consumption of raw materials, industry is suffering due to low productivity and economic inefficiency. Thus, the circumstance has led to employ alternative building materials to overcome productivity and cost inefficiency with favourable impacts on sustainability. Polymer has become a global phenomenon with increasing demand as sustainable alternative. Polymer facilitates multiple applications in building construction due to its supreme properties and characteristics. Thus, this research focused develop a quantitative model based on factors related to productivity enhancement and cost reduction to measure the applicability of polymer materials in Sri Lankan building construction. A mixed approach consisting of semi structured interviews followed by a questionnaire survey was adapted for conduct this study. 12 experts were selected for the semi structured interviews and 34 respondents participated for the questionnaire survey. The significance of favourable impact to the productivity and cost efficiency of using polymer materials have been identified in the study. The study discussed the applicability of polymer types in building sector in Sri Lanka and derived resulted in a quantitative model to measure applicability of polymer adoption in the terms of productivity and cost related factors. Study concluded that inherent properties of polymers, buildability, ability to prefabricate, life cycle cost, handling would improve the applicability to local context. Further, relationship identified through the regression model would assist practitioners to select polymer materials while enabling researchers to improve the quality of the products.

Keywords: *Alternative construction material; Cost reduction; Polymer; Productivity.*

1. INTRODUCTION

The rapid increase of the population and complex needs of the people have complicated the nature of building constructions (Guribie and Tengan, 2019). As the industry faces multiple issues related to its outcome and the process, the productivity of the construction industry and cost reduction are receiving an increasing attention (Enshassi *et al.*, 2013). Meanwhile, most traditional construction materials have caused significant amount of

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environmental issues, health and safety issues, cost inefficiencies and productivity issues (Occupational and Environmental Health Department, 1999). On the contrary, the construction industry is considered to be one of the key industries with a significant influence over the economy (Bekdik, 2017). Therefore, there is no doubt that increasing the productivity of the construction industry and the materials being used will play a positive role in the overall economy.

In light of the above, Shinde and Hedaoo (2017) suggested that innovative practises would be ideal for improvement of construction productivity. The authors further claimed that introduction of polymer technology to the construction industry could reduce energy and raw material wastage while enhancing the quality of materials. Despite being limited to non-loadbearing applications such as mechanical, electrical and plumbing related systems during the initial stages of adoption (Masuelli, 2013; Headley, 2014), polymers are now being used in primary load bearing elements as well (Hughes *et al*., 2018). Halliwell (2010) claimed that reasons behind the rapid increase of use of polymer related materials can be the considerations the cost, quality and time related aspects.

Even though, most countries have extended their construction sector to incorporate polymer materials (Halliwell, 2010; Zhou *et al*., 2018), Sri Lankan construction industry has failed to move beyond the primary applications of polymers (Gunawardena *et al*., 2016). Further, most of the materials that can be used to produce polymer are being disposed as wastes causing environmental issues (Udagama and Kulatunge, 2014; Stone, 2019). Thus, it is very crucial to carry out an assessment of the applicability of polymer related materials in Sri Lankan building construction industry.

Therefore, this research attempts to analyse the applicability of polymer materials as alternatives for building construction in Sri Lanka. Initially the existing literature was critically reviewed to examine the polymer types and their characteristics that suitable for building construction in productivity and cost reduction perspective. Thereafter, interviews were conducted among experts to identify the motivators and challenges to use polymer building materials in building construction in Sri Lanka. Subsequently, a questionnaire survey was conducted based on gathered data develop a quantitative model based on factors related to productivity enhancement and cost reduction to measure the applicability of polymer materials in Sri Lankan building construction.

2. LITERATURE REVIEW

2.1 ALTERNATIVE MATERIALS FOR BUILDING CONSTRUCTIONS

The construction industry utilizes wider range of materials compared to others, mainly for the purposes of structural material, finishes, and services related materials (Ahmed and Sturges, 2015). Gama (2012) observed that global construction activities consume 40% of global energy and 30% of raw materials while being responsible for about 35% of carbon dioxide and 28% of landfill materials as construction waste. Hence, the dependency on traditional materials for construction, may not only be harmful for the environment but also for the economy as well (Sinha and Harison, 1995). Therefore, according to Gama (2012) the United Nations Commission has been promoting the importance of alternative building materials for human settlements since the early 1990s. On the other hand, polymer related alternatives provide the best solutions for addressing inefficiency, environmental issues, technological barriers, and cost effectiveness of the products (Correia, 2015).

2.2 POLYMER BUILDING MATERIALS AS AN ALTERNATIVE

A polymer is a material usually composed of a hydrocarbon compound and has a wide range of applications and uses (Ruuska and Häkkinen, 2014). Polymer is basically produced by processing Carbon (C) with Hydrogen (H), Oxygen (O), Nitrogen (N) and other organic or inorganic elements (Calhoun and Peacock, 2006).

A composite material is a material made of two or more constituent materials having significantly different physical or chemical properties, when combined, produces a material having properties different from those of the respective components (Fazeli *et al*., 2019). These polymer types have very different properties from each other and are therefore used in completely different applications. Polymers are materials with increasing consumption as engineering materials ranging from non-loadbearing applications to primary load bearing functions in the last several years (Koca, 2016; Hughes *et al.*, 2018).

2.3 CHARACTERISTICS OF MATERIALS AFFECTING PRODUCTIVITY

Despite being a prominent industry in most countries, the construction industry has suffered from decades of long unproductivity (Bekdik, 2017). According to the Organisation for Economic Co-operation and Development's (OECD) definition, 'productivity' is defined as a ratio between the output volume and the volume of inputs (OECD, 2019). Similarly, the U.S. Bureau of Labour Statistics defines productivity as a measure of economic performance that indicates how efficiently inputs are converted into outputs (Bekdik, 2017). Despite, the definitions and measures of productivity, it is a concept that is difficult to measure and is often defined by reference to the basic resources used and expressed as output from labour, machinery, or capital invested (Cheetham and Lewis, 2001).

Labour productivity is affected by several factors, but buildability is among the most important (Jarkas, 2010). Buildability is defined as the extent to which the design of a building facilitates ease of construction (Cheetham and Lewis, 2001). Furthermore, Poh and Chen (as cited in Jarkas, 2010), emphasized in an empirical study of 37 completed buildings concluded that designs with a high buildable score will result in more efficient usage of labour. So that it is understood that buildability has a high impact on productivity. The other factor which affects the productivity is the level of prefabrication (Jarkas, 2010). Prefabrication facilitates the effective use of inputs in the process of making outputs and results in less wastage, time consumption and better performance (Cheetham and Lewis, 2001). Therefore, it can be concluded that adopting materials which facilitates prefabrication in the construction tend to show higher productivity. The other considered factor for productivity is easiness of handling (Jarkas, 2010). If some materials are fragile or else hard to carry in operation so the labours take more time to perform a particular task (Bekdik, 2017). According to the facts described, it can be concluded that Buildability, Ability to Prefabricate, Handling easiness of materials contribute to the level of productivity in the construction projects.

2.4 CHARACTERISTICS OF MATERIALS AFFECTING COST REDUCTION

Construction costs form part of the overall costs incurred during the development of a built asset such as a building (Kovacic and Zoller, 2015). Very broadly, construction costs are those costs incurred by the actual construction works themselves, and on some projects may be determined by the value of the contract with the contractor/builder. However, the construction contract may include costs that might not in themselves be considered literal construction costs (hard costs), such as fees, profits, overheads, and so on. There are some indirect factors which affect cost effectiveness (Cheetham and Lewis, 2001). According to Jarkas (2010), buildability factor also affect the construction cost. Author further described that with improved buildability not only excessive material wastage can be minimised but also labour hours can be effectively utilised. However, Heralova (2017) argued that considering only the construction cost in order to obtain sustainable design with economic optimization in the early design stages, is not enough. Further author described that in order to gain the maximum value for money, all costs incurred over the whole life span must be estimated. Furthermore, the types of material specified, the quality of the design and the contracting method have to be chosen directly upon operation and maintenance costs (Boussabaine and Kirkham, 2004). Thus, in material selection maintenance cost should be considered rather than the initial cost. Hence, Akgul and Giritli, (2015) and Koca (2016) suggested polymers as an alternative to many applications due to the durability and less maintenance cost.

According to the above findings the identified factors can be integrated to measure productivity enhancement and cost reduction in building construction. The factors are listed out with their impacts in Table 1.

Table 1: Factors to measure productivity enhancement and cost reduction

Factor	Impact
Buildability	Productivity/cost reduction
Ability to prefabricate	Productivity
Reduction in LCC	Cost reduction
Handling easiness	Productivity/cost reduction

2.5 THE IMPORTANCE OF STUDYING THE USE OF ALTERNATIVE MARTIALS IN BUILDING CONSTRUCTION

The inefficiency and negative environmental impact of construction activities had led United Nations Commission to promote the importance of alternative building materials and it has further increased with concepts of sustainability (Gama, 2012; Heralova, 2017). Further, Shinde and Hedaoo (2017) and Zhou *et al*., (2018) believe that capability of polymers to produce strength-to-weight ratios, uplifted lifestyles and high-quality building features material would enable higher productivity by eliminating major challenges and barriers in construction while providing cost effective solutions.

With regard to the Sri Lankan context, Gunawardena *et al*. (2016) highlighted the potential of using innovative materials to produce better-performing buildings in Sri Lanka using non-traditional building systems (Gunawardena *et al*., 2016). Similarly, Udagama and Kulatunge (2014) criticized limited usage of polymer materials and the reluctance to create more quality and sustainable material in larger scale while having most of the recyclable materials disposed to landfills by the other industries. According to Gunawardena *et al.* (2016), in order to construct better performing buildings, the construction methods should be changed to innovative processes with alternative enhanced quality materials and equipment rather than conventional building systems. Even though, there are many global researches being carried on the adoption of polymers for construction there is a significant deficit with regard to the local context. Thus, it is very crucial to carry out an assessment of the applicability of polymer related materials in Sri Lankan building construction industry.

3. METHODOLOGY

The research concerns about the applicability of polymer material and its influence on productivity and cost reduction in Sri Lankan construction industry. Hence, in order to explore motivators and challenges with regard to the Sri Lankan context the qualitative research approach was initially selected as it allows to evaluated opinions regarding a certain phenomenon as explained by Gray (2004). However, the influence of polymer material on the productivity and cost reduction could not be explored due to the limited number of professional competent with both building construction and polymer materials. According to Cherry (2000), in such instances, qualitative approach would derive more subjective towards their respective field. Additionally, variables related to applicability based on productivity and cost reduction cannot be feasibly studied under a case study for this research as the dependent and independent variables cannot be organised as anticipated. Therefore, quantitative approach was selected to identify the influence on productivity and cost reduction as it allows to observe relationships between factors or scenarios as per Cherry (2000). Hence, the overall research approach was the mixed approach which is blend of quantitative and qualitative approach that is used simultaneously in the same study but in different stages.

3.1 EXPERT INTERVIEWS

Semi-structured interviews help collect data to understand and explore new ways of seeing a research topic (Cohen and Crabtree 2006). The interviewees, selected using purposive sampling to enable data saturation at the correct level, were all professionals. In selecting the interviewees, their availability for the interviews, willingness to take part in face-to-face interviews, and the ability to communicate (Etikan *et al*., 2016) were considered. Table 2 presents the details of the respondents.

Table 2: Summary of respondents for expert interviews

Categories	Government Sector	Private Sector
Architects	2	2
Engineers	2	2
Quantity Surveyors	2	2

In addition to verifying the validity of the literature review findings, the interviewees indicated factors specific to government and private organizations. The collected data were manually analysed using directed content analysis because it reduces the volume of the data to be handled and facilitates the categorisation of the data by improving their contextual meaning as explained by Bengtsson (2016).

3.2 QUESTIONNAIRE SURVEY

A questionnaire survey was subsequently used to identify the of relationship applicability of polymer material based on productivity and cost reduction. According to Cherry (2000), quantitative data collected through questionnaire survey can be interpreted using statistical test for greater populations by considering a sample. Therefore, it allows to explore the relationship between the identified variables in a larger scale. However. When selecting participants for this study purposive sampling was used to select participants based on their knowledge, professional affiliations, working experience. From the 45 prospective participants, 40 (88.89%) responded, however 6 were incomplete. Therefore, 34 (75.56%) completed questionnaires were considered for the analysis. Table 3 presents the details of the respondents.

Table 3: Details of questionnaire survey respondents.

Variable	Categories	Frequency	Percentage
Sector	Private	23	67.65%
	Government	11	32.35%
Area of Expertise	Quantity Surveying	12	35.29%
	Engineering	13	38.24%
	Architecture	9	26.47%
Work Experience	0 -5 years	15	44.12%
	5 - 10 years	13	38.24%
	More than 10 years	6	17.65%

Gathered data from questionnaire have been analysed in Statistical Package of Social Sciences statistical package (SPSS). Linear regression modelling has been used to identify the of relationship applicability of polymer material based on productivity and cost reduction. Furthermore, T- Test was carried out to evaluate the significance of issues for the implementation of polymer.

4. DATA ANALYSIS

4.1 APPLICABILITY OF POLYMER MATERIAL TO PRODUCTIVITY ENHANCEMENT AND COST REDUCTION

To observe the influence on productivity enhancement and cost reduction, four vital factors were identified from the literature to be inquired through the interviews. Number of respondents who expressed positive responses are given in Table 4.

Table 4: Response for factors affecting productivity and cost reduction from interviews

Factors affecting productivity and cost	Government sector			Private Sector		
	Prior Knowledge	Prior Experience	Potential	Prior Knowledge	Prior Experience	Potential
Buildability	6	2	6	6	5	6
Ability to prefabricate	6	3	6	6	5	6
Handling	6	3	6	6	4	6
Reduction of LCC	6	1	6	6	4	6

Majority of the professionals from the private sector had used polymer material in their projects. Government professionals had limited exposure due government policies on use of alternative material. Respondents highlighted 'Buildability', 'Ability to prefabricate' and 'Handling' as prominent features of polymer composites which had led them to select such material over traditional material. The private sector respondents stated that both improvement of productivity and cost reductions had been observed with the use of polymer composites. The government sector respondents on the other hand, had observed prominent cost reduction over productivity increments given the limited applications of these materials. However, respondents unanimously agreed on the significant influence over cost reduction and productivity improvement compared to the traditional materials.

Figure 1 depicts the opinion on applicability of polymer application of the government and private sector professionals in different areas of expertise.

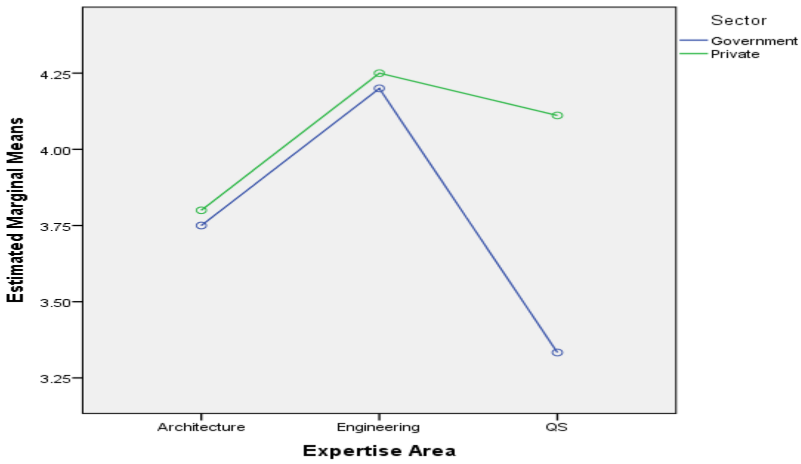

Figure 1: Means of opinion on applicability of polymer material

The government and private sector professional's opinion on applicability of polymer materials are further detailed in Table 5 can be assessed through the identified means of applicability.

Table 5: Summary of Two-way Anova test for applicability

Expertise Area		Mean	N	95% Confidence Interval	
				Lower Bound	Upper Bound
Architecture	Government	3.750	4	3.096	4.404
	Private	3.800	5	3.215	4.385
Engineering	Government	4.200	5	3.615	4.785
	Private	4.250	8	3.788	4.712
QS	Government	3.333	3	2.579	4.088
	Private	4.111	9	3.675	4.547

According to Figure 1 and Table 5, in all three areas of expertise private sector professional's level of applicability is higher as well as other two variables analysed previously. As discussed in previously, the sample size of government sector is not affected as it is the smallest size of sample. Since the private sector professionals have more awareness and usage, they have identified its applicability in Sri Lankan context rather than government sector. But compared to other two variables, this variable has slightly increased means. In the engineering professionals there is slight difference between two means. By considering the areas of expertise, QS professionals in government sector have the least mean, but vary from other two variables as QS professionals in private sector tend to show higher mean than architecture professionals in private sector. Thus, it is obvious that QS professionals' opinion on applicability is more significant than architecture professionals. Reasoning for this obtained results could be described as follows.

Applicability on polymer building materials based on factors that are directly affecting QS aspects. Buildability enhancement and therefore increase in productivity resulting reducing labour cost. Hence it is sufficiently affecting the QS aspects of cost, time. As cost mangers, they would like to manage their cost plans from cost overruns. But as architecture related professionals, they do not mainly concern on cost and technical aspect but the aesthetic view and value of designs. As the applications of polymer materials are not directly addressing architectural aspects, the means could lie on lower level according to their opinion. But with adopting different types of polymer related applications, this matter could be addressed.

4.2 LINEAR REGRESSION MODEL

To determine the relationship through regression modelling, a simple equation was formulated by using data collected from 34 professionals in the building sector. In this section, a relationship of factors affecting applicability were considered. The linear regression model was established with the aid of SPSS software tools and the sample of 34 professionals who responded were considered as input to the model. Figure 2 displays R and R Square values.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.836[a]	.821	.853	.14452

a. Predictors: (Constant), Mean HE, Mean Buildability, Mean LCC, Mean Prefabrication

Figure 2: Model summary of linear regression

According to the model summary, R value equals to 0.836, which means the relationship between these independent variables of factors and the dependent variable of applicability of polymer materials, has a positive and significant value. Significance of this value can be interpreted in accordance with correlation coefficient analysis. Hence, it is obvious that the strong positive relationship with these considered independent variables towards the dependent variable. Furthermore, R squared value of 0.821 can be interpreted as that 82.1% of the subjected dependent variable was derived from the considered four independent variables.

Figure 3 displays the coefficients of all the four variables and constant which derive the equation between independent and dependent variables. When considering the integrity and the accuracy of the formula, the significance (p-value) factor can be considered. It illustrates the influence of null hypothesis when the coefficient is zero. A low significance or p- value (<0.05) indicates that the null hypothesis can be neglected as the low impact.

As per the results, the constant has zero significance that explains a higher reliability of the value to the sample. All the variables consist of significances within the allowable level (< 0.05). In here, buildability factor has the highest positive relationship with applicability as denoted by the low p-value.

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
1 (Constant)	-2.244	.297		-11.785	.000
Mean Prefabricability	.267	.073	-.197	-1.714	.011
Mean Buildability	.399	.004	-.285	-1.315	.009
Mean LCC	.185	.027	-.217	-1.931	.001
Mean HE	.161	.063	-.584	-1.170	.004

a. Dependent Variable: Applicability of Polymer

Figure 3: Coefficients of dependent variables for applicability

The computed formula on applicability of polymer material can be elaborated as follows.

$$App = 0.267(F1) + 0.399(F2) + 0.185\ (F3) + 0.161(F4) - 2.244 \qquad (01)$$

Where, App = Applicability, F1 = Ability to prefabricate, F2 = Buildability, F3 = Life Cycle Cost and F4 = Handling

All above factors share positive relationships with the apllicability of polymers to the construction industry of Sri Lanka. Eventhough a small sample was selected due to limited number of professionals competent in both polymer technology and building sector in Sri Lanka, model has obtained significant figures that determines the huge impact of considered variables. Hence literature findings of these four factors which affect to applicability are significantly validated through this model.

5. DISCUSSION

Overall findings of this research suggest that, factors affecting productivity and cost reduction of material which were identified from the literature review are apllicable for polymer materials in Sri Lankan context as well. Buildability of polymers obtained the highest coefficient denoting highest influence on apllicability. The findings revealed that ability of molymer materials to be moulded into various shapes and sized with their mechanical properties helps to enhance the buildability acknowleding the findings of Koca (2016). Polymers may help to increase buildability by providing various sizes and shapes which can reach the intended places. Similarly, polymer's degree of prefabrication was also revealed to have a significant influence on improving productivity. is comparatively higher than other materials. Polymers with different shapes and sizes may encourage and improve off site fabrications which may lead to reduce construction waste similar to findings of Shinde and Hedaoo (2017). Moreover, admixture, curing agents can be also considered as examples where polymers enhancing the productivity while determining the utmost performance of the structure. Handling of polymer alternatives was identified with the least influence for the applicability of polymer material to the Sri

Lankan context. Most of the polymer applications are light weight but provide higher tensile strength therefore significantly contribute to the similar to the findings of Bekdik (2017). Not only the permanent works, but also the temporary works related to the building construction also affect the productivity. Thus, rather than using conventional formworks such as timber, glass reinforced plastic can be used.

Low lifecycle costs were also found to be a significant factor for the apllicability of ploymer materials to the Sri Lankan context. Therefore, as identified by Koca (2016) low cost and durablity of material have a signifannt influence on LLC, thereby, polymers are materials in general compared to other conventional materials. Most of the polymers are less expensive than other alternatives and less weight, easy handling in operations thus less cost in transporting handling cost. As most of the polymer types have wide range of production forms wastage is minimised.

The regression model identified the potential of Buildability and Ability to prefabricate to improve productivity and cost efficiency. Prefabrication and buildability of polymer composites facilitates the effective use of inputs in the process of making outputs and results in less wastage, time consumption and better performance as identified by Cheetham and Lewis (2001). Furthermore, the fidnings confirmed that the more easiness of handling the materials results in a higher productivity similar to the findings of Jarkas (2010). As per the findings from both interviews and questionnaire surveys, the durability and less maintenance cost, make polymers ideal for many applications as highlighted by Akgul and Giritli (2015). Regression analysis revealed that, all above factors share positive relationships with the apllicability of polymers to the construction industry of Sri Lanka.

6. CONCLUSIONS AND RECOMMENDATIONS

The study primarily focused on developing a quantitative model based on factors related to productivity enhancement and cost reduction to measure the applicability of polymer materials in Sri Lankan building construction. The collected data through 34 respondents who work in building industry as different areas of expertise have been used to build a regression model as quantitative measure of applicability of polymer materials in Sri Lankan building sector. The model has been supported by many other different statistical tools to check the reliability and the consistency of the ultimate outcome. Scale reliability test was carried out to check the internal consistency of the data set obtained from 34 professionals. Variable computation was carried out to measure statistical measures of central tendency and dispersion. The obtained significance values were within the allowable level. The level of integrity was clearly visualised with very low standard errors of all factors resulted in the model. Further, model was elaborated as an equation to measure the applicability of polymer materials in Sri Lankan building construction. As observed throughout the study, polymers are highly useful in achieving productivity and cost concerns. Thus, recommendations can be extended to adopt polymer materials in designing and developing specifications to achieve less wastage, high durability, and less time consumption in the process. Further, relationship identified through the regression model would assist practitioners to select polymer materials while enabling researchers to improve the quality of the products.

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ASSESSING THE CARBON EMISSION REDUCTION BY GRID-TIED PHOTOVOLTAIC (PV) TECHNOLOGY FOR BUILDINGS IN SRI LANKA

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ABSTRACT

Energy related carbon emission of buildings is a major cause of global warming. In order to mitigate energy related carbon emission, buildings tend to adopt renewable energy technologies. Amongst renewable energy technologies, grid-tied PV technology has gained the interest of building energy consumers as an alternative energy source. Nevertheless, there is considerably low implementation of grid-tied PV technology in Sri Lanka, especially as a carbon reduction strategy. A key reason for lack of implementation of grid-tied PV system is that majority of buildings still depend on traditional energy sources for their total energy needs. Hence, there is a need of highlighting the importance of grid-tied PV system to penetrate the existing traditional energy market. The aim of this study is therefore to assess the possible energy related carbon reduction of grid-tied PV system for buildings in Sri Lanka. Accordingly, total of four (4) buildings were selected as case studies, including two buildings with grid-tied PV technology and two other buildings that are totally dependent on traditional energy sources. Subsequently, carbon footprint assessment was conducted to four (4) buildings specifying to energy related carbon emitting activities. And research findings revealed that selected two buildings with grid-Tied PV technology achieve an average reduction of carbon by 3379.77kg and 3013.06kg respectively per month compared to traditional-energy buildings. Consequently, this work has successfully identified that buildings with grid-tied PV technology achieve a reduction in energy related carbon emission compared to buildings with traditional energy sources.

Keywords: *Buildings; Carbon footprint assessment; Carbon reduction; Grid-tied PV technology.*

1. INTRODUCTION

World energy consumption is rapidly growing with the economic and population growth (Pérez-Lombard *et al.,* 2008). Dincer (1999) stated that increasing traditional energy supply leads to environmental problems including air pollution, ozone depletion, radioactive emissions and forest degradation. Expressing similar view, Menyah *et al.* (2010) explained that traditional energy resources contribute to carbon dioxide emission, which continues to deteriorate the quality of environment. According to Khan *et al.*

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(2020), energy consumption is a key driver of global carbon emission. Global warming has elevated by the ever-increasing energy related carbon emissions and this has grabbed the attention of both practitioners and academics (Zhang and Cheng, 2009). Accordingly, adoption of renewable energy technologies to achieve zero greenhouse gas emissions has come to the surface (Sardianou and Genoudi, 2013). Dovì *et al.* (2009) stated that development and implementation of renewable energy technologies offer several benefits, such as carbon emission reduction, cost saving and waste reduction to the user.

Amongst renewable energy sources, solar energy technologies have clear environmental benefits compared to traditional energy sources, thereby leading to sustainable energy generation (Tsoutsos *et al.,* 2005). Consequently, energy users are influenced to adopt solar systems such as grid-tied PV technology to address shortfalls of conventional energy system (Boontome *et al.,* 2017). However, there is considerably low implementation of grid-tied PV technology in Sri Lanka, especially as a carbon reduction strategy. Hence, this study focuses on assessing the energy related carbon reduction potential of grid-tied PV system for buildings in Sri Lanka. Accordingly, the aim of this research was to assess the possible energy related carbon emission reduction of grid-tied PV system in buildings in Sri Lanka. The paper structure begins with an introduction to the study, followed by a literature review on energy consumption, carbon emissions in buildings and PV technology. The research methodology, data collection, and data analysis are presented next, and finally, the paper presents conclusions derived from research findings with recommendations.

2. LITERATURE REVIEW

2.1 ENERGY CONSUMPTION AND CARBON EMISSION OF BUILDINGS

Building sector plays a major role in economy, accounting for about 40% of global energy consumption and over 30% of CO_2 emissions (Yang *et al.,* 2014). Similarly, Omer (2007) explains in his studies that globally, buildings accounts for about 40% of the world's total energy usage and offcie buildings accounts for a large portion of that relative to other sectors. The growth in population, increasing demand for building services and comfort levels, together with the rise in time spent inside buildings will influence the continuous improvement of the energy in buildings (Pérez-Lombard *et al.,* 2008). Due to high energy consumption, building energy has become one of the major sources of carbon emission, which increase the environmental pollution by releasing large amount of carbon dioxide (González and García Navarro, 2006). According to Lu (2020), one-third from the total energy related carbon emissions emerge from the building sector. Further, authors suggest one way of reducing building energy related carbon emission is to adopt renewable energy sources as an alternative to conventional energy sources. Especially grid-tied PV technology has become one of the major renewable sources in energy industry since it reduces the emission of Green House Gas (GHG) and air pollution (Wang *et al.,* 2017).

2.2 GRID-TIED PV TECHNOLOGY FOR CARBON EMISSION REDUCTION

Madeti (2017) defines grid-tied PV technology as a system that contains electricity generating solar PV power system which is integrated to utility grid. Grid connected PV system ensures maximum use of energy from the utlity grid and solar power system itself (Karki *et al.,* 2012). Figure 1 depicts the function of a grid-tied PV system, from the harvesting of solar energy by solar modules to the transmission of that energy to the local utility grid. Componenets of grid-tied PV system consist of PV arrays connected to the utility grid by means of power conditioning unit (Vázquez and Vázquez, 2018). This is alos known as the inverter, which is the primary component of grid-tied PV system (Bhatia, 2014). Further to author, the power conditioning unit converts the DC power into AC power generated by photovoltaic system to the required voltage and power quality. Grid-tied PV technology varies from different sizes such as small scale system (mostly rooftop and building integrated PV, in kW) for residential purposes and large scale systems (in megawatt size) for solar power stations (Parida *et al.*, 2011). Grid-tied PV system offers range of benefits, especially positive environmental impact in terms of carbon emission (Gunerhan *et al.,* 2008). Even government supports are excuted to promote worldwide power generated from grid-tied PV system to reduce the rising environmental and energy problems (He *et al.,* 2012).

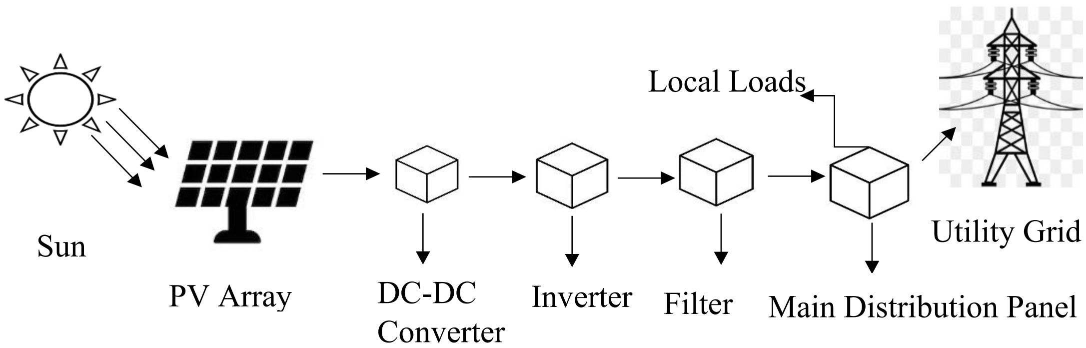

Figure 1: Grid-tied solar PV system (Source: Adaramola, 2014)

The driving force behind the use of clean and renewable energy is global energy demand and environmental concerns (Borges Neto *et al.,* 2010). Authors further revealed that solar power as one of the inexhaustible and CO_2 free sources of energy in the world. Solar energy could play a significant part in greening the energy portfolio of the nation (Sarzynski *et al.,* 2012). Solar photovoltaic power generation is generally considered as one of the most desirable renewable energy sources due to its immense capacity to reduce air pollution and energy usage (Hosenuzzaman *et al.,* 2015). Authors declared that there are zero release of CO_2, NO_x and SO_2 emission during PV system operation and it does not contribute to global warming. The PV industry's technological advances derive from attempts to lessen greenhouse gas emissions and abide by existing sustainable development principles (Bakhiyi *et al.,* 2014). Accordingly, authors explain that compared to fossil fuels, the PV industry is an ideal contributor to reducing greenhouse gas emission and to control carbon footprint of worldwide entities. Even, organisations are currently concern about their carbon footprint which motivate them to adopt renewable energy technologies to assess and reduce their carbon footprint (Lenzen *et al*., 2010).

2.3 ASSESSMENT OF ORGANISATIONAL CARBON FOOTPRINT

Carbon footprint is total emission from organisation, company, or a person expressed in terms of carbon dioxide and can be measured primarily for organisations, individuals, countries and products (Wiedmann and Minx, 2007). All types of organisations affect global carbon emission; therefore, calculation of organisation's carbon footprint is beneficial for managing the environmental impact (Robinson *et al.,* 2018). Especially, carbon footprint assessment enables organisations to assess their carbon impact after an implementation of carbon reduction strategies such as renewable energy technologies (Robinson *et al.,* 2018). Awanthi *et al.* 2018 explained that in addition to quantifying the organisation carbon emission, assessment of carbon footprint allows organisation to identify and target reduction from its emission sources.

ISO 14064 and GHG protocol are the two key internationally accessible standards that can be adopted by organisations for carbon footprint assessment (Gao *et al.,* 2013). According to ISO 16064, the key steps of calculating organisational carbon footprint can be identified as follows:

- Definition of organisation boundaries: Determines which proportion of the organisation is included in calculation of CFP (Carbon Footprint).
- Establishing operational boundaries: Establishment of operational boundaries recognize GHG emissions and removals regarding organisation's operations. In here GHG emissions and removals categorized into three scopes as direct emission, energy indirect emission and other indirect emissions.
- Calculation of CFP: Within established boundaries accurate consumption data should be collected.
- Reporting and verifying: It requires organisation to prepare report in order to facilitate inventory verification, participation in a GHG program, or to inform external or internal users.

According to ISO 14064, first step of organisational carbon footprint assessment is to define organisation boundaries followed by determining operational boundaries. When considering operational boundaries, ISO 14064 and GHG protocol divide GHG emission into three sources, such as scope 1, scope 2 and scope 3 (Ozawa-Meida *et al.,* 2013). According to the standards, three (3) defined scopes of carbon emission can be displayed in Table 1. This study only focuses on scope one and two covering the energy related carbon emission of buildings.

Table 1: Three scopes of carbon emission

Scope	Scope Definition
Scope 01	Direct GHG emission caused by sources that are owned or controlled by the company
Scope 02	Indirect carbon emission, that is GHG emission from generation of purchased electricity consumed by the organisation.
Scope 03	Other indirect emissions and it is an optional reporting category

(Source: Matthews *et al.,* 2008)

After determining the organisational and operational boundaries carbon footprint calculation is conducted. According to Intergovernmental Panel on Climate Change (2006), CFP can be calculated based on common simple methodological approach. ISO 14064 explains that the carbon footprint can be calculated by simply GHG activity data multiplied by GHG emission factors. Activity Data (AD) is the data collected related to the energy direct, indirect and other indirect activities. The emission factors published in different sources can be found and used as Emission Factor (EF) in carbon assessment (Intergovernmental Panel on Climate Change, 2006). Accordingly, in this research carbon footprint was calculated based on the above calculation method introduced under ISO 14064. This basic calculation method is further used in study conducted on Sri Lanka carbon footprint of an organisation: a case study, faculty of agriculture, university of Ruhuna (Awanthi and Navaratne, 2012). This equation is presented in the methodology section as Equation 01.

3. METHODOLOGY

This research uses the case study research strategy for achieving the research aim; to assess the possible energy related carbon reduction of grid-tied PV system in buildings in Sri Lanka. Multiple case study design was adopted. Accordingly, four (4) buildings were selected as case studies, including two buildings with grid-tied PV technology and two other buildings that are totally dependent on traditional energy sources. Two types of buildings have been chosen to make it easier to compare carbon emissions from buildings with grid-tied PV system and buildings with traditional energy sources. Criteria considered in case selection are presented in Table 2.

Table 2: Criteria considered in case selection

	Case A	**Case B**	**Case C**	**Case D**
Type of Building	Office Building	Office Building	Office Building	Office Building
Location	Colombo 02	Colombo 02	Colombo 03	Colombo 11
Number of floors	12	11	10	13
Height of floor (ft)	12ft	12ft	12ft	12ft
Floor area of the building (m^2)	7900m^2 per floor	7500m^2 per floor	5200m^2 per floor	8500m^2 per floor
Number of occupants	620	650	650	620
Source of power supply	Grid-tied PV technology, utility grid and standby power	Grid-tied PV technology, utility grid and standby power	Utility grid and standby power	Utility grid and standby power

Within the selected cases, document review and semi structured interviews were conducted to collect the data. Organisational CFP assessment guidelines, electricity bill documents, records of diesel consumption of generator and power generation record documents of solar panels were reviewed with respect to documents. Power consumption data was readily available for 2017/2018 period. Hence, 2017/2018 period was considered when reviewing documents such as electricity bill documents, records of diesel consumption of generator and power generation record documents of solar panels. Accordingly, in this study carbon footprint assessment base year was considered as 2017/2018. The interview guideline was used in conducting semi structured interviews, where two respondents from each case were selected according to their role performed (one managerial level respondent and one executive level respondent in each case). The collected data from case studies were analysed using carbon footprint assessment procedure based on ISO 14064. Hence, under carbon footprint assessment, Equation 01 was used to calculate the carbon footprint.

$$\textit{Carbon foot print (CFP)} = \textit{Activity Data (AD)} \times \textit{Emission Factor (EF)} \qquad (01)$$

Carbon footprint was measured in kilograms (kg). Identified Activity Data (AD) of this study are average monthly electricity consumption, average diesel consumption, monthly average power generation of solar panels. Equations 02, 03 and 04 were used to compute the aforementioned activity data.

$$\textit{Average monthly electricity consumption} = \frac{\textbf{Total electricity Consumption (kWh)}}{\textbf{Number of Months}} \quad (02)$$

$$\textit{Average monthly diesel Consumption} = \frac{\textbf{Total Diesel Consumption (liter)}}{\textbf{Number of Months}} \quad (03)$$

$$\textit{Monthly average solar power generation} = \frac{\textbf{Total Solar Power generation (kWh)}}{\textbf{Number of months}} \quad (04)$$

Accordingly, average monthly electricity consumption, diesel consumption and solar power generation were calculated by dividing total consumptions for the year by number of months per year. Subsequently, emission factors (EF) were developed using published data by Sri Lanka Sustainable Energy Authority (SEA). Emission factors were presented in kilograms of carbon dioxide per one unit of activity data. The emission factors considered for this study are displayed in Table 3 explicating the amount of carbon dioxide emitted from diesel and electricity.

Table 3: Carbon dioxide emitted from diesel and electricity

Fuel	**Unit**	**CO_2 emission**
Electricity	kg/kWh	0.71
Diesel	kg/l	2.74

Finally, the results of carbon footprint assessment were used to indicate the potential carbon reduction of grid-tied PV system compared to buildings with traditional energy sources. The key findings derived through case analysis are presented below.

4. FINDINGS AND DISCUSSION

4.1 ASSESSMENT OF CARBON FOOTPRINT

Assessment of carbon footprint was conducted for two (2) buildings with grid-tied PV technology and two (2) buildings with traditional energy sources. Two types of buildings were selected to facilitate comparison between carbon emission of grid-tied PV system and traditional energy sources. The selected organisations are aware of building carbon emissions and the respondents stated that they are familiar with the concept of assessment of carbon footprint. However, as per the respondents, they do not conduct carbon assessment for their respective organisations due to time, labour and cost constraints. The respondents further emphasised that lack of interest of managers on carbon assessment and lack of carbon reduction projects within the organisation as an added reasons for the absence of carbon assessment. Hence, interviewees acknowledged that there is a lack of understanding of organisation’s carbon emissions.

In this study, carbon footprint assessment was only conducted for energy related emission activities (Refer section 2.3). Accordingly, data analysis and findings of carbon footprint assessment for each case study are designed under two structured steps as follows.

- Step 1 - Calculation of total energy use

As the first step of building carbon footprint assessment, energy sources and their respective consumptions were identified under the calculation of total energy use. Thus, the findings and discussion of the total energy use is further discussed in Section 4.2

- Step 2 - Assessment of Carbon emission

Based on the total energy use calculated (Step 01), carbon footprint was calculated for all 04 buildings under the section of carbon emission assessment (Step 02). Accordingly, the findings and discussion of the carbon emission assessment is elaborated in Section 4.3.

4.2 CALCULATION OF TOTAL ENERGY USE

Energy sources and their total electricity consumption of each case was identified as the first step of carbon footprint calculation. Table 4 summarises the energy sources consumed by the selected cases.

Table 4: Energy Sources of the Selected Cases

Energy Sources	Case A	Case B	Case C	Case D
Diesel Generator	✓	✓	✓	✓
Utility Grid	✓	✓	✓	✓
Grid-Tied PV Technology	✓	✓	-	-

According to the data presented in Table 4, Cases A and B use grid-tied PV technology as an energy source along with diesel generator and utility grid. And in Cases C and D, total energy consumption depends on diesel generator and public utility grid. As a result, as shown in Table 4, the energy consumption of Cases C and D is totally dependent on traditional energy sources whereas the total energy consumption in Cases A and B is a mix of traditional and renewable sources. Considering the identified energy sources, average monthly energy consumption of each source was measured in order to calculate the total energy consumption of selected cases, which is summarised and displayed in Table 5.

Table 5: Total electricity consumption of the cases

	Buildings with Grid-Tied PV Technology		Buildings without Grid-Tied PV Technology	
	Case A	Case B	Case C	Case D
Generator Diesel Consumption	26.25 litres	100 litres	37.33 litres	3810.8 litres
Utility Grid	144508.08 kWh	30838 kWh	13835.41 kWh	576480 kWh
Grid-Tied PV Technology	4760.24 kWh	4243.75 kWh	-	-
Monthly Average Total Energy Consumption	26.25 litres + 149268.32 kWh	100 litres + 35081.75 kWh	37.33 litres + 13835.41 kWh	3810.8 litres + 576480 kWh

According to Table 5, diesel consumption was omitted in total electricity calculation (as the diesel consumption calculated in litres is only used for carbon emission calculation).

The utility grid consumption and the electricity generated by solar panels were only considered in calculating total electricity consumption. Thus, the total energy consumption indicated in Kilowatt hour (kWh) along with generator's diesel consumption in litres as presented in Table 5.

4.3 ASSESSMENT OF CARBON EMISSION

Carbon emission assessment was conducted by calculating carbon footprint of total energy use of selected buildings. Amount of carbon emission (kg) from energy consumption (kWh) of buildings were calculated by carbon footprint assessment. Further, carbon emissions by energy consumption derived from carbon footprint equation (Equation 01) presented in methodology section. Calculated energy based monthly average carbon emissions for selected cases are presented in Figure 2.

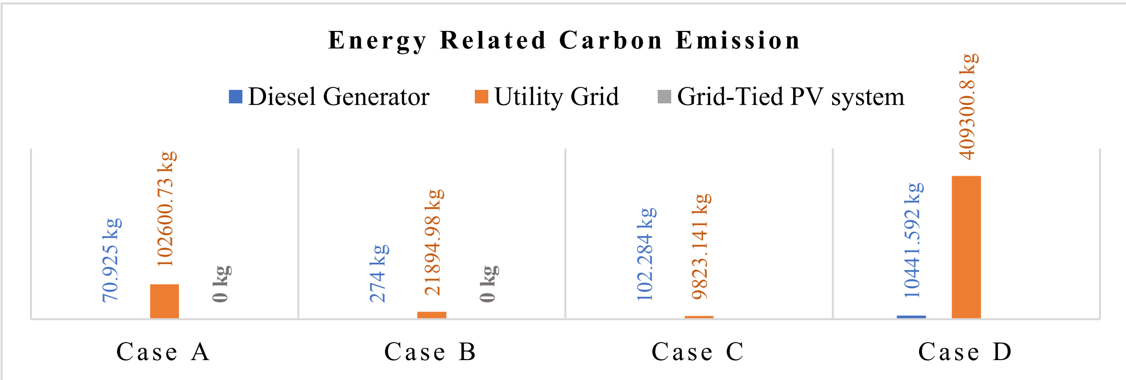

Figure 2: Energy related total carbon emission of the cases

Figure 2 presents the carbon emission generated by each energy sources of the cases. Accordingly, Cases A and B emit carbon from both diesel generator and utility grid while achieving zero carbon emission from grid-tied PV technology. Moreover, Cases C and D emit carbon from all the utilised energy sources; diesel generator and utility gird as indicated in Figure 2. In all four cases, diesel generator and utility grid emit carbon dioxide in the process of generating energy. This is because, as shown in Table 3, each unit of electricity and diesel consumption emit 0.71kg and 2.74kg of carbon dioxide, respectively.

Compared to Cases C and D, the energy sources of Cases A and B include a grid-tied PV system, which generates energy by extracting solar energy. Therefore, portion of the total energy of Cases A and B are produced with renewable energy technology. And the application of renewable energy system support Cases A and B to generate renewable energy without emitting carbon emission. Accordingly, as presented in Table 5, grid-tied PV systems of Cases A and B generate 4760.24 kWh and 4243.75 kWh respectively, which have zero impact on carbon emission (Figure 2).

Nevertheless, the energy mix of Cases C and D comprise of utility grid and diesel generator. Accordingly, the total energy demand is entirely catered by conventional energy sources. Therefore, the energy sources of Cases C and D actively participate in carbon emission, as shown in Figure 2.

4.4 POTENTIAL OF CARBON EMISSION REDUCTION

Calculation of total energy use and assessment of carbon footprint, enable to determine the potential for carbon emission reduction of grid-tied PV system. Under the calculation of total energy use, three different energy sources were identified in Table 4. In addition to conventional energy sources, Cases A and B use grid-tied PV technology as a renewable energy source to support their energy demand. This combination of renewable (grid-tied PV system) and non-renewable (local grid) energy can be elaborated as shown in Figure 3. According to Figure 3, Cases A and B incorporate solar energy to their energy supply, leading to energy saving of 4760.24 kWh (3%) and 4243.75 kWh (12%) respectively from total electricity generation. This portion of power generation considered as renewable with zero carbon emission. Furthermore, as shown in Figure 3, the remaining energy demand of Cases A and B, which is 149268.32 kWh (97%) and 35081.75 kWh (89%) are catered by local utility grid. This is subjected to energy related carbon emission.

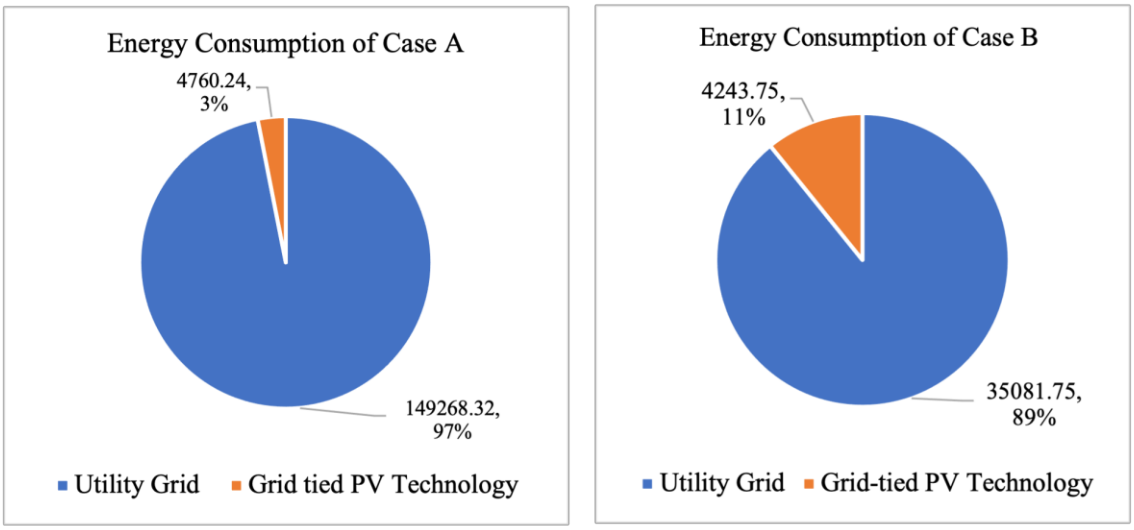

Figure 3: Energy consumption of cases A and B

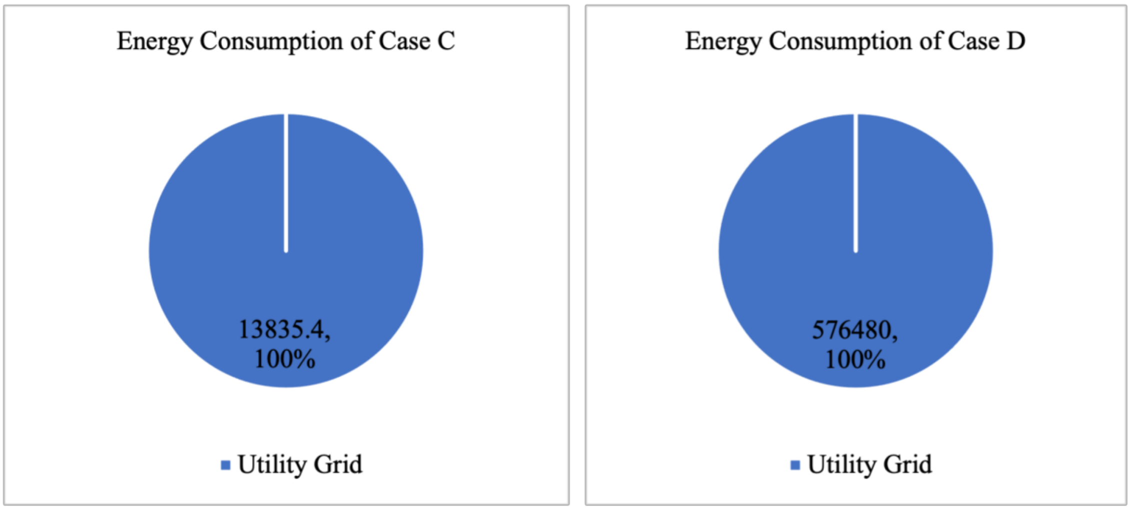

Figure 4: Energy consumption of cases C and D

However, Cases C and D rely their total energy consumption on traditional energy sources, which does not support any energy or carbon reduction. This can be further elaborated using the pie charts given in Figure 4. Accordingly, Cases C and D rely on traditional energy systems (100%), which leads to maximum carbon emission without any possible reduction. Therefore, compared to Cases A and B, Cases C and D have more impact on environment in terms of energy related carbon emission.

The carbon reduction from grid-tied PV system can also be elaborated in following way. If it is assumed the generated electricity by grid-tied PV technology is purchased by grid, it gives arise to carbon emission since it is non-renewable energy source. This can be further described using Table 6. According to Table 6, solar panel of Cases A and B generate electricity of 4760.24 kWh and 4243.75kWh respectively and has zero impact on carbon emission.

Table 6: Carbon emission of A and B if PV energy is purchased by grid

Case Building	**Energy Produced by Grid-Tied PV technology** *(Assume this amount is purchased by grid)*	**Emission factor**	**Carbon emission**
Case A	4760.24 kWh	0.71	3379.77
Case B	4243.75 kWh	0.71	3013.06

Table 6 shows if the electricity produced by grid-tied PV technology is purchased by grid, it will be subjected to emission factor of 0.71 kg/kwh. Subsequently, carbon emission will be 3379.77 kg per month for Case A and 3013.06 kg per month for Case B. Therefore, with the implementation of grid-tied PV system, Cases A and B have gained a reduction of carbon emission by 3379.77 kg and 3013.06 kg per month. Therefore, this again prove the potential of grid-tied PV technology to minimise the impact of building's carbon emission.

5. CONCLUSIONS

It was revealed that compared to traditional-energy buildings, grid-tied PV buildings obtain reduction in energy and carbon emission for the building. Two buildings with grid-tied PV technology indicate energy saving of 4760.24 kWh (3%) and 4243.75 kWh (12%) respectively from monthly total energy of the building. In addition, due to the energy saving, both buildings achieved a reduction of carbon by 3379.77kg and 3013.06kg respectively per month. Consequently, this work has successfully identified that buildings with grid-tied PV technology can achieve a huge reduction in energy related carbon emission compared to buildings with traditional energy sources.

In spite of the detailed assessment of the possible energy related carbon reduction of grid-tied PV system for buildings in Sri Lanka, some limitations are still presented in this paper. First, the sample size of the survey in this study is relatively small. Thus, cautions should be given when the analysis results are interpreted. Second, the calculation of carbon emission was limited to energy related activities. Third, findings from this study apply to office buildings in Sri Lanka exclusively, which may vary in other different locations, sectors and countries. Despite these limitations, this study is still valuable, since it delivers an understanding of potential carbon reduction of the grid-tied PV buildings compared to the traditional-energy buildings of Sri Lanka. For further research actions, potential carbon reduction of grid-tied PV system can be studied in other sectors of Sri Lanka.

Further, it is recommended that steps can be taken to enhance the implementation of grid-tied PV system in Sri Lanka's built environment. And the energy consumers need to be made aware of carbon reduction potential of the grid-tied PV system. In Sri Lanka, energy consumers are becoming increasingly interested in reducing energy related carbon emission to reduce environmental impact. Thus, government can financially assist the new PV users to penetrate the solar PV market by introducing capital subsidies. Therefore, buildings can actively participate on reducing energy related carbon emission and thereby contribute to the betterment of Sri Lanka.

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ASSURING SUSTAINABLE CONSTRUCTION AT PROJECT FEASIBILITY STAGE IN SRI LANKA

G.P.D.P. Senanayake[1] and H. Chandanie[2]

ABSTRACT

Construction activity is commonly considered to have adverse impacts on the environment, which is the basis of sustainable development for human being. Further, sustainability should be addressed mostly in developing countries, such as Sri Lanka, where a considerable amount of construction works is currently in progress and remain to emerge in the future. It is considered that the proper development and operation of a construction project can make significant contribution to the mission of sustainable development. However, the existing difficulty is the lack of the guidance for implementing sustainable development principles in construction industry. Therefore, this research intends to bring the necessity of mandated project feasibility studies as a guideline for sustainable development in the Sri Lankan Context. The research aim was approached through a qualitative survey strategy. To solicit the perceptions of experts on the identified sustainability performance criteria, a semi-structured interview survey was conducted. Ten experts were selected through purposive sampling strategy, who had experience in sustainable construction and project feasibility evaluation criteria. The manual content analysis method was used to analyse the collected data. Findings of the research revealed that though numerous sustainability assessment tools are being practised, there is a failure in sustainable construction in the current context. Thus, the minimum sustainability requirements were identified under the three pillars of sustainability, aiming to develop the project feasibility study as a guideline and to ensure sustainability performance from the project inception stage. These findings are helpful for industry practitioners especially the project owners to initiate a sustainable construction with concerted actions of all project stakeholders to safeguarding the future.

Keywords: *Government policies, Minimum sustainability requirements, Project feasibility study, Sri Lanka, Sustainable construction.*

1. INTRODUCTION

The construction industry and its activities have significant impact on the environment economy, and society (Osei, 2013). Further, the construction industry is continuously exploring appropriate strategies required to make constructions more sustainable (Abidin, 2010; Kandil *et al*., 2010), due to its negative impact (Sfakianaki, 2019). Appreciation of the significant impacts of construction activities on Sustainable Development (SD) has led to the development of various management approaches and methods to guide construction participants in achieving better project sustainability performance. However,

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government policies and regulations act as the primary solution to mitigate adverse effects from construction activities (Zhang *et al.*, 2012).

The SD was defined in Brundtland's report published by World Commission on Environment and Development as meeting the current generation's necessities and aspirations without minimising the future potential (World Commission on Environment and Development (WCED), 1987, p. 43). When concerning construction as a business, the fusion of sustainability is about achieving a mutually beneficial outcome for project stakeholders and a satisfactory profit for the developers (Hutchins and Sutherland, 2008; Zuo and Zhao, 2014). Sustainability performance of an individual construction project across its life cycle is an indispensable aspect in attaining the goal of SD. Hence, incorporating them in the project's inception stage is the most critical phase for sustainable decision-making (Braganca *et al.*, 2010; Heralova, 2017). Although Environmental Impact Assessment (EIA) and feasibility study include sustainable assessment criteria at early construction stages (Li *et al.*, 2010), only EIA is under the legal system of environmental protection as the guideline for the ecological consequences. Therefore, implementing a feasibility study as a policy guideline to comply with sustainable requirements may be the best option as feasibility criteria are better matched with the three pillars of sustainability.

Generally, the implementation of Sustainable Construction (SC) practices in developing countries was found to be low (Abidin, 2010; AlSanad, 2015). Sri Lanka (SL), as a developing country, has a high demand for SC even though the country is not adequately furnished with SC practices (Jayalath and Gunawardhana, 2017). The research findings of Athapaththu and Karunasena (2018) suggested that contracting organisations established in SL lack in adopting existing SC practices. The proper implementation of SC has been obstructed by many barriers (Adetunji *et al.*, 2003), where lack of project owner's demand has been considered as the main barrier for SD (Pitt *et al.*, 2009). However, SD is still regarded as a 'nice-to-have' practice by the owners that enhances usual practice without being incorporated into decision making (Du Plessis, 2002). Therefore, governments can explicitly assist in introducing sustainability into the construction sector through policies and guidelines while balancing the interests among economic, social, and environmental stakeholders through rewards and penalties (Chong *et al.*, 2009). Shen *et al.* (2010) identified the existing social, economic, and environmental attributes relating to sustainability in the project feasibility study. Yet, there is a research gap in studying the shifting of the traditional method of a project feasibility study to a new path while embracing the principles of SD in the Sri Lankan Context. Thereby, it is necessary to research minimum sustainability requirements in implementing the project feasibility study as a policy guideline for every project within a country. This research aims to discover minimum sustainability requirements to embrace the principles of SD into project feasibility checks on construction work in SL. The aim was achieved by critically reviewing the relationship between feasibility studies and assuring sustainability to identify sustainability performance criteria at project inception stage and accomplishing the minimum sustainability requirements essential to be achieved by construction projects from the country perspective.

2. LITERATURE REVIEW

2.1 THE RELATIONSHIP BETWEEN PROJECT FEASIBILITY STUDIES AND ASSURING SUSTAINABILITY

The concepts of SD should be integrated into all stages of the project life cycle (Tam *et al*., 2012). The Royal Institute of British Architects (RIBA) Plan of Work organises the project life cycle into a process of eight (08) stages: i.e. (i) strategic definition, (ii) preparation and briefing, (iii) concept design, (iv) spatial coordination (v) technical design, (vi) manufacturing and construction, (vii) handover, and (viii) use of a building (Royal Institute of British Architects (RIBA), 2020). The different sustainability tools have been developed to evaluate the success of the development over the stages of the project life cycle in terms of balancing energy and environment while considering the social and technological aspects (Clements-Croome, 2004). Even though there are number of sustainability assessment tools, the time of application (Wilkinson and Reed, 2007), single-dimensional nature (Ding, 2008), regional variations (Kohler, 1999), complexity (Crawley and Aho, 1999), lack of government intervention are identified as limitations of current sustainability assessment tools to achieve SC.

The early involvement of stakeholders, even before the design stage, will ensure the successful execution of SC (Tam *et al*., 2012). Hill and Bowen (1997) suggested that more attention should be given to the application of environmental, social, and economical assessment for implementing a construction project in particular at project feasibility stage. At this stage, the new project will be investigated with multiple options while addressing the issues in such a way as to why, when, and how to invest (Shen *et al*., 2007). The preliminary feasibility study and the project proposal are conducted at this stage, where the most feasible option will be detailed into a proposal with the needed sustainable activities of the client to make the investment decision (Shen *et al*., 2007). However, the effectiveness of sustainability assessment tools at the inception stage is limited due to the limited project information at the beginning (Shen *et al*., 2010). Hence, the sustainability criteria that can be assessed in the project's inception have been identified by Shen *et al*. (2007). Shen *et al*. (2010) had analysed 87 feasibility study reports of various types of projects in China and identified eighteen economic, nine social, and eight environmental performance attributes. Table 1 illustrates the findings of both papers.

Table 1: Sustainability criteria at the inception stage

Sustainability criteria at Inception Stage		
Economic	**Social**	**Environmental**
Governmental strategic development policy Tax policy Demand and supply analysis Market forecast Project function and size Market competition Location advantage Technology advantage	Influence on the local social development Provision capacity of employment Provision capacity of public services Provision capacity of public infrastructure facilities Provision of the infrastructures for other economic activities	Eco-environmental sensitivity of the project location Ecological assessment Air impacts Water impacts Noise impacts Waste impact

Sustainability criteria at Inception Stage		
Budget estimate Financing channels Investment plan Life cycle cost Life cycle profit Finance risk assessment Return on Investment (ROI) Net Present Value (NPV) Pay-back period Internal Rate of Return (IRR) Scale and business scope The effect on the local economy	Safety standards Improvement to the public health Cultural and heritage conservation Development of new settlement and local communities Land use Safety assessment	Environmentally friendly design Energy consumption performance Land consumption

Although the currently used environmental building assessment tools have given less attention to financial aspects, the project feasibility studies include more concern over financial criteria as per the table above. Hence, the number of SCs has been reduced in practice due to the profit-driven culture in the industry (Shen *et al*., 2010). Therefore, even the projects are environmentally friendly, and they will make it less attractive to developers as they may be too costly to build. Thus, both environmental issues and financial considerations should be given equal concern in the feasibility evaluation framework (Larsson, 1999), including environmental goals, sustainability certification, and the budget for sustainability. Hence, Shen *et al*. (2010) highlighted the necessity of shifting the project feasibility study to a new dimension by embracing more social and environmental principles of SD into it.

2.2 OVERVIEW OF SUSTAINABLE CONSTRUCTION IN SRI LANKA

The successful implementation of SD principles is a must to overcome environmental issues in developing countries (Zeng *et al.*, 2002; Shen *et al.*, 2005). Yet SL has not taken sufficient measures to mitigate the current challenges that occur in the construction industry (Jayalath and Gunawardhana, 2017). In SL, the GREENSL® rating system is introduced in 2010 by the Green Building Council of SL as an assessment tool to guide SC. Along with that, Tsunami Sustainable Building Guidelines for South-East Asia was published. It was a SC management guideline with several environmental, safety, and financial benefits (United Nations Environment Programme, 2007). There are 64 LEED, and GREEN^{sl} certified green buildings in SL (Green Building Council Sri Lanka (GBCSL), 2020). For example, Heritance Kandalama is one of the LEED Bronze rated hotels in the world (Seneviratne, 2014) and MAS Intimates Thurulie-Clothing Factory is the first LEED Platinum rated newly built manufacturing factory in the world (MAS Holdings, 2020).

The Sri Lankan government has already implemented several rules and regulations to support local green growth (Thalpage and Karunasena, 2016). The primary legislation for environmental conservation in SL was the National Environmental Act. According to this Act, Part IV C requires Environmental Impact assessment (EIA) approval for 'Prescribed Projects,' which are listed under the Act and government gazette notifications (De Mel *et al*., 2009). Further, there are many Physical Planning Acts and Ordinances such as Urban Development Authority (UDA) Law No 41 of 1978, Town and Country Planning

Ordinance No. 16 of 1946, Housing and Town Improvement Ordinance No.19 of 1915, Municipal Council Ordinance, Urban Council Ordinance and Pradeshiya Sabha Act of 1987 for protection of the Environment and promoting economic, social, and physical development at early stages. However, the legal framework in SL has accomplished environmental aspects compared to economic and social issues (Abeynayake, 2010). Therefore, SL has experienced unsustainable development during the past decades. Abidin *et al*. (2012) argued that with more government actions, the construction activities will move towards better environmental, social, and economic safeguards. Yet there is a lack of policies and regulations that directly concerns Sustainability practices in SL compared to environmental protection (Hewage and Mallika, 2011). Finally, issuing the devised project feasibility criteria as a sustainability guideline as approval for project commencement will uplift the green building practices in SL.

3. METHODOLOGY

The major objective of this study is to find out the minimum sustainability requirements that can be incorporated into the project feasibility study to assure SC and used by all project participants to understand and improve sustainability performance at inception stage. The data used for data collection were mainly from a comprehensive literature review. The qualitative research approach was selected as the best method to collect data due to the lack of knowledge and experience on both sustainability and project feasibility study with Sri Lankan construction professionals and it is difficult to go for a large number of respondents for the data collection. A preliminary list of sustainability performance criteria gathered was presented through semi-structured interviews to the invited professionals for their comments. There were ten (10) experts with more than 20 years of experience. They were selected through judgemental sampling technique, including two (2) quantity surveyors from road projects, two (2) quantity surveyors from building projects, two (2) civil engineers from building projects, and four (4) civil engineers from water projects. These interview discussions provide valuable comments on the selection of the minimum sustainability requirements. However qualitative data obtained from expert interviews were analysed through manual content analysis by tracking the findings within identified themes.

4. RESULTS

Findings of the Expert survey can be elaborated under the three pillars of sustainability as identified in the literature review and the interviewee’s opinions were analysed through manual content analysis and the obtained summary is presented in Table 2. Criteria in the Table includes literature findings in Table 1 and criteria from LEED sustainability assessment tool. The common view of the respondents was marked as “✓” in Table 2.

Out of 79 sustainability performance criteria identified, 77 were from the literature findings and remaining one was from expert interviews. That proposed criterion was Cost-Benefit Analysis (CBA). Then experts identified 68 criteria as minimum sustainability requirements to assess all the project at the feasibility stage as illustrated below. However, to make the project feasibility study as a guideline under the law of SL, the collected data was analysed to come up with the criteria which are not assessed in EIA and government authorities. Hence, ultimately 36 criteria were found to be the final output that need to be mandated to come up with the sustainable feasibility guideline.

Table 2: Common view of the respondents

Literature Findings	**Common View of Expert Survey Findings**			
Sustainability performance criteria	**Minimum sustainability requirements**	**Feasibility study**	**EIA**	**Government authorities**
Economic sustainability factors				
Government strategic development policy	✓	✓	✓	-
Tax policy	✓	✓	-	-
Market forecast	✓	✓	-	-
Demand and supply analysis	✓	✓	-	-
Market competition (Sell/rent price competition)	✓	-	-	-
Project Promotion	✓	✓	-	-
Project scope, scale, and functions	✓	✓	✓	-
Effects on the local economy	✓	✓	-	-
Location advantage	✓	✓	-	-
Technology advantage	✓	✓	✓	-
Budget estimate	✓	✓	-	-
Financing channels	✓	✓	-	-
Investment plan	-	✓	-	-
Total life cycle cost and profit	✓	✓	-	-
Financial risk assessment	✓	✓	-	-
Overhead cost	-	✓	-	-
Uncontrolled inflation.	✓	✓	-	-
Fluctuation in foreign currency.	✓	-	-	-
Return on investment (ROI)	-	✓	-	-
Net present value (NPV)	-	✓	-	-
Pay-back period	-	✓	-	-
Internal rate of return (IRR)	-	✓	-	-
Project Affordability	✓	✓	-	-
Regulation in export-import limitation	✓	-	-	-
Change in loan interest rate.	-	✓	-	-
Influences of domestic product and resources use policy	✓	-	-	-
Policy in stopping subsidy	✓	✓	-	-
Increasement in regional minimum payment for workers.	✓	-	-	-
Cost-Benefit Analysis	✓	✓	-	-
Social sustainability factors				
Influence on local social development (welfare)	✓	✓	-	-

Literature Findings	Common View of Expert Survey Findings			
Provision of the infrastructures for public/ economic activities	✓	✓	-	-
Influence on land prices in the surrounding location.	✓	-	-	-
Influence by surrounding people to the new development (protest)	✓	✓	✓	-
Land use and its relationship with immediate surroundings	✓	✓	✓	-
Provision capacity of employment	✓	✓	-	-
Provision capacity of public services (access to public services)	-	✓	-	-
Improve public health and safety standards/ assessment	✓	✓	-	✓
Cultural and heritage conservation	✓	✓	✓	✓
Development of new settlement and local communities/ resettlement	✓	✓	-	-
Thermal comfort	-	✓	-	-
Day lightning and natural ventilation	✓	✓	-	✓
Acoustic performance and noise control	✓	-	✓	-
Indoor air and water quality performance	✓	-	✓	-
Low emitting materials	✓	-	-	-
Indoor occupant health and safety quality performance	✓	-	-	-
An unhealthy political climate for investment.	✓	✓	-	-
NGO involvement in the investment plan	✓	✓	-	-
Lack of law enforcement.	✓	-	-	-
Environmental sustainability factors				
Access to the location	✓	✓	✓	-
Influences of traffic jams around the location.	✓	✓	-	✓
Unsupported facilities and other infrastructures around the location	✓	✓	-	✓
Protection of environmentally sensitive project location	✓	✓	✓	✓
Selection of project location with high development priorities	✓	✓	✓	-
Access to public and ecological transportation	✓	-	✓	-
Reduce parking footprint	✓	-	-	✓
Protect or restore natural habitats and promote biodiversity	✓	✓	✓	-

Literature Findings	Common View of Expert Survey Findings			
Green space for environmental and social interaction	✓	-	✓	-
Site assessment for sustainable design options	✓	✓	-	✓
Building water conservation	✓	✓	-	✓
Leak detections and innovative water-efficient equipment	✓	-	-	-
Water-efficient landscaping	✓	-	-	-
Water recycling and reuse	✓	-	✓	-
Rainwater management	✓	-	-	✓
Construction and demolition waste management	✓	✓	✓	-
Innovative technologies for waste reduction	✓	-	✓	-
Optimise energy performance	✓	✓	-	-
Participation in demand response energy technologies and programs	-	✓	-	-
Renewable energy production	✓	-	-	-
Enhanced refrigerant management	✓	-	-	-
Recycle and renewable material use	✓	-	-	-
Local and regional materials	✓	✓	-	-
Environmentally friendly design	-	✓	-	-
Building orientation	✓	-	-	-
Air impacts	✓	-	✓	-
Noise impacts	✓	-	✓	-
Water impacts	✓	-	✓	-
Other sustainability factors				
Environmental Management Certificate	✓	-	✓	-
Green Building Accredited Experts to support investment	✓	-	-	✓
Inappropriate technology in the construction and operation phase	✓	-	-	-

4.1 ECONOMIC SUSTAINABILITY CRITERIA

Economic Performance Criteria (EPC) are used for assessing economic performance of construction projects. These criteria are used to reflect market availability, project financing and economic benefit from implementing a construction project. Through the literature findings, a list of EPC has been identified and they were directed to the interviewees to select minimum feasibility requirements.

It can be seen from Table 2 that out of the 29 EPC, 22 were selected as the minimum sustainability requirements at project feasibility study, 24 were already being assessed in the current project feasibility study, 3 were included in the EIA and no EPC were assessed in the governmental authorities. Hence it is clear that EPC were given less consideration in the mandated sustainable assessment criteria which were used for sustainable decision making at project inception stage.

As evident through the respondents' views, tax policy, project scope, scale and functions, location advantage, the influence of domestic product and resources use policy, technology advantage, and budget estimate are the most critical factors to be considered under economic sustainability requirements at project feasibility stage. Although these EPC are given good attention in conducting project feasibility study, market competition, fluctuation in foreign currency, regulation in export and import limitation, influence in domestic products and resource use policy, and increasement in regional minimum payment for workers were given limited attention in conducting project feasibility study where experts suggested them under the minimum sustainability requirements at feasibility stage.

Other than this, experts highlighted that tax policy needs to be implemented according to any framework where government should provide tax concessions and subsidy to identified projects to promote SC. Then that will expose to new technologies available in foreign countries it will increase the work efficiency. Further, the strategic development policy in SL changes with the government changes, where any strategy should be implemented through national policy as they are not changed with the ruling party.

4.2 SOCIAL SUSTAINABILITY CRITERIA

Social Performance Criteria (SPC) are used for assessing social performance of construction projects. Through the literature findings, a list of SPC have been identified and they were directed to the interviewees to select minimum feasibility requirements.

It can be seen from Table 2 that out of the 19 SPC, 17 were selected as the minimum sustainability requirements at project feasibility study, 13 were already being assessed in the current project feasibility study, 5 were included in the EIA and 3 of SPC were assessed in the governmental authorities. Same as EPC, SPC were also given less consideration in the mandated sustainable assessment criteria which were used for sustainable decision making at project inception stage.

It seems that social responsibilities have not been given due consideration in Sri Lankan projects. This is considered a major reason for causing the huge gap between the rich and the poor in the society. As evident through the respondents' views, influence on local social development, influence by surrounding people to new development, Land use and its relation with immediate surroundings, improve public health and safety standards/ assessment, cultural heritage conservation, development of new settlement/ local communities/ resettlements, unhealthy political climate, and lack of law enforcement are the most critical factors to be considered under social sustainability requirements at project feasibility stage. Although above SPC are given good attention in conducting project feasibility study, influence by surrounding people to new development, lack of law enforcement, and most of indoor environment quality criteria were given limited attention in conducting project feasibility study where experts suggested them under the minimum sustainability requirements at feasibility stage.

Moreover, to expert opinion, providing employment opportunities to local labourers will be a social benefit to the public as well as an economic benefit local economy, where indirectly the society will get indirect opportunities to earn by providing accommodations, shops. Further a proper law should be implemented through local government to approve building permit only if the sewerage line is taken up to the board connection.

4.3 ENVIRONMENTAL SUSTAINABILITY CRITERIA

Environmental Performance Criteria (EnPC) are used for assessing environmental performance of construction projects. In fact, a large number of research works have been conducted in this area and many EPC were identified compared to other pillars of sustainability. This may be because most works consider only the environmental factors when comes to the sustainability.

It can be seen from Table 2 that out of the 28 EnPC, 26 were selected as the minimum sustainability requirements at project feasibility study, 13 were already being assessed in the current project feasibility study, 12 were included in the EIA and 7 of EnPC were assessed in the governmental authorities. Hence it is clear that EnPC were given considerable attention in the mandated sustainable assessment criteria which were used for sustainable decision making at project inception stage. This is because EIA required on projects mainly concern on the four major environmental pollutions, including air, noise, water and waste.

As evident through the respondents' views, access to location, protect or restore natural habitats and promote biodiversity, green space for environmental and social interactions, site assessment for sustainable design options, air impacts, noise impacts, water impacts, and rainwater management are the most critical factors to be considered under environmental sustainability requirements at project feasibility stage. Although this EnPC are given good attention in conducting the project feasibility study, water conservation mechanisms, renewable energy production, enhanced refrigerant management, recycle and renewable material use, and building orientation were given limited attention in conducting project feasibility study where experts suggested them under the minimum sustainability requirements at feasibility stage.

As implementing construction projects has been a driving force to the economic growth in SL over previous decades, the effects of the construction industry on the degrading environment are huge. One of the major reasons for this is considered as the lack of consideration given to the environmental protection in the project feasibility study. Hence based on the above analysis, it is found that the EPC are given more concerns than that given to the SPC and EnPC in conducting construction project feasibility study.

5. CONCLUSIONS

SC is not yet standard practice in SL. This paper concludes that the proper development and operation of a construction project can make a significant contribution to the mission of SD. There is the existence of a lack of the guidance for implementing the SD principle in the construction business, and the lack of mechanism of assessing the practice of applying the principle at the project feasibility stage. Further, the traditional practice of assessing the feasibility of a construction project concerns more on the economic and social contribution of a construction project. Hence this research used project feasibility study as the sustainability tool to ensure SC from the inception stage earns the full benefits environmentally, socially, and economically by targeting the right group criteria. Hence, that right group includes 36 sustainability out of 79 to facilitate sustainability decision making. Based on those principles, the judgment can be made as to whether or not the development of a construction project is in line with SD principles. Thus, there was a requirement of guideline for sustainable decision making and it was fulfilled by assisting project feasibility study towards sustainability. It is proposed to implement the identified minimum sustainability requirements after benchmarking each criterion under possible government authority. However, this becomes an effective practice for SCs rather than governing under other sustainable assessment tools.

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BARRIERS IN IMPLEMENTING SUSTAINABLE PILING CONSTRUCTION PRACTICES IN SRI LANKA

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ABSTRACT

The construction of pile foundation is a multifaceted activity among rest of the construction activities that are performed by heavy machines, materials, and energy sources generating substantial amount of CO_2 and greenhouse gases along with many other forms of environmental pollution. Sustainable piling construction guarantees that the whole piling process meets environmental sustainability and ultimately human health and wellbeing. Many countries around the world, including United States, China, the United Arab Emirates, are in the forefront of reengineering piling construction activities. Implementation of sustainable practices in piling construction Sri Lanka is still at a low level. Succinctly, several hindrances and barriers can be identified when adopting sustainable piling construction practices. Hence, the aim of this paper is to identify the environmental impact due to the current piling construction practices in Sri Lanka and to investigate barriers in implementing sustainable piling construction practices. A questionnaire survey was conducted among thirty (30) experts in piling construction. Significant barriers were identified using the relative importance index technique in data analysis. The findings revealed that among the ten (10) barriers identified, cost overrun and poor pile design, investment risk, lack of awareness of sustainable techniques and technologies as the top three (3) barriers in implementing sustainable piling construction practices. The study clearly identified the need for improving sustainability practices that can also enhance cost-effectiveness and performance efficiency. Findings of this study will be useful in formulating strategies to overcome the barriers and improve sustainability practices in the local construction industry.

Keywords: *Barriers; Environment impact; Piling construction; Sustainable practices.*

1. INTRODUCTION

Construction industry worldwide is a significant cause for degradation of the environment and contribute to pollution and global warming. In the recent era, climate change has become a critical challenge to the entire biosphere, primarily caused by greenhouse gases (GHGs). The phenomenon of GHGs is the retention of heat by Carbon Dioxide (CO_2) and other greenhouse gases within the atmosphere (Hannigan *et al.,* 2016) causing an

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increase in average temperature, subsequently global warming and climate change (King and Harrington 2018). According to the analysis of Seo *et al*. (2016), 40% of the resources that contribute to the world economy are consumed by the construction industry, which is responsible for the generation of around 40% to 50% of the GHGs. Most of the construction activities do directly rely on machineries which accounts for 50% of all CO_2 emissions produced by the construction industry due to their excessive volume of energy consumption (Jassim *et al.,* 2017).

Chen *et al*. (2019) have emphasised that the contribution of CO_2 and other greenhouse gasses (GHGs) in the construction sector is significant since a huge proportion of machinery is utilized in piling construction. Ghoraba *et al*. (2016) have stated that piling is one of the most complex construction tasks and several uncertainties can be encountered during the execution which led to cost overrun, materials wastages, and delay in project completion. Bored pile construction is identified as the most common practice of piling method (Taghavi *et al.,* 2015). Sandanayake *et al.* (2014) mentioned that bored pile construction is employed by heavy machines, materials and energy that generate a high emission rate of CO_2 and waste generation.

Sustainable construction encompasses three prime pillars viz. economic, environmental, and social performance of the industry (Li *et al.,* 2018). In terms of piling construction, sustainable practices focus on material usage, energy consumption, wastage generation, noise and vibration, and impact to the ground (Ametepey *et al.,* 2015). As cited by Basu *et al*., (2014), cost-effectiveness and sustainability can be achieved by implementing sustainable practices in piling construction through adequate soil investigation, economic design, and efficient usage of machinery, materials, and resources. Even though "environmental sustainability" and "going green" have been major concepts in the construction industry for a long time, statistics make evident that the side-effects of construction activities are contributing to some negative impact on every nation (Ojo *et al.,* 2015). Consequently, re-engineering the entire construction process, including piling activities has become significant to decrease the environmental impacts.

Sri Lanka is significantly slow in accepting sustainable piling construction practices, where many barriers can be identified during the implementation process. The majority of the construction contractors are not capable of overcoming these barriers. Thus, these barriers need to be studied well before implementation. Although many past studies have been conducted on the environmental impact of the construction industry in general, none of studies have attempted to identify the impact on the environment due to current practices with piling construction in Sri Lanka. Therefore, aim of this paper is to identify the environmental impact of the current piling construction practices and investigate barriers in implementing sustainable piling construction practices in Sri Lanka.

2. LITERATURE SYNTHESIS

2.1 PILING TYPES AND CONSTRUCTION PRACTICES

Pile is the columnar component in a foundation that transfers load from the superstructure to weak soil at shallow depth, compressible strata or water, or less compressible soils, or rock (Babu *et al.,* 2020). Building foundations, machinery foundations, and bridge piers and abutments, embedded retaining walls are supported by piles to carry out vertical and horizontal loads (Xu *et al.,* 2015). Mucciacciaro and Sica (2018) have declared that displacement piles where the material of the pile, or a former into which the pile is to be placed, is forced into the ground, by displacing the ground. The analysis of Misra and Basu (2011) have indicated that from the environmental impact point of view, the driven piles perform better in the sandy profile but, for the clayey profile, the performance depends on the design load. Additionally, it has been revealed that a geographical investigation is executed to find out the rock mass or soil properties of where the structure is supposed to be laid. Common methods used for proceeding in the process of boreholes are percussion boring, shell and auger, wash boring, auger boring, and rotary drilling in replacement piles (Hannigan *et al.,* 2016). Moreover, the excess consumption of concrete is due to some causative factors that can be identified in piling construction. Over break arises due to the local collapses of the pile bore walls resulting in cavities and cause to the wastage of concrete (Jami *et al.,* 2019). Mantha and de Soto (2019) have mentioned that the quality and level of the boring support fluids are required to be kept under tight control during pile bore drilling to avoid such bore wall collapses. Besides, it is revealed that the efficiency in the drilling operation will reduce the risk of borehole collapse, resulting in a reduction in excess concrete consumption. Similarly, if the temporary casing is extracted too rapidly with an insufficient head of concrete, defects may occur in the pile construction due to soil contamination of the concrete (Wang and Wang 2020). Proper coordination in the rate of concrete injection and the rate of extraction of the auger in piles is necessary to avoid necking in the piles. Hole cleaning essentiality needs to be carried out as immediately as possible after the boring has finished, otherwise, the mud penetrated from the boring will subside and creates difficulties in cleaning the hole, or else the hole can be collapsed as well (Gan *et al.,* 2015). Whereas in replacement piles, the ground is removed by augering, drilling, etc., and the soil is replaced with cast-in-situ concrete. All these major activities in the piling process are supported by sub-activities that involve various techniques, plants, and equipment.

2.2 ENVIRONMENTAL IMPACT DUE TO CURRENT PILING CONSTRUCTION PRACTICES

According to Misra and Basu (2011), the impact on the environment connected with piling construction can be commonly recognised in terms of emissions of CO_2 which are based on volume and energy consumption, waste generation and soil contamination, noise, and vibration, water, and air pollution. The main materials in piling construction are concrete and steel. CO_2 and GHGs are produced by the manufacturing, utilizing, and transporting of concrete and steel (Miller 2018). Approximately 460kg of CO_2 is generated per ton of reinforcement steel and a cubic meter of in-situ concrete produces 1770kg of CO_2 emissions (Miller *et al.,* 2016). Moreover, fossil fuel used in heavy machinery in pile construction is also known as a significant contributor to CO_2 emission as it produces 2.62kg of CO_2 emission from 1 litre of diesel, and 0.537 kg of CO_2 emission per 1 kWh of electricity usage (Masih-Tehrani *et al.,* 2020). Saravanan (2011) has revealed that even though epoxy coated steel is used for piling construction in the UAE as corrosion protection to the reinforcement, the coating factories consume a lot of energy for this process, resulting in GHG emissions. Poor control of such kinds of activities leads to increase in global warming and climate changes which are the key issues of sustainability. Howell (2015) has revealed that contamination arising from the effects of aggressive ground conditions on materials used in piles, creation of preferential flow paths, driving contaminated materials during installation and process of concreting or grouting allow surface water infiltration into contamination causing the risks of subsequent exposure to site workers and residents. Wu *et al*. (2020) and Zha *et al*. (2018)

have emphasised that potable water is used for concrete manufacturing and pile drilling activities and it is being produced in most countries by desalination process of seawater or natural water resource. For this process, huge amount of fossil fuel is burned which in turn creates CO_2 emission in the atmosphere. Noise is created by large diameter piles during sealing into the ground by using a Kelly bar of the drilling rig or hammer (Mangushev 2016). Moreover, it may lead to vibrations for temporary casing installation using a vibrator. As per Xu *et al*. (2015), the real drilling technique is free of vibrations; the engine operation and Kelly bar operation in the drilling rig results in the drilling process making some noise. According to the geophysical investigation of the building foundation of Mohsenian *et al*. (2019), ground-borne vibrations that occur from piling construction lead to energetic strains within adjacent buildings. Such kinds of vibrations may be significant enough to affect the structure but the more frequent concern is occupants' disruption (Babu *et al.,* 2020). Piling construction is predominantly powered by the successful utilization of materials, natural resources and heavy plants (Mohajerani *et al.,* 2016). As a result, the scarcity of natural resources has become a threat to sustainable construction.

2.3 SUSTAINABLE PILING PRACTICES

The application of sustainable development practices to the construction industry reflects as sustainable construction (Shan *et al.,* 2017). As per Gaikwad and Shelavale (2017), construction and design approaches which encourage the fulfilment of goals allied with the triple bottom lines, which are "economic sustainability" for inspiring economic growth, "environmental sustainability" for minimizing environmental impacts, and "social sustainability" for social wellbeing are known as sustainable construction practices. It donates tremendous utility to create economic, environmental, and social development and ultimately the sustainable built environment (Ojo *et al.,* 2015). The use of viable practices in piling construction may achieve cost-effectiveness and sustainability. The enhancement of construction quality, efficiency, and safety are of utmost critical aspects of sustainable piling construction. Further, Saravanan (2011) has revealed that sustainable practices in piling construction played a major role to attain competitive advantage through cost-effectiveness, performance efficiency, and sustainability during the 2008 construction industry recession in the United Arab Emirates (UAE). The key areas to be focused in improving the sustainable piling process are as follows.

Reduction of CO_2 emission is mainly associated with minimizing fuel and materials consumption and reducing waste generation in piling construction, which can be achieved through quality improvement of construction processes by implementing sustainable construction practices (Ametepey *et al.,* 2015). Noise and pollution are associated with the selection of the method of piling construction; suitable methods, and alternative ground stabilisation technologies can be used according to the viability to avoid environmental impacts (Jassim *et al.,* 2017). An adequate geotechnical investigation should be carried out before pile foundations are designed and the method of construction determined. It is essential to carry out a site exploration to ascertain the character and variability of the strata underlying the site of the proposed structure. As per Jami *et al*. (2019), the concept of reuse and recycling describes the idea that all components and materials can ever be reused, refurbished, and recycled, support life, and never have to be deposited as waste. Ground improvement techniques can be adapted for an increased range of ground conditions and environmental constraints. In-situ ground improvement using the high energy compaction and monitoring technologies comprises the improvement of the engineering properties of in-place ground materials at depth, both above and below the groundwater level (Saravanan 2011). The main advantage of this system is emphasized by Scott *et al*. (2019) as; quicker completion, no excavation is needed and there are no impacts on the environment, and this process involves very lesser equipment requirements in comparison to pile foundations. Likewise, sustainable piling construction technologies and techniques ensure that designed and constructed structures comply with high environmental standards and minimise the utilisation of resources, reducing waste, promoting the environment, and preserving human health and wellbeing (Yin *et al.,* 2018).

2.4 BARRIERS IN IMPLEMENTING SUSTAINABLE PILING CONSTRUCTION METHODS: GLOBAL ASPECTS

Lack of awareness on the relationship between environmental impacts and sustainable benefits becomes the major barrier for sustainable constructions (Gan *et al.,* 2015). According to Xu and Shi (2018), poor design and supervision of engineers have become a barrier to minimise material usage and related carbon footprint reduction. " Lack of piling construction expertise" has been highlighted as a key concern by Gianella and Stuedlein (2017). Moreover, lack of knowledge of ground improvement technologies and efficient pile construction techniques of the Engineer will hinder sustainability and cost-effectiveness in piling construction. Misra and Basu (2011) have mentioned that purchasing reusable anchors, and fuel efficiency devices will help contractors to reduce operational cost, however, the initial cost is required for the procurement and installation of such items in the process. Furthermore, contractor thinking only from the financial perspective also hinders the implementation of energy-saving measures which in the long run may make a substantial saving in cost and environmental friendliness. Hence, the risk attached to implementing a new method is crucially high in the construction industry, it can either be positive or negative and results in a reluctance to the contractor's attitude to introduce sustainable construction practices (Shan *et al.,* 2017). Unavailability of sustainable materials at the same time as the availability of unsustainable materials acts as a barrier to the use of sustainable materials in construction. Even though the relatively low cost of electricity and low energy prices are main causes of high electricity consumption in the Gulf Cooperation Council (GCC) countries (Taghavi *et al.,* 2015), high energy cost including electricity, fuel, oil, and gas affected cost-effectiveness and ultimately sustainability in Asian counties (Mangushev 2016). Hence, the electricity demand in GCC countries is exceeded and it resulted in increment in CO_2 emission. Hannigan *et al*. (2016) have mentioned that sustainable regulations and policies are to encourage sustainability practice in the construction industry, by awarding incentives and rewards to the organisations that practice sustainability. The lack of having such kind of rules and regulations reflects as a major barrier.

Zhussupbekov and Omarov (2016) have highlighted that the lack of skill level is also a barrier to sustainability, as sustainable construction needs skilled workers for the minimization of material wastages and maximizing process efficiency for added value by minimization of resource depletion, minimization of environmental degradation and creating a healthy built environment. Lack of coordination to manage resources more efficiently in piling construction is also a barrier for sustainable construction.

3. METHODOLOGY

The study focuses on identifying the impact on the environment due to current practices with piling construction and investigates barriers in implementing sustainable piling construction methods to minimise environmental issues in Sri Lanka. Thus, a quantitative research approach was adopted since it involves collecting and converting data into a numerical form (Jabbar 2017) so that statistical calculations can be made (Quick and Hall 2015) and conclusions are drawn, generalizing it across groups of people (Kas *et al.,* 2019). Besides, the literature was used as a secondary source to identify the impact on the environment and global barriers in implementing sustainable piling construction, and subsequently, all these factors were questioned in a questionnaire survey which was conducted to investigate the significant barriers to implementing the sustainable piling construction method to minimize environmental issues in Sri Lankan construction industry. According to Ikart (2019), a questionnaire survey helps to gather information from people about a predefined research problem and collects data during a short period from a large number of respondents scattered over a wide geographical area. The questionnaire can be divided into sections following the research objectives and included with both open-ended questions to encourage the respondent to provide free responses and closed-ended questions to get straightforward responses with quick answers (Antwi and Kasim 2015). The questionnaire survey was conducted among industry practitioners selected using the purposive sampling method to ensure that all the respondents had the relevant knowledge, authority, and experience in piling construction. Accordingly, 45 questionnaires were distributed among the survey participants and 30 questionnaires were eligible to consider for the detailed analysis which was received within the stipulated survey time frame. Besides, the number of respondents was limited due to time constraints, the accessibility issues with piling experts, and travel restrictions in Sri Lanka. The composition of the respondents is illustrated in Table 1.

Table 1: Details of respondents

		Percentage
Type of Organization	Piling construction firms	53%
	Civil construction firms	44%
	Consultancy firms	3%
Designation of Respondents	Project manager	24%
	Engineer	33%
	Quantity surveyor	40%
	Other	3%
Work Experience (Years)	less than 5	33%
	5 to 10	54%
	10 to 15	10%
	More than 15	3%
Experience in Green Construction Projects	Yes	33%
	No	67%

Quantitative data that is gathered from the questionnaire survey were analysed using the relative importance index (RII). RII is a well-recognized statistical tool used to measure the relative significance of several attributes and rank them (Wilfred and Sharafudeen 2015). The barriers to implementing the sustainable piling construction method that significantly affects the Sri Lankan construction industry were identified based on their RIIs that were calculated using Equation 01. According to Khaleel and Nassar (2018), the effect of each barrier group with RII values as Very High (RII > 0.8), High (RII 0.8-0.6), Average (RII – 0.6- 0.4) and Less (RII < 0.4).

$$RII = \frac{\Sigma (W n)}{A \times N} \tag{01}$$

Where, W- rating of each factor given by the respondent, n - frequency of the responses, N - total number of responses, A - highest weight.

4. RESEARCH FINDINGS AND DISCUSSION

The significance of the study is ascertained through the critical comparison of literature findings and analytical research findings. The key findings of the study are discussed in the following sub-sections.

4.1 AWARENESS OF SUSTAINABILITY ISSUES IN THE PILING CONSTRUCTION

The environmental impacts identified through the literature review were questioned under the following major impact categories during the survey.

1. Water, air, and sound pollution
2. Carbon emission and depletion of the ozone layer
3. Climate change and global warming
4. Scarcity of natural resources

Initially, the level of awareness was investigated to gather the present state of knowledge among the professionals engaged in piling construction. Figure 1 depicts the general awareness of the respondents concerning the sustainability issues in piling construction. The level of awareness is identified in terms of strong, moderate, weak and unawareness.

As shown in Figure 1, 30 % to 46% of respondents had strong awareness that due to piling construction there is an impact to above factors as denoted in blue. None had total unawareness.

Mohsenian *et al.* (2019) have emphasised the point revealed by Mangushev (2016) that climate change and global warming is an indirect result of piling construction and the awareness of it is at a low level. Yin *et al*. (2018) have mentioned that very few contractors and private developers are aware and spend efforts in considering the environment and developing the concept of recycling building materials. Shan *et al*. (2017) have concluded that the level of knowledge and awareness of project participants, especially project managers, with regards to environmental impacts of piling construction processes needs to be enhanced. Gaikwad and Shelavale (2017) have agreed with Zhussupbekov and Omarov (2016) by pointing that enhancing the awareness of the major environmental impacts of piling construction processes will help to improve the effectiveness of environmental management systems.

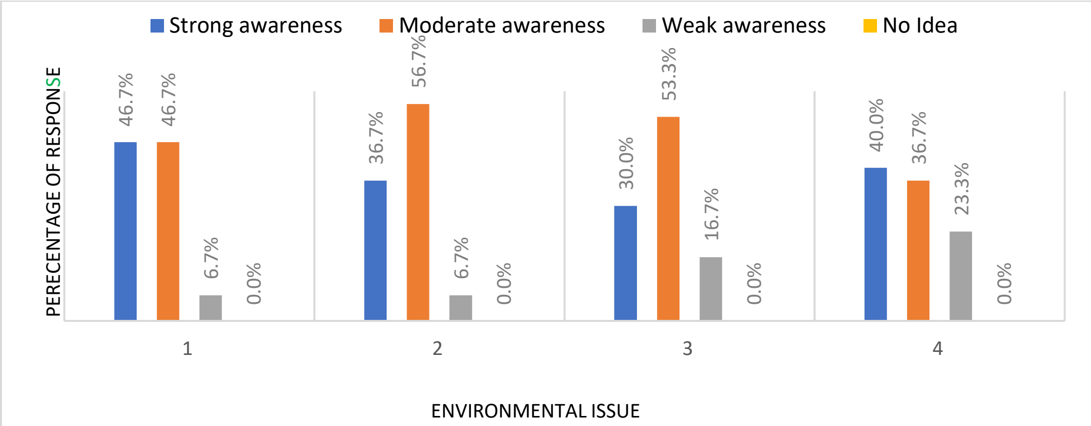

Figure 1: Awareness of the respondents on environmental impact due to piling construction

Further, the results indicate majority of the respondents have some kind of awareness about the environmental impact due to piling construction in Sri Lanka and moreover, the study revealed that majority of firms and institutions do not have proper environmental impact assessment practices.

4.2 BARRIERS IN IMPLEMENTING SUSTAINABLE PILING CONSTRUCTION IN SRI LANKAN CONSTRUCTION INDUSTRY

Based on the secondary data, ten barriers were identified, and respondents were asked to rank the relevancy of each barrier considering the Sri Lankan construction industry using the Likert scale 1 to 5 and the results are presented in Table 2.

Table 2: Barriers in implementing sustainable piling construction in the Sri Lankan construction industry

Description	SA	A	MA	D	SD	RII	Rank	Effect
Poor skill level and knowledge of labourers	5	8	10	3	4	0.647	6	High
Poor coordination among parties and site condition	4	9	11	5	1	0.667	4	High
Cost overrun due to poor pile design	4	17	7	1	1	0.747	1	High
Lack of awareness on sustainable pile construction techniques and technologies	6	10	7	5	2	0.687	3	High
Rules and regulations	3	5	9	10	3	0.567	8	Avg.
Investment risk	4	13	10	3	0	0.720	2	High
Lack of piling construction expertise	4	8	10	6	2	0.640	7	High
High cost of energy including electricity, fuel, oil, gas, etc.	3	10	12	4	1	0.667	4	High
Unavailability of sustainable materials	1	6	10	11	2	0.553	10	Avg.
Lack of awareness on environmental impacts and sustainable benefits	3	2	14	8	3	0.560	9	Avg.

SA: Strongly Agree-5; A: Agree-4; MA: Moderately Agree-3; D: Disagree-2; SD: Strongly Disagree-1

As depicted in Table 2, seven barriers were identified as significant barriers since RII values were between 0.6 and 0.8 in scale. According to the respondents, cost overrun due to poor pile design has been revealed as the major barrier to implementing sustainable piling construction practices in Sri Lanka. During the construction planning and design stage, sustainability assessment can be incorporated to ensure the overall sustainability and the cost-effectiveness of the project. The analysis of Meena and Luhar (2019) has indicated that in the utilisation of resources, driven piles use resources more efficiently than drilled shafts and ultimately avoid the cost overrun. Efficient and reliable pile design leads to saving of resources usage and the cost in piling construction and increases the profit (Saravanan 2011). Moreover, the design phase is fundamentally important in sustainable construction because it is responsible for defining the sources and the constructive technology that will be implemented by avoiding nonvalue added activities on site. The investment risk is recognised as the second most impacted barrier, which takes RII values as 0.720. The risk attached to implementing sustainable practices in piling construction is higher (Monahan and Powell 2011) and it leads to the contractor's reticence to implement sustainable construction (Li *et al.,* 2018).

Lack of awareness on sustainable pile construction techniques and technologies was highlighted through literature review and it is positioned as the 3rd barrier to sustainable piling construction in Sri Lanka. In-situ ground improvement is a modern technique of piling construction which has several advantages such as high speed of construction, less excavation, less equipment needed, cost effectiveness and environmental friendliness (Scott *et al*., 2019). Sondermann *et al.* (2016) have discussed Vibro stone columns (VSC) and they revealed that it is an economical and environmentally sustainable alternative to piling foundation solutions. Rapid impact compaction is a technique utilizing a 7-ton hydraulic piling hammer that repeatedly hits the ground with a heavy 1 to 1.5m diameter steel foot (Gianella and Stuedlein 2017). As per the respondents, such kind of piling construction techniques and technologies are not implemented in Sri Lanka due to a lack of knowledge.

Subsequently, "Poor coordination and condition of the site", "High cost of energy including electricity, fuel, oil, gas, etc." have been identified as the next important barriers to implement sustainable piling construction and RII value was0.667. Site pre-investigation, sub-surface obstacles, soil type, maintainability of pile equipment, lack of experience, disposal system of excavated soil, and site restrictions are the summarised basic factors affecting the productivity of the installation process of piling (Taghavi *et al.,* 2015). Construction waste disposal on-site is a critical issue and it results in environmental concerns such as degradation, habitant destruction, soil and groundwater contamination, and even generation of methane (Shan *et al.,* 2017). Even though the high cost of electricity and high energy prices has significantly impacted in Sri Lanka, Qader (2009) has argued that organizations in UAE ignored the opportunity for energy conservation and related triple bottom line benefits which can be achieved by adopting sustainable practices, due to the cheaper energy cost and sufficient availability of fossil fuel.

Poor skill level and knowledge of labourers and lack of piling construction expertise were identified as next significant barriers where RII was 0.647 and 0.640 respectively. It was similarly confirmed by Zhussupbekov and Omarov (2016) who identified that the poor skill level of labourers significantly influences the waste generation, quality of works, completion schedule, and the overall cost. Involvement of the most appropriate piling construction expertise with the required skill level and experience to deliver the sustainable project provide also the best value for money to the client (Monahan and Powell 2011). Rules and regulations, which motivate sustainable piling construction practices; lack of awareness on environmental impacts; and sustainable benefits, and unavailability of sustainable materials were identified as average effect barriers related to the Sri Lankan context since RII values of those three factors were less than 0.6. Jami *et al*. (2019) emphasised that rules and regulations, which motivate sustainable piling construction and unavailability of sustainable materials are barriers in Asian countries than the lack of awareness on environmental impacts and sustainable benefits, as it is confirmed by the survey results from the respondents. Hannigan *et al*. (2016) have emphasised that government plays an imperative role in accomplishing sustainability through the development and enforcement of the rules and regulations, which must be accepted by the industries. Even though, unavailability of sustainable materials is identified as a barrier to implement sustainable piling construction through secondary data, out of thirty (30) respondents eleven (11) respondents disagreed in the survey and placed it in 10^{th} rank in the Sri Lankan context.

5. CONCLUSIONS

The literature synthesis of this paper focused on piling construction, its impact to the environment and investigated barriers to implementing sustainable piling construction methods. The study revealed that there is an impact on water, air, and sound pollution; CO_2 and GHGs emission and depletion of the ozone layer; climate change and global warming, and scarcity of natural resources due to current practices of piling construction which ultimately effect on the environment. The findings also revealed that still less attention is given for the impact assessment of the eco system.

The literature synthesis also highlighted different technologies in piling construction and the underlying environmental concerns. Alternative technologies and improvement measures also have been identified. A range of barriers that lead to lack of sustainable practices in piling construction was identified from the literature synthesis and summarized in to ten (10) key factors.

In the global perspective, lack of awareness on the relationship between environmental impacts and sustainable benefits has become the major barrier for sustainable constructions. High energy cost including electricity, fuel, oil, and gas affected cost-effectiveness and ultimately sustainability. Sustainable practices in piling construction play a major role to attain competitive advantage through cost-effectiveness, performance efficiency, and sustainability. Contractor thinking only from the financial perspective hinders the implementation of energy-saving measures which in the long run may make a substantial saving in cost and environmental friendliness. Need of skilled workers for the minimization of material wastages and maximizing process efficiency for added value that minimise resource depletion, environmental degradation for creating a healthy built environment is also a key barrier.

The detailed questionnaire survey investigated the barriers that hinder sustainable piling practices in the Sri Lankan construction industry using the Relative Index Ranking. Findings showed that cost overrun due to poor pile design, investment risk, and lack of awareness on sustainable pile construction techniques and technologies as the most significant barriers to implement sustainable piling construction practices in Sri Lanka.

There is a need for promoting awareness among the professionals engaged in piling and construction on sustainable piling practices while also improving the skills of the workforce. The findings of this study will be useful in formulating strategies to overcome the barriers in sustainable piling practices and introducing new piling technologies in the Sri Lankan construction industry.

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BARRIERS IN PRACTICING LIFE CYCLE COSTING TECHNIQUES EXPERIENCED BY SRI LANKAN QUANTITY SURVEYORS

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ABSTRACT

Life Cycle Costing (LCC) is a tool, which can evaluate all the building-related costs over a specified period of time, as mentioned in the agreed scope. Though there are number of benefits, LCC practices of consultants in the building industry are claimed to be weak. Hence, the aim of this research is to investigate barriers in practicing LCC techniques experienced by Sri Lankan quantity surveyors. Accordingly, a mixed approached was followed in data collection through a questionnaires survey and a series of expert interviews. However, in Sri Lanka, building construction consultants are not practicing the LCC concept to a greater extent. This research identified, lack of awareness on the LCC tool by employers and practitioners, lack of knowledge on LCC and lack of previous data as the major barriers for practicing LCC techniques in local context. It was suggested that enhancing the practice of LCC through conducting various awareness programme on LCC concept, build up and maintain the proper database and introducing user friendly tools, applications, calculations methods, guidelines and regulations, will lead to avoid above mentioned barriers, which will ultimately enhance the proper practice of LCC concept in the Sri Lankan quantity surveyors.

Keywords: *Building; Construction; Life Cycle Costing (LCC); Sri Lanka.*

1. INTRODUCTION

Investing significant sum of money in the construction sector requires a careful appraisal to ensure that optimum use is being made of the sums invested. Yet often, investors or owners focus only on the initial cost when they make decisions and then they tend to ignore future maintenance costs and operation costs (Davies, 2004). LCC is a tool which also assists to determine possible cost reductions throughout the project life cycle (Bull, 1993). LCC is an approach to prior stage building project evaluation, that seeks to determine total expenditure of a facility by analysing all initial costs of purchasing and other associated costs including operational and maintenance costs throughout the design life of proposed building project (Kirk and Dell'Isola, 2003). According to Cole and Sterner (2000), discounting of future costs to present values is one of the key aspects in performing LCC. The authors state that this aspect of LCC enable the design option

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comparison to be made on a level playing field (Cole and Sterner, 2000). In addition, LCC can be used to predict the cash flow of an asset, for budgeting, for cost planning, for tendering, and for cost reconciliation. Further, LCC is a useful tool in design option appraisal and in assessing the present and likely maintenance costs in the future (Kelly and Hunter, 2009). Furthermore, ultimate conclusions from LCC output represents the total cost commitment of a facility, evaluation of various alternatives leading to reduce the unnecessary costs, enhance the cost transparency, recognise the different cost drivers and identification of risk factors as benefits of using the LCC techniques (Knauer and Moslang, 2005).

In the construction sector LCC is mostly used by the consultants as a tool for various purposes. Yet, in Sri Lanka, construction consultants are claimed to be heavily backward in practicing these LCC techniques. Therefore, this study intends to investigate barriers in practicing life cycle costing techniques experienced by Sri Lankan quantity surveyors.

2. LITERATURE REVIEW

2.1 LIFE CYCLE COSTING (LCC)

LCC has been defined as a technique which can use to measure all costs related to construction, operation, and maintenance of a construction project over a particular timeframe (Heralova, 2017).

Accordingly, the LCC technique gives an emphasis to a whole or the total cost approach consumed during the acquisition of a capital cost project or asset, rather than merely concentrating on the initial capital costs alone. Hence, LCC facilitates considering optional solutions for different variables involved and sets up hypotheses to test the confidence of the results achieved. Taking into account the initial capital costs, maintenance costs and replacement or the salvage costs and expressing these costs in comparable terms, this LCC as an asset management technique allows the operating costs of premises to be evaluated at frequent intervals, in which also can be recognised as its unique advantages (Ashworth *et al*., 2013). According to Ellram (1995), LCC is more concerned about capital or fixed assets (Ellram, 1995). Differently, another study stated that LCC can be used for any sort of a product (Aseidu and Gu, 1998). However, the main motivation for the implementation of LCC methods in the construction industry is LCC being identified as a tool for decision making (D'Incognito *et al*., 2015). Many professionals use LCC techniques for different applications leading to different purposes. Decision making at the design stage, to determine the performance impact throughout the lifespan of buildings, selection of most cost-effective project from a series of alternatives and assessment of new installation services against existing installation services can be recognised as some generic purposes of application of LCC techniques in the construction industry (Dale, 1993).

Furthermore, ultimate conclusions from LCC assessment output represents the total cost commitment of a facility which can be effectively utilise for reduction of building ownership cost, evaluating economic aspects of a project, enhancing the risk management process, monitoring the cost performance of a project, control design development, identify the cost of project, enhance the cost transparency, and also in recognising the different cost drivers as key benefits of application of LCC techniques (Knauer *et al.,* 2005).

2.2 BARRIERS FOR PRACTICING LCC

Akhlaghi (1987) conducted a case study, which was carried out to compare the LCC in five factory buildings in typical companies. In the study the authors analysed and measured each building's LCC and each case showed optimal performance of costs-in-use. During the study, the authors found a major barrier on the application of LCC as not having sufficient appropriate database, to cover the cost and performance (Akhlaghi, 1987).

In UK, another research study was conducted by Hunter et al., (2005), which carried out to develop a framework document and WLC input technique for use in public sector to enable QS. The methodology of this study comprised of four (04) phases. First stage was to have investigative interviews with the industrial expertise. The second stage is the comprehensive literature review. The presentation of WLC IT Tool is the third stage. The fourth stage was the demonstration at the annual SCQS conference for feedback. In this study the researchers faced various challenges during the study. Conclusively, the authors determined that major challenges are in collecting the LCC (capital, facilities management, and disposal) data. The lack of previous data of the building elements and services is the reason behind this challenge (Hunter *et al*., 2005). Samani *et al.* (2018) conducted a research aimed at comparing the LCC analysis of prefabricated composite buildings and masonry buildings in USA. The authors considered the four (04) life cycle stages; construction operation, maintenance and demolition, and buildings in the cities of Los Angeles, El Paso and San Francisco. The results of their study provided that, the significance of construction cost for both prefabricated and masonry structures are and higher value of maintenance and demolition costs of the prefabricated buildings. In addition, they identified that, the inadequate previous data and necessary hierarchy level of stakeholders as barriers in implementing LCC (Samani *et al*., 2018).

Higham *et al.* (2015) conducted a research aimed at evaluating LCC use in the UK practice. The authors used both qualitative and quantitative approaches for their study. Qualitative approach was used to understand the context-specifics whereas quantitative approach was used to test hypothetical generalisations. Meanwhile, this study showed, lack of awareness on the LCC tools by the employers and practitioners, unreliability of data, need of employers to keep the budget within short-term horizons and lack of common methods as inhibitors of the implementing LCC as an early phase project evaluation tool in the UK (Higham *et al*., 2015). In another study conducted by Herlova (2017), which carried out to study significant influence of LCC to the feasibility study in the government sector construction projects. This study identified and summarised the opportunities and challenges of using LCC in an early phase by means of a literature review and case studies. Accordingly, lack of industrial standards for reporting LCC and lack of previous cost data were identified as barriers to LCC implementation (Heralova, 2017).

D'Incognito *et al.* (2015) conducted a study to identify the actors and barriers to the adoption of LCC and LCA techniques in the construction industry. The study comprised two stages. In the first stage, they reviewed the previous research and the evaluation was done using content analysis. In the second stage, they designed a questionnaire survey based on the content analysis results. The questionnaire survey was conducted with selected professionals and industry experts in LCC and Life Cycle Analysis in construction sector. This study found that the organisational culture as the most significant barrier, when adopting LCC and LCA in the built environment. In addition, software tools, regulations and standards, data and information, approach and methodology were identified as the technical barriers for the same. Furthermore, this study revealed, incentive taxes and high costs of implementation as the financial barriers (D'Incognito *et al*., 2015). Korpi and Ala-Risku (2008) reviewed reports on LCC applications to provide an overview of LCC uses and implementing feasibility in the built environment. In the study the authors found that the characteristics of the operating environment encourages the implementing of LCC, purposes for calculating LCC, how do LCC implementations conform to the different methods, and how do the characteristics of the operating environment affect to the methods used in LCC analysis. In addition, the authors mentioned that lack of reliable data, lack of formal guidelines and lack of standards are the reasons for the slow adoption of the LCC (Korpi and Ala-Risku, 2008).

Lindholm and Suomala (2007) conducted a research aimed to discuss LCC management and practical challenges related to collecting adequate data and practicing long-term cost management in an uncertain environment. In this study the authors determined; inconsistent data collection, scarce of the LCC practice by employers and practitioners, different opinions of stakeholders as the major challenges in adopting LCC in built environment (Lindholm and Suomala, 2007). A generic framework for collecting whole life cost data for the building industry was presented by El-Haram *et al.* (2002). To achieve the aim, the study was conducted in six (06) levels as project level, phase level, category level, element level, and task level. In each level the authors found the data used to calculate WLC. The study determined that building consistent data on the execution of building elements and services, difficulties in arriving conclusions on LCC process of a building and, inadequate data of the building elements and services as major problems in LCC adoption in construction industry (El-Haram *et al*., 2002).

Dale (1993) determined in his study that, inadequate joined up thinking regarding the life cycle construction process of the building or the project, and fragmented nature of the built environment sector are the major problems to practice the LCC in construction industry (Dale, 1993). In addition, Cole and Sterner (2000) identified organisation structure as the main restricted reason for LCC adoption in public sector (Cole and Sterner, 2000). Furthermore, Steen (2005) conducted a research to investigate the possibilities of using LCA results to identify and estimate environmental costs or benefits in an LCC. In this study, the author mentioned that lack of enforcement capacity, lack of knowledge of who caused what damages to whom, lack of regional and global consensus as the preventing reasons when practicing this principle (Steen, 2005).

According to Norman (1990), the most difficult barrier to the implementation of LCC in the built environment is the unavailability of a useable and reliable data base. Positively, the study mentioned of many professionals and government bodies who are now involved in building data bases to in overcoming this barrier (Norman, 1990). Olubodun *et al.* (2010) conducted a research aiming to appraise the levels of application of LCC in the UK construction industry. The study revealed, lack of understanding on LCC, lack of standardised methodology, complex process, deficiency of accuracy in results and, artificiality of the process as barriers for implementation of LCC in the UK construction industry (Olubodun *et al*., 2010). According to Bruce-Hyrkas *et al*. (2018), difficulties in understanding, information is not timely for the design process, non-availability of building LCC background data, enabling non LCC experts to do the calculations reliably, inability to use existing building data efficiently and heterogeneous requirements of various certifications are the challenges of performing LCC in building construction industry (Bruce-Hyrkas *et al*., 2018).

In 2017, Schmidt and Crawford carried out a research to develop an integrated framework for assessing the life cycle of greenhouse gas emissions and LCC of buildings. Meanwhile, the research identified lack of transparent input data, lack of transparent calculations, and lack of early-stage design applications and lack of adjustable personal parameters as the major challenges to implementation of LCC approach (Schmidt and Crawford, 2017). According to Opoku's (2013) work, there are several barriers in practising LCC in the construction industry; i.e. not requested by employers, lack of consistent and reliable data on cost and performance, lack of interest/motivation from the employers, lack of understanding on LCC, lack of standard methods for practising LCC, and inadequate data on durability (Opoku, 2013). In Malaysia, another study conducted was by Khiyon and Mohamed (2018) to investigate the barriers and drivers of whole life cycle costing of sustainable facility management for PPP/PFI projects in Malaysia. The study revealed lack of incentives, lack of standards and methods, lack of motivation and inconsistency in underlying methodology and philosophy as the main barriers of implementation LCC in sustainable facility management for PPP/PFI projects in Malaysia (Khiyon and Mohamed, 2018).

The literature discussed above lead to identify the barriers for the built environment in practicing LCC techniques. The important barriers which affect the practicing of LCC in the construction sector are summarised in Table 1.

Table 1: Barriers affecting practising LCC in built environment

Barriers	References
Lack of previous and unrealistic data	[1], [2], [3], [4], [5], [6], [7], [8], [9], [12], [15], [16], [17]
Lack of software tools	[6]
Lack of awareness on the LCC tool by employers and practitioners	[4], [13], [16]
Lack of common methods in calculating LCC	[4], [6]
Lack of industrial standards for reporting the LCC	[4], [5], [6], [7], [13]
Lack of knowledge on LCC	[11]
Lack of formal guidelines	[6], [7]
Lack of regional and global consensus	[11]
Lack of transparency in calculations	[14], [15]
Lack of motivation / lack of interest from the employers	[16], [17], [18]
Lack of regulations and standards	[6], [17]
Need of employers to budget within short-term horizons	[4]
Different organizational cultures	[6], [11]
Complexity in approach and methodology	[6], [13], [17]
Incentive taxes	[6], [18]
Different opinions of stakeholders	[8], [10]
Managerial role	[3]

Barriers	References
Difficulties in arriving conclusions on LCC process of a building	[9]
Deficiency of accuracy in results	[13]
Artificiality of the process	[13]
Lack of early-stage design applications	[14], [15]
Lack of adjustable personal parameters	[10], [15],
High costs of implementation	[1], [4], [6]
Fragmented nature of the built environment	[9], [10]
Technological barriers	[6]

[1] (Akhlaghi, 1987), [2] (Hunter *et al*., 2005), [3] (Samani *et al.*, 2018), [4] (Higham *et al.*, 2015), [5] (Heralova, 2017), [6] (D'Incognito *et al*., 2015), [7] (Korpi and Ala-Risku, 2008), [8] (Lindholm and Suomala, 2007), [9] (El-Haram *et al*., 2002), [10] (Dale, 1993), [11] (Cole and Sterner, 2000), [12] (Steen, 2005), [13] (Norman, 1990), [14] (Olubodun *et al*., 2010), [15] (Bruce-Hyrkas *et al*., 2018), [16] (Schmidt and Crawford, 2017), [17] (Opoku, 2013), [18] (Khiyon and Mohamed, 2018)

3. RESEARCH METHOD

In the early stage of research, the background study and literature review were carried out to gain the knowledge from different sorts of resources; i.e. journal articles, conference proceedings, books, and electronic sources etc. The background study provided the basic idea of the knowledge gap and existing knowledge level related to the research problem. The literature review revealed the clear and deeper real scenario of the research problem. According to Creswell (2014), there are three research approaches as quantitative, qualitative, and mixed method. After considering the characteristic of this research, the mixed approach was identified as the best-suited approach.

Based on the findings of the literature review, to find out the barriers in practicing LCC experienced by the Sri Lankan quantity surveyors, a questionnaire survey was carried out with a quantitative approach. A closed-ended questionnaire was carried out allowing both manual and e-based responding options. Accordingly, 120 qualified quantity surveyors from different professional levels were selected as the sample through personally made requests. Ultimately, 85 dully filled questionnaires were collected with a response rate of 70.83%. The research sample of 85 quantity surveyors contains various designation categories of quantity surveying professions and quantity surveyors with range of experience levels, with the aims of gathering more accurate data. Accordingly, 18 assistant quantity surveyors, 41 quantity surveyors, 14 senior quantity surveyors, and 10 chartered quantity surveyors contributed with their input to the research. Further, 20 professionals out of 85 respondence are having more than ten years' experience and 29 professionals out of 85 are having more than five years' experience. Based on the 'Mean Weighted Rating' formula (Equation 01), quantitative data were analysed.

$$Mean\,Weighted\,Rating = \frac{\sum(V_i x F_i)}{n} \qquad (01)$$

Where, V_i -Rating given by the respondent, F_i - Frequency of responses, and n - Total number of responses.

After analysing the questionnaire survey data, a series of expert interviews was carried as the qualitative approach to elaborate the barriers and provide necessary mitigation actions for the same. The population for this study was considered only for charted quantity surveyors, working in the building construction industry in Sri Lanka. For this research, the target populations were limited to chartered quantity surveyors of both genders working at Colombo district. Using the convenience random sampling method, four (04) charted quantity surveyors working in consultancy services of building sector was selected. Table 2 shows the general information of the participated interviewers.

Table 2: General information of the interviewers

Interviewee	Position	Experience
R1	Chartered Quantity Surveyor	30 Years
R2	Chartered Quantity Surveyor	26 Years
R3	Chartered Quantity Surveyor	23 Years
R4	Chartered Quantity Surveyor	18 Years

4. DATA ANALYSIS AND RESULTS

4.1 QUANTITATIVE DATA ANALYSIS

The analysis of the collected data through the questionnaire survey is presented and discussed in the below section.

4.1.1 Barriers for Practicing LCC in Building Construction Consultants

LCC concept provides various benefits through its vivid applications in the construction industry context. However, the above literature review revealed 25 barriers for adopting LCC in building construction industry. According to the respondent's feedback, mean weight rate was calculated for each identified barrier. The analysis found lack of previous data, lack of awareness on LCC techniques by employers and practitioners, lack of common LCC calculation method, lack of industrial standards for reporting LCC outcome, lack of knowledge regarding LCC techniques, lack of formal guidelines, and lack of interest in the employers and practitioners as the common barriers for Sri Lanka building construction consultants in practicing LCC techniques. Table 3 presents the barriers of practising LCC techniques by quantity surveyors in Sri Lankan construction industry.

Table 3: Barriers in practising LCC in Sri Lankan building construction industry

Rank	Barriers	Mean Weighted Rate
01	Lack of awareness on the LCC tool by employers & practitioners	1.38
02	Lack of knowledge on LCC	1.30
04	Lack of previous data	1.29
05	Lack of industrial standards for reporting the LCC	1.15
06	Lack of motivation/interest from employer & practitioners	1.11
07	Lack of formal guideline	1.07
08	Technological barriers	1.00

4.2 QUALITATIVE DATA ANALYSIS

This section presents the qualitative data analysis in which the data were gathered through expert interviews. Based on the analysis of collected data of the questionnaire survey, expert interviews were mainly focused to obtain practical solutions for the identified barriers in quantitative analysis.

4.2.1 Solutions for the Identified Barriers

The following barriers have been identified as barriers for building construction consultants in practicing LCC techniques in Sri Lankan construction industry. The solutions for identified barriers are discussed below.

- Lack of awareness on the LCC tool by employers and practitioners

R2 expressed, *"enhancing the practice of LCC*" is the solution for lack of awareness on the LCC tool by employers and practitioners. Further, all the interviewees mentioned that conducting new awareness programmes regarding LCC as the commonly accepted solution for the lack of awareness on LCC by employers and practitioners. In addition, R2 stated "*introducing various user-friendly tools, applications and systems*" also as a solution for the same barrier. Beside from that, R3 and R4 interviewees expressed the importance of including LCC techniques as a module in education courses.

- Lack of knowledge on LCC concept

According to all the respondents, the solutions for the lack of knowledge on LCC concept is, conducting courses on LCC for the employers and practitioners. In addition, R2 stated that enhancing the practice of LCC is also helpful. Moreover, R3 added that "*by showing the comparison of LCC in different options and show the long-term savings of applying LCC for the employers*". In addition, the R4 expert said, "*include the mentioned area as a module in education courses*" as a solution for this barrier.

- Lack of previous data

Respondents R1, R2, R3 and R4 conveyed the necessity of maintaining a database, as a solution to this barrier. According to the perspective of R2 and R3, this database can be maintained by employers, contractors, and design consultants. However, R4 representative expressed, "*in order to maintain a database in solution to this barrier, data must be collected from employers, however, employers are very reluctant to give those data*". Therefore, the recognised regulatory body has to make interference to build up and maintain the database. Further, R1 and R3 stated that, CIDA, IQSSL, IESL, and SLIA are the possible regulatory bodies, who can interfere for this issue and gather cost data for building up the database.

- Lack of industrial standards for reporting the LCC

All the interviewees mentioned that establishing proper new standards by relevant organisations or institutions as the solution for this barrier. R4 stated, "r*ecognised regulatory body has to take the responsibility to do that*". Further, R1 suggested CIDA as a regulatory body and R3 suggested SLS as probable regulatory bodies.

- Lack of formal guidelines

All the participants stated establishing a proper, user-friendly guideline as the solution for this barrier. R3 suggested that SLS or other relevant organisations should introduce new guidelines.

- Lack of interest regarding the LCC by the employers and practitioners

R1 and R2 mentioned, introducing user-friendly tools, applications, systems, and guidelines as a solution for the mentioned barrier. In addition, R3 and R4 interviewees emphasised, the need for improving the awareness on LCC tool and benefits of applying LCC techniques. Further, R3 expressed, "*implementing LCC for the project can be a high initial cost*", therefore, commonly employers are reluctant to practice these techniques. Further, the participants suggested that "*if it is possible to find out to capitalise long-term maintenance cost and as an investment today*", it will lead to mitigate the barrier.

- Lack of common LCC computing method

R1 and R2 interviewees stated introducing user-friendly new common calculations method as a solution for this barrier. R3 expressed "*new computing method can be prepared based on standard designs and LCC based designs*". R4 mentioned the need for improving the education courses pertaining to this area as a module will lead to mitigate this barrier in the long run.

- Technological and software barriers

According to all interviewees, the solution for technological and software barrier is to introduce new suitable technologies and software tools for the industry. However, R1 stated "*these software's are very expensive therefore it is necessary to improve the funds to adopt these technologies and software tools*". In addition, R3 and R4 expressed, local practitioners and employers, are backward in adopting new technology due to their attitude and culture. Therefore, changing the practitioners and employers' attitude and the culture of local context will help to mitigate mentioned barrier.

- Lack of regulations

All respondents suggested to establish and implement the prevailing rules and regulations accordingly as a solution for the mentioned barrier. Further, R3 stated that "*by changing practitioners and employer's attitude*" above-mentioned barrier can be mitigated.

5. CONCLUSIONS

In the international context practice of LCC techniques were limited due to various barriers. Comparatively, the Sri Lankan quantity surveyors are very reluctant to practice LCC techniques due to different barriers. Lack of awareness of the LCC tool by employers and practitioners, lack of knowledge on LCC, lack of previous data, lack of interest from the employers and practitioners, lack of common LCC calculation method, lack of formal guidelines lack of industrial standard for reporting LCC are the most frequent barriers hindering practice of LCC techniques in local building construction sector. In addition, the lack of industry regulations, various technological and software tools restriction also discourage the implementation of LCC.

Moreover, the intervention of industry practitioners and government will lead to enhance the practice of LCC, mitigating the above barriers. However, most of the solutions for the above barriers are interconnected. Therefore, recognised professional bodies within local construction industry like CIDA, IQSSL, IESL and, SLIA can promote the practice of LCC concept in Sri Lanka building construction industry by initiating the new awareness programme focusing on the benefits and applications of LCC concept, improve the training of LCC, introducing user friendly systems, and applications of LCC and including LCC as a module of education courses. In addition, government involvement through regulations and control on the prevailing or new LCC regulations, standards and guidelines will provide the solutions for the above barriers. Further, lack of previous and live data is one of the major barriers in local and international context in practicing LCC techniques. However, a proper data base is maintained by RICS in the UK. Therefore, it is necessary to build up and maintain the proper database in the Sri Lanka to avoid this particular barrier. Adopting the UK system, the regulatory bodies in Sri Lanka must take responsibility to develop and maintain a proper data base. As the responsible regularity bodies CIDA, IQSSL, IESL, and SLIA could take up the responsibility to gather and develop cost data base.

The above solution can avoid or mitigate the above barriers while contributing to the better practice of LCC techniques by quantity surveyors in Sri Lanka.

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CHALLENGES AND ISSUES OF ENVIRONMENTAL PROTECTION INSTRUMENTS RELATED TO INFRASTRUCTURE DEVELOPMENT PROJECTS IN SRI LANKA

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ABSTRACT

The construction industry is required to improve sustainability to increase the rapid growth of the economy of Sri Lanka. The Central Environmental Authority (CEA) has introduced Environmental Impact Assessment (EIA) survey, Initial Environmental Examination (IEE), and Environmental Protection License (EPL) as environmental protection instruments that have been correlated with construction projects. To interrupt the smooth performance of the EIA, IEE, and EPL, many challenges have been associated with these procedures. The research problem was approached through six preliminary interviews to refine the identified challenges and issues related to EIA, IEE and EPL with their processes within the Sri Lankan context. Based on the preliminary interview results, forty questionnaires were distributed to investigate the level of significance of the challenges and issues with regard to EIA, IEE, and EPL related to development projects. For this research, mixed research approach is used. Collected data were analysed in terms of statistical analysis and content analysis using NVivo 12 software respectively. The analysed data were revealed different issues of EIA, IEE, and EPL instruments in Sri Lanka. Especially challenges related to regulatory bodies were identified. According to the research, there were many adverse effects due to the ineffective implementation of environmental protection regulatory instruments. Similarly, it revealed that issues were affected to the time, cost, and quality of the construction projects. Ultimately, it provided proper guidance for implementing EIA, IEE, and EPL instruments and the necessity of implementation of a post-monitoring mechanism for environmental protection instruments.

Keywords: *Environmental impact assessments; Environmental instruments; Environmental issues; Environmental protection.*

1. INTRODUCTION

Development projects support people to meet social needs and affect the economic growth of a country (Abidin, 2010). To achieve expressive growth in the economy, developing countries must promote infrastructure development projects (Lenferink *et al.*, 2013). Traditional constructions and designs focus only on their time, cost, and quality

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and, little attention is paid to environmental impacts (Ofori, 1990). Infrastructure development projects are considered the most environmentally unfriendly human activity among various kinds of construction activities (Gu and Sheate, 2010). Sustainable Developments addresses the integration of triple bottom line principles within the Social, Environmental and Economic dimensions of sustainable construction (Fugar and Agyakwah-Baah, 2017). Proper environmental protection instruments lead to manage the environmental impacts of construction projects, by minimising the unexpected delays, reducing the cost of construction, and assisting in considering a range of measures on-site by determining the major environmental impacts towards sustainable developments (Gangolells *et al*., 2009). In Sri Lanka, Environmental Impact Assessment survey (EIA), Initial Environmental Examination (IEE), Environmental Protection Licensing (EPL) are the major environmental protection regulatory instruments that are available to regulate environmental impacts of Construction projects (Samarakoon and Rowan, 2008). EIA is applicable for mega-development projects and IEE for minor development projects by enforcing the National Environment Act (NEA), and EPL for all construction activities published in the Gazette No.1533/16 dated 25.01.2008 (Zubair, 2001). The effective implementation of EIA, IEE, and EPL procedures is impeded mainly by challenges and issues in Sri Lanka (Kodituwakku, 2010).

EIA, IEE, and EPL are important environment management and regulation tools, which have been established to mitigate the negative impacts and increase the positive impacts to the environment and the general public, which occurs due to construction and development activities (Bradley and Swaddling, 2018). The effectiveness of the implementation of environmental impact assessment procedures often remains a challenge (Cashmore *et al*., 2015). They are weaknesses in several EIA, IEE, and EPL practices, lack of provisions for EIA, IEE assessments, weak compliance monitoring, insufficient quality control exercised over EIA reports, deficiencies in the government and lack of expertise involvement, challenges due to political and economic influences etc (Bradley and Swaddling, 2018). In Sri Lanka, the entire EIA process is bypassed by some developers through various kinds of unauthorised pathways (Zubair, 2001). It was found that there was a limited number of research on the challenges of implementing environmental protection regulatory instruments such as EIA, IEE, and EPL in the Sri Lankan context. Owing to the absence of proper information, this research seeks out to address this gap by exploring the challenges and issues of environmental protection instruments and to make recommendations for the effective implementation of EIA, IEE, and EPL for infrastructure development projects in Sri Lanka.

2. LITERATURE REVIEW

2.1 INFRASTRUCTURE DEVELOPMENTS

New infrastructure developments would be located in developing countries, which consist of many of the world's most biologically rich and ecologically sensitive ecosystems (Grumbine *et al*., 2018). To achieve sustainable output from highly invested infrastructure developments in the 21st century, people wanted to develop their nations, at the same time protecting the environment, preserve its existence, and doing less harm to society. That is why people have introduced environmental regulations and impact management instruments as an effort to mitigate environmental and sociological impacts (Finer and Jenkins, 2018).

2.2 ENVIRONMENTAL PROTECTION INSTRUMENTS

2.2.1 EIA Survey

The core purpose of the EIA survey is to establish the inseparable linkage between the environment and sustainable development (Hannayake *et al*., 2012). The EIA process recommends several steps and procedures for a project to reduce the negative environmental impacts and strengthen the positive environmental impacts (Hák *et al*., 2016). According to various researchers, five objectives of EIA were identified, which fall under several types of constructions and infrastructure development projects as given in Table 1.

Table 1: Purposes of EIA

Purpose	Source
Control of projects and their environmental impacts	(Arts and Saunders, 2014)
Promote an adaptive management approach and maintain decision making flexibility	(Gangolells *et al*., 2009)
Improve technical and scientific knowledge	(Fadl and Fadel, 2014)
Improve public acceptance and awareness	(Fadl and Fadel, 2014)

2.2.2 IEE

IEE is a short and simple study, which is applied for the projects, with less environmental impacts, while the EIA is considered as a full assessment of the effects of a project with high environmental impacts (CEA, 2013). The main objectives of an IEE study are to identify the biophysical, socio-economic and cultural environment; identify, predict and evaluate, possible beneficial and adverse impacts; and finally recommend environmental mitigation and enhancement measures along with environmental monitoring requirements, which are practical and site-specific for a proposed development project (Bhatt, 2013).

2.2.3 EPL Process

EPL is a regulatory document under NEA to control the discharge of effluents, depositions of wastes, emission of smoke/gases, or excessive noise/vibration into the environment by construction activities (NEA, 2000). EPL processes have been interrelated with the EIA, IEE procedures within the construction and development processes (Environmental Pollution and Control Division, 2009). Obtaining an EPL through the approved procedure is the major requirement of a recognised EPL (Environmental Pollution and Control Division, 2009).

2.3 ADOPTION OF EIA, IEE AND EPL IN SRI LANKA

In 1981, the EIA was first introduced to Sri Lanka under the Coast Conservation Act, No. 57 of 1981 (Hannayake *et al*., 2012). EIA, IEE and EPL for the entire country were introduced by the National Environmental (Amendment) Act No.56 of 1988 (Hapuarachchi *et al.,* 2016). The first EIA was conducted in Sri Lanka for the Accelerated Mahaweli Development Project in 1980 (Sivaramanan, 2017). Between 1981 and 2005, there were more than 460 EIAs and IEEs completed, within Sri Lanka, and most of them (87%) were carried out under the NEA and just 6% of the EIAs and IEEs were carried out under the North-western Provincial Environmental Statute (NWPES) and 5% of them under the Coast Conservation Acts and remaining 3% under the Asian Development Bank and World Bank regulations (Samarakoon and Rowan, 2008).

2.4 PROCEDURE OF EIA AND IEE IN SRI LANKA

The EIA procedure is compulsory for projects, which are located in ecologically sensitive areas and also for mega-developments projects in Sri Lanka (Gunawardena, 2000). The EIA process is applied only to "Prescribed Projects" and executed through a nominated Project Approving Agency (PAA), under the provision of section 23Z of the NEA, which has been specified by the Minister of Environment (GOSL, 1995). In Sri Lanka, the EIA and IEE process could be considered as a very simple and straightforward process and it includes six major steps of Environmental Impact Assessment (Environmental Impact Assessment Unit, 2006).

1. **Preliminary information** - The initial stage of the EIA and IEE process, which will lead to the key decision, either carrying out an assessment or not. This stage initiates with the submission of preliminary information about the prescribed development project by a Project Proponent (PP) (International Institute for Sustainable Development, 2020).
2. **Environmental Scoping** - This is a key step in preparing an EIA and IEE because it could identify the most important issues in the EIA and IEE process and eliminate those that are less important (Fadl and Fadel, 2014).
3. **EIA, IEE Report Preparation** - The EIA and IEE report is a summary of several key important project components, including project description, social and environmental impact assessments, mitigation measures, and related management and monitoring plans. In this step, all the data collected in the previous steps is composed into a detailed and comprehensive report, which will analyse and synthesise the data according to the requirements (Amato *et al*., 2017).
4. **Public Participation (only for EIA) and Evaluation of the Report** - The evaluation report shall be performed to validate the accuracy of the information and procedures used in the EIA and to ensure that all relevant mitigation steps and all accumulated and essential impacts are addressed in the EIA report (Wijayadasa, 1994).
5. **Decision Making** - PAA determines whether to approve the project based on the Technical evaluation committee’s recommendation and if the PAA is not the CEA, the CEA permission should be obtained prior to granting approval (CEA, 2013).
6. **Compliance Monitoring** - Compliance monitoring provides details on the social and environmental impacts of the project over the entire life cycle of the project (Su *et al*., 2017).

2.5 LEGAL FRAMEWORK ON EIA, IEE AND EPL IN SRI LANKA

Sri Lankan Parliament enacted legislation on environmental protection, spanning over two centuries that took the form of royal decrees and customary law (Weeramantry, 1997). Afterward various environmental regulations implemented by the British rulers continue to be applied and enforced. Currently, four environmental assessment legislation have been implemented mainly, and four institutions are in charge of these legislation (Liyanawatte and Dias, 2017).

They are namely:

- Central Environmental Authority in charge of the **National Environmental Act** (NEA, 1988) - NEA is enacted to serve as the main legislation for environmental protection. The EIA, IEE and EPL instruments were introduced by the NEA, in order to drive sustainable developments for the entire country.
- Department of Coast Conservation in charge of the **Coast Conservation Act** (CCA, 1981) - EIA was first introduced by the Coast Conservation Act. The "Coastal zone" includes areas with an average high-water level of 300 meters and an average low water level of 2 kilometres. CCA requests developers applying for a permit (activities in the coastal zone) to provide EIA, IEE related to the development project. According to CCD, EIA must be carried out when the effect of the project is significant and also the constructions cannot be carried out in “No Build Areas”.
- North-western Provincial Council in charge of the **North-western Provincial Council Environmental Statute** (NWPES, 1990) - Only the Northwestern Province (NWP) in Sri Lanka has enacted a provincial statute that supersedes the writ of NEA in that province. Legal provision for EIA, IEE and EPL in the NWP is given by the NWPES. The EIA and IEE procedure and the EPL procedure have been combined, within NWP according to NWPES.
- Department of Wildlife Conservation in charge of the **Flora and Fauna (Amended) Act** (FFA, 1993) - Any construction project that is supposed to be carried out within one mile of the boundary of any national reserve must be subject to an EIA. Clients should obtain written approval from the Director-General of the Department of Wildlife Conservation before implementing such projects.

3. RESEARCH METHODOLOGY

For this research, a mixed approach was adopted due to the requirement of assessing subjective data as expert’s opinions and identify the level of significance as questionnaire survey responding levels. When collecting data from the experts all the relevant parties were involved. Similarly, due to the sensitivity of the environmental data, the semi-structured interviews were carried out not only with the construction experts but also with a legal expert, an environmental expert, NGO personnel involved in environmental matters, and an expert in the government sector involved in environmental matters, who have more than 10 years of experience. In the first stage, six expert interviews were carried out to achieve targets such as for the confirmation of suitability of identified challenges and issues of EIA, IEE, and EPL under three subcategories such as challenges and issues related to, legislation and regulatory agencies, the current performance of EIA, IEE and EPL in Sri Lanka and through literature review. The research was received 40 responses from a questionnaire survey out of 46, in order to identify the level of significance of each challenge and issue related to EIA, IEE, and EPL instruments.

In this research, preliminary interview results were analysed through manual content analysis. Parametric tests were selected as data analysis techniques of the questionnaire survey. Minitab 17 software was used to analyse the questionnaire survey data to achieve the main objective of the questionnaire survey. Suggestions and recommendations which had been given by experts at stage - II were analysed using content analysis which was done using NVIVO software version 12. Figure 1 illustrates the data collection methods used for the study.

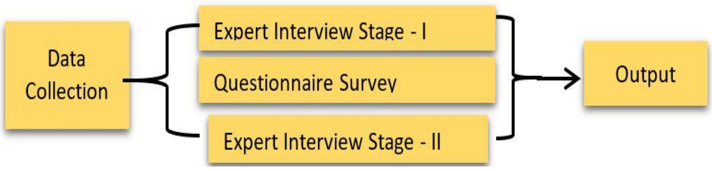

Figure 1: Data collection

4. RESEARCH FINDINGS

4.1 DETAILS OF RESPONDENTS

Table 2 provides the details of the experts who were involved in the expert interview stages I and II.

Table 2: Details of interviewees for expert interview stages I and II

Interviewee	Profession	Years of Experience	Field
E1	Chartered Quantity Surveyor	15	Construction (Specialised in Infrastructure Developments)
E2	Chartered Quantity Surveyor	12	
E3	Chartered Civil Engineer	16	
E4	Lawyer/Former Legal Manager engaging in environmental-related activism	10	Legal Field -specialised for EIA/IEE and EPL related cases
E5	Director in a government body	10	Government
E6	Environmentalist (well experienced environmental-related activism)	18	Environment

The quantitative analysis was carried out using the data collected from the results of the questionnaire survey and it was distributed to 46 experts in serval industries and 40 experts replied to the questionnaire (refer Table 3).

Table 3: Respondents of the questionnaire survey

Designation of the respondents	Years of Experience					Number of Respondents
	5 to 10	**10 to 15**	**15 to 20**	**20 to 25**	**more than 25**	
Quantity Surveyor	7	3	3	1		14
Project Manager	2	2	1		3	8
Construction Manager	3		2	2		7
Legal Experts		2	1			3
Environmentalists		2			2	4
Members in NGOs involved in environmental matters	1	1				2
Relevant officials in government institutions		1	1			2
	Total Responses					**40**
	Total Distributed					**46**
	Rate of Response					**87%**

4.2 CHALLENGES AND ISSUES RELATED TO EIA, IEE AND EPL IN SRI LANKA

According to the literature findings, seventeen challenges and issues related to EIA, IEE, and EPL were identified. Those challenges and issues are,

- Related to legislation and regulatory agencies of EIA, IEE, and EPL in Sri Lanka
- Related to the current Performance of EIA, IEE, and EPL in Sri Lanka
- Related to the process of EIA, IEE and EPL in Sri Lanka.

After the expert interview stage - I, those challenges and issues were refined according to the level of relevance provided by each expert. According to the experts, four challenges and issues were eliminated from the literature findings and ten new facts were added and those refined twenty-three factors were listed out in the questionnaire survey to derive the level of significance of each factor. In the questionnaire survey, the experts have presented their responses. In this way, their opinions regarding the questionnaire were analysed, and the opinions were reviewed utilising the RII method. Five important levels are transformed from RII values as given in Table 4: high (H) (0.8 ≤ RII ≤ 1), high-medium (H-10 M) (0.6 ≤ RII ≤ 0.8), medium (M) (0.4 ≤ RII ≤ 0.6), medium-low (M-L) (0.2 ≤ RII ≤ 0.4) and low (L) (0 ≤ RII ≤ 0.2) (Taherdoost, 2016).

4.3 CHALLENGES AND ISSUES RELATED TO LEGISLATION AND REGULATORY AGENCIES

Table 4 illustrates the derived analysis results for the facts of challenges and issues related to legislation and regulatory agencies of EIA, IEE and EPL. Data analysis was done in Minitab 17 software. It shows the RII values for individual causes in descending order with their ranks.

The first rank received "Loopholes due to the list of prescribed projects (RII 0.92)", and it is the most significant cause according to the analysis results. Over 60% of experts marked scale as "Strongly agree" for this cause. All these eight factors are challenges and issues related to legislation and regulatory bodies, and the level of their significance are differing with RII values.

"Shortcomings and constraints in provisions for the public review by the gazette" took the second-highest RII value (RII 0.87) among eight factors. The third highest RII value (RII 0.76) was received by the factor of "Lack of apprehension provisions for EIA, IEE and EPL violators". In addition to that "Inadequacy of provisions in the NEA for PAA" and "Lack of qualified staff in CEA and CCD" factors received the lesser level of significance with 0.49 and 0.55 of RIIs respectively.

Table 4: Results of challenges and issues related to legislation and regulatory agencies of EIA, IEE and EPL

No	Challenges and issues related to legislation and regulatory agencies	RII	Rank	Level of Significance
1	Loopholes due to the list of prescribed projects	0.92	1	High
2	Shortcomings and constraints in provisions for the public review by the gazette	0.88	2	High
3	Lack of apprehension provisions for EIA, IEE and EPL violators	0.76	3	High-medium

No	Challenges and issues related to legislation and regulatory agencies	RII	Rank	Level of Significance
4	Enforcement of separate statute for the North-western Province instead of NEA	0.68	4	High-medium
5	Lack of guidance, given by the CEA to PP (client) in EIA, IEE, or EPL	0.65	5	High-medium
6	Improper guidance of CEA for a proper EIA, IEE and EPL implementation	0.61	6	High-medium
7	Inadequacy of provisions in the NEA for PAA	0.55	7	Medium
8	Lack of qualified staff in CEA and CCD	0.49	8	Medium

4.4 CHALLENGES AND ISSUES RELATED TO THE CURRENT PERFORMANCE OF EIA, IEE AND EPL IN SRI LANKA

One to eight causes were analysed and derived their RII values. Table 5 indicates the evaluated results in descending order. The level of significance is indicating their RII values and ranks.

Table 5: Challenges and issues related to the current performance of EIA, IEE and EPL in Sri Lanka

No	Challenges and issues related to the current performance of EIA, IEE, and	RII	Rank	Level of Significance
1	Inadequate post EIA, IEE, and EPL monitoring	0.95	1	High
2	Problems with existing environmental data	0.87	2	High
3	The inability of identifying the cumulative impact of multiple projects in an area	0.87	2	High
4	Less consideration on reasonable alternatives	0.83	4	High
5	Unavailability of quality, technical and procedural guidelines for the processes	0.80	5	High
6	Low quality of the reports, produced by the current EIA, IEE and EPL mechanisms	0.76	6	High-medium
7	Lack of public awareness	0.73	7	High-medium
8	EIA and IEE always govern a reactive mechanism, not a proactive mechanism	0.67	8	High-medium

The highest RII value of 0.95 was taken “Inadequate post EIA, IEE and EPL monitoring" and it is marked as rank one. Likewise, over 70% of experts marked scale as “Strongly agree” for this cause. That is the most significant issue related to the current performance of EIA, IEE and EPL in Sri Lanka. Rank two with an RII value of 0.88 had been taken by both “Problems with existing environmental data” and “Inability of identifying the cumulative impact of multiple projects in an area” factors.

4.5 CHALLENGES AND ISSUES RELATED TO THE PROCESS OF EIA, IEE AND EPL IN SRI LANKA

There are seven factors for challenges and issues related to the process of EIA, IEE and EPL in Sri Lanka. Those results were computed through Minitab 17 and a summary is presented in Table 6 in descending order.

Table 6: Results of challenges and issues related to the process of EIA, IEE and EPL in Sri Lanka

No	Challenges and issues related to the process of EIA, IEE and EPL in Sri Lanka	RII	Rank	Level of Significance
1	Influences of the politics to EIA, IEE and EPL processes	0.93	1	High
2	Inadequacy of funds to run many of the PAAs and other EIA cells	0.83	2	High
3	Lack of professional ethics of EIA consultants	0.80	3	High
4	Conflicts of interests for the PAA	0.75	4	High-medium
5	Lack of tolerance standards	0.72	5	High-medium
6	The limited time frame which is given for PAAs	0.70	6	High-medium
7	Influences due to various economic aspects	0.63	7	High-medium

"Influences of the politics to EIA, IEE and EPL processes" (RII 0.93) received the rank one, and it is the most significant cause in this category. Over 70% of experts marked scale as "Strongly Agree" for that cause. the rank two was taken for "Inadequacy of funds to run many of the PAAs and other EIA cells" with an RII value of 0.83. Accordingly, "Lack of professional ethics of EIA consultants" took the third-highest position (RII 0.80).

4.6 REMEDIES TO OVERCOME THE CHALLENGES AND ISSUES

According to the similar phenomena that have been identified from the previous research carried out in several countries, the solutions were introduced for the most significant top five challenges and issues related to environmental protection regulatory instruments. Therefore, in this research, also the most significant top-five ranked challenges and issues which were ranked using RII were derived to identify recommendations from the experts. For that, an expert interview stage II was carried out.

After analysing challenges, suitable solutions to overcome the most significant challenges were discovered under the expert interviews - stage II. The expert who was interviewed initially (E1), was given a chance to provide suggestions and recommendations for the challenges and issues, commonly for each category, and for the challenges specifically mentioned by him. After E1, all other interviewees were asked for providing solutions for the major challenges and issues identified under each subcategory. Likewise, the following solutions were generally identified and agreed upon by the experts under each category of challenges and issues.

Table 7 elaborates nineteen (19) suggestions and the number of references for each, that were identified for mitigation of challenges and issues. Suggestions with a greater number of references according to NVivo analysis could be identified as more vital facts.

Table 7: Suggestions to overcome the challenges and issues

Category of challenges and issues	Suggestions to mitigate	No of References
Challenges and issues related to legislation and regulatory agencies	1. The list of projects prescribed and the limitations should be reduced	**6(6)**
	2. The time allocated for public review and involvement especially for complex development projects should be increased	**5(6)**
	3. Strictly enforce apprehension provisions for people who bypass EIA, IEE and EPL procedures	**6(6)**
	4. Quality and technical guidelines should be prepared and make available to get proper guidance for the employers when implementing a construction project	4(6)
	5. NWPES should be abolished and NEA should be enforced for the whole country	**6(6)**
Challenges and issues related to the current performance of EIA, IEE, and EPL in Sri Lanka	6. Environmental cells of the PAA should be occupied with, full-time talented staff and other related facilities which are required for proper EIA and IEE monitoring	4(6)
	7. The environmental data which are required for the EIA/ IEE and EPL procedures should be accumulated and made available to the relevant PP and EIA and IEE consultants by the relevant PAA	5(6)
	8. The environmental data limitations and shortcomings must be highlighted by the CEA and the actions must be taken to obtain them	3(6)
	9. The PAA should develop a scheme of taxes or levies to cover up the costs related to EIA and IEE	2(6)
	10. Identification of the types of development projects to be promoted in each region and implemented within the country with the intercession of the CEA	**5(6)**
	11. Areas to be reserved for environmental conservation and industries should be zoned within the country	4(6)
	12. The provisions for multiple PAAs, in the NEA, should be followed in the case of multi-sector infrastructure development projects	4(6)
	13. All officials in the EIA, IEE and EPL should be aware of all environmental aspects of project appraisal	**5(6)**
Challenges and issues related to the process of EIA, IEE and EPL in Sri Lanka	14. The regulations related to EIA and IEE procedures have to be strengthened and expanded in order to give more supervision on infrastructure developments	4(6)
	15. Proper safeguards such as improved transparency must be in place to make sure that the Project Approving Agencies are not inattentive or politically influenced	**5(6)**

Category of challenges and issues	Suggestions to mitigate	No of References
	16. Financial problems and difficulties have to be overcome by levies, which make the client and the government 50% to 50% for essential services	**5(6)**
	17. A proper mechanism should be introduced to monitor the unethical actions of EIA consultants	2(6)
	18. The CEA should develop a code of conduct for EIA and IEE consultants with the help of suitable professional bodies	**6(6)**
	19. The tolerance standards which have been given by the CEA for the discharge of construction wastes should be amended as a more comprehensive outcome	3(6)

5. CONCLUSIONS AND RECOMMENDATIONS

The construction industry can be considered a highly contributing sector in the economy of a country. When considered the Sri Lankan construction industry, currently there are many infrastructure development projects are being carried out in order to fulfil the requirements of a rapidly growing population. Due to this rapidly growing requirement of infrastructure development projects, there is also an increasing huge adverse impact on the environment by the constructions. With the intention of regulating this issue, the Sri Lankan government has introduced several legislations and controlling bodies to implement several worlds recognized environmental protection regulatory instruments in order to regulate the adverse impacts on the environment by the construction industry and pushing them towards the expected sustainable outcome. EIA, IEE, and EPL are the main instruments that could be identified as environmental protection (regulatory) instruments in Sri Lanka. According to the research, recommendations that were identified, it would recommend the following areas to overcome challenges and issues of EIA, IEE, and EPL related to infrastructure development projects in Sri Lanka:

- The current list of prescribed projects which are interpreted in NEA should be expanded and strictly enforce apprehension provisions and laws for people who bypass EIA, IEE, and EPL procedures.
- NWPES should be abolished and NEA should be enforced for the whole country
- The all the relevant environmental data which are required for an EIA, IEE, and EPL should be collected by the relevant PAA for the ease of the clients.
- Financial difficulties of regulatory bodies and PAAs should be sorted out by levies, which should not only be applied to clients but also to the government 50% to 50%.
- There should be proper safeguards to make sure that the Project Approving Agencies are not inattentive or politically influenced.
- The CEA must provide proper guidance when implementing EIA, IEE, and EPL instruments and especially should implement post-monitoring mechanisms effectively.

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CLIMATE CHANGE CHALLENGES FACING SRI LANKA: A LITERATURE REVIEW

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ABSTRACT

The earth's climate has changed throughout history and climate change can be identified as an inevitable phenomenon which is being experienced by the whole world. When considering the Sri Lankan context, it is no different to the global context in that the country's climate has already changed. Sri Lanka, being an island state, is vulnerable to many climate change impacts including high-temperature levels, adverse weather events, sea level rising, and changes in precipitation patterns. The many challenges that arise from these climate-related issues are projected to continue through this century and beyond. Thus, climate change mitigation and adaptation have become the most appropriate ways to restrain these climate change challenges in Sri Lanka. It is paramount to get a broad understanding of how disastrous these climate change challenges are, prior to implementing appropriate responses to overcome them. This urges the need for conducting an in-depth investigation of prevailing climate change challenges in Sri Lanka. Thus, this study presents the prevailing climate change challenges facing Sri Lanka through a conceptual framework, that has been developed based on the existing literature. The developed framework reveals how these prevailing climate changes can lead to a number of challenges. These challenges were identified under three main categories as economic, social, and environmental challenges. The knowledge generated through this literature review will be the focus of future research.

Keywords: *Climate change; Climate change adaptation; Climate change challenges; Climate change mitigation; Sri Lanka.*

1. INTRODUCTION

Climate can be identified as a complex and interactive system which consists of the atmosphere, water bodies, land surface, and living beings, etc. (Adedeji *et al.*, 2014). The internal dynamics of the climate system can be significantly influenced by various external factors resulting in a number of changes in the system. The earth's climate has been constantly changing over geological time, contributing to a number of variations all over the world (Esham and Garforth, 2013). Indeed, climate change can be identified as significant fluctuations in the prevailing state of average weather patterns on the planet that last over several decades or longer (Riedy, 2016). In recent decades, climate change has become an alarming issue which is being experienced by the whole world (Esham and Garforth, 2013). More concisely, it can be identified as one of the greatest challenges

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facing humanity in this era (Swim *et al.*, 2011). No country is immune to the impact of climate change (De Costa, 2017) and hence it is imperative to explore the dangerousness of the prevailing and expected climate changes in Sri Lanka in a detailed manner.

When it comes to the Sri Lankan context, the situation is not different to the global context, in that the country has been drastically affected by many climate change challenges (Baba, 2010). The science community in Sri Lanka has shown ample evidence that the country's climate has significantly changed over time (Eriyagama *et al.,* 2010). Although Sri Lanka seems somewhat distant from the other countries in the world, nestling in the midst of the Indian Ocean, it is often regarded as a country predominantly vulnerable to climate changes, as stated by Baba (2010). These climate changes have led to a number of challenges, whereby a spill over effect has occurred mainly on the economic sector, on communities, and on the natural environment of the country (World Bank Group [WBG], 2020). These challenges have created many obstacles with regard to the development of the country; therefore, pertinent actions need to be followed in order to overcome these challenges. In this context, climate change mitigation and adaptation have been acknowledged as the most appropriate ways to counteract these climate change challenges (Hettiaratchi, 2020).

Importantly, it is imperative to know exactly how disastrous these climate change challenges are since such knowledge will directly lead to the successful implementation of responsive actions with regard to climate change. Thus, an in-depth investigation needs to be conducted to explore the prevailing climate change challenges in Sri Lanka. Hence this study aims to comprehend the prevailing climate change challenges facing Sri Lanka. This aim is achieved by developing a conceptual framework based on the existing literature to gain a broad understanding of how disastrous these prevailing climate change challenges could be within the Sri Lankan context.

2. RESEARCH METHODOLOGY

An extensive review of literature facilitates the researcher to strengthen the base of the study by gathering prevailing knowledge regarding the research area. Thus, comprehensive literature analysis and arguments were brought to explore the prevailing climate change challenges facing Sri Lanka. In doing so, the deductive approach which begins with the general and ends with the specific was followed. Accordingly, climate change, which is the broad theme of the study was narrow down to the theme of climate change challenges and under that theme, three main categories were derived as economic, social and environmental to explore the challenges. The existing knowledge were obtained through various sources such as journal articles, conference papers, e-books, and other publications. Ultimately, a conceptual framework was developed by compiling the key literature findings to gain a broad understanding of how disastrous these prevailing climate change challenges could be in Sri Lanka.

3. GLOBAL CLIMATE CHANGE

In recent decades, climate change has arisen as a growing issue all over the world, adding considerable stress to society and the environment (Adedeji *et al.*, 2014). As per the findings of Riedy (2016), generally, the term "climate change" refers to a change in average weather conditions on the earth that persists over an extended period of time. These changes in climate may be due to natural internal processes within the climate system (including volcanic eruptions, solar variations, changes in land surface properties, and the earth's orbital changes) or to human-driven external forces including greenhouse gas emissions from the many human activities such as burning fossil fuels, increasing livestock farming, large scale irrigation and the cutting and burning of forests (Intergovernmental Panel on Climate Change [IPCC], 2007). However, with the rapid developments that have taken place in the world, human-driven or anthropogenic forces have become the key reasons, over the natural processes, for the occurrence of these climate changes today (Swim *et al.*, 2011; Nianthi and Shaw, 2015).

Indeed, a number of devastating impacts can incur on community structures and on ecosystem functions due to these climate changes (Piao *et al.*, 2019). According to Adedeji *et al*. (2014), the evidence regarding these climate changes is compelling globally, where the precipitation patterns are changing, sea levels are rising, the whole world is getting warmer day by day, and severe weather events such as floods, droughts, storms, etc. are constantly occurring. Added to this, long-term data relating to the fossil records, atmospheric CO_2 levels, and the melting glaciers, which have been discovered by the scientists, can also be identified as the signs of global climate change (Warm Heart Worldwide Inc. [WHW], 2020). These impacts of global climate change are getting worse day by day, leading to catastrophic consequences on ecosystems as well as on human wellbeing (Butler, 2018).

4. IMPACTS OF CLIMATE CHANGE IN SRI LANKA

Sri Lanka occupies a unique position in the Indian Ocean and, owing to its geographical location, it has become a significantly vulnerable country to climate change, leading to a number of impacts (De Costa, 2017). These impacts mainly include rising temperatures, changes in precipitation patterns, rises in sea level, and an increase in extreme weather events. As stated by Eriyagama and Smakhtin (2010) and Institute of Policy Studies of Sri Lanka [IPS] (2018), in recent times, the intensity and frequency of these extreme weather events due to climate change have increased significantly within the country triggering a large increase in natural disasters. When considering Sri Lanka, floods, landslides, prolonged droughts, coastal erosion, and hazardous heatwaves can be identified as the major natural disasters which can occur due to climate change (Climate Change Secretariat, 2016). 96% of these natural disasters in Sri Lanka are cause by the adverse impacts of climate change, where the country has become the fourth most climate change affected country in 2016 as per the Global Climate Risk Index (2018).

According to WBG (2020), Sri Lanka, being a tropical country, regularly experiences very high temperatures with an average maximum of 32^0C, where this situation can develop into hazardous heatwaves. Furthermore, Sri Lanka experiences an annual probability of severe droughts of about 4% as a result of these adverse increases in temperature level. According to Baba (2010), Sri Lanka is mostly impacted by sea-level rises resulting from these thermal expansions, leading to coastal erosion, the intrusion of salinity, and shoreline retreat as the direst consequences. In fact, the study by Han *et al.* (2010) revealed that Sri Lanka have been faced for many coastal geo-environmental disasters which mainly occur due to the huge thermal expansions resulting from climate changes. Furthermore, Palamakumbure *et al.* (2020) affirmed in their recent study that gradual and cumulative coastal erosion can be expected in the future within the coastal areas of the country, influencing many geomorphological features such as lagoons, coral reefs, marshlands, sandy ridges, etc. In addition, floods and landslides which occur every year can also be identified as other extreme weather events arising from these climate changes (Palliyaguru and Amaratunga, 2008). These predictions are further supported by Eriyagama and Smakhtin (2010) who state that the average rainfall in the country and the intensity of the daily rainfall has increased significantly at many times of the year, triggering a large increase in landslides as well as flood events within the country. They further assert that there are increased occurrences of lightening hazards as well due to the changes in precipitation patterns in many regions of the country. Therefore, it can be seen that many kinds of frightful weather events can occur due to climate change in Sri Lanka and these lead to a number of challenges which are discussed in detail in the next section.

5. CLIMATE CHANGE CHALLENGES IN SRI LANKA

As discussed previously, a wide variety of devastating impacts can occur due to climate change in Sri Lanka leading to enormous economic, social and environmental challenges (Yamane, 2009). This means a detrimental effect can occur mainly in the economic sector, in the social wellbeing of the country, and in the natural environment due to these climate-related issues (WBG, 2020). These climate change challenges are broadly visited in the next subsections.

5.1 ECONOMIC CHALLENGES

As disclosed by Withanachchi (2019), it is paramount to know how disastrous the impacts of climate change can be on the economy of the country, which is the backbone of the country's development. When considering the economic challenges, many areas can be broadly explored as follows. The agriculture has been played a prominent role in Sri Lankan economy in many ways (United Nations Development Programme [UNDP], 2017). Indeed, it approximately contributes 7% of the Gross Domestic Product (GDP) of the country, provides 80% of the domestic food requirement, absorbs 30% of the labour force, utilizes 43% of the total land area, and provides the livelihoods for 70% of the rural population in Sri Lanka (Withanachchi, 2019). At the same time, it is the most sensitive sector with regard to climate change, whereby agricultural production and farm assets have been significantly impacted upon due to the many climate-related hazards during recent years (Climate Change Secretariat, 2016). In this context, it is witnessed that climate change has critically impacted upon the agricultural sector, leaving food production, foreign exchange, and employment at terrible risk. For example, De Costa (2010) has disclosed that both rice and tea production in Sri Lanka is intimately linked with the temperature levels, whereby long term shifts in rainfall patterns and temperature regimes have created substantial damage with regard to national food security, to foreign exchange, and to the livelihoods of the people who depend on such cultivation. According to WBG (2020), many effects such as the impact on water resource availability, soil erosion, alterations in carbon dioxide availability, and the arrival of invasive species can occur due to climate change and resultant weather events, weakening greatly agricultural productivity. At the same time, a notably high dependency of the economy on fisheries can also be identified in Sri Lanka, where the health of the fisheries can be prominently influenced by climate change (WBG, 2020). Rising temperatures and ocean acidification, resulting from the climate changes, have created a significant impact on the fisheries, weakening many areas of the economy. It is evident that fishery stocks, fisheries' habitats and the fish harvesting sector is steadily being impacted upon, as asserted by Arulananthan (2017).

The tourism industry has also done a remarkable job in leveraging the Sri Lankan economy (Tam, 2019). The same idea was brought forward by Salpage *et al.* (2019) who stated that Sri Lanka, being an attractive destination for tourists, earns a significant amount of foreign exchange for the national economy through tourism. More importantly, it contributes to nearly 11% of the country's GDP as the third largest foreign exchange earner in the country (Salpage *et al.*, 2019). In Sri Lanka, the majority of the tourism sector has been established along the coastal zone of the country and the coastal areas have largely been influenced by the adverse impacts of climate change including sea level rises, river flooding, coastal erosion, and extreme rainfall (Tam, 2019). As a result, a spill over effect has occurred on the nature-based tourism in the coastal zone of Sri Lanka.

Moreover, the energy consumption within the country has also prominently risen due to the increase in temperatures (Hettiarachchi *et al.*, 2014). In general, a one-degree increase in the ambient temperature level will lead to a 0.5%-8.5% increase in electricity demand within the country, whereby a significant share of that amount can be identified as being due to the increase in electricity demand associated with rise of temperature due to climate change (WBG, 2020). Although Sri Lanka has abundant energy resources to ensure energy conservation within the country such as solar energy, hydropower and wind power, energy conservation has been critically undermined due to the impact of climate change (Hettiarachchi *et al.*, 2014). Accordingly, high energy consumption can be identified as another key economic challenge that arises due to the impact of climate change.

In contrast, sometimes the aforementioned areas have contributed conversely to the occurrence of climate changes since agriculture, industrial processes and energy production can be identified as the major sources of greenhouse gases in Sri Lanka (Arora, 2019). Thus, it is obvious that the opposing side of the occurrence of a number of challenges on many sectors due to the climate changes (i.e. contribution of many sectors for the occurrence of climate changes) has also happened.

5.2 SOCIAL CHALLENGES

Many of the climate-related issues are likely to disproportionately influence communities in Sri Lanka, leading to a number of short-term and long-term effects (WBG, 2020). As stressed by Withanachchi (2019), the standard of living of people in Sri Lanka has been significantly impacted due to these climate changes and, thereby, the country's economy is also impacted. Agriculturally-based communities in Sri Lanka are vulnerable to many severe weather events including droughts, floods, landslides and increased temperature levels, largely, leaving their livelihoods at greater risk which can impact upon their livelihoods (Esham and Garforth, 2013). Similarly, coastal communities have also been heavily impacted upon due to sea level rises and cyclones resulting from climate changes, as disclosed by Tam (2019). More importantly, these impacts of climate change have tended to enhance societal inequalities, leading to a large increase in poverty within the country (Climate Change Secretariat, 2016). This is mainly because of the direct repercussions on the basic living patterns of the people due to considerable impacts on their settlements and infrastructure. Thus, it can be argued that the living styles of the communities within the country have been enormously impacted upon due to these climate changes. In here also, the opposing side of the occurrence of challenges due to climate changes can be identified (refer Section 5.1), whereby the living patterns of people (including many activities such as burning fossil fuels and cutting down forests) have fuelled the occurrence of climate changes (Kottawa-Arachchi and Wijeratne, 2017).

Human health can be identified as another key concern that can be impacted due to climate change. Presently, health impacts (including deaths and disabilities) caused by severe weather events have been reported more frequently than before in Sri Lanka (Madurawala, 2011). As indicated by Cho (2020), the outbreak of many types of diseases can be identified as a crucial problem today in Sri Lanka due to the adverse impacts of climate changes. These health issues include respiratory diseases, allergies, cancers, foodborne diseases, waterborne diseases, and impacts on mental health (Ministry of Health, 2017). At the same time, deaths also can be happened when these health issues have become more critical. Furthermore, problems in accessing safe food and drinking water are also inevitable as the issues that affect human wellbeing due to climate change (Madurawala, 2011). Actually, country's water resources have been noticeably impacted (refer Section 5.3) and food production has been considerably interrupted (refer Section 5.1) due to these climate change impacts. Also, the spreading of kidney disease and incidents of dengue can be regarded as some of the recent examples of major health issues that have arisen in Sri Lanka, mostly as a result of extreme weather events (Cho, 2020). Moreover, as depicted by Ranagalage *et al.* (2017), most of the urban areas in Sri Lanka have tended to encounter a relatively higher temperature in their surroundings rather than that in rural areas due to the heat island effect as well as thermal expansions arising from climate change (WBG, 2020). Therefore, a number of health issues can occur for people in urban areas due to their exposure to extreme heat. Moreover, sanitation issues and other social problems are significantly unavoidable alongside these adverse impacts of climate change in a country like Sri Lanka which is still developing. As stated by the World Health Organization [WHO] (2015), the risk of spreading different types of diseases in Sri Lanka will largely increase towards 2070 with the prolonged exposure to the extreme impacts of climate change.

In this context, it can be argued that a huge impact has occurred with regard to the social wellbeing of the country due to climate change.

5.3 ENVIRONMENTAL CHALLENGES

To date, climate change has adversely impacted upon the natural environment, altering many natural systems connected to the eco-systems, the water cycles and the biodiversity of Sri Lanka (Eriyagama and Smakhtin, 2010). Many ecosystem services, which are indispensable for the existence of human beings, have heavily declined as a result of these impacts on the environment.

Water resources can be identified as a crucial part of the environment as they fuel domestic activities, agricultural activities, many industrial activities, and also provide a significant share of power generation within the country (Eriyagama *et al.*, 2010). Furthermore, besides fulfilling the needs of human beings, the survival of all ecosystems mainly relies on water resources. Although various water resources can be seen in Sri Lanka based on its topography, the availability, supply, distribution, use and conservation of these water resources mainly depend on the climatic conditions of the country (Climate Change Secretariat, 2016). Hence, these water resources can be largely impacted upon due to the catastrophic effects of climate change on the country. As identified by Eriyagama *et al.* (2010), groundwater can be polluted and water resources can be reduced in many areas of the country, leaving the quality and quantity of the country's water resources at huge risk. Being a tropical country, the lack of drinking water has become the biggest issue in many areas in Sri Lanka, more so than ever before, which is being steadily amplified due to the recent droughts resulting from climate change (Cho, 2020).

Sri Lanka currently enjoys a rich and unique diversity of fauna and flora, providing many economic and environmental benefits (Kottawa-Arachchi and Wijeratne, 2017). However, the biodiversity of these ecosystems has significantly changed and has been reduced due to the impacts of climate change. As noted by the National Oceanic and Atmospheric Administration [NOAA] (2019), the natural habitats of species are being changed and modified, while the timing of natural events (such as flowering and egg-laying) are shifting considerably, altering the life patterns of many species in a negative manner. The temperature level of the ecosystems in urban areas can be vastly increased due to climate change coupled with the urban heat island effect, as discussed in section 5.2. Sri Lanka has a biologically rich and diversified coastal environment with unique ecosystems (such as beaches, lagoons, marshlands, bays, sand dunes) and a variety of water bodies (Climate Change Secretariat, 2016). All these ecosystems have been affected significantly due to sea level rise, coastal erosion, inundation, and the many other impacts of climate change. Furthermore, the ocean has become more acidic with the absorption of nearly 30% of the CO_2 released into the atmosphere, leaving marine life in great danger (NOAA, 2019). Accordingly, it is obvious that the natural environment has also been crucially affected by the adverse impacts of climate change in Sri Lanka, creating many challenges.

Overall, the impacts of climate change in Sri Lanka are widespread and they have created a number of social, economic, and environmental challenges which are increasing day by day. Therefore, appropriate actions need to be taken by respective parties in order to overcome the aforementioned climate change challenges. In this context, climate change adaptation and mitigation have become appropriate ways to withstand the prevailing climate change challenges, as discussed in the next section.

6. CLIMATE CHANGE MITIGATION AND ADAPTATION

When it comes to combating the climate change challenges, mitigation and adaptation have been acknowledged as a crucial activity (United Nations Educational Scientific and Cultural Organization [UNESCO], 2019). Climate change mitigation refers to altering the proximate causes for climate changes directly or indirectly to limit the extent of climate change (Swim *et al.*, 2011). That means, it includes the actions taken to reduce and curb the causes of climate change. According to Mertz *et al.* (2009), climate change adaptation can be broadly explained as making adjustments by social, economic and ecological systems to reduce their vulnerability to the actual, as well as expected, climate change challenges. They further elaborated that climate change adaptation mainly comprises actions which need to be performed to reduce vulnerability or to enhance resilience. Accordingly, it is apparent that mitigation addresses the causes of climate change, while adaptation attempts to address its impacts, as noted by UNESCO (2019). As noted by Yamane (2009), sometimes the impacts of climate changes appear unescapable even with the mitigation strategies. Hence, many scientists and other relevant parties have been focusing their attention on implementing climate change adaptation as an alternative or supplementary strategy to mitigation measures (Yamane, 2009). To date, a wide range of actions have been undertaken in this direction throughout the world to reduce adverse climate change challenges. Paris Climate Change Agreement which was established in 2015, Sendai Framework for Disaster Risk Reduction, which was adopted for the period of 2015-2030, and Cancun Adaptation Framework, which was adopted in 2010 can be regarded as some examples for those climate change mitigation and adaptation actions (Hewawasam and Matsui, 2019; Kelman, 2015).

When considering the Sri Lankan context, mitigation and adaptation for the constantly happening climate changes has become an urgent need for the country in order to overcome the identified climate change challenges. In Sri Lanka, a significant contribution can be identified in the implementation of climate change mitigation through a number of actions and plans (Climate Change Secretariat, 2016). For instance, the Ministry of Environment, with the collaborative efforts taken by Climate Change Secretariat, have implemented a Technology Needs' Assessment (TNA) and a National Climate Change Policy including many policy statements to cover climate change mitigation. Further, many programmes like the Haritha Lanka Programme have targeted many strategies and actions as climate change mitigation measures to cope with prevailing and expected climate change challenges (Hewawasam and Matsui, 2019).

When considering adaptation, the successful implementation of climate change adaptation in Sri Lanka would mainly have to take account of the country's vulnerability to climate change and its adaptive capacity (Climate Change Secretariat, 2016). Many significant gaps and barriers can be identified in the country's adaptive capacity which mainly includes knowledge and skills, technologies, information, and livelihood assets, as further stated by the Climate Change Secretariat study. Thus, there is a crucial requirement to bolster the adaptive capacity of the country towards successful climate change adaptation. Presently, many initiatives have taken steps to implement climate change adaptation in Sri Lanka in order to respond to the adverse impacts of climate change (Eriyagama and Smakhtin, 2010; Hewawasam and Matsui, 2019)). These initiatives have been formulating and implementing different types of policies and plans as the adaptation responses by reducing vulnerability and enhancing resilience. The National Environment Policy (NEP), the National Climate Change Policy of Sri Lanka, the National Agriculture Research Policy, the National Adaptation Plan (NAP) for Climate Change Impacts in Sri Lanka and the National Policy on Disaster Management can be identified as some examples of such policies for climate change adaptation in Sri Lanka (Hewawasam and Matsui, 2019; WBG, 2020). Added to this, a Clean Development Mechanism (CDM) policy and a few CDM projects have also been implemented in Sri Lanka to reduce greenhouse gas emissions into the atmosphere (Eriyagama and Smakhtin, 2010). Also, the adoption of Nationally Determined Contributions (NDCs) for climate change mitigation and adaptation under the Paris Agreement in 2016 can be regarded as a foremost commitment in this direction (Hewawasam and Matsui, 2019).

In this context, it is obvious that somewhat stable and persistent support has gained from the policymakers and other relevant parties for the implementation of climate change policies and plans in Sri Lanka to cope with the adverse impacts of climate changes. Those parties need to be further encouraged to strengthen the inclusion of climate change considerations into prevailing, as well as new, policies and plans for the successful implementation of climate change mitigation and adaptation in Sri Lanka (UNDP, 2017).

7. THE CONCEPTUAL FRAMEWORK

The previous sections discussed the threat of climate change (which has now become a severe crisis in Sri Lanka) by identifying the impacts of climate change and the resulting challenges. Furthermore, climate change mitigation and adaptation were identified as appropriate ways of overcoming those challenges. A broad understanding of how disastrous these climate change challenges are within the Sri Lankan context can be illustrated through a conceptual framework, as shown in Figure 1.

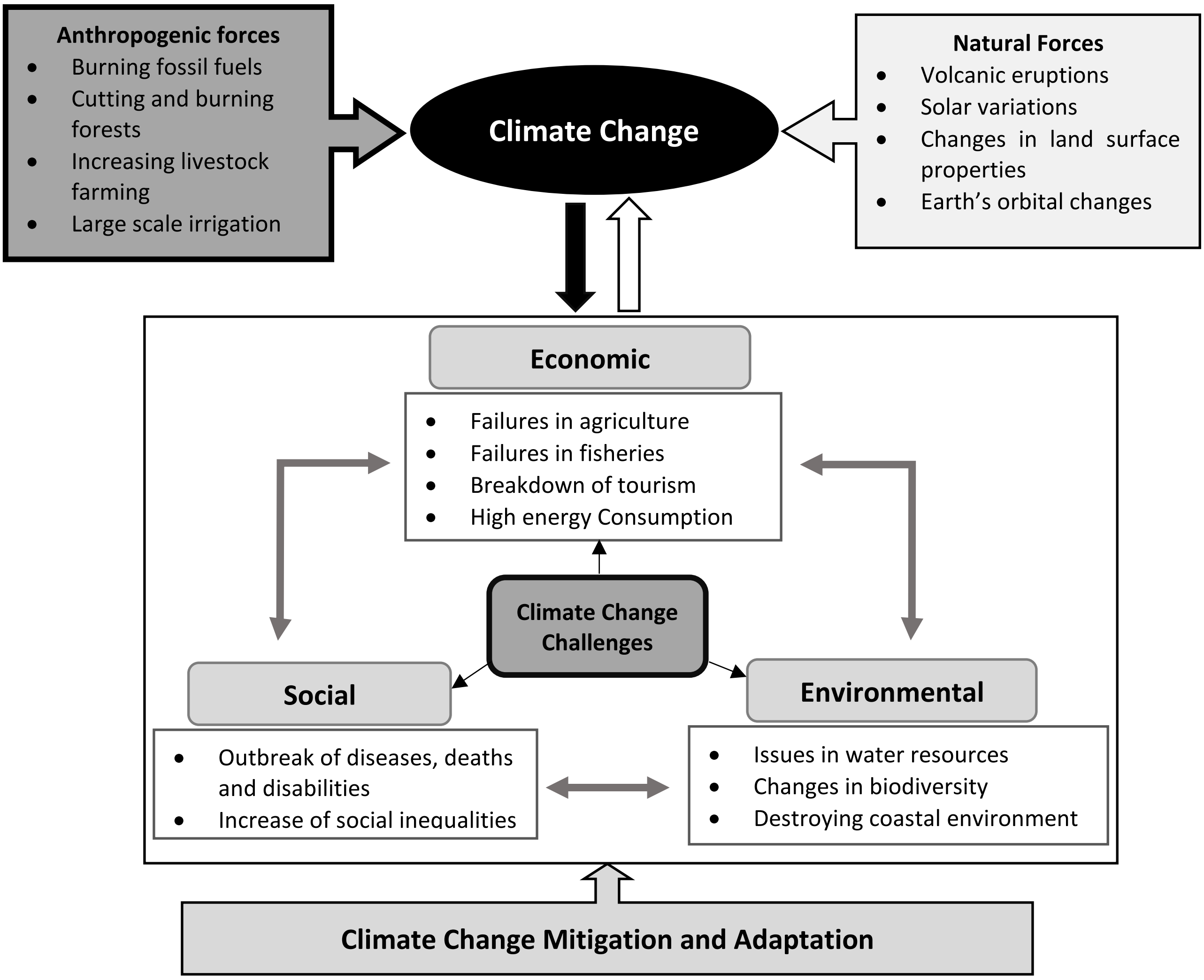

Figure 1: Conceptual framework

As depicted in this framework, changes in weather conditions can occur due to many reasons which can be identified as natural forces and anthropogenic or human-driven forces. Among these two categories of reasons, because of rapid developments, human-driven forces have become the key reasons for the occurrence of these climate changes in Sri Lanka today as highlighted in this framework. Accordingly, many challenges can incur significantly due to the devastating impacts of climate changes. As presented in this framework, those challenges can be identified under three main categories namely, economic, social, and environmental challenges which means that the country's economy, communities, and the natural environment are the areas that are strongly affected by climate change. The main vulnerable areas under each category are also presented in this framework in order to gain a broad understanding of how disastrous these climate change challenges can be/are. Further, these three main categories of challenges are strongly interconnected where the challenges of one category can highly relates with the challenges of another category. It was clearly presented by using two point arrows in the framework. For example, failures in agriculture, which is an economic challenge can be a reason for the increase of social inequalities which is a social challenge. Also, issues in water resources, which is an environmental challenge can be a social challenge as well since it leads to many diseases for the communities sometimes. In contrast, some of these areas have provided a significant contribution to the occurrence of climate change in some situations. For example, while climate change has impacted on the effectiveness of the areas of tourism, agriculture, fisheries, energy consumption and the living patterns of people, these areas have also influenced, conversely, to the occurrences of climate change. This is clearly shown in the framework by using two arrows, whereby the black arrow represents the impact of climate change in many areas and the white arrow represents the contribution of some areas towards climate change. Finally, as discussed in Section 5 of this paper, climate change mitigation and adaptation are regarded as the appropriate ways of overcoming the identified climate change challenges which are already happening, and will happen in the future, in Sri Lanka.

8. CONCLUSIONS AND THE WAY FORWARD

This extensive review of the literature is intended to comprehend the prevailing climate change challenges facing Sri Lanka in a detailed manner since it is beneficial to get a broad understanding of how disastrous these challenges are/can be prior to the implementation of mitigation and adaptation responses to overcome them. According to the existing literature, it is evident that climate change, which is mainly man-induced, has become one of the biggest problems facing mankind in this era. Generally, climate change can be identified as changes in the average weather conditions of the planet which last over an extended period of time. These anticipated changes in climate mainly include changes in precipitation patterns, higher temperatures and changes in the occurrence of weather events such as floods, droughts, landslides, storms, etc. The impacts of these climate changes have created catastrophic consequences on ecosystem functions as well as on human civilisation, resulting in enormous climate change challenges. These climate change challenges in Sri Lanka have been identified in a broader view in this paper under three main categories, namely economic, social and environmental challenges. Furthermore, a deep insight into each category of challenges was discussed comprehensively, as per the prevailing literature. The influence on agriculture and fisheries, the tourism sector, and the energy consumption within the country were investigated under the economic challenges, while the impact on living patterns of the people and the health of the communities were discussed under the social challenges. Similarly, environmental challenges were emphasised with relevance to the impact on water resources, biodiversity, and the coastal environment of the country. Accordingly, it was proven that a number of challenges can be identified which are already occurring, and will occur in the future, due to the adverse impacts of climate change in Sri Lanka.

These challenges can be overcome significantly by implementing climate change mitigation and adaptation responses and many initiatives have already been undertaken within the country in this direction. The findings generated through this study can assist policymakers and other relevant parties in obtaining a broad understanding with regard to the prevailing as well as expected climate change challenges in Sri Lanka, leading towards the successful implementation of climate change mitigation and adaptation measures. Furthermore, this paper is an initial conceptualisation of an investigation on the climate change challenges facing Sri Lanka whereby the findings will contribute to a roadmap on implementing climate change policies with regard to climate change adaptation in Sri Lanka as a way forward of this paper.

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COMPARISON BETWEEN THE TERMS CONSTRUCTABILITY AND BUILDABILITY: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Buildability deals with the optimal integration of construction expertise at various project stages to achieve the overall project goals. Incorporation of buildability improves the construction project performance in terms of its cost, quality, productivity, safety, and results early completion. Thus, having a sound understanding of buildability concept is paramount for finding solutions for transforming current practices towards successful project deliveries. The numerous past studies reviewing the concept of buildability in the past have highlighted the interchangeability of the terms "constructability" and "buildability". However, in some studies, these two terms contradict rather than considered similar. Moreover, the application of the concept of buildability is widely discussed during the design phase while some studies recommend it to be applied in the construction phase. Thus, there is no clear consensus on the clarity of the key constructs of these terms or when to apply buildability. This paper aims to systematically review the application of the concepts "buildability" and "constructability" in the construction sector and compare the definitions to understand the key constructs and best phase of the construction project for its applicability. A structured literature review covering indexed publications from 2011-2021 was carried out to identify the existing literature. Following a Systematic Literature Review (SLR) technique, a total of 38 out of 162 research contributions have been considered for an in-depth analysis. The choice of interpretations, comments, statements, perspectives, and definitions used in 38 studies were examined. The study identified the key constructs of two terms and recommends applying buildability throughout the lifecycle of the project.

Keywords: *Buildability; Constructability; Construction; Systematic literature review.*

1. INTRODUCTION

The construction sector plays an important role in the socio-economic development of a 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). 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). To achieve this goal, construction companies should complete the projects within their anticipated budgets and

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durations, and expected quality targets (Polat *et al.,* 2014). However, in most construction projects severe time and cost overruns occur due to various factors (Arditi *et al.,* 2017; Habibi and Kermanshachi, 2018; Ogbu and Adindu, 2019). Poor quality in construction projects has also become a common phenomenon in the world (Eriksson *et al.*, 2019; Buba *et al.*, 2020). The root causes of these issues have been identified as overbudgeting, lack of effective communication, lack of design integration, poor constructability, disregarding buildability (Rosayuru *et al.,* 2018; Farrell and Sunindijo, 2020; Johnson and Babu, 2020; Kwofie *et al.,* 2020b, 2020a). Among these causes, buildability has been identified as one of the main factors (Ansyorie, 2019; Al Khatib *et al.,* 2020; Al-Fadhli, 2020). This is because buildability improves conceptual planning, procurement processes, construction methods, and involving stakeholders in the decision-making to achieve their satisfaction (Al-Fadhli, 2020).

Buildability is a concept deals with the optimal integration of construction expertise at various project stages to achieve the overall project goals (Naoum and Egbu, 2016). Leader *et al.* (2004), stated that buildability and its further improvement, could contribute to early completion of projects, a saving in project costs and costs of change orders (variations), enhance quality, improve safety performance, and achieve a high level of productivity rate. Some researchers stated that constructability and buildability are two identical concepts, except that buildability is typically used in the UK while constructability is usually used in the USA (Kalsaas *et al.*, 2018; Finnie *et al.,* 2018, 2019; Ansyorie, 2019; Ding *et al.,* 2019). Whereas some researchers contradicted these two terms rather than considered similar (Capone *et al.,* 2014; Contrada *et al.*, 2019; Ding *et al.,* 2019). Further, Kazaz *et al.* (2017) stated that "constructability" is best applied during the design stage. However, some studies stated that buildability is applicable throughout the entire project life cycle (Zolfagharian *et al.*, 2012; Al-Fadhli, 2020; Samimpey and Saghatforoush, 2020). Accordingly, despite the significant value addition these concepts make to the outcome, there is still no consensus on clarity of the key constructs of these concepts or in which project stage the improvement measures should be implemented.

As described above, many studies show that research on this topic is fragmented, and not been coordinated. Thus, it is worth exploring the perceptions under these two terms to understand and compare the terms "buildability" and "constructability" and thereby derive the key constructs. This study systematically reviews the literature on "buildability" and "constructability" to understand how these terms have been interpreted and to provide clarity on which phase of the construction project is the best suit to apply buildability concept. Therefore, this paper aims to systematically review the application of the concept "buildability" and "constructability" in the construction sector.

Accordingly, the paper is structured as follows. First, the research methodology adopted for the study is presented. This is followed by the results and discussion of the findings. A table is presented within the results, reflecting the SLR findings in a form of a tabulated summary. Finally, the conclusion is presented summarising the key findings of the study.

2. METHODOLOGY

2.1 THE PROCESS OF SYSTEMATIC REVIEW

SLR technique was used to carry out the literature search as this is widely practiced as a system-driven way of collecting unbiased literature. Biolchini *et al*. (2005) defined a systematic review as "specific methodology of research, developed to gather and evaluate the available evidence pertaining to a focused topic". A systematic review must firstly aim for comprehensive treatment of a particular topic through a search of an appropriate electronic database. Applying an appropriate analysis method to identify key concepts in the research question, develop appropriate search terms to describe these, and determine inclusion and exclusion criteria is essential when making the final selection of articles. The following keywords are considered for the question of this research (refer Table 1).

Table 1: Keywords for the SLR

Population	Intervention
"Construction*"	"Constructability" OR "Buildability"

Rather than selecting random studies for systematic reviews, PRISMA method was adopted to improve the quality of review as it follows a four-phased flow diagram. There should be a sound research question supported by a precise aim and objectives in order to develop the search strategy, the eligibility criteria, and the study selection which are very important components of the PRISMA checklist (Eriksen and Frandsen, 2018).

2.2 SEARCH STRATEGY/INITIAL RESULTS

The systematic review is based on indexed publications. The database considered was Scopus Document Search, which consists of multidisciplinary publications. Following the identification procedure, 136 records were identified through a database search. Additional 26 records were identified through other sources. Only the records that were explicitly related to the research question were selected through other sources. To avoid losing the relevant important articles while conducting the initial search, the terms "Definition", "Characteristics" and "Explanation" were eliminated from the string. Accordingly, "Constructability" OR "Buildability" AND "Construction*" was the search string used.

A systematic review must provide a clearly defined boundary such that only studies relevant to the topic are included. This research included only full-length peer-reviewed articles in the "construction" context. The articles were selected if the terms "constructability" or "buildability" was detailed in the title, abstract, keywords, or within the text in the articles. As a result, 162 studies were identified for review.

2.3 ELIGIBILITY CRITERIA

It is necessary to have eligibility criteria for the selection which need to be appraised for the validity, applicability, and comprehensiveness of a review (Moher *et al.*, 2015). These eligibility criteria identify the inclusion and exclusion conditions for the study. Table 2 presents the eligibility criteria for this study.

Table 2: Eligibility criteria

Inclusion Criteria	Exclusion Criteria	Rationale
Sources published in English language	Sources published other than in English	English is the international and the universal language.
Publication year from 2011 -2021	Publication year prior to 2011	Avoiding out of date results

Inclusion Criteria	Exclusion Criteria	Rationale
Published sources	unpublished sources and studies under review	Unpublished articles and under review articles were not included
Research areas: Social Sciences, and Engineering	Research areas: Computer Science, Medicine, Business Management and Accounting, Economics and Finance, etc.	Research areas related to construction and built environment
Document type: Articles, Conference Papers, Book Chapters, Books	-	-
Terms "Buildability" and "constructability" in topic, abstract, and body	-	-

The number of full-text articles reviewed for eligibility is similar to the difference between the screened records and the exclude records (162-124=38). 38 articles were considered eligible for full-text review. During the full-text review, 18 articles were found applicable to the research question. The reasons for excluding the articles after the full-text review were recorded.

2.4 STUDY SELECTION AND DATA EXTRACTION

The selection of the articles is depicted in the flow diagram shown in Figure 1.

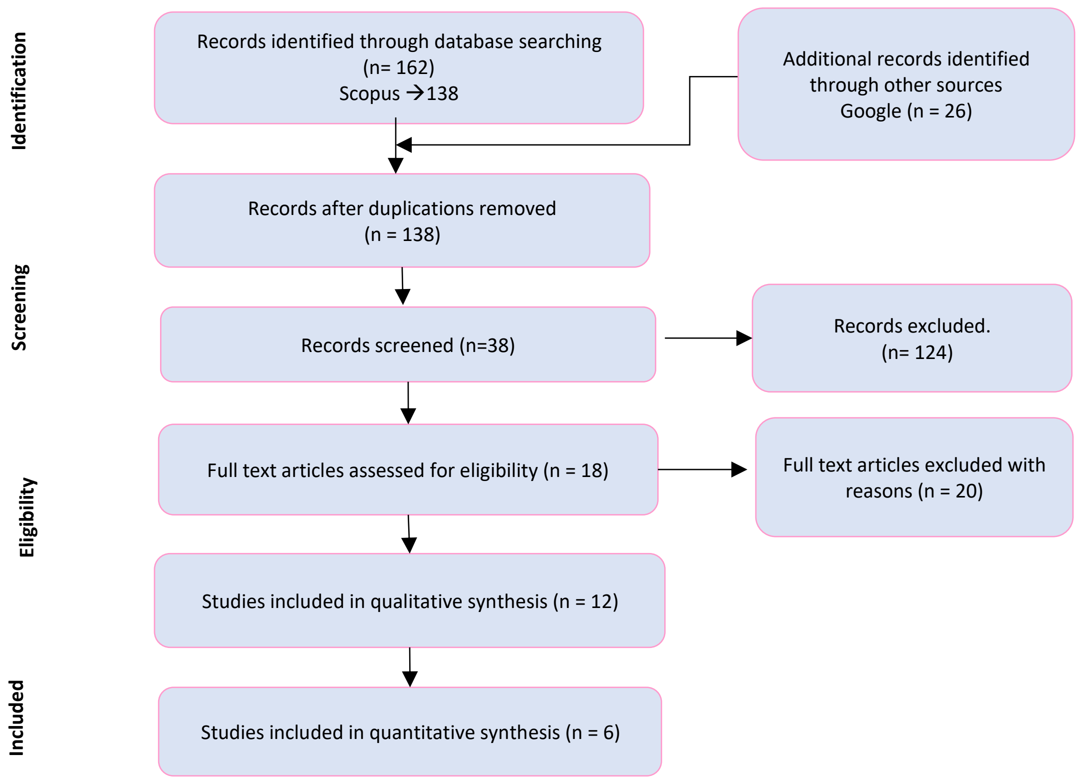

Figure 1: Flow diagram

To avoid reviewing the same article from different databases, the duplications were removed. The title, abstract, keywords, authors' names, journal name, and year of publication, access type, and source name of the identified records were exported to an Excel spreadsheet. All the identified articles were subjected to title and abstract screening initially and categorized as: relevant, irrelevant, and unsure by a single reviewer. In this stage, (1) articles not relating to keywords, (2) articles not contributing to the definition of buildability or constructability, and (3) articles that were completely irrelevant to the research area were excluded. Upon the title and abstract screening, the final set of articles was concluded for the second screening. In the second screening process, the full text of all the relevant articles were reviewed and the necessary data was extracted. In this study, mainly the extracted items used were the definitions, statements, comments, and perspectives of constructability and buildability. Geographic location of the study, methodology, and whether the authors focused on both constructability and buildability, which phase of the construction project was applicable, and the year of publication were also considered to derive conclusions and recommendations.

3. RESULTS

3.1 DEFINITIONS

Following the analysis of 18 articles, 15 definitions were found (refer Table 3). Furthermore, additional statements defining the terms “constructability” and “buildability” found in the studies were categorized into several definitional attributes of buildability.

Several studies pointed out that the terms “constructability” and “buildability” are two different terms used interchangeably in different parts of the world (Kalsaas *et al.*, 2018; Finnie *et al.,* 2018, 2019; Ansyorie, 2019; Ding *et al.*, 2019). Generally, “constructability” is more frequently used in Indonesia, France, Turkey, Korea, Taiwan, South Africa, Iran, Norway, and Iraq. “Buildability” is mostly adopted by United States and Singapore although both the countries use both terms. Asia (includes Singapore, Indonesia, Korea, Taiwan, Iran, Malaysia, and Iraq) uses both terms interchangeably. Europe (France, Italy, and Norway) mostly use “constructability”, but Italy and France use both terms interchangeably.

With regard to the definitions, there are two common definitions for constructability that have been cited in the referenced articles as shown in Table 3. The Construction Industry Institute (CII) in United States defined “constructability” as “the optimal use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives” (CII, 1986). And the Construction Industry Institute Australia (CIIA) defined “constructability” as “the integration of construction knowledge in the project delivery process and balancing the various project and environmental constraints to achieve project goals and building performance at an optimum level” (CIIA, 1996).

The most frequently cited definition within the selection criteria of the articles for buildability was defined by the Construction Industry Research and Information Association (CIRIA) in the UK as “the extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building” (CIRIA, 1983).

Table 3: Data analysis

Reference	Definition	Other Attributes - Interpretations / statements
(Aktas *et al.*, 2012)	(CII, 1986)	Constructability is an abstract concept that enables successful realization of building projects given that critical factors are correctly identified [Arditi's (2002), Lam's (2009), Saghatforoush's (2009) and Lam's (2012) studies as cited in Aktas *et al.* (2012)].
(Zolfagharian *et al.*, 2012)	(CII, 1986)	Constructability is not only limited to design stage but should be considered during whole project lifecycle.
(Yustisia, 2014)	(CII, 1986)	To avoid accidents and various dangers in the construction process that could lead to loss of property, objects, and human lives the concept of constructability can be implemented to achieve the project objectives.
(Capone *et al.*, 2014)	Constructability, which embraces the functions both of project management and design, covering a wider scope than Buildability.	Constructability interacts with the project management techniques that utilize optimally knowledge and experiences on building effective, to improve the achievement of the project objectives.
(Getuli *et al.*, 2015)	(CII, 1986)	improved design; better construction methods; more accomplished site management; more effective teamwork
(Kazaz *et al.*, 2017)	(CII, 2016) "The interaction between design and construction phases in construction project is defined by the term constructability (Yang, *et al.'s* 2003 study cited in Kazaz *et al*. (2017)).	"Constructability is an indicator of the design quality."
(Lee *et al.,* 2017)	(CII, 1993)	Although review on constructability covers entire phase of a project, the term is mainly used to indicate understanding of the possibility of construction in phase prior to the construction.
(Liau and Lin, 2017)	(CII, 1986)	The aim of the constructability is found the ways to improve and increase the cost efficiency of the construction project, improve the quality of the project, and this concept as a bridge between designer and construction companies
(Govender *et al.*, 2018)	(CII, 1986), (CIIA,1996)	
(Kalsaas *et al.*, 2018)		Good constructability can be expected to yield lower costs and quicker production for the contractor, if they are otherwise operationally efficient and external risks are manageable.
(Lee *et al.*, 2018)	The definition of constructability varies slightly from country to country, but the common concept is to foster	to utilize constructability knowledge effectively, the right information at the proper time should be provided to the design team. The

Reference	Definition	Other Attributes - Interpretations / statements
	efficient decision-making by fully reflecting construction knowledge and experience from the early stages of the project.	information should also have appropriate levels of detail to enable its successful integration with specific design activities.
(Finnie *et al.*, 2019)	(CII, 1986)	
(Ansyorie, 2019)	(CII, 1986) Constructability is also defined as the extent to the design facilitate ease of construction [Bakti and Trigunarsyah's (2003) study cited in Ansyorie (2019)].	Constructability (or buildability) is the ability to construct a building efficiently, economically and to agreed quality levels from its constituent materials, components and sub-assemblies.
(Contrada *et al.*, 2019)	(CII, 1986) (CIRIA, 1983)	Constructability enhances buildability which does not focus only on labor productivity, but it also aims to reach and guarantee building performance levels.
(Ding *et al.*, 2019)	Constructability is one of the project management methods to evaluate the whole construction process.	It is defined as a concept with relative, not absolute, value to increase optimization capacity of resources, such as workforce, time, cost, quality and working environment conditions [JadidAlEslami *et al.*'s (2018) study as cited in Ding *et al.* (2019)].
(Al-Fadhli, 2020)	"an effective technique that implements a detailed review of design drawings, documents, specifications, and construction processes by highly experienced engineers, working with original team of the project before construction mobilization" [Douglas and Gransberg's (2009) study cited in Al-Fadhli (2020)].	"the constructability focuses on optimizing the whole construction process. Effective constructability applications ideally begin at the conceptual and planning phase and continue to construction."
(Samimpey and Saghatforoush, 2020)	(CII, 1986) (CIIA, 1992) Constructability is one of the techniques that connect the implementation and construction phases to the design and planning phases.	Constructability is a project management technique, which examines construction logic from beginning to end, in order to identify obstacles, restrictions, and potentials.
(Jadidoleslami *et al.*, 2021)	(CII 1986)	Constructability is one of the project management methods to evaluate the whole construction process.

These definitions bring together the ability of the transformation of a design into construction as well as sufficient incorporation of such contractor's know-how as early as possible in the procurement process. On the other hand, there is a consensus that the design stage is critical for implementing buildability (Latham, 1994; Low, 2011; Ding *et al.*, 2019). Adding to this, Contrada *et al*. (2019), Naoum and Egbu (2016), and Lam and Wong (2011) asserted that if a proactive contractor is involved at the pre-construction stage with advanced works, programme planning, and materials procurement, as well as the buildability of project design will be remarkably enhanced.

For example, Bakti *et al*. (2003) stated that "constructability or buildability is a project quality improvement technique that if implemented throughout the project delivery process, mitigates the challenges" whereas, Capone *et al.* (2014) stated that "constructability, which embraces the functions both of project management and design, covering a wider scope than the Buildability". Adding to this, Contrada *et al*. (2019) stated that "constructability" is a concept that enhance "buildability" extending the practice of sharing knowledge to the whole construction lifecycle. Accordingly, application of buildability has to be done throughout the life cycle of a construction project.

Based on the various definitions of constructability, the most frequently used keywords were "integration of construction knowledge", "optimum use of construction knowledge and experience", "optimization of the design and execution of a construction", "balancing the various project and environmental constraints", "reflecting construction knowledge and experience from the early stages of the project", "ease of construction", and "adoption of construction techniques and processes". For buildability, the frequently used keywords were "optimal integration of construction expertise and experience", "ease of construction", "design that facilitates building construction", "construct efficiently, economically and to agreed quality levels", "project quality improvement technique", and "design and detailing". Figure 2 shows the identified key constructs of the two terms as similarities and differences.

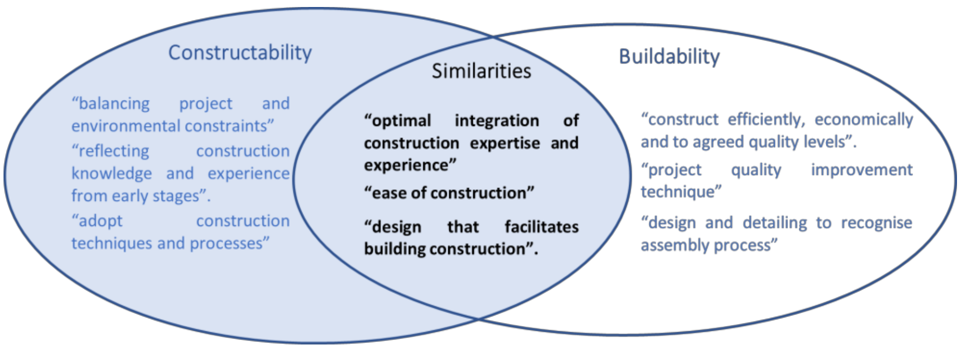

Figure 2: Similarities and differences identified in the key constructs.

3.2 OTHER DEFINITIONAL ATTRIBUTES OF BUILDABILITY

The definitional attributes that should be included in the terms "buildability" and "constructability" have been identified and categorized under (1) Interpretations/ Comments/ statements, and (2) Perspectives.

Two (02) studies interpreted constructability (or buildability) as a project management technique to review construction processes from start to finish during the pre-construction phase. There were two (02) studies out of the 18 that have considered BDAS (Buildable Design Appraisal System). Two (02) studies have confirmed that if buildability is considered during the design phase itself, will lead to enhanced safety performances. Four (04) studies out of the 18 selected studies have recommended using modern technology such as AR (augmented reality), 3D workspace modelling, BIM (Building Information Modelling) in the construction projects to improve buildability. 11 studies out of the 18 have recommended the application of buildability and constructability throughout all the phases of the construction projects whereas 8 studies recommend considering buildability and constructability during the design phase.

4. CONCLUSIONS

Constructability and buildability are two terms used in the literature to discuss the optimum use of construction knowledge and experience in the construction process. The purpose of this paper is to systematically review the terms "buildability" and "constructability" in the construction sector to compare and identify the similarities and differences in the key constructs. Thus, to provide useful insights to the stakeholders in identifying the key constructs that need to be incorporated to enhance the construction project performance. A structured literature review covering indexed publications from 2011 to 2021 was carried out to identify the existing literature. It is noted that the definitions of these terms have not significantly emerged over time.

Although constructability and buildability can be used interchangeably, differences between them could still be found. The researchers found that buildability concerns more on design whereas constructability covers the wider scope, and it embraces project management systems, safety performance, value engineering, and use of modern technology. This study also reveals that it is equally important to apply constructability or buildability throughout the entire life cycle of construction projects.

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COMPARISON OF SKILLS BETWEEN SRI LANKAN AND FOREIGN CONSTRUCTION LABOUR

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ABSTRACT

Construction significantly influences a country's economy. The labour efforts are the lifeblood of construction operations. The construction industry has been facing many challenges due to skill shortages in many countries. This study aimed to compare the work-related skills of Sri Lankan labour against foreign labour forces. A qualitative study methodology was adopted through literature reviews and expert interviews to identify the labour skills which influence the productivity of construction operations. The interviews were conducted in two categories. The first category focused on identifying significant labour skills, the second category was conducted to compare the labour skills between Sri Lankan and foreign labour. Chinese, Indian, Bangladeshi, Nepalese, Saudi Arabian, Malaysian and Korean labour forces were considered in the pair-wise comparison process. Statement categories and codes were developed to perform this qualitative comparison. The overall results show the need of developing cognitive and self-management skills of Sri Lankan labourers, where the transferable skills are not much important. The study pointed up the importance of developing technical skills of Sri Lankan labour in concreting, bar bending, plastering, tiling, welding, electrical work and equipment handling, to reach the levels of leading foreign labour forces. Labourers' commitment, punctuality, participation, self-motivation and problem solving were the significant self-management skills in this regard. Kappa statistics resulted in the inter-rater reliability of these findings at a substantial level. The study outcomes can be helpful for the skills development authorities to take actions for filling the skills gap, and also for some foreign construction sectors in similar scenarios.

Keywords: *Construction industry; Labour skills; Performance; Productivity; Sri Lanka.*

1. INTRODUCTION

The construction industry serves nearly other industries because all economic value creation occurs in or through the built environment. The construction sector has a very strategic role in infrastructure development and facilities that supports the nation's GDP (Henny and Moh, 2012). Profitability of the construction mainly depends on the

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utilization of labour force (Shreyanka and Ashwin, 2019). Labour is the most valuable asset in construction projects since it combines all other resources in construction activities. Poor performance of labour has been a major problem to the construction firms in developing countries, this significantly influences the productivity of construction operations (Anil *et al*., 2019).

In general, the majority of construction labourers join the industry from poor education and economic background in most developing countries. Their skill levels vary in a wide range. They are considered either skilled or unskilled depending on their skill level (Fernando *et al*., 2016). The labour skills can be improved through education and training, work methods, health facilities, motivational factors, use of tools and materials, work quality and some other labour related factors (Manoharan *et al*., 2020).

Considering the Sri Lankan perspective, most of the construction experts reveal that the labour skills are not up to the required standards in order to improve the productivity of construction operations (Halwatura, 2015). The skill shortage of labour has been significantly affecting the progress of construction projects (Fernando *et al*., 2016; Manoharan *et al*., 2020). This was identified as one of the most significant delay causes in the construction projects in Sri Lanka (Kesavan *et al*., 2015a, 2015b). The Industry Sector Skills Councils (ISSC) of Sri Lanka confirmed the absence of cognitive, soft and job-specific technical skills among the labourers working in construction sites, as stated in the Construction Industry Sector Training Plan 2018-2020 of the Tertiary and Vocational Education Commission of Sri Lanka. In the local labour market, the Sri Lankan economy has been gradually transitioning from a mere labour-sending economy into one that both sending and receiving workforce. The skill shortage of Sri Lankan labour makes the contractors to receive foreign labour force into the Sri Lankan construction sector. After the end of the post-war in Sri Lanka, the construction industry has attracted the government's attention as well as private sector to invest heavily in infrastructure development projects within the country. As a result, a large number of construction projects are ongoing in various categories of infrastructures namely transport, energy, water, environment and waste management, aero, maritime trade hub, high-rise building, housing and township, industrial cities and tourist cities. In a typical construction project, labour cost is significant and represents between 30% and 50% of the total project cost (Shan *et al*., 2015). Considering the importance of improving the productivity of labour operations, this study focused to compare the work-related skills of the Sri Lankan labour force against foreign labour in construction. This may allow the skill development authorities to take necessary actions to fill the skills gap, leading to influence on the Sri Lankan economy.

2. LITERATURE REVIEW

There have been several studies investigating the labour skills in the construction sector of many countries. The literature review of this study highlights the lack of studies that focused to systematically compare the work-related labour skills between construction labour forces from different countries. In order to compare the labour skills between the countries, it is important to study the significant areas related to labour skills that identified as the major factors affecting the productivity of construction in many countries recently.

Dinh and Nguyen (2019) focused on labour performance in the construction industry in Vietnam and identified that the labourers' physical abilities and attitudes significantly influence the productivity of construction operations. The physical ability of labourers was identified as the key factor affecting the progress of construction activities in India (Shashank *et al*., 2014; Dharani, 2015). This has been one of the major problems for the contractors in the construction industry in Qatar too (Abdulaziz *et al.*, 2012). The attitude of labourers was highlighted as a significant factor affecting the progress of construction projects in Indonesia (Soekiman *et al.*, 2011), South Africa (Orando and Isbariye, 2018) and Sri Lanka (Fernando *et al.*, 2015). It is also stated that the Indian (Anil *et al.*, 2019) and Indonesian (Soekiman *et al.*, 2011) labourers must have specific attention on their reduction of alcohol and drug usage. Labourers' communication skills and their ability to adapt to changes in the environment were highlighted as critical in the construction industry in Spain (Robles *et al.*, 2014). Saravanan and Surendar (2016) stated that Indian labourers do not have proper understanding of other co-workers during the construction operations. Labourers' commitment in construction activities was identified that needs to be improved in the construction industry in Egypt (Shehata and El-Gohary, 2012). Brent and Leighton (2013) found that the punctuality of labourers was not at the required level in the construction sector of Trinidad and Tobago.

Labourers' lack of skills in health and safety practices was identified as one of the major problems in the construction of pre-stressed concrete bridges in Egypt (Nourhane *et al.*, 2018). This was also found that needs to be improved for the Indian (Anil *et al.*, 2019) and Australian (Rami and David, 2014) labour forces. Labourers' cognitive skills on construction methods were highlighted as one of the major factors affecting labour productivity in the construction projects in India (Mistry and Bhatt, 2013), Iran (Parviz and Hosseini, 2012) and New Zealand (Serdar and Jasper, 2011). The skilled labour supply of the South African construction sector was examined in a study (Windapo, 2016) and revealed that the learning skills of labourers need to be specifically improved. Silva et al. (2018) pointed out that the same problem exists among the Sri Lankan labourers in construction.

Considering the Sri Lankan construction sector, the technical skills of labourers on bar bending, carpentry, plumbing, painting and electrical works were identified by Jayawardena *et al.* (2007) that need to be improved. Poor equipment handling skills of the Sri Lankan labourers were identified as the major resistance for the productivity improvement in construction (Dolage *et al*., 2010). The technical abilities of labourers were highlighted as significantly influencing the performance of road construction projects in Sri Lanka (Wijekoon, 2015). The Sri Lankan labourers' poor understanding skills on technical drawings lead to the rework in many construction tasks (Widanagamachchi, 2013). The Construction Industry Sector Training Plan 2018-2020 of the Tertiary and Vocational Education Commission of Sri Lanka revealed that inadequate supply of labour, low quality standards of new entrants and existing workforce are the major problems of the skills gap in the Sri Lankan construction sector. It also revealed that unskilled labourers need to develop their cognitive skills in numerical activities. With respect to non-cognitive skills, positive attitudes and productivity skills were highlighted that need to be improved. Overall, sources confirmed that there is a lack of technical and soft skills among the labourers in the construction sector of Sri Lanka.

3. METHODOLOGY

A comprehensive academic investigation and structured interviews were performed to investigate the skills of Sri Lankan and foreign labour forces in construction operations. From the past studies conducted in different countries, the academic investigation focused to identify the skills of labourers that significantly influence the productivity of construction operations. The academic articles were found through searching the keywords 'construction', 'labour', 'skills', 'performance', 'Sri Lankan labour' and 'Foreign labour' in popular online search engines. Some past studies were identified according to the recommendation from subject experts. The academic investigation included a total of 34 past studies conducted in 17 countries, namely Sri Lanka (8), India (7), South Africa (3), Indonesia (2), Nigeria (2), Australia (1), Egypt (1), Lithuania (1), New Zealand (1), Palestine (1), Qatar (1), Singapore (1), Spain (1), Trinidad & Tobacco (1), Turkey (1), United Kingdom (1) and Vietnam (1). Among these studies, 30% were conducted in the last 5 years, whereas more than 70% were conducted in the last 10 years.

3.1 INTERVIEWS

Two categories of structured interviews were conducted among the experts from the construction industry in Sri Lanka.

Interview Category 1 focused to identify the labour skills that significantly influence the productivity of construction operations, based on the current practices of the industry. The interviews consisted of 32 construction experts who are expertise in handling labour operations in building, road/ highway, bridge, water supply and irrigation construction projects. The directors, project managers, engineers, construction supervisors and technical officers participated in the interviews. Among them, 84% had experience in building construction projects, where 72% had experience in road/ highway and bridge construction projects, and 66% had experience in water supply and irrigation works. All the interviewees had more than 5 years of work experience in the construction field, where 69% of them had more than 10 years of work experience.

Interview Category 2 was conducted to compare the skills of the Sri Lankan labour force with foreign labour forces. It consisted of 17 construction experts who had sufficient experience in working with foreign labour forces namely Chinese, Indian, Bangladeshi, Saudi Arabian, Nepalese, Malaysian and Korean. Table 1 provides the detailed profile of the construction experts interviewed in this category.

Table 1: Detailed profile of the construction experts (Interview category 2)

Profile	Variable	Percentage of Interviewees
Work experience with the foreign labour forces in construction field	Less than 1 Year	-
	1 – 2 Years	18%
	2 – 3 Years	23%
	3 – 4 Years	35%
	4 – 5 Years	06%
	More than 5 Years	18%

Profile	Variable	Percentage of Interviewees
Experience in the types of construction	Buildings	88%
	Road, Highway & Bridges	71%
	Water Supply & Irrigation	53%
	Dredging & Others	18%
Experience with the foreign labour forces (At least one year work experience must be with the respective foreign labour force)	Chinese	71%
	Indian	53%
	Bangladeshi	41%
	Nepalese	35%
	Saudi Arabians	65%
	Malaysian	47%
	Korean	24%

3.2 DATA ANALYSIS

The qualitative study methods recommended by Caulfield (2019) were performed as shown in Figure 1.

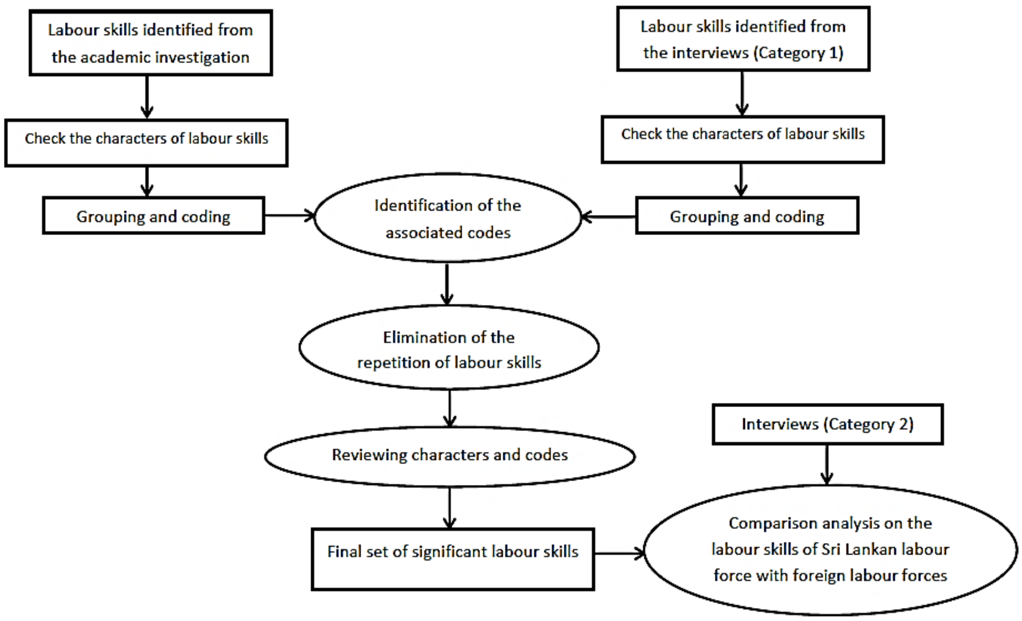

Figure 1: Qualitative analysis study methodology

Based on the data collected from the academic investigation and interviews (Category 1), the characters of labour skills were checked with the current practices in the construction field. Based on these characters, the skills were grouped into three major categories namely cognitive, transferable and self-management skills. According to Schuster *et al.* (2020), cognitive skills are the core skills that the brain uses to think, read, learn, remember, reason and pay attention. Transferable skills are the qualities that can be transferred from one job to another. Self-management skills are the abilities to control actions, feelings and thoughts (Carmeli *et al.*, 2006). The necessary codes were assigned to each skill element based on the groups. The associated codes were determined between the skills elements identified from the academic investigation and interview data. The repetition of labour skills was eliminated based on the identified associated codes. The characters, codes and groups were reviewed again. It was checked that no data is missing from being sorted in some themes and each theme had a specific identity. This process ensures the creditability of each theme. The final set of significant labour skills was then produced. The identified set of labour skills were compared between Sri Lankan and foreign labour forces through the interviews (Category 2).

A total of seven pairs were considered in the paired comparison analysis as shown in Figure 2. A minimum of one year of work experience of the interviewee with the corresponding foreign labour force was considered as a requirement to validate the response in each pair category. Based on the interviewees' experience and observations with the corresponding foreign labour force, the labour skills were highlighted according to the following statements. These statements were developed with the symbols ('++' / '+'/ '--' / '-') through the discussions with the experts.

- Statement Category 1: Sri Lankan labour force needs to be improved significantly (--) / moderately (-), compared to the corresponding foreign labour force
- Statement Category 2: Corresponding foreign labour force needs to be improved significantly (++) / moderately (+), compared to Sri Lankan labour force

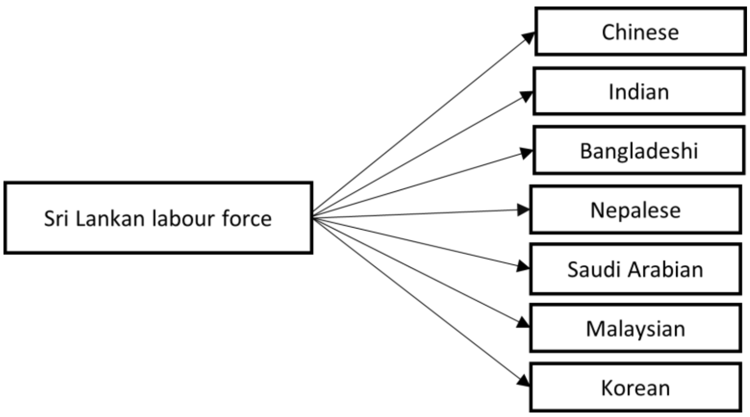

Figure 2: Pairs for comparison analysis

The results were summarised and closely observed for each item under each and every pair. To obtain the final outcome for each cell in the comparison process, the statement category was decided at first based on the majority of responses. The statement symbol was then finalized based on the majority of responses between the symbols in the respective statement category.

According to Herrera *et al*. (2019) and Isara *et al.* (2013), the inter-rater measurement agreement tests were used to check the agreement between the interviewees through Kappa statistics. The level of agreement based on the values of the Kappa statistics was graded as follows as mentioned in Isara *et al*. (2013).

- < 0: less than chance agreement
- 0.01 - 0.20: slight agreement
- 0.21 - 0.40: fair agreement
- 0.41 - 0.60: moderate agreement

- 0.61 - 0.80: substantial agreement
- 0.81 - 0.99: almost perfect agreement
- 1.0: perfect agreement

4. RESULTS AND DISCUSSION

According to the qualitative study methodology shown in Figure 1, the significant labour skills in construction were identified in three categories namely cognitive, transferable and self-management skills. The comparison results of these skills between Sri Lankan and foreign labour forces are shown in Table 2.

Table 2: Comparison of skills between Sri Lankan and foreign labour forces

Labour skills	Sri Lankan labour force compared with						
	Chinese	**Indian**	**Bangladeshi**	**Nepalese**	**Saudi Arabian**	**Malaysian**	**Korean**
Math and language literacy (C1)		+					
Measuring (C2)							
Estimating (C3)							
Understanding drawings (C4)	-			-	-	-	-
Material handling (C5)	-		+		-	-	-
Equipment/Tool handling (C6)	-	-		-	-	--	--
Concreting (C7)	--				--	--	--
Bar bending (C8)	--				--	--	--
Brick work (C9)					-	-	
Plastering (C10)	--				-	--	-
Tiling (C11)	--		-	-	--	--	-
Carpentry (C12)	-	+	++	+	-	-	-
Plumbing (C13)	-			-	--	-	-
Painting (C14)	-				-	-	-
Welding (C15)	--		--	--	--	--	--
Working with electrical sources (C16)	--	-	--	--	--	--	--
Learning ability (T1)	-					--	--
Reading, writing and listening (T2)		+					
Leadership (T3)							
Planning (T4)							
Multiple work coordination (T5)							
Management/Organizational skills (T6)							
Teamwork (T7)	-	--	-	+	-	--	-
Physical ability (T8)							
Communication (T9)							
Memorization (T10)							
Analytical skills/abilities (T11)							

Labour skills	**Sri Lankan labour force compared with**						
	Chinese	**Indian**	**Bangladeshi**	**Nepalese**	**Saudi Arabian**	**Malaysian**	**Korean**
Ability to work in different climatic conditions (S1)	-	-			-		-
Critical reasoning (S2)							
Problem solving (S3)	-					-	--
Decision making (S4)							
Psychology (S5)							
Reduction of alcohol and drug usage (S6)							
Self-motivation (S7)	-		-	-	-	-	--
Commitment (S8)	--			-	--	--	--
Participation (S9)	--			-	--	--	--
Punctuality (S10)	--			-	--	--	--
Understanding with other workers (S11)	+	+	+	+	+		

C: Cognitive skills; T: Transferable skills; S: Self-management skills

'--': Sri Lankan labour force needs to be improved significantly, compared to corresponding foreign labour force;

'-': Sri Lankan labour force needs to be improved moderately, compared to corresponding foreign labour force;

'++': Corresponding foreign labour force needs to be improved significantly, compared to Sri Lankan labour force;

'+': Corresponding foreign labour force needs to be improved moderately, compared to Sri Lankan labour force

Comparing the Sri Lankan labour with the Chinese labour, the cognitive and self-management skills of Sri Lankan labour have to be improved much, where there were not many significant gaps identified in transferable skills. The results are almost similar comparing with Saudi Arabian, Malaysian and Korean labour forces too. The technical skills of Sri Lankan labour in concreting, bar bending, plastering, tiling, welding, electrical works and equipment handling, were identified that need to be significantly improved to reach the level of the above-mentioned foreign labour forces. A moderate level of improvement is needed for the Sri Lankan labour force, when it comes to plumbing, painting, working with drawings and material handling skills. The Sri Lankan labourers' commitment to the assigned tasks, punctuality and participation were highlighted as significant in the category of self-management skills. Self-motivation and problem-solving skills of the Sri Lankan labour are also needed to be considered along with their ability to work in different climatic conditions.

The Sri Lankan labourers have a better understanding of other workers when it is compared to Chinese, Indian, Bangladeshi, Nepalese and Saudi Arabian labour. They also have better technical skills in carpentry work, compared with Indian, Bangladeshi and Nepalese labour. Table 3 provides the inter-rater measurement agreement test results obtained through Kappa statistics.

Overall, the level of agreement based on the values of Kappa statistics ensures the inter-rater reliability of the findings. The agreement level was almost perfect between the interviewees when the Sri Lankan labour skills are compared with Malaysian and Korean labour forces. It was at a substantial level when the comparison was performed with the other five labour forces.

Table 3: Kappa analysis results of agreement between the raters

Comparison of Sri Lankan Labour with	p_o	p_e	Kappa	Interpretation (Agreement)
Chinese	0.866	0.500	0.733	Substantial
Indian	0.956	0.860	0.688	Substantial
Bangladeshi	0.915	0.750	0.659	Substantial
Nepalese	0.870	0.596	0.679	Substantial
Saudi Arabian	0.816	0.500	0.633	Substantial
Malaysian	0.911	0.500	0.821	Almost perfect
Korean	0.934	0.502	0.868	Almost perfect

p_o is the relative observed agreement among raters; p_e is the hypothetical probability of chance agreement

4.1 DISCUSSION OF THE RESULTS

According to the skill-levels of labour forces from different countries presented in Table 3, the results show that the Arabian, Chinese, Korean and Malaysian labour forces were leading in the list. Considering the Malaysian construction sector, labourers' cognitive skills in understanding drawings and their planning abilities were very poor more than a decade ago (Kadir, 2005). Karim *et al.* (2013) highlighted the need of improving the self-management skills of Malaysian labourers in construction. The current study reveals that the technical and self-management skills of Malaysian labourers have been well-improved in construction. Purnamasari *et al.* (2014) reported that most of the foreign labourers in Malaysia were low skilled that leads to less productivity and assurance of quality in the construction industry. There were only 46,000 foreign labourers in Malaysia compared to 310,000 skilled Malaysians living abroad in 2010, this indicates highly educated Malaysians seek higher skilled jobs elsewhere (Purnamasari *et al.*, 2014). Singapore provided special incentives to attract skilled Malaysian workers such as longer work permits and possibility of permanent resident (Hasan, 2008). Purnamasari *et al.* (2014) highlighted the 6% of GDP spent on education and training, and RM4.1 billion spent on post-secondary vocational and technical education (TVET) in Malaysia. The efficiency of this initiative helped in closing the skills gap among Malaysians. An 80% increment of skilled workers was reported between 2015 and 2016 in Malaysia (Najib *et al*., 2019). Considering the foreign labourers in Malaysia, Najib *et al.* (2019) stated that most of them work in low value-added activities with low remuneration in the construction projects. Najib *et al*. (2019) has also pointed out that Malaysia can create more skilled local labour force and the industry can pay them higher, the country will then be able to break the reliance on foreign workers.

More than a decade ago, self-motivation of labourers was determined as a significant factor contributing to construction delays in the Saudi Arabian construction sector (Assaf and Al-hejji, 2006). The current study confirms that the self-motivation of Saudi Arabian labourers has been well-improved at present. According to Al-Emad and Rahman (2017), recent improvements of incentives and salary packages may be the reasons for this. Considering the foreign workers in Saudi Arabia, they can earn better salary which offers a better life to their relatives at home countries. But, they need to pay large amount of money to recruitment agencies in their home countries. This causes them debts before starts working. The foreign workers also face many challenges in their daily life not only related to technical matters but also related to their social adaptation lifestyle in Saudi Arabia (Al-Emad and Rahman, 2017).

Considering the Sri Lankan construction sector, this study highlights the need of improving self-motivation of labourers. According to Ong and Teh (2012), new rewarding systems should be developed to motivate the labourers in the construction industry. The technical skills of Sri Lankan labourers on bar bending, carpentry, plumbing, painting, electrical works and equipment handling were identified as significantly affecting the progress of construction activities more than a decade ago (Jayawardena *et al*., 2007; Dolage *et al*., 2010). The current study also reveals the same results. This indicates the recent improving practices in the industry and education sector did not address the issues related to technical skills of Sri Lankan labourers at sufficient levels.

5. CONCLUSIONS

The study has presented the results of the significant work-related skills of labour in construction along with the systematic comparison of Sri Lankan labour against some other foreign labour forces. The methodology used in this study, can be applied to perform further comparison processes between various groups/sectors on work-based aspects. This may lead to get more solutions for identified problems of a particular sector, also to apply better practices in the work operations. The study has displayed the areas where the Sri Lankan construction industry should have an attention to reach the skill levels of the leading foreign labour forces. The deviation of Sri Lankan labour skills against foreign labour forces in different categories can be understood based on the symbols used in this study. This will be very helpful for the skill development authorities and training providers in Sri Lanka to take necessary actions for filling the skills gap in the industry. The study outcomes will push them to have more focus on cognitive and self-management skills in the existing/newly developing vocational training programmes for construction workers. This may lead the construction sector to make a significant influence on the country's economy. The study recommends developing a work-site training model and exercises to improve labour skills in construction sites. The awareness sessions can be conducted among construction firms in order to upgrade their current practices considering labour skills development. The study also recommends future studies focus on comparing the labour skill levels with the productivity levels in various types of construction operations. The study findings will be beneficial not only to the Sri Lankan construction sector but also in some foreign construction sectors, in order to upgrade their industry-related and skills development practices.

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COVID-19 AND INFORMAL LABOUR IN CONSTRUCTION: A NARRATIVE ANALYSIS OF WEBINAR DISCUSSIONS

Chandana Jayalath[1] and K.K.G.P. Somarathna[2]

ABSTRACT

Many countries after a remarkable spike in COVID-19 cases, opted to lockdown and quarantine curfew that restricted the movement of people. Construction is one of the main sectors experiencing a clear impact due to COVID-19. As a significant growth driver of the economy, the domestic construction industry employs nearly one million of the population directly in various trades. Unfortunately, almost every project has been severely hampered. It is, therefore, prudent to address the impact of the pandemic on construction labour at the outset and end of the crisis to prepare for any future challenges or opportunities that it may undergo. This study aims to investigate the effect of COVID-19 on the construction industry's survival and possible measures to be taken in both the short and the long run. This paper summarizes using a narrative analysis of the key takeaways of 15 webinar discussions on the COVID-19 impact and outlook of the construction sector in Sri Lanka. The impacts and fallouts have been addressed by key industry personnel. The study found the most prominent impacts of COVID-19 are the suspension of projects, labour impact, and job loss, time overrun, cost overrun, and delay in payments. The findings of this study shed light on the consequences of the sudden occurrence of a pandemic and raise awareness of the most critical impacts which cannot be overlooked. The findings also help project stakeholders prepare for any future worst-case scenarios.

Keywords: *Construction labour; COVID-19; Informal labour; Labour crisis; Pandemic.*

1. INTRODUCTION

The outbreak of COVID-19 has enormously affected almost every participant in the construction industry, be them contractor, consultant or client. Since the supply chains have been disrupted, there is a potential of cost over run (Bailey *et al*. 2020; Robertson, 2020). Due to the recent travel restrictions, managing workforce is a challenging task. Increased health, safety and environmental issues led for higher expenses to the contractor (Turrini, 2020). Labour shortages, governmental restrictions including ban on gatherings and the contractor's personnel, or suppliers are either ill or under quarantine, are the situations causing critical delay and inability to meet the initial deadlines (Shorter and Nairac, 2020; European International Contractors, 2020). The demand for middle income apartments are likely to be offset by the current and expected economic downturn (PWC, 2020). During the COVID-19 pandemic, the situation drastically deteriorated first by the

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shortage of material supply. Following the spread of the virus, many countries started implementing several measures to reduce the movement of people, and that has mainly affected the progress of construction work because it requires on-site work. Globally, millions of employees lost their jobs. In the construction industry, almost every tradesman lost their jobs and most of the small enterprises are not able to pay salaries during lockdowns. The literature about the pandemic is still scarce, especially in the construction industry sector. Hence, it is crucial to investigate the impact of the pandemic in the construction industry with reference to the impact on labour. This research depends largely on the opinions expressed by the key industry personnel via webinar discussions recently taken place in electronic media.

2. LITERATURE SURVEY

COVID-19 has been spreading drastically all over the world and is considered by the World Health Organization (WHO) as a pandemic (WHO, 2020). It has had far-reaching severe consequences. All the business activities have been shut down except for a few vital projects which are necessary to support the health system and safety of the people. Relatively, it has limited the business operations and companies have shifted to Work-From-Home (WFH) concept. However, in the construction industry, all the workers inevitably need to nearly work on-site either to perform activities or to monitor whether the work is done correctly (Financial Times, 2020). This is basically how the construction industry is different from other industries. Hence, it is crucial to appreciate how the construction industry addresses this unforeseen situation. Several studies have attempted to investigate the impact of COVID-19 on the economy and industrial sectors. A study by Fernandes (2020) addressed the economic impact of the pandemic outbreak on the economy of 30 countries and found that the gross domestic product (GDP) is likely to be hit by 3-6% or might fall by 15% in some countries.

The study revealed that the service-oriented economy is negatively impacted, and jobs are at risk and the countries that depend on foreign trade are likely to be affected the most in their GDP. Another study by Ayittey *et al*. (2020) shows that commerce, tourism, and trade are the most impacted sectors. Nicola *et al*. (2020) reported that the restrictions implied by the authorities had reduced mobility causing many industries to shut down the business operations. Ivanov (2020) studied the effect of the outbreak on the supply chain and found that almost every economic sector has been impacted negatively and it may take a longer time to recover. Harari (2020) also expressed that the COVID-19 pandemic is the biggest crisis of the generation, and it may take years to recover and action must be taken decisively to subsidize and plan new strategies to avoid the travail of humankind. Chalam (2020) found that the Indian real estate sector has been severely affected and declination has been considerably recorded. Helm (2020) also pointed out that the total lockdown caused by COVID-19 has severely curtailed economic activities. The construction industry with no exception has been severely affected by the COVID-19 pandemic.

Since the supply chains have been disrupted, it has been difficult to complete on time and there is a potential for cost overrun (Bailey, 2020; Robertson, 2020). Due to the recent travel restrictions and uncertainty around travel locally and globally, managing the workforce is a challenging task. Increased health, safety, and environmental issues lead to higher expenses for the contractor (Turrini, 2020). Labour shortages, governmental restrictions including a ban on gatherings, and the contractor's personnel or suppliers being ill or in quarantine, are the situations causing critical delay and inability to meet the project deadlines (Shorter, 2020; Osha, 2020). Delays in the completion of projects are partly due to the interruptions in the supply chain as voluminous raw materials are manufactured in China. Negative cash-flows, delays in the supply chain, and low investor confidence create a more problematic situation within the industry (William, 2020; European International Contractors, 2020).

As European International Contractors stated, the uptake of cross-border projects will require a higher- administrative burden as quarantine periods across the world vary in length. COVID-19 affects key cost components of construction projects (material and labour), and these challenges to on-going project delivery, companies' liquidity, and whole business models (Jayalath, 2020). Further, sub-contractors are unable to perform. Equipment rental companies are starting to face problems with equipment left on inoperative sites. The bankruptcy of smaller companies, contractors, subcontractors, and design professionals are frequent (European International Contractors, 2020). Disputes with main-contractors and sub-contractors, back-to-back force majeure claims under concession agreements to avoid liquidated damages are some of the complexities that arise (European International Contractors, 2020). As mentioned, force majeure clauses often list specific events such as earthquakes, earth slips, Tsunami, etc. Many such clauses will include in the list under Acts of God, which would not, however, seem to describe or encompass a global pandemic such as COVID-19 (Jayalath, 2020). Meanwhile, the liquidity crisis of companies with a high level of debt and low cash reserves, insolvency issues will linger the stakeholders to more disappointment (Deloitte, 2020). A significant increase in claims for delays or increased costs is because of the COVID-19 outbreak (Jayalath, 2020).

The Sri Lankan experience is not that far from global observations. The lockdown and curfews have restricted the distribution and retail of cement and dry mortar goods across the island (Economy next, 2020). The handover dates were postponed. Hence, suppliers were in a dilemma as the operating costs are increasing through, increases in, raw material costs, logistics, and expenditure related to special hygienic facilities (Economy next, 2020). The guidelines of Epidemiology Unit - Ministry of Health - Sri Lanka, stated that contractors need to supply all the hand hygiene facilities, facial masks, and other relevant personal protective equipment (PPEs) at the workplace, which may cause an additional cost. In Sri Lanka, several high-rise building projects have slowed down owing to the delay in the procurement of materials from China and the curfew. Lockdowns in China also adversely affected the industry as Chinese contractors undertake many construction projects in Sri Lanka (PWC, 2020). Thus, large-scale public sector construction activities may be suspended temporarily (Colombo Page, 2020). As such, the Sri Lankan construction supply chain was massively impacted due to the lockdown of China.

3. RESEARCH AIM AND OBJECTIVES

The aim of this research is to inspire dialogue among the decision-makers around the issue of informal labour in the construction industry during the COVID-19 pandemic. The objectives are to harness the outcome of a series of webinar discussions that took place within the period of March 2020 to April 2020 from both retrospective and prospective practical analysis, reveal the challenges that are currently being faced by industry personnel and recommend actions for implementation. More specifically, the discussion will consider not only the challenges in terms of labour dynamics induced by the COVID-19 crisis, but also the opportunities the pandemic presents for these pertinent processes in the construction industry.

4. RESEARCH METHODOLOGY

A literature review was carried out using research papers and technical articles that appeared in open free access sources on the internet since January 2020 where the spread of COVID-19 became evident and declared a pandemic by the WHO. A thorough review of webinar outcomes that are in the public domain was undertaken to identify various issues at the contracting firm level. Webinars are a frequent online qualitative research approach. For example, webinar delivery platforms as a tool for collection of qualitative data are popular because of ease of use and cost-effectiveness (Mandy *et al*., 2019). Wen Ni Tiong *et al.* (2020) confirmed that data derived from webinar sessions are consistent with the quantitative results, and the potential of its uses as a new research tool to collect quality observation data. Out of a series of COVID-19 webinar recordings freely available in the internet, the selection of webinar recordings has been based upon the topic of the webinar discussion and stake of the professional organization has in disseminating construction labour data. 19 webinar sessions that address some of the key issues arising from the pandemic, were purposely selected. These include the lessons to be learned and sharing best practices to benefit construction and infrastructure firms over the challenging months ahead. All sessions were free to attend and were hosted on the Zoom webinar platform the profile of which is given in Table 1.

Table 1: Profile of the webinar discussions

Webinar	Organizer and Date	Theme of Focus Group Discussion
1	FIDIC, April 8, 2020	COVID-19: and its impact on contracts, supply and labour, activities on site and dealing with force majeure
2	RICS Sri Lanka, April 27, 2020	COVID-19 and the impact of real estate market in Sri Lanka; free webinar session ii. focused on vertical living, urban resilience, and re-emergence of the construction industry
3	RICS UK, May 1, 2020	Ensuring construction site safety and project continuity during COVID-19
4	FIDIC, May 5, 2020	COVID-19: how lockdown is enabling more digital and remote working
5	FIDIC, May 7, 2020	COVID-19: managing employment relationships, employees and health & safety requirements
6	BASL, May 10, 2020	Impact of COVID-19 in the sphere of labour law and industrial relations in Sri Lanka
7	FIDIC, June 3, 2020	Coming out of COVID-19: What will the 'new normal' look like and how will we get there?
8	IESL, July 7, 2020	The impact of COVID-19 on construction and infrastructure development: path to recovery and progress
9	AIQS, August 22, 2020	Post COVID-19 construction operations and employment management strategies for the construction industry in Sri Lanka and an overview of the middle east

Webinar	Organizer and Date	Theme of Focus Group Discussion
10	PAQS, August 27, 2020	Pandemic claims and resolutions for quantity surveyors
11	PAQS, September 23, 2020	Surviving post covid new norms for young professionals
12	PAQS, September 27, 2020	Status of construction industry and the effects of COVID-19 pandemic
13	IQSSL, Nov 23, 2020	Impacts of COVID-19 pandemic on the construction industry
14	CPWR-NIOSH-OSHA, Feb 25, 2021	Protecting construction workers: guidance on mitigating and preventing the spread of COVID-19 in the workplace
15	FIDIC, March 2, 2021	Working together in the new normal

4. FINDINGS AND DISCUSSION

Table 2 provides the key findings from the webinar content.

Table 2: Key outcomes of webinar discussions

Webinar	Experience/Impact	Alternative/Recommendation
01	The labour crisis created by the COVID-19 pandemic has increased global unemployment by almost 25 million.	Retaining of employment, with deducted salaries for those who have been made to stay at home instead of terminating them.
02	The impact is profoundly severe in the case of seasonal labour such as in domestic construction	Due to the nature of the industry, most of the value additions are done on-site. It would be ideal to shift to a phased-out approach to implementation that allows the necessary time (in the initial phases) to gather first-hand information about project characteristics, personnel, and cultural nuances so that the delivered solution can be tailored appropriately.
03	Most informal economy workers have suffered massive damage to their capacity to gainfully engage in some form of income earning.	Companies require a stimulus package as a short-term measure to ensure wages to employees for months experiencing no work.
04	Working from home is not possible unless computer facilities, software, essential hard copies, soft files, etc. are provided to the employees.	Arrangements must be made by the authorities to provide computer facilities, an uninterrupted network, and other essential facilities.
05	The biggest risk seems to be the continuation of work and accommodation in line with social distancing measures.	Working arrangements that reduce onsite labour congestion is the only option.

Webinar	Experience/Impact	Alternative/Recommendation
06	Delays are stemming from a shortage of craftspeople due to shelter-in-place restrictions and delays occasioned by shortages of government workers available to perform inspections, issue permits, etc	Online approval methods may be feasible in some cases.
07	In certain jurisdictions, the hardship may allow parties to seek relief based on an exceptional and unpredictable change of circumstances that affects the businesses.	Under many laws, parties must continue to exhaust all reasonably available means to continue performing their obligations, notwithstanding the existence of a force majeure event.
08	Employment protection has been threatened and the loss of income and businesses has threatened the business continuity.	Both the EPF and ETF contributions to be continued during this time – guaranteeing continued social security. Establishments must be allowed to prorate payments according to the number of hours worked by each employee.
09	Computer servers, electronic items, manufacturing tools, testing equipment, and documents idle in offices, sites, and workshops would be damaged or destroyed due to non-maintenance. Also, there can be damages to important data due to overheating, rats, and termite attacks.	Allowing, with some control, at least a technician and the owner must be present to minimize losses. It is better to implement a work schedule on a roaster basis to ensure no damages due to non-maintenance/operation of tools and equipment
10	The construction supply chain is highly impacted, generating project slippage and/or extra costs. Enhanced focus on worker safety and increased cost pressure could accelerate the move to offsite construction methods. The efficiency and controlled environment of factory production can help in leveraging labor costs and in optimizing project schedules.	It is important to increase competitiveness among the engineering and construction companies in terms of improving the balance between site work, office engineering and factory assembly, etc. Meanwhile taking migratory actions is inevitable. Apps can help keep a track of workers' locations while on the job, in full compliance with privacy regulations, so management can quickly identify potential exposure to the virus.
11	The epidemic and the predictions of environmental changes are bound to reset the status quo.	The industry may need to be more flexible and ready to effect structural changes: We need to commence a dialogue and identify weaknesses and recommend adjustments and/or re-orientation.

Webinar	Experience/Impact	Alternative/Recommendation
12	The unprecedented loss of productivity among workers because of distancing requirements, new safety protective gear requirements, and safety procedures-all in addition to the sick and quarantined workers who are absent.	In the short term, it's going to be phased out working arrangements while focusing on other key areas like improvement of business processes, eliminating non-value adding activities, reducing wastage, and driving workforce with KPIs and training and development.
13	Site congestion is inevitable in building projects than road and infrastructure projects	It is always important to adhere to government directives to maintain discipline at the ground level. Health and safety protocol is imperative.
14	Informal traders are particularly impacted by social distancing rules and have less access to clean water and sanitation. Additionally, with 60% of women across Sri Lanka employed in the informal sector, COVID-19 threatens their economic self-sufficiency from plying their trade and contributing to the livelihood of their household.	Produce necessary policy measures to enhance social protection coverage and support mechanisms to protect informal workers if they lose their livelihoods while emphasizing the nature of women labour
15	First, informal workers often work in economic sectors that carry a high risk of virus infection. Among others, waste recyclers, street vendors and food servers, construction workers, transport workers, and domestic workers are particularly at risk to contract with COVID-19.	In response, many low and middle-income countries have started implementing measures for those in the informal sector and self-employed workers. Policy responses include cash transfers as well as the deferral or reduction of loans, rents, or utility bills for low-income people for the duration of the pandemic.

The fact that the construction as an economic subsector is an informal labour sector has been reiterated in almost every webinar session. Informal workers mean those who work in jobs that are not registered with local authorities or covered by formal working arrangements. This kind of labour does not fall within the tax net, nor eligible for basic social security. During the COVID-19, the informal economy workers faced a lot of issues such as the impact of lockdown and other containment measures. They have no permanent working arrangements or areas, and they faced a challenge to affect by COVID-19 because of the non- arranged work ethic and without the occupational safe workplaces. As Shorter (2020) and Osha (2020) reiterated that governmental restrictions including ban on gatherings, and the contractor's personnel or suppliers being ill or in quarantine, are the situations causing critical delay and inability to meet the project deadlines. All the webinar discussions emphasized this matter. As such, informal economy workers got an economically and socially challenged life. In Sri Lanka, two million workers are employed informally in the construction sector but there is limited research on how they have been affected due to COVID-19.

The webinar discussions have shed some new thoughts on how to cope with construction labor issues during the pandemic. Retaining of employment with deducted salaries, introducing phased-out approach in sequencing work in hand, offering a stimulus package as a short-term measure of survival, working arrangements that reduce onsite labour congestion work schedule on a roaster basis to ensure no damages due to non-maintenance/operation of tools and equipment, apps that help keep a track of workers' locations while on the job, eliminating non-value adding activities, reducing wastage and among the temporary measures to ease out the current situation. Policy responses include cash transfers as well as the deferral or reduction of loans, rents, or utility bills for this information labour. One of the common perceptions encountered across all the webinar sessions is the importance of a policy directive specific to construction labour management.

While the construction industry begins to find the new normal, the findings will help in strategizing the way forward in near future and navigate the COVID-19 downturn. In nutshell, while informal employment is universally characterized by a lack of social protection, exposure to occupational health and income risks for informal workers is determined by the specific physical and social environments of their workplaces. Efforts to improve the economic status of informal workers should consider the contexts in which informal work takes place to develop tailored interventions for informal workers.

5. CONCLUSIONS

As COVID-19 crisis worsens, its effects on construction industry in Sri Lanka became a key issue and priority. A number of webinar sessions has been organized by professional entities that have some kind of stake in taking care of the wellbeing of the industry. Much attention has been paid to the question of its consequences and the remedial measures available to navigate and ease out the labour crisis. The biggest risk seems to the site congestion and the difficulty to maintain social distancing measures due to the very nature of the industry. Hence, it is high time the professionals and industry regulators together revisit the circumstances and work out a strategy to work 'in harmony with COVID-19' for a less interrupted construction legacy thought-out the country. The findings of this research are introductory to the construction industry stakeholders and policymakers. However, some of the findings can be used to understand the impact of the unforeseen and uncontrolled pandemic on construction-related other industries and other sectors in general. This will help improve the plans to cope with any encountered circumstances.

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CUSTOMER LOYALTY TOWARDS SUSTAINABLE HOTELS: CASE STUDIES IN SRI LANKA

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ABSTRACT

The hotel sector is directly combined with customer loyalty as it has become increasingly obvious by incorporating its' antecedents with customer satisfaction and trust. Customer loyalty is influenced by customer satisfaction of hospitality service when it is significantly related to service quality. Sustainability is an important concept that can adapt to achieving customer loyalty in the Sri Lankan hotel sector. Indeed, most conventional hoteliers in Sri Lanka do not have the idea of success in achieving customer loyalty through the sustainability concept. Also, despite the abundance of research on the concept of sustainability, a gap in literature could be identified, when it comes to analysing the customer loyalty aspects toward sustainable hotels in Sri Lanka. This study is therefore aimed to bridge the gap that exists in the literature to prove the success of adopting the concept of sustainability in achieving customer loyalty. A qualitative research approach with two case studies was used to achieve the aim of the study. The selected cases include two green-certified five-star hotels which are under the topmost sustainable hotels in Sri Lanka according to Sri Lanka Tourism Development Authority. A total of 10 interviews were conducted from both cases. The collected data were analysed using content analysis. The customer loyalty aspects were identified on the deriving basis of self-influence factors of customers and their consideration of benefits in sustainable hotels. The study unveils an analysis of the interconnection between sustainable hotels and customer loyalty. The findings provide the path to conventional hotels to identify the success of implementing sustainability concept in achieving customer loyalty.

Keywords: *Considerations of benefits, Customer loyalty; Self-influence factors; Sustainability.*

1. INTRODUCTION

Sustainability is a concept that can be defined through interconnected domains namely, environment, economy, and society (Baumgartner and Ebner, 2010). Sustainability has become a major area among different kind of buildings such as commercial buildings, industrial buildings, hotels, and hospitals (Abdellatif and Al-Shamma'a, 2014). The hotel industry has been identified by many researchers as the most capable sector in applying sustainability concept compared to other sectors while hotels tend to integrate with its world widely (Zhang *et al*., 2010). A sustainable hotel can be identified as an entity with a structure that has made important environmental improvements for minimising its

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impact on the natural environment (Jones *et al*., 2014). Sustainable hotels have an important role in reducing the negative impact on the environment since hotels consume energy, water, waste, materials, and land much more efficiently than buildings simply built to code (Chen, 2015). In today's world, hotels have developed platforms to address sustainability concept in response to requests from guests, investors, and stakeholders as they tend to consider the financial and non-financial benefits of it (Assante *et al*., 2012). Among those stakeholders, customers play a major role in gaining service from sustainable hotels as sustainability performance influence their decisions of preventing environmental impacts (Robinot and Giannelloni, 2015).

Customer loyalty has been identified as a key factor in the Sri Lankan hotel sector as it is the most important strategic mechanism of best practices among hotels (Miththapala *et al.,* 2013). The customer loyalty of the hotel sector is created through customer satisfaction of hospitality service when it is significantly related to sustainability which is a part of service quality (Cheng and Rashid, 2013). Many hotels' customers tend to value hotels that adopt eco-friendly practices and demonstrate sustainability (Liat *et al.,* 2014). Customer loyalty with hotels' sustainability performance is seen as essential for their success and the hotel industry's existence depends on the effective way to alert customers to their sustainable operations (Smith *et al.,* 2015).

Numerous studies have been conducted by researchers of developed countries by exploring ways of achieving customer loyalty in the hotel sector through sustainability but, in Sri Lanka, this is yet to be studied. Contexts of developed and developing countries are different from each other. Thus, the studies conducted in hotel sector of developed countries cannot be directly generalised with the context of developing countries (Sambhanthan and Good, 2012). This proves that there is a necessity in investigating the way of achieving customer loyalty of the Sri Lankan hotel sector through the sustainability concept, which so far has not been addressed yet in the research. Therefore, this paper aimed at bridging this knowledge gap that exists in the literature to prove the success of adopting sustainability in achieving customer loyalty.

2. LITERATURE REVIEW

2.1 CUSTOMER LOYALTY IN HOTEL SECTOR

Anuwichanont *et al*. (2011) explained customers are more influenced by the existence of the hotel sector among stakeholders as their decisions of gaining service from hotels is more important. Moreover, customers are influenced by sustainable activities in different ways as, circumstances of sustainability impact customers' decisions (Anuwichanont *et al*., 2011). Therefore, customers are willing to be loyal to the sustainable practices of hotels directly and influenced by circumstances of sustainability (Chen, 2015). The customer loyalty of the hotel sector will be created through customer satisfaction of hospitality service which is significantly related to the service quality (Cheng and Rashid, 2013). Hotels consume a vast amount of energy, water, and discharge a huge amount of waste so that, the negative impact on the environment should be highly concerned (Kasimu *et al*., 2012). A greater hotels' participation towards sustainability by committing to those identified impacts, the customer loyalty is influenced in numerous ways (Han *et al*., 2009).

2.2 CUSTOMER LOYALTY IN SUSTAINABLE HOTEL SECTOR

Keeping a long-term guest loyalty is undoubtedly essential for hotels' long-term success as well as having customer loyalty in environmental practices is undeniably fundamental for the success of sustainable hotel management (Han *et al*., 2009). In recent years, hoteliers are active in establishing an enduring relationship with conscious customer loyalty regarding sustainability by making various entities (Jiang and Kim, 2015). Nowadays, hoteliers want to improve competitiveness through promoting a sustainable hospitality service by implementing eco-friendly attitudinal profiles of customers and influencing ecological buying behaviours (Jiang and Kim, 2015). The sustainability of hotels influences customer loyalty based upon two main aspects, namely, self-influence factors of customers (refer Section 2.2.1) (Chen, 2015), and consideration of benefits that occurred through sustainable hotels (refer Section 2.2.2) (Blackman and Rivera, 2010).

2.2.1 Self-influence Factors of Customers

There are customers of the hotel sector that, motivates by their own will due to the sustainability performance through their preference and willingness of being loyal to sustainability practices (Chen, 2015). As further explained by Chen (2015), it positively impacts customer loyalty through their individual decisions of consuming sustainable hotels. There are three main self-influence factors, namely 'Behavioural intention of customers', 'Environmental concern of customers' and 'customer attitudes of preferring natural resources. These factors are described in the below subsections respectively.

- **Behavioural Intention of Customers**

Behavioural intention is the customers' willingness to pay certain ranges of prices for products or services by leaving positive remarks about the product or service (Han *et al*., 2009). Guests in hotels as the primary stakeholders tend to prefer to deal with hotel services that are less harmful to the natural environment (Lita *et al*., 2014). The customers who are likely to pay for a sustainable hotel, are typically more sophisticated and to varying degree of concern about environmental issues (Lita *et al*., 2014). People who are more familiar with the hospitality of hotels are more conscious about sustainability and the hotel industry currently faces increasing demands to achieve environmental responsiveness (Anuwichanont *et al*., 2011). These customers believe in the value provided by sustainable hotels which can be identified as, environmentally friendly properties whose managers are eager to institute programs that save water, energy, and reduce solid waste and money (Lita *et al*., 2014).

- **Environmental Concern of Customers**

Anuwichanont *et al*. (2011) identified customers' environmental concern as an individual orientation of each hotel guest towards the environmental impacts. Nowadays many individuals and communities have paid attention to the importance of engaging in eco-friendly sustainable behaviours which proves the customer attitudes toward environmentally, economically and socially sustainable behaviours (Chen, 2011). When hotel guests are conscious of the importance of environmental issues, it increases the level of responsibility of consuming an environmentally, economically, and socially sustainable hotel service (Chen, 2015). A Research by Pathak (2015) has proved that about 80% of guests consider themselves as environmentally conscious customers and 62% of guests tend to concern about environmental issues when selecting a hotel.

- **Customer Attitudes of Preferring Natural Resources**

Nowadays, customers tend to prefer natural environmental factors rather than gaining comfort through artificial energy consumption factors in their leisure in hotels (Yusof and Jamaludin, 2014). There is a positive impact on sustainability and a reason for many environmental, economic and social benefits (Yusof and Jamaludin, 2014). When it comes to, architectural design of the hotel local materials like clay tiles, bamboo and local timber dominate the design approach of hotels and provide an aesthetic appearance that guests prefer to feel (Jauhari, 2014). On the other hand, using daylights instead of using artificial lighting fixtures, through building orientation and glass walls, is a trending demand among hotel guests with attitudes of preferring natural resources (Wang, 2012). This factor is established as "use only natural lighting during daytime hours" in the framework of adopting green practices among hoteliers (Mousavi *et al.,* 2017).

2.2.2 Consideration of Benefits in Sustainable Hotels

There are hotel customers who do or do not have any personal willingness to consume sustainable hotels but, they would choose sustainable hotels considering benefits such as low operational cost, increasing overall image, and market differentiation, believing in the influence of those benefits towards their customer loyalty (Blackman and Rivera, 2010). Three main factors come under the category of consideration of benefits in sustainable hotels, namely, 'Low operational cost of sustainable hotels', 'overall image of sustainable hotels' and 'Market differentiation of sustainable hotels'. These three (03) factors are described in the below subsections respectively.

- **Low Operational Cost of Sustainable Hotels**

Adopting sustainability practices for a hotel helps to reduce operational cost while improving the performance of the hotel activities (Kularatne *et al*., 2019). Moreover, the operational cost of a hotel can be more effective when it tends to adopt sustainability practices such as using energy-efficient lighting, using natural ventilation and daylighting. Hotels can be identified as a facility which consumes huge amounts of energy, non-recyclable good, and natural resources while contributing greatly to environmental degradation, therefore, sustainability is a solution not only reduces environmental harm but also cut back operational cost (Jiang and Kim, 2015). Reduction of operational cost is directly connected with the price that customer should pay to gain the service from the hotel. If the hotel guest perceives the fairness of price of hospitality service it helps to grow step by step optimistic emotion towards the hotel by keeping a better customer loyalty (Fernando, 2019).

- **Overall Image of Sustainable Hotels**

The overall image of a hotel can be identified as a combination of impressions, beliefs and thoughts which collect consumer perceptions towards attributes of a hotel (Chen, 2015). A sustainable hotel image is a positively effective factor towards consumers' perceptions and increases their revisit intention for a future stay (Kularatne *et al*., 2019). A better sustainable application covering the triple bottom line including environment, economy and society helps to establish a brand image so that customers tend to consume hotel service with a considerable demand (Dissanayake *et al*., 2016). Furthermore, studies conducted by the IHEI (2020), reveal that 90% of hotel guests prefer to stay in a hotel that reduces environmental impact and adopt sustainable practices as it improves the hotels' overall image. The overall image created by the sustainability of a hotel is very important to influence the degree of customer loyalty (Cheng and Rashid, 2013).

- **Market Differentiation of Sustainable Hotels**

Currently, both the Sri Lankan government and hoteliers have led an attempt to develop programs to promote environmental sustainability among hotels (Fernando, 2019). IFC has stated that the "Greening Sri Lankan hotels" program conducted by the Sri Lankan government, play an important role in developing knowledge about energy efficiency and better water utilisation to make hotels keep in market differentiation. If a hotel tends to adopt the most possible sustainable applications, it helps to create a unique hospitality service and offer a unique experience for guests (Marques *et al*., 2016). The same authors stated that an effective market differentiation of a hotel through a sustainable policy improves customer loyalty as it impacts customer satisfaction. A sustainable hotel can create a great marketing strategy that helps to be differentiated and providing customers with what they need (Jauhari, 2014).

However, when it comes to the Sri Lankan context, despite the abundance of research on the concept of sustainability, a gap in literature could be identified when it comes to analysing the customer loyalty aspects, i.e., self-influence factors of customers (refer Section 2.2.1) and consideration of benefits that occurred through sustainable hotels (refer Section 2.2.2) toward sustainable hotels in Sri Lanka. Thus, in bridging this knowledge gap, this study intended to investigate the adaptability of sustainability in achieving customer loyalty. The subsequent section discusses the methodology adopted in bridging the knowledge gap.

3. RESEARCH METHODOLOGY

This study aims to investigate the ways of achieving customer loyalty of the hotel sector through the sustainability concept, which so far has not been addressed as a research in Sri Lanka. Thus, the research question of the study was developed as follows:
***RQ*: "How sustainability could affect customer loyalty in the Sri Lankan hotel sector?"**

A qualitative research approach was followed since it is considered to be the most suitable approach in achieving the aim of the study based on the research question (Yin, 2014). The study followed an in-depth exploration of the contemporary phenomenon, i.e., investigate the ways of achieving customer loyalty of hotel sector through sustainability concept within its real-world context, with a 'how' type of research question. Thus, adopting the case study research strategy can be justified. A holistic multiple case design (Yin, 2014) was selected with "customer loyalty" as the unit of analysis while sustainable hotels being the case boundary. Yin (2014) recommended that the number of cases should be decided based on literal replications or theoretical replications expected through the study. Therefore, this study was limited to two (02) expecting literal replications. Further, the high data saturation experienced during data analysis justified the adequacy of the number of cases selected. The selected two (02) cases were the representation of topmost sustainable hotels among the few sustainable hotels in Sri Lanka. Both hotels are constructed and currently operates by following 'sustainability' as the main theme. Moreover, interviewees were selected based on the purposive sampling which falls under the non-probability sampling where the researcher has used expertise to select a sample that is most useful to attain the purpose of the research, which is to investigate how the sustainable practices would affects the customer loyalty. Thus, a total of ten (10) interviews were conducted from both cases. Table 1 provides a profile of selected cases and interviewees.

Table 2: Profile of case studies and interviewees

Case	Respondent	Management/ Customer	Designation of managerial level respondents	Work experience of managerial respondents
Case A A green certified five-star hotel Located at Uva Province A building complex spread across 38 acres of land	AM1	Management	Chief Engineer	15
	AM2	Management	Environmentalist	15
	AC1	Customer	-	-
	AC2	Customer	-	-
	AC3	Customer	-	-
Case B A green certified five-star hotel Located at North-Western Province A building complex spread across 208 acres of land, which the hotel area is around 8 acres	BM1	Management	Learning and Development Manager	25
	BM2	Management	Sustainability in charge	15
	BC1	Customer	-	-
	BC2	Customer	-	-
	BC3	Customer	-	-

The interview guideline focused on customer loyalty aspects identified through the literature review. Interviewees were requested to elaborate their answers as per the current exposure to the customer loyalty aspects. The collected data was analysed using content analysis. The findings were extracted through analysis of case findings using an abductive analysis.

4. RESEARCH FINDINGS AND ANALYSIS

A detailed description of the cross-case analysis of Case A and B are presented in two subsections: one describes the "Self-influence factors of customers (Section 4.1)" and one describes "Consideration of Benefits in Sustainable Hotels (Section 4.2)".

4.1 SELF-INFLUENCE FACTORS OF CUSTOMERS

According to the literature findings, three main self-influence factors make customers loyal to sustainable hotels (refer Section 2.2.1). The perceptions of both managerial level and customer level respondents towards these three factors are analysed in Sections 4.1.1 to 4.1.3 while Section 4.1.4 discusses a unique self-influence factor, which was derived through analysis of research findings specific to the Sri Lankan context.

4.1.1 Behavioural Intention of Customers

The willingness comes from customers' behaviour in being sophisticated while getting satisfied about sustainability related services are the behavioural intentions of customers. They are loyal to sustainable hotels with the intention to pay money in a certain range while leaving a positive remark. Managerial level respondents of both cases agreed that there are customers who tend to visit both hotels considering their behavioural intentions. Respondent AM1 justified this fact by stating "*it is very rare to find customers who visit our hotel just to spend a leisure time because our hotel is based upon the green concept and customers who appreciate it*". When it comes to customers' perspective, AC1, AC3, BC1, and BC2 clearly mentioned that their knowledge and awareness on sustainability is the cause of being loyal with these hotels through behavioural intention. On the other hand, respondent, BC3 also mentioned that his behavioural intention influences him to prefer sustainable hotels where he stated, "*I think my behavioural intention is created through present social media evolution. Nowadays, people tend to promote about sustainability and publish impacts of environmental pollution along with evident real incidents. So that, it influences me to appreciate sustainability even in a hotel stay".* It seems customers tend to choose sustainable hotels as their behaviour influences from awareness on sustainability.

4.1.2 Environmental Concern of Customers

The consciousness about environmental pollution among customers influences them to deal with sustainable hotels to integrate with sustainability initiatives. It contributes to the hotel industry for attracting customers with environmental concern. Management of both cases reviewed that, there are customers who tend to be loyal to these hotels due to their concern for the environment. Managerial level respondent AM2 stated, "*there are customers who do not aware of the sustainability practical scenarios but, very fond of the environment".* Respondent BM1 explained that "*our hotel is in the high priority level in Sri Lanka for customers who care about the environment. So, majority of the customers come to this hotel, are with high environmental concern. For them, each sustainability practice is important".* However, feedbacks from managerial level respondents proved that awareness or knowledge on sustainability does not impact on environmental concern and respondent BC3 who introduced himself as a customer who do not have much knowledge on sustainability stated "*considering the current incidents on environmental pollution in Sri Lanka, my concern towards the environment is influenced so I appreciate this sustainable hotel and its practices".* Respondent AC2 stated *"I am not aware of a lot of sustainability practices, but I know it is environmentally friendly so that, there is a minimum impact on nature"* and he further mentioned his environmental concern is highly influenced to prefer this hotel and to be loyal with it.

4.1.3 Customer Attitudes of Preferring Natural Resources

Some customers are looking forward to experiencing the spectacularism of natural resources through their visit to sustainable hotels. The main concern of these customers is to avoid technological and typical applications of conventional hotels. Thus, the customers with attitudes of preferring natural resources tend to choose the service from sustainable hotels. Both the management respondents from both cases mentioned that preferring natural resources is one of the basic and initial intentions of customers who visit these sustainable hotels. On the other hand, managerial level respondent BM1 stated, "the *majority of the customers who visit this hotel tend to prefer, natural rock pool, outdoor dining, cave dining, and walking around forest rather than staying inside an air-conditioned room as their attitudes directly interrelated with sustainability practices and to experience them".* Further, all the managerial level respondents explained that, if customers require a more technologically advanced hospitality service, which includes, full air conditioned, and high energy consumed, closed environment in a crowded city area, they will not be loyal to these sustainable hotels. This fact was further justified by customer level respondents from both cases and especially AC1 stated "*my attitudes are integrated with natural resources in the hotel sector, so that, when choosing a hotel, I concern about the availability of natural resources such as natural ventilation and day lighting which reaches my attitudes and intentions"*.

4.1.4 Educational Purposes of Customers

The educational purposes of customers are a novel self-influence factor that has been investigated through the analysis of empirical research findings. Managerial level respondents from both cases suggested that other than customers' behavioural intention, environmental concern, and attitudes of preferring natural resources, customers tend to visit these sustainable hotels for their educational purposes. Mainly, managerial level respondents from Case A stated *"nowadays, people tend to get to know about sustainability. So that, researchers, and environmentalists choose to have a valuable stay in green-certified hotels to observe the sustainable practices"*. It was further apparent through findings that customers such as researchers, university students, environmentalists tend to visit Case B for their educational purposes as this hotel is considered as the best sustainable model in the Sri Lankan hotel sector. Additionally, respondent BM1 stated "*most of them tend to publish their findings and communicate with others about the hotel which continuously leads to increase our customer base and their loyalty"*. Each year, there is a certain customer base that arrives at these hotels due to their educational purposes and it makes them loyal toward hotels. All the managerial level respondents presented the reason for this self-influence factor mentioning that, the unavailability of many sustainable hotels in Sri Lanka. Hence, the customers with educational purposes tend to visit and achieve their purposes which will influence them to be loyal.

Table 2 provides the identified self-influence factors that affect customer loyalty towards sustainable hotels in Sri Lankan context.

Table 2: Customer loyalty aspects of Sri Lankan sustainable hotels- self-influence factors

Self-influence factors of customers	Customers who take into consideration	Feedback by management	Remarks
Behavioural intention	AC1, BC1, BC3	These customers are intelligent customers who appreciate sustainability.	Customers with sustainability awareness/ knowledge influence from this factor.
Environmental concern	AC1, AC2, AC3, BC1, BC2, BC3	The major influenced factor among sustainability.	Sustainability knowledge does not matter as customers who care about environment influence from this factor.
Customer attitudes of preferring natural resources	AC1, AC3, BC2, BC3	This is the competitive factor to win customers over conventional hotels as more conventional hotels are located in urban areas.	The location of hotels is the major influence on this factor because a location which expose to more natural resources attract customers. (E.g.: hotels near to forest, sea)

Self-influence factors of customers	Customers who take into consideration	Feedback by management	Remarks
Educational purposes*	AC1, BC1	A special opportunity among sustainable hotels to reach the educational sector.	The published articles and books generate customer loyalty without any cost as it influences customers.

*Represents the new self-influence factor that has been identified through data collection.

4.2 CONSIDERATION OF BENEFITS IN SUSTAINABLE HOTELS

Other than self-influence factors, customers consider the benefits of sustainable hotels as a factor, to be loyal to sustainable hotels. Those benefits facilitate enhancing the customer loyalty of sustainable hotels while influencing them to visit continuously. According to the literature review findings, there are three (03) benefits that customer takes into consideration in being loyal with sustainable hotels (refer Section 2.2.3). The perceptions of both managerial level and customer level respondents towards these three benefits are analysed in Sections 4.2.1 to 4.2.3. However, it is revealed that low operational cost is not relatable with hotel customers in Sri Lanka (refer Section 4.2.1).

4.2.1 Low Operational Cost of Sustainable Hotels

The operational cost of sustainable hotels is comparatively less due to sustainable practices although it incurred high cost at the implementation stage. Especially, managerial level respondents of case B mentioned that there are a lot of sustainability practices such as, use of solar power plants for electricity generation, application of natural ventilation and use of daylighting, and use of LED lights, which directly supports to reduce operational cost. Apart from the above sustainable practices, case A use in-site Reverse Osmosis (RO) plant, in-site Effluent Treatment Plant (ETP) and STP (Sewage Treatment Plant). These practices have facilitated Case A to reduce the water consumption of the hotel. This is because, the whole water consumption is managed using treated seawater which directly reduces operational cost. On the other hand, when considering the impact of low operational cost on customer loyalty, there should be a price reduction, which customer must pay for the hospitality service they receive. In this context, managerial level respondents of Case A stated "*customers will not get the real benefit of sustainability through the prices, as hoteliers like us tend to value the speciality of the sustainability concept. There are only a few hotels which are based upon the sustainability whereas, our management tends to value it by in*creased prices compared to other luxury hotels in Sri Lanka". In this context, it became evident that customers do not receive the benefit of low operational cost arisen due to sustainability, as both cases do not reduce the price of hospitality service.

4.2.2 Overall Image of Sustainable Hotels

A hotel creates its overall image through sustainability, and it helps to have a competitive advantage among other hotels as well. Simply, the value that has created from the overall image of hotels facilitates to attract more customers as loyal customers. It is because, there is a certain range of customers who consider the overall image of a hotel when deciding their loyalty. Managerial level respondents of both cases described that overall image is the factor which influences the first impression of a hotel for the new customers who visit these hotels for the first time. Managerial level respondent BM1 further stated "*some customers do not see the sustainability practices inside the hotel until they visit* *this hotel. Until that, the main reason for choosing this hotel for their stay is the overall image which portrays the sustainability"*. Thereby, it is evident that the overall image of the hotel is mostly benefited for newly attended customers. It is not only the new customers but also it supports to increase the continuous visitation of customers who continuously visit sustainable hotels being loyal due to overall image. These customers will serve as advocates to the hotel by giving free publicity among the society in addition to the other media such as newspapers, well-established websites for customer reviews, social media and the hotel's official website.

4.2.3 Market Differentiation of Sustainable Hotels

As the Sri Lankan hotel sector consists of a comparative number of conventional hotels than sustainable hotels, a hotel that follows sustainability can differentiate in the whole hotel market which in another way, attract customers. The sustainability practices followed by the hotel make it a differentiated entity that reaches customers who consider market differentiation. Market differentiation of both cases have been defined by managerial level respondents in a very positive manner as they believe customers have been achieved through market differentiation they have created. Hotel management of both cases believes adaptation of sustainability practices as a marketing tool. This is because, sustainability is the main pillar that acts in being differentiating in the market. Further, respondent AM2 stated "*one of our main activities is to provide a unique experience for customers in a beautiful living setup through a luxury amidst nature and wildlife so that, our hotel is differentiated in the market through this sustainability marketing tool"*. On the other hand, respondent BM1 stated "*this hotel has already established its name in the market due to the created market differentiation of sustainability"*. In this context, it is evident that market differentiation of Case A and B is a factor which exists in hotel market for achieving customer loyalty as sustainable hotels. When it comes to customer level respondents, respondent AC2 stated "*it positively impacts customers like me to choose sustainable hotels as there is a certain group of customers who visit hotels considering its' market differentiation"*. Table 3 depicts the consideration of benefits in which would affects the customer loyalty towards sustainable hotels in Sri Lankan context

Table 3: Customer loyalty aspects of Sri Lankan sustainable hotels - consideration of benefits

Consideration of benefits in hotels	Customers who take into consideration	Feedback by management	Remarks
Low operational cost**	-	The price that customer must pay is not reduced as sustainable hotels value their uniqueness	Price is high compared to other conventional luxury hotels.
Overall image	AC2, AC3, BC2, BC3	It reaches a new customer base who did not know about these hotels	Depend on the progress of sustainability as the main pillar is sustainability.
Market differentiation	AC2, AC3, BC2, BC3	These hotels differentiate from other hotels through sustainability	Selected hotels are the two topmost sustainable 5-star hotels in Sri Lanka.

**Represents the inapplicable benefit in Sri Lankan sustainable hotels which was identified through data collection.

4. DISCUSSION

By reviewing the literature, two aspects were revealed which describes how the sustainable practices of hotels would affect the customer loyalty: namely; self-influence factors of customers (refer Section 2.2.1), whereas the customers of the hotel sector that motivates by their own will due to the sustainability performance through their preference and willingness of being loyal to sustainability practices (Chen, 2015) and the consideration of benefits that could gain via the sustainable hotels (Blackman and Rivera, 2010) (refer Section 2.2.2). The literature findings were identified in general and were not specific to Sri Lankan hotel industry. However, these findings were almost similar to the Sri Lankan context conferring to the case study findings. For instance, In the aspect of self-influence factors, three factors were revealed by the literature, namely; behavioural intention of customer, environmental concern of customers and customer attitudes of preferring natural resources which were also confirmed through the case study refer (Sections 2.2.1 and 4.1], except the factor ***"educational purposes"*** which was solely identified to the Sri Lankan context revealing that there is a separate customer base who are visiting these hotels in order to achieve objectives of research, books, documentary programs and other educational activities and become loyal with these hotels (refer Section 4.1.3). In addition to the self-influence factors, the other aspect identified was the consideration of benefits that could gain through sustainable hotels. Most of these benefits identified through the literature were also analogous to the Sri Lankan context, such as overall image and market differentiation (refer Sections 4.2.1 and 4.2.2). However, even though, Kularatne *et al*. (2019) and Jiang and Kim (2015) have identified ***"low operational cost of sustainable hotels"*** also as a benefit, case study findings revealed that low operational cost holds a different perspective in Sri Lankan hotels towards the fact of granting service to customers for low prices (refer Section 4.2.1) portraying that it is not applicable to the Sri Lankan context.

5. CONCLUSIONS

Sustainability is a concept which has the capability of enduring and maintaining itself while making biological systems to remain healthy, diverse, and productive over time. When considering the sustainability of hotel sector, it creates environmental improvements to the structure for the purpose of minimising its' impact on environment. Sustainable hotels have a vast potential on achieving customer loyalty through a better sustainability performance. Thus, this paper was aimed at analysing the aspects where the sustainability could the affects the customer loyalty in Sri Lankan hotel industry. Two aspects were identified through the literature review such as self-influence factors of customers and the consideration of benefits that could gain via the sustainable hotels (refer Sections 2.2.1 and 2.2.2), which could achieve customer loyalty through sustainability practices. Behavioural intention, environmental concern, customer attitudes of preferring natural resources and educational purposes were the four (04) factors identified respective to the aspect of self-influence factors in the Sri Lankan context (refer Section 4.1). Moreover, two (02) facts were revealed following the aspect of consideration of benefits in sustainable hotels which are pertinent to the sustainable hotels in Sri Lanka; namely, overall image (refer Section 4.2.2) and market differentiation refer Section 4.2.3) which were slightly differed from the literature findings. The verdicts of this paper claims on the importance of sustainability in attaining the customer loyalty in the hostels in Sri Lanka by identifying several aspects. Thus, the knowledge engendered through this research study would enable the hoteliers including researchers to be aware of the importance in adapting sustainability which will correspondingly leads to conquer customer loyalty that is still unaware amid the most of conventional hotels in Sri Lanka.

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DEVELOPMENT OF A FRAMEWORK FOR FLOOD MITIGATION IN FIJI

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ABSTRACT

A large portion of infrastructure was flooded by water running off pavements or overflowing from the drainage systems in Fiji. The main objectives of this study are to identify the most suitable drainage management solution to reduce the overflow of the drainage system in Fiji, and to develop a framework of drainage management systems. The literature review was conducted to identify various drainage systems used to mitigate flooding around the world. After the review, the characteristics of Fiji such as climate pattern, location and soil type were analysed in the case study section. Secondary data which was obtained from Australia, Norway, the Netherlands, the U.S., Korea, and China were used in the research. The characteristics of Fiji were then mapped to other countries and a scoring system was created to analyse the suitability of different flood mitigation techniques in Fiji. Finally, multiple flood management strategies were proposed, and a drainage management framework for flood mitigation was developed.

Keywords: *Fiji; Flood mitigation systems; Framework; HPC.*

1. INTRODUCTION

It is undeniable that there is a relationship between climate change and flooding events, which seems to be a global issue nowadays. Fiji is one of the Pacific Island Countries and Territories (PICT) which is affected by floods. According to World Bank (2021), due to natural disaster, the economic losses on a per capita basis in Fiji are very high.

Historically, the 3 worst cyclonic activities happened to Viti Levu Island, which is the largest island in Fiji. These include a hurricane that struck in February 1931, Hurricane Kina in 1993, and Cyclone Ami in 2003 (McGree *et al.,* 2010). These cyclonic events have caused a total of 251 fatalities with multi-million dollars loss in infrastructure (Terry *et al.,* 2004; McGree *et al.,* 2010; Yeo and Blong, 2010). However, one of the most recent severe flooding events has shown that cyclonic activities are not the only reasons which lead to disaster in Fiji. Due to Fiji's climate pattern, historical rainfall amount over five days was triggered by a persistent monsoon trough in January 2009, therefore, the Ba, Nadi and Sigatoka rivers in Viti Levu island were severely flooded, and within the Ba River catchment, the flood was reaching 3m above the average flood level at the Rarawai mill (McGree *et al.,* 2010). Due to the combined effect from cyclonic activities and local

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climate pattern in Fiji, there are signs which show the frequency of flooding events seems to be increasing in numbers. (BoM and CSIRO, 2011).

Sung and Kim (2012) have mentioned that not all countries have the intention or technology to develop or implement new generation material for flood mitigation. However, Fiji as a developing country needs to act fast to be able to defeat extreme climate condition. As climate changes, public service such as road drainage systems in Fiji is urgently needed to be modified or improved by potential innovative technologies. However, innovative technologies for managing flood are usually established and used in developed countries, therefore, discrepancies in urban and natural environment must be considered under the context of Fiji. Thus, since the popular drainage management systems around the world are mainly case-based and potentially incompatible with the scenario in Fiji, there is a need to develop a context-specific flood mitigation framework for Fiji. To achieve this, a self-adaptive and flexible flood mitigation framework can potentially be used to assist Fiji to save on construction and operational cost of drainage management systems when applying innovative technologies. And then, this fully developed system can alleviate the constraints between urban and natural environment to help Fiji to develop further on infrastructure and prevent extreme flooding events from reoccurring.

Due to the similarities in different countries' climate condition and urban development, common innovative drainage management systems such as Low Impact Development (LID), floodplain and High Permeability Concrete (HPC) have been selected as potential drainage management systems for Fiji. In the U.S., LID as a recently developed stormwater management technique has been used to manage surface water from impervious surfaces to promote infiltration on adjacent pervious surfaces (Holman-Dodds *et al.,* 2003). Holman-Dodds *et al.* (2003) examined the relative impacts of different forms of urbanization based on experiments on LID. In addition to the LID system, the floodplain system is also one of the innovative water management strategies to reconnect the lakes to the mainstream to reduce the impact of flooding. This strategy sometimes can be incorporated with other infrastructures such as levees. In China, the floodplain system has been considered based on its social value. The government has used floodplain with a moderate number of levees to restore the balance between human and nature. However, in the Netherlands, due to the coastal and low-lying features of the country, levees play the leading role with floodplain in preventing catastrophic flood problems from triggering (Wenger, 2015). In respect to the HPC system, permeable concrete segmental paving has been implemented in the Australian urban road system (Shackel and Pearson, 2003). Based on the general estimation of factors like rainfall pattern, variabilities in climate and soil conditions, Shackel and Pearson (2003) have proved that permeable concrete has very high flexibility and strong adaptability at the pre-design stage of constructing a comprehensive drainage system. From these case studies, it can be seen that due to the increase in urbanised areas of these countries that different flood management strategies have been deployed based on the variation in countries' characteristics such as weather, rainfall pattern, geological information, geographic information and location.

To the authors' knowledge, there are no other researchers who have attempted to solve the drainage system overflow by implementing these new techniques in Fiji. However, flood mitigation techniques from these countries can be modified to be adopted in the context of Fiji. Thus, the objectives of this study are:

- To review and identify various drainage systems prevalent around the globe.
- To refine the drainage systems by conducting comparative analysis between Fiji and other selected countries.
- To develop a framework of drainage management systems that can be implemented in Fiji by evaluating various methods of optimising or reducing overflow from drainage systems.

2. LITERATURE REVIEW

There are about 3 major innovative drainage management systems that are available in the world. These techniques include LID, floodplain/ levees and HPC. In this section, these techniques will be reviewed.

2.1 LOW IMPACT DEVELOPMENT (LID)

Low Impact Development (LID) is an integrated drainage management design approach used to address stormwater and environmental impacts often associated with conventional land development. As an effective stormwater management strategy, LID has been given more attention due to its promising findings in the recent 5 years (Huang *et al.,* 2014). Although it is well known for its eco-friendly and relatively low-cost features, the applications of LID vary depending on countries. In fact, from this conducted literature review, model-based techniques are commonly used to predict and simulate the performance of LID practices. Furthermore, by quantifying countries' characteristics such as weather, rainfall pattern, geological information, geographic information, and location into these models that this strategy can be further developed based on either graphical interpretation or mathematical approach to demonstrate a relatively integrated outcome. The following reviews have demonstrated the common LID models and techniques that countries would normally use when the concept of LID has been considered qualitatively and quantitatively.

At present, one of the commonly used model-based techniques to mitigate flooding around the world is called Storm Water Management Model (SWMM) (Huber, 1988; Rossman *et al.,* 2005). SWMM as the basic model has been incorporated into different LID practices for various countries which shows a certain level of compatibility and adaptability to resist climate changes. This type of storm management strategy has been identified across developing countries and developed countries such as China and Norway (Huang *et al.,* 2014; Hailegeorgis and Alfredsen, 2018). In China, Storm Water Management Model version 5 (SWMM5) has been used to simulate the processes in LID practices based on the model which is developed by the U.S. Environmental Protection Agency (USEPA) (Huang *et al.,* 2014). Huang *et al.* (2014) explored unique approaches to validate and interpret their data based on this model specifically to the characteristics of China. However, the conducted LID research in Norway did not directly apply the SWMM technique. Instead of using this model-based technique, researchers in Norway used SWMM as a control variable to compare their own self-developed mathematical flooding mitigation approach with typical SWMM approaches to enable themselves to understand the advantages and disadvantages of their own systems (Hailegeorgis and Alfredsen, 2018).

Based on the U.S. model, the success of the SWMM5 demonstrates the compatibility of the LID flood mitigation approach in Tianjin, China (Huang *et al.,* 2014). Furthermore, Huang *et al.* (2014) also helped to validate the LID drainage system for the potential to improve stormwater management strategy worldwide. In this case study, Huang *et al.* (2014) have attempted to use graphical interpretation, a performance radar chart (PRC) to attract attention from the readers by visually presenting the performance and functions of LID alternatives such as bio-retention, cistern system, porous pavement, grass swale and infiltration trench. Under a semi-arid climate condition in China, the efficiency index for water balance was integrated with the PRC in conjunction with the long-term numerical simulation to be staged as the first step (Li *et al.,* 2019). And then, the characteristics of that region such as weather, rainfall pattern, geological information, geographic information have been parametrized into the change in total runoff (%), change in peak flow (%), rainfall captured by LID on-site (mm), the ratio of saved rainfall on-site and lag time (min) these 5 indicators, and projected as a polygon to demonstrate the optimum LID option (Huang *et al.,* 2014). The outcome of similar research also suggests that porous pavement as one of the LID alternatives has the best performance to reduce runoff and increase infiltration except for lag time under small rainfall events (less than 25.4mm) (Huang *et al.,* 2014; Tsegaye *et al.,* 2019). However, technically speaking that porous pavement can be categorised into other knowledge bodies of flood mitigation strategies such as HPC. On the other hand, since the information is conveyed to the readers through graphics like polygon that it is useful for readers to gain general ideas and information about the potential LID alternatives but not in details. However, in comparison to the case study in mid-Norway that this SWMM5 LID approach is widely adaptable and can be further developed and modified based on countries' and regions' characteristics (Hailegeorgis and Alfredsen, 2018).

2.2 FLOODPLAIN/LEVEES

Floodplain is a nature-based flood control measure, which is an area of land adjacent to a stream or river which stretches from the banks of its channel to the base of the enclosing valley walls, and which experiences flooding during periods of high discharge (Reckendorfer *et al.,* 2013). A levee or embankment is an elongated naturally occurring ridge or artificially constructed fill or wall, which regulates water levels. It is usually earthen and often parallel to the course of a river in its floodplain or along low-lying coastlines (Skublics *et al.,* 2016). For the application of floodplain, levees sometimes are needed to maintain the balance between the artificial construction and the natural environment, which means a high level of cooperation among relevant stakeholders is the key for this flood control measure to work. Therefore, based on countries' location and historical climate data that this type of techniques is usually guided by countries' policies, because it usually requires a long-time span to be fully conducted.

In China, Boekhorst *et al.* (2010) have recognized that floodplain can improve water quality and recover fish stocks based on the perspective of the development of the ecosystem. Therefore, it can be said that the floodplain is not only reconnecting the lakes to the mainstream rivers but also restoring the balance between human and nature (World Resources Institute, 2021). However, the process to restore floodplain is not easy. In the Dongting and Poyang lakes and the Yangtze River regions in 1998, the flooding problems with 1,461 polders, 2.42 million people in 620,000 households created high risk and huge pressure on water and land resources and demands of food supplies (CCICED, 2004). Therefore, the Chinese government started to restore the floodplain by demolishing polders to release floods from 479 polders with an area above 66.7ha each, and 189,000ha of inundated arable land since 1998. By the end of 2003, a total of 2,900km^2 land has been restored as floodplains with an increase in flood storage capacity up to 13 billion m^3 (CCICED, 2004). The situation is different in the Netherlands. Due to the lowland feature, the Netherlands government has deployed multiple flood prevention techniques to adapt to this weakness. The major concept in the Netherlands is to reduce the water level to gain more room. For example, from 2009, the Noordwaard area of the Netherlands has been transformed from an area protected by levees to an area open to high water (Dutch Government, 2006). In the Netherlands, newly constructed flood channels can make river water flow in and out of the Noordwaard during periods of high water, which can lower water levels by 30cm at Gorinchem and 60cm at the inlet in Werkendam (Dutch Government, 2006). For both China and the Netherland, it can be seen that huge risks have been attached to each of these government-led floodplain approaches, which means large scale flood mitigation projects could frequently involve policies. Therefore, it is important to be familiar with the social context in different countries.

2.3 HIGH PERMEABILITY CONCRETE (HPC)

Regarding adaptability, High Permeability Concrete (HPC) is worth emphasizing and analysing. As a durable and flexible material, HPC can adapt to any kind of weather, rainfall pattern or soil condition without almost any restriction. Different types of HPC can be incorporated into either the traditional gravity sewer drainage systems or newly invented climate-oriented drainage systems. On the other hand, due to its flexibility that HPC provides a good value for money for many countries or clients to maximise their chance to prevent overflow from extreme rainfall events.

HPC facilities the flexibility, drainage efficiency and budget performance of its related flood management strategies. In Australia, Shackel and Pearson (2003) focused more on the efficiency of the drainage system. Due to heavy rainfall and flash flooding in a relatively short amount of time, Shackel and Pearson (2003) have decided to pursue pavements using porous surfacing including porous asphalt, porous rigid concrete and porous pavers as the potential solutions for Australia. To achieve rapid infiltration of rainwater through vertical openings and drains under Australian rainfall conditions, pavers such as Grass-Stones or Grids, Widened Joint Paving Systems and Eco-Pavers have been considered (Shackel, 2006). Since Eco-Pavers provide the highest infiltration of water among permeable pavements and are based on well-proven conventional paver shapes that this type of HPC has already been applied to the Olympic Boulevard at the Homebush Olympic site, Sydney (Shackel and Pearson, 2003). However, drainage efficiency can also be demonstrated based on pollution removal mechanisms. The conducted research has proven that concrete eco-pavers with base materials can lower the pollutant outflow readings than these conventional impervious concrete surfaces which means that the received rainfall has more pollutants than surface runoff from concrete eco-paving (Tota-Maharaj *et al.,* 2012). Furthermore, after the self-purification of eco-pavements, less contaminant has been found in the downstream and groundwater bodies because the transport capacity of the surface runoff has been reduced for the catchment outlet and the groundwater receives filtered infiltrated runoff from the eco-pavements (Tennis *et al.,* 2004). Therefore, the eco-paving technique does not require either groundwater or downstream treatments which can be considered as a huge potential cost saving. As a systematic structural design approach, Shackel and Pearson (2003) have applied the 'LOCKPAVE' computer program published by the Concrete Masonry Association of Australia (CMAA) to design permeable pavements. Since the structural tests of different eco-pavers have shown that they have similar load-spreading properties to conventional pavers. Therefore, 'LOCKPAVE' can be directly applied to this type of HPC. As an integrated computer modelling approach, although the 'LOCKPAVE' design program has also taken into account the modelling of material selection of base and sub-base layers, it barely considers many factors such as rainfall pattern, variabilities in climate and soil conditions (Shackel and Pearson, 2003). To optimise the functionality of the selected HPC material, a comprehensive analysis that includes these factors would provide clients with enough opportunities to test out and help them to decide the most suitable climate-oriented flood management strategy of using HPC at the early stage of construction. This type of modelling based on conventional computer testing procedures is easily achievable, flexible and can be improved by inputting and assigning more parameters, which could significantly improve the performance of budget control for developing countries or private sectors.

3. METHODOLOGY

A comprehensive literature review of papers was conducted to discuss various drainage systems used to mitigate flooding around the world. Based on the library database, research papers addressing common drainage systems such as Low Impact Development (LID), floodplain/levees and High Permeability Concrete (HPC) systems were reviewed.

After the comprehensive literature review, the characteristics of Fiji such as climate pattern, location and soil type were reviewed and analysed in the case study section. The characteristics of Fiji were then mapped to other countries which are reviewed in the literature review section such as China, Norway, the Netherlands, Australia, the U.S., and Korea through a flood mitigation framework. After that, a scoring system was created to analyse the adaptability for Fiji among flood mitigation techniques such as LID, floodplain/ levees and HPC. According to the justification of Sellitto and Burgess (2005), a modified scoring system of the framework was established by considering the value of the criteria (c_i) only. Firstly, the characteristics of Fiji were identified to analyse potential drainage management solutions. Secondly, each country's characteristics were closely examined and compared against the characteristics of Fiji. Thirdly, indices were added to the scoring system subjected to the value of the criteria (c_i) which were either be 1 index 'met criteria' or 0 index 'did not meet criteria'. After all the characteristics in Figure 1 had been cross-checked, all the indices in Table 1 were added up, and the total score for LID, floodplain/ levees and HPC were known. After that, the flood mitigation system which has the highest score in Table 1 would have been the most adaptable drainage management system for Fiji.

At the end of this research, a suitable drainage management framework was proposed for Fiji. Firstly, a flood mitigation framework for Fiji was drawn for comparative analysis based on the characteristics of reviewed countries. This procedure would give relevant stakeholders a deeper understanding of the relationship based on all the mapping factors from various countries. Secondly, from the framework, a scoring system was created. In respect to Fiji, the highest index in the scoring system based on the framework represents the optimal drainage management system choice for Fiji.

4. CASE STUDY

In 2009, Viti Levu, one of the largest Pacific islands in Fiji, experienced one of the heaviest rainfalls and unprecedented flooding on the historical record, which led to the death of 8 people, thousands of people were displaced, and roads were washed away. Nadi, Sigatoka, Labasa, Ba and many rural villages on this island were heavily affected, especially Nadi. Due to characteristics of Fiji include its location, climate pattern and soil type, there are signs which show the frequency of flooding events seem to be increasing in number and size (Leal, 2013). Furthermore, as climate changes, heavy precipitation events are expected to rise even with relatively small average temperature increases, which could potentially destroy Fiji's infrastructure caused by significant flooding.

Fiji is located in the Pacific region composed of 22 Pacific Island Countries and Territories (PICT), which are scattered over one-third of the globe and covers a total area of some 194,000 square kilometres (World Bank, 2021).

The climate pattern in Fiji is tropical marine, which easily triggers extreme rainfall from November to April every year. Due to Fiji's geographic location that warm seasons bring even heavier rainfall for larger islands, especially inland.

The soil in Fiji can be grouped into 8 major types which include young sandy soils formed around the coast of the islands; fertile, deep agriculturally important alluvial soils occupying the valley bottoms; shallow and moderately-deep, dark coloured, nutrient-rich soils on rolling and hilly land; sandy and silty moderately-deep to deep soils formed from volcanic materials containing particles of unweathered parent material; deep, highly weathered clay-rich soils, often acidic and of low base saturation, derived from basic parent materials; deep, highly weathered oxide-rich clay soils of limited agricultural value; deep sandy soils derived from acid parent materials having clay increases in subsoils, usually strongly weathered and of low base saturation; peats occupying low-lying areas in valleys or on plateaus. Specifically, focus on urbanized areas in Fiji, it can be seen that the soil types are usually combined with beach sand and deep, highly weathered clay-rich soils (McGree *et al.,* 2010).

5. RESULTS AND DISCUSSION

The findings which are obtained from the literature review and combined with Fiji's characteristics will be presented in this section. Furthermore, the features of analysed flood mitigation systems and Fiji's drainage management framework will also be presented.

5.1 FEATURES OF LID, FLOODPLAIN/ LEVEES AND HPC

LID as an eco-friendly and low-cost flood mitigation system has been applied in multiple countries such as China, Italy, Norway, the U.S., and Turkey. LID also has multiple different sub-categories such as greywater systems, pavements, soak holes/infiltration trench, swales, rainwater harvesting tanks, rain gardens, urban forests, rainwater barrels and stream daylighting to match up with different purposes of flood mitigation. Since LID provides a number of flood mitigation solutions at competitive prices, it can be suitable for developing countries like Fiji. This is due to the relatively small impact of the LID system on the local environment of Fiji, and the relatively higher affordability for the Fiji government to construct the system than others.

Floodplain/ levees are suitable for low-lying countries such as the Netherlands. The major mechanism of floodplain/levees is either demolishing polders to release floods from polders or deploying multiple flood prevention techniques include demolishing polders, flood channel and open to high water. Since agricultural land occupies a relatively large portion of the low-lying area in Fiji, it can be said that floodplain/levees are potentially suitable for countries like Fiji. This is due to the similar environmental features among these countries. Besides, in respect to the soil type and location of Fiji, the analysed area of the Netherlands is located in a coastal region with clay soil as its major soil type which is also similar to Fiji.

HPC as an innovative technology demonstrates a significant number of features include high durability, high flexibility, high adaptability, high resistance to climate changes, high-cost efficiency, high drainage efficiency, easily mixed and formed on-site and eco-friendly with low maintenance rate. In respect to Fiji, similar soil types have also been found in the analysed countries such as the U.S. and Australia which have applied HPC as their drainage management systems. In respect to climate pattern, porous asphalt, porous rigid concrete, and porous pavers are the 3 potential flood mitigation solutions of HPC which can be used for various intensity of rainfall in Fiji. Therefore, HPC can be suitable for Fiji.

5.2 FIJI'S DRAINAGE MANAGEMENT FRAMEWORK FOR FLOOD MITIGATION

Traditionally, countries' scenario has been assessed by individually measuring countries' characteristics. Several methods currently exist for these measurements on an equal basis. For example, 'Soil type' is the same as important as the 'Location' when comparing characteristics among countries. A weighted average approach is the main non-invasive method used to determine the proportional relevance of each component (Sellitto and Burgess, 2005). The synthesis of the weighted average framework was done according to the procedure of Sellitto and Burgess (2005). For a weighted average (WA) calculation, Sellitto and Burgess (2005) have considered assigning a weight for each observation (w_i) against the value of the criteria (c_i). The cohort of the value of the criteria (c_i) was divided into two groups according to the value assigned to the criteria. To identify any feature, this value will either be 1 'met criteria' or 0 'did not meet criteria'. In this paper, to understand how 'Soil type', 'Rainfall Pattern and Weather' and 'Location' as targeted groups to regulate potential drainage management solutions for Fiji, the associated characteristics from each country have been compared against selected flood mitigation systems. According to the justification of Sellitto and Burgess (2005), to reduce the human error caused by subjectivity, a modified scoring system of the framework has been established based on the consideration of the value of the criteria (c_i) only.

Numerous papers have been analysed based on 6 countries and a framework has been developed. The framework will be interpreted as follows. For example, the major soil type in the analysed area of the Netherlands is clay soil under floodplain/levees mitigation system is given the same equivalence value as the major soil type in Fiji as it is also clay soil. Therefore, 1 index will be given to the Netherlands in the column of 'Floodplain/ Levees' in Table 1. To correlate each group in the framework with the characteristics of Fiji to find the most adaptable flood management technique for Fiji, Table 1 has been created. The top row of Table 1 has been divided into 3 sections which are the names of the reviewed flood mitigation techniques including LID, floodplain/ levees and HPC. After that, each column of the reviewed flood mitigation techniques has been further divided into 3 sub-categories which are 'Soil Type', 'Rainfall Pattern and Weather' and 'Location' for mapping the 3 groups in the framework on the left side of Figure 1. Furthermore, the left end column of Table 1 represents the reviewed countries' names of flood mitigation techniques. Finally, the bottom row of Table 1 represents the total scores for each reviewed flood mitigation technique for the adaptability of Fiji.

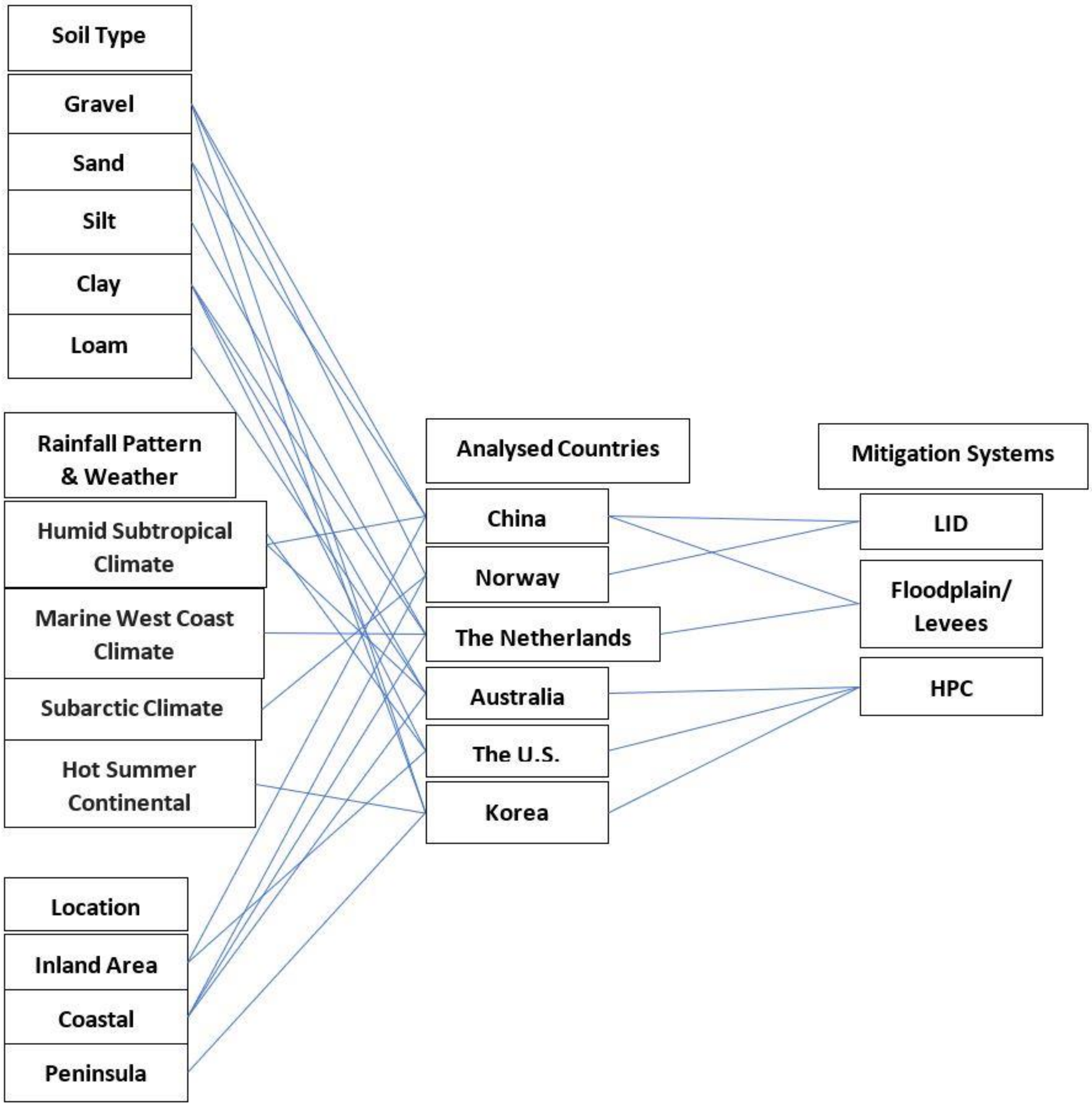

Figure 1: Flood mitigation framework for Fiji

Table 1 shows the scoring system of the developed framework for Fiji. This scoring system for Fiji is based on the 5 characteristics of Fiji. For the geological information and geographic information in the case study section, it is known that the major soil type in urbanized areas of Fiji is beach sand and clay soil. In respect to weather and rainfall pattern, tropical marine is the climate pattern in Fiji featured with extreme rainfall from November to April every year. For the location, Fiji is an island country. Therefore, the 3 groups include 'Soil type', 'Rainfall Pattern and Weather' and 'Location' in the framework from Figure 1 will be compared against with above Fiji's characteristics, and if there is a match that 1 index will be added to that flood mitigation technique for that specific country under one of the 3 groups in Table 1. For example, the major soil types in the Netherlands are silt and clay from Figure 1, therefore, 1 index will be added to the cell where sub-categorized column 'Soil Type' under the section of 'Floodplain/Levees' intercepts with the row of 'The Netherlands' in Table 1 because clay soil is one of the major soil types in Fiji.

Table 1: Scoring system of the framework based on Fiji's characteristics

Countries	LID			Floodplain/ Levees			HPC		
	Soil Type	Rainfall Pattern and Weather	Location	Soil Type	Rainfall Pattern and Weather	Location	Soil Type	Rainfall Pattern and Weather	Location
China	-	1	-	-	-	-	-	-	-
Norway	-	-	1	-	-	-	-	-	-
Netherlands	-	-	-	1	-	1	-	-	-
Australia	-	-	-	-	-	-	1	1	1
U.S.	-	-	-	-	-	-	1	1	-
Korea	-	-	-	-	-	-	-	-	-
Total	2			2			5		

The scoring system in Table 1 can be considered as a part of an optimization process for Fiji. Therefore, with the considerations of the framework from Figure 1 and the scoring system from Table 1, a suitable drainage management framework for flood mitigation is developed for Fiji. From Table 1, HPC is the most adaptable flood mitigation system for Fiji as it has the highest index 5 in total to satisfy all the 5 characteristics of Fiji. This result is achieved after the scoring system has been used to crosscheck all the mapping factors with the framework from Figure 1.

The scoring system in Table 1 has yielded four important findings for design considerations of drainage management system in Fiji.

- In this study, although the major soil types in Fiji are beach sand and clay soil, only clay soil has been considered because an artificial drainage system cannot be built in the sand.
- Loam is the mix based on sand, silt and clay (Ni *et al.,* 2016). Although both loam and clay soil are the major soil types in Australia, only 1 index has been added to the cell where the column of 'HPC' intercepts with the row of 'Australia', because the major soil type in Fiji is clay soil only.
- There is no reviewed country has a tropical marine climate pattern like in Fiji, therefore, the humid subtropical climate pattern has been considered as it is the closest climate pattern to Fiji.
- Although Australia is an island country, the size of Australia is much larger than the size of Fiji.

Therefore, in this study, it is assumed that only countries located in the coastal area will be granted 1 index based on the characteristics of Fiji.

Based on the developed flood mitigation framework for Fiji, professionals in Fiji such as government consultants and engineers can apply this framework quite easily. Firstly, government consultants can initiate the data collection process to shortlist a number of flood mitigation systems because they have easier access to data than most other relevant stakeholders. After all the collected data has been categorised as input to be allocated into the flood mitigation framework for Fiji (refer Figure 1), engineers and government consultants can work together and use the scoring system (refer Table 1) to calculate the index for each flood mitigation system. After all the scores have been calculated for the shortlisted flood mitigation systems, government consultants can propose the system which has the highest index in the feasibility study report of infrastructure development of Fiji.

6. CONCLUSIONS

To sum up, a suitable drainage management framework for flood mitigation has been established for Fiji. This framework provides relevant stakeholders with opportunities to make their best decisions on infrastructure development for Fiji. In the context of Fiji, the most adaptable flood management technique is HPC based on Fiji's characteristics including weather, rainfall pattern, geological information, geographic information, and location. Based on the framework and the scoring system, multiple potential flood management strategies have also been proposed. The developed framework can be used as a guideline by relevant stakeholders such as governments, builders, engineers, consultants, and contractors.

Nonetheless, since HPC is only one part of the flood management strategy, other underdrain systems should be explored further. Underdrain strategies such as full infiltration, partial infiltration and full attenuation might be useful to improve the adaptability of HPC. However, since only secondary data has been used in this study, future researchers can investigate other drainage systems by collecting primary data.

Although the framework still has room for improvement, it is believed that HPC can be an applicable drainage management system for Fiji to mitigate flooding and resist future climate changes.

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DISPUTE AVOIDANCE FROM THE PERSPECTIVE OF PROCUREMENT METHODS: A CONCEPTUAL FOCUS

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ABSTRACT

Disputes are unavoidable in construction projects due to their complex characteristics and involvement of different parties, which can interrupt the smooth construction process. Hence, proper dispute avoidance strategies need to be implemented to avoid disputes beforehand. On the other hand, the previous researchers suggested that there is a link between disputes and procurement methods. Therefore, the current research investigates the disputes in the construction industry from the perspective of different procurement methods. A systematic literature review was carried out to identify the available procurement methods in the construction industry, disputes and dispute avoidance strategies and the features of the procurement methods from the perspective of disputes. Firstly, a total of fifty-two key research papers on the research area were employed to review. The literature findings revealed that the industry has moved towards collaborative approaches from the traditional procurement method with higher dispute frequency because as per the findings the likelihood of disputes seems less in the projects procured under collaboration. It further revealed that the inherent features of collaborative approach such as teamwork, relationships and mutual understanding give less prosper towards disputes. Therefore, the findings of the review conclude that the selection of collaborative procurement method at the early stages of a project can reduce the possibilities of disputes from the perspective of procurement methods.

Keywords: *Construction industry; Disputes; Procurement methods.*

1. INTRODUCTION

The construction industry is one of the major industries, which plays a vital role in the economy of any country (Illankoon *et al.,* 2019). It has become more competitive and complex due to the increasing demands of the employers and the global economic downturn (Farooqui *et al.,* 2012). A procurement method can be considered as a key stage that ensures the successful delivery of a construction project despite the challenges (Wang *et al.,* 2018) and the selection of procurement methods depends on the goals and objectives set forth, cost, time and quality (Lædre *et al.,* 2006). Further, the author pointed out that the methods used for the selection of procurement routes should be improved or otherwise it will overrun on cost, time and quality. Different types of procurement arrangements are available and each procurement method is consisted of advantages and disadvantages concerning the delivery of the project, dispute occurrence and selection of Dispute Resolution Mechanisms (DRM) (Mante *et al.,* 2012).

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The disagreements between the parties in a project may later turn into disputes (Illankoon *et al.,* 2019). Construction disputes have become a major impediment that affect the performance of a construction project, causing the contribution of various practices to avoid disputes (De Alwis *et al.,* 2016). The actions, or inactions of the employer, contractor or other consultants are the main reasons for disputes (Farooqui *et al.,* 2012). Disputes become expensive in terms of finances, personnel, time and opportunity costs, if they are not managed and resolved promptly (Farooqui *et al.,* 2012) while damaging the contractual relationships between the parties (Illankoon *et al.,* 2019). Hence, adherence to DRM is essential because the study by Li and Cheung (2019), indicated that a cleaner output of construction works could be obtained through efficient dispute management. Dispute management can be implemented at the early stage of a project to avoid and resolve the disputes effectively beforehand (Francis *et al.,* 2017).

The practice utilised in the industry when a dispute occurs is either Alternative Dispute Resolution (ADR) or litigation process (De Alwis *et al.,* 2016). However, according to the authors, the drawbacks of DRM in the practical application have paved the path to the dispute avoidance concept. Moreover, Mante *et al.* (2012) stated that the disputes in a project depend on how it is procured and also procurement method is a crucial factor considered in dispute avoidance (De Alwis *et al.,* 2016). Yusof *et al.* (2011) indicated that the traditional procurement method has the highest rate for disputes due to its key features and the other innovative methods like design and build, management and partnering methods have the capability of reducing the disputes. On the other hand, the working atmosphere of collaborative approach can be useful to avoid disputes (Elhag *et al.,* 2020). Therefore, a link of the relationship between the procurement methods and the occurrence of the disputes can be identified especially in terms of dispute avoidance.

Nevertheless, available literature on construction disputes tends to give more attention to dispute resolution than dispute avoidance (Naji *et al.,* 2020). Furthermore, the growth of complexity and competitiveness in the construction industry has gained a reputation for disputes in the last few years (Elhag *et al.,* 2020) and different types of procurement methods have also developed with the evolvement of construction procurement (Oyegoke *et al.,* 2009). Thus, with the time elapsed, the key features of each method may have varied as well as along with the occurrence of disputes and dispute avoidance strategies. Therefore, this research aims to identify the procurement methods used in the construction industry, dispute avoidance strategies to be implemented through the stages of a project and the features of the procurement methods from the perspective of disputes in order to avoid the possible disputes considering the procurement methods.

2. RESEARCH METHODOLOGY

Literature reviews in research are conducted for numerous purposes (Okoli and Schabram, 2010). Systematic literature review facilitates to conduct a study in a methodical manner minimising researchers' bias (Khallaf *et al.,* 2018). Further, the authors stated that it provides higher reliability in establishing frameworks and consistency in data collection comparatively to other literature review methods. Moreover, a systematic literature review enables the researchers for an explicit and reproducible to collect and combine the existing knowledge and to develop a research gap and provides suggestions for further research (Ahmed *et al.,* 2017). Therefore, adhering to this method, the current research reviews the procurement methods in the construction industry, disputes, dispute avoidance strategies and dispute avoidance from the perspective of procurement methods considering the features of each method.

A comprehensive literature review was carried out based on systematic literature review by referring reliable sources. The research mainly focuses on relevant sources published within the study area related to procurement methods, disputes and dispute avoidance and the findings are aligned accordingly in the sections. A total of fifty-two (52) articles were employed for the study. Sections 3 and 4 provides brief introductions about procurement and disputes respectively. Thereafter, dispute avoidance strategies are identified through the stages of a construction project as in section 5. Subsequently the features of procurement methods, especially in terms of causes of disputes, frequency of disputes and dispute avoidance strategies in each are presented in section 6.

3. PROCUREMENT METHODS IN THE CONSTRUCTION INDUSTRY

The procurement method is a key method which creates the client's pre-conditions to ascertain the objectives of a project successfully, preventing project failure and dissatisfaction of the client (Ratnasabapathy and Rameezdeen, 2010). Various procurement methods have advanced along with the development of new concepts and technologies Chanudha *et al.* (2017) and Mante *et al.* (2012) recognised them as traditional, integrated approaches, management-oriented and collaborative/relationship-based methods. Ratnasabapathy *et al.* (2005) identified lump sum, measure and pay, and prime cost as the common variants of traditional method; design and build, package deal, turnkey, develop and construct, novated design and, build and concession contracts as in the integrated method. According to Rahmani *et al.* (2017), management-oriented method is mainly divided as management contracting and construction management while partnering, joint ventures, alliancing and voluntary agreements can be identified as arrangements of collaborative method (Ratnasabapathy *et al.,* 2005).

Earlier, traditional method was the only available option where the architect designs the building and the contractor bids for the project referring the drawings (Joseph and Jayasena, 2008). The report by the Charted Institute of Building (CIOB, 2010) stated that the traditional method is the most understood process in the construction industry with its utilization over a long time period. Nevertheless, a high number of disputes can occur in this method due to its key features (Mante *et al.,* 2012). McDermotti and Khalfan (2012), stated that recently, novel procurement methods are implemented to achieve more integrated and organised processes. Moreover, Naoum and Egbu (2016), stated that alternative procurement methods like design and build, management contracting and construction project management are introduced to overcome the problems from lack of integration, separation of design from construction, improper communication, uncertainty, changes in environment and client's expectations. Furthermore, Elhag *et al.* (2020) emphasised the use of collaborative approach due to its benefits as improved relationships and communication, better productivity and decrease of disputes and litigation. Moreover, change in attitudes and emphasis on trust are the guiding factors of dispute prevention scheme in collaborative method (Mante *et al.,* 2012).

4. DISPUTES IN THE CONSTRUCTION INDUSTRY

Disputes can be considered as a major factor obstructing the successful completion of a construction project due to its high cost and time consumption (Naji *et al.,* 2020). Moreover, disputes are unavoidable because of the complexity, involvement of multi-parties in a project (Abeynayake and Weddikkara, 2013), poor preparation of contract documents, inadequate planning, financial issues and communication issues (Farooqui *et al.,* 2012). Disputes may arise from the commencement to the execution of works because both the parties constantly have to satisfy shared obligations on both sides and a single default case is sufficient to interrupt the balancing pendulum and the entire development (Pawar and Patil, 2014). Therefore, the findings by Farooqui *et al.* (2012), concluded that construction disputes shall be avoided and cautiously managed to obtain a smooth construction process as prevention of disputes is better than cure.

5. DISPUTE AVOIDANCE STRATEGIES

The disputes must be investigated thoroughly and as soon as possible to determine the causes of disputes and relate them to the pre-construction phase to reduce or eliminate them before the commencement of the construction (Naji *et al.,* 2020). De Alwis *et al.* (2016) identified briefing stage, pre contract stage and post contract stage as the major stages in a construction project in preparation of a dispute avoidance model for the Sri Lankan construction industry. Hence, here the dispute avoidance strategies from 21 studies are categorized according to the above mentioned phases in Table 1.

Table 1: Dispute avoidance strategies

Dispute Avoidance Strategies	Sources
Briefing stage	
Selection of most appropriate procurement method	[4], [19], [20]
Selection of collaborative approach/partnering as procurement method	[6], [7], [13], [16]
Specify the quality standards to follow	[4]
Assess the financial risks due to government policy changes	[4]
Pre-contract stage	
Proper preparation of contract documents	[2], [4], [19]
Intervention of an independent third party at the start of the contract [E.g.: Dispute Board (DB)/Dispute Resolution Board (DRB)/Dispute Adjudication Board (DAB)/Dispute Resolution Adviser (DRA)]	[1], [7], [8], [9], [10], [11], [12], [14], [15], [18]
Implementation of proper dispute clauses in the contract	[11]
Proper allocation of risks	[2], [3], [4], [7], [11], [21], [19]
Identify the link between the dispute's occurrence and pre-construction phase	[17]
Selection of contractors	[4]
Early contractor involvement	[13], [15]
Time management by the contractors	[4]

Dispute Avoidance Strategies	Sources
Post contract stage	
Proper administration of contract documents	[19]
Negotiating in an event of differentiating in matter	[3], [19]
Early notification and resolution of the dispute	[19]
Constructability	[13]
Lean construction/Supply chain integration	[13]
Stakeholder management alignment	[13]
Use ADR filter mechanisms	[3], [11]
Team building	[4], [6], [11], [15], [21]
Role of the parties	[4]
Study about occurrence and causes for disputes	[6], [15], [17]
Quality assurance	[4]
Improved relationships	[5], [6], [21]
Patch perceptions of fairness	[6], [11], [21]

[1] Abeynayake and Weddikkara (2013); [2] Cheung (2014); [3] Connerty (2006); [4] De Alwis *et al.* (2016); [5] Chan and Suen (2005); [6] Elhag *et al.* (2020); [7] Gebken and Gibson (2006); [8] Gerber (2001); [9] Hardjomuljadi (2020); [10] He (2010); [11] Jannadia *et al.* (2000); [12] Jones (2006); [13] McGeorge *et al.* (2007); [14] MohdDanuri *et al.* (2016); [15] Mosey (2019); [16] Mustaffa and Bowles (2004); [17] Naji *et al.* (2020); [18] Ong and Gerber (2010); [19] Thusharika and Abeynayake (2016); [20] Yusof *et al.* (2011); [21] Zhu and Cheung (2020)

The findings imply that dispute avoidance may commence from the preparation of contracts and selection of procurement methods as well. Appointment of a third party like a DB, DRB, DAB or DRA at the start of the contract is the most significant dispute avoidance method identified by most of the authors. Other than that, a balanced allocation of risks is also given priority by the researchers as a dispute avoidance strategy and it is important because according to De Alwis *et al.* (2016), construction related risks are one of the main causes of disputes. Furthermore, the selection of suitable procurement method, taking actions to improve the performance as a team and examining the dispute causes and clauses in the contract have a considerable effect on dispute avoidance.

Mante (2015) also identified several sets of dispute avoidance strategies which utilise procurement and management of relationships and, management related processes of construction projects. The findings of Table 1 have highlighted the selection of the most suitable procurement method and on the other hand, several authors recognised the collaborative/partnering approach itself as a method of dispute avoidance. The strategies such as team building, improved relationships and communication are also identified as dispute avoidance strategies by the authors which are the special characteristics of the collaborative approach as identified by Elhag *et al.* (2020). Moreover, the early involvement of the contractor is also identified as a dispute avoidance strategy where the focus again moves towards procurement methods because in management oriented, design and build, and collaborative methods early contractor involvement is clearly visible as per Table 2. Therefore, it can be identified that the selection of the proper procurement method has a huge impact on dispute avoidance as per the findings. Moreover, the collaborative approach has a significant impact on dispute avoidance in projects because most of the identified dispute avoidance strategies are recognisable as key features of the collaborative approach and several researchers recognised the method itself as a dispute avoidance strategy.

6. FEATURES OF THE PROCUREMENT METHODS FROM THE PERSPECTIVE OF DISPUTES

According to Rameezdeen and De Silva (2002), the construction procurement arrangements in the Sri Lankan context can be categorised as; separated systems (traditional method), integrated systems (design and build method), management-oriented systems and collaborative systems. Moreover, the features of the procurement systems may have different impacts on disputes and dispute avoidance. Therefore, the features of the procurement methods which are applicable in the Sri Lankan context, are illustrated in Table 2, elaborating the involvement of the parties, suitability of the method, early contractor involvement, causes of disputes, frequency of disputes and dispute avoidance strategies based on the literature findings.

Table 2: Features of procurement methods from the perspective of disputes

	Traditional method	**Design and build method**	**Management oriented method**	**Collaborative/ Partnering**
Involvement of parties	Contractor is selected after the design is completed (Rahmani *et al.*, 2017).	Contractor is responsible for both design and construction (Teon, 2014).	Entire process is managed by the contracted consultant (Rashid *et al.*, 2006).	Collaboration between the client and the project team (Mante *et al.*, 2012).
Suitability	Projects with separate responsibilities for design and construction (Rashid *et al.*, 2006).	Clients with less experience in design (Lesniak *et al.*, 2012). Projects with high priority in buildability (Naoum and Egbu, 2015).	Fast track projects (Sivkumaran and Perera, 2015) and projects with more commercial risk (Rahmani *et al.*, 2017)	High risk and high value projects (Rameezdeen and De Silva, 2002). Any kind of construction project (CIOB, 2010).
Early contractor involvement	×	✓	✓	✓
Causes of disputes	1.The contractors tend to reduce quality by providing lack of buildability, forcing design alternations.	1.Dissatisfaction of the client with the quality and design of the final outcome. 2.Abortive work.	1.The absence of single point responsibility for design and construction (CIOB, 2010).	1.Unforeseen circumstances and drawbacks (Sinha and Jha, 2020).

	Traditional method	Design and build method	Management oriented method	Collaborative/ Partnering
	2.Contract variations (Elhag *et al*., 2020). 3.Lack of communication. 4.Price competition. 5.Fragmentation (Mante *et al*., 2012). 6. Separation of design and construction (CIOB, 2010)	3.Imprecisions in the client's brief. 4.Conflicts between the brief and contractor's proposal. 5.Valuation of variations. (Mante *et al*., 2012).		
Frequency of disputes	Higher (Yusof *et al*., 2011).	Less. (Mante *et al*., 2012).	Less (Yusof *et al*., 2011).	Less. (Mante *et al*., 2012).
Dispute avoidance strategies	Implement alternative procurement methods as design and build and collaboration (Mante *et al*., 2012).	Early involvement of the contractor (Elhag *et al*., 2020). Implement collaborative method (Mante *et al*., 2012).	Implement collaborative (partnering and trust) method (Mehany *et al*., 2018).	The characteristics of collaborative method like social relationships, non–opportunistic behaviour, trust, faith, changing attitudes and respect among the participants (Elhag *et al*., 2020; Mante *et al*., 2012).

The tabulated data of numerous studies indicate that the features of procurement methods vary with the type of the procurement method. The involvement of the contractor in traditional method occurs only after the design is completed, but the design and build contractor contributes from the early stages in both design and construction, improving the buildability. The appointed contractor in management-oriented method manages the total process while increasing the opportunity for more fast track and high risk projects. Collaborative arrangement is especially suitable for projects with high value and risks. However, the findings imply that irrespective of the implemented procurement method, disputes may arise due to various reasons. The traditional method is recognised as the method with the highest frequency for disputes while other methods have comparatively a less frequency. The reason for an increased number of disputes in traditionally procured projects is due to the main features of the procurement process (Mante *et al.,* 2012) and as it is extensively subjected to variations, leading to an increase in cost and time extensions (Yusof *et al.,* 2011). As per Table 2, several causes of disputes are identifiable in the traditional method due to issues like less quality, variations, lack of communication, separation of design and construction etc. In the design and build method as well disputes may arise with client's dissatisfaction with quality, ambiguities in the client's brief and the contractor's proposal, variation issues and abortive work. The main reason for disputes in management-oriented method is the lack of single point responsibility and unforeseen circumstances in collaborative approach. However, most of the researchers identified collaboration as a procurement method to avoid disputes successfully considering its key features and as collaboration between the project participants is claimed to lead for fewer disputes (Osipova and Eriksson, 2011). According to Table 2, the implementation of collaborative approach was significantly highlighted as a dispute avoidance strategy to be adopted under each procurement type.

However, the selection of the most suitable procurement method that is the most satisfactory to execute the works can avoid disputes (Thusharika and Abeynayake, 2016). As the costs related to adversarial relationships in the construction industry have become more obvious, collaborative practices began to emerge and interest in informal and less adversarial dispute resolution procedures have developed (Musonda and Muya, 2011). As per the findings, considerable attention towards the selection of collaborative approach is given to avoid disputes beforehand because its characteristics like social relationships, non-opportunistic behaviour, mutual trust, faith, changing attitudes and respect among the project participants have increased the consideration towards it. Figure 1 presents the conceptual framework derived through the findings of the study.

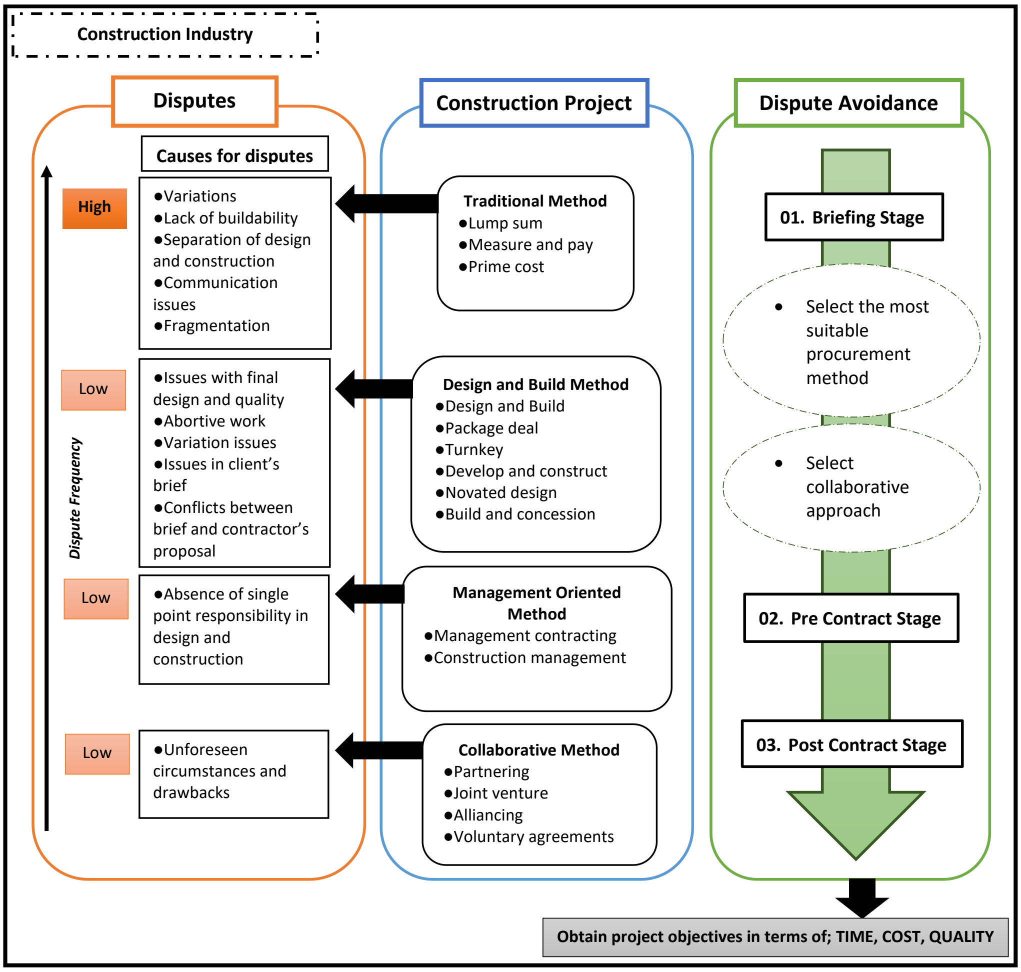

Figure 1: Conceptual framework for disputes from the perspective of procurement methods

As per the developed framework, dispute avoidance can be initiated irrespective of the adopted procurement method in order to ensure the successful completion of a project while obtaining the objectives in terms of time, cost and quality. The procurement method with the highest rate for disputes is traditional method and the lowest is the collaborative method. Each method has various kinds of dispute causes which vary with the procurement type mainly because of the features of them. The causes of disputes respectively to each method is presented in the framework. On the other hand, dispute avoidance may take place at three major stages of a construction project: namely; briefing, pre contract and post contract stages. However, this research aims to elaborate the concept of dispute avoidance from the perspective of the procurement methods. According to the findings, selecting the most suitable procurement approach at the briefing stage acts as a dispute avoidance strategy and collaborative approach was mainly highlighted as a significant method with the capability of avoiding disputes. Disputes are inevitable irrespective of the used procurement type. Therefore, the industry practitioners must rethink of adopting dispute avoidance strategies from the commencement of the project, especially in terms of selecting a procurement method. Figure 1 clearly illustrates the key causes of disputes in each procurement method and the importance of selecting collaborative approach at the briefing stage. However, the developed model only identified the contextual aspects of dispute avoidance from the perspective of procurement methods and further investigations are required to ascertain the connection.

7. CONCLUSIONS

Disputes are common in construction projects because of the complex and competitive characteristics and involvement of different parties. If the disputes are not avoided or managed properly, it may affect the performance and the final outcome of a project. Hence, in the present competitive environment in the construction industry, the possibilities for disputes should be reduced and proper mechanisms should be implemented to reduce them. However, attention towards dispute avoidance should be high due to the disadvantages of DRM. Procurement method is a key factor which contributes to the successful completion of a project. Previous research pointed out that the method of how a project is procured contributes to the disputes that arise. Therefore, this study was conducted to further study the disputes in the construction industry from the perspective of procurement methods. A systematic literature survey was carried out by referring to reliable resources in the area of the research. The research identified the relationship between disputes and procurement methods in terms of the frequency of occurrence of disputes in each procurement method, causes for disputes and suitable dispute avoidance strategies for each method. The findings implied that in the traditional procurement method, dispute frequency is high compared to the other alternative methods mainly because the design and construction are separated. However, the research findings depict that disputes can be avoided by adopting the most suitable procurement method. Implementation of collaborative approach was highlighted to avoid the disputes beforehand and the discovered dispute avoidance strategies as well were included with the special characteristics of this method. The key features of it like improved relationships and communication, early contractor involvement, trust and understanding have the capability of dispute avoidance. The ability of collaborative approaches to avoid disputes from occurring is identified and proved in this research through the findings of previous research. Therefore, this research suggests that effective ways of dispute avoidance should be considered beforehand in every construction project, mainly by selecting a more collaborative procurement approach based on the findings. The findings of the study enable the industry practitioners to identify the features of the procurement methods which may cause and avoid the disputes and to recognise the dispute avoidance strategies which can be implemented throughout a construction project. The study can be further continued to develop a strategic framework to avoid disputes by investigating the causes of disputes and dispute avoidance strategies adopted in the projects procured under each procurement method, and the effects of disputes in each procurement method.

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DYNAMIC SUPPLY CHAIN CAPABILITY ANALYSIS OF HONG KONG-ZHUHAI-MACAO BRIDGE CONSTRUCTION: A TOPIC MODELING APPROACH

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ABSTRACT

Prefabricated construction as a preferred construction approach instigated significant technological advancements in construction supply chains in Hong Kong (HK). The Hong Kong-Zhuhai-Macao Bridge (HZMB) was a milestone prefabricated construction project which was successfully constructed using these industrial advancements. However, the project itself was a great challenge as it was highly vulnerable to disruptions due to complex supply chain processes. In this regard, increased resilience could be the key to boosting project performance through enhanced Supply Chain Capabilities (SCCs), where identifying SCC dynamics becomes essential. Therefore, this study employed the Topic Over Time Modeling approach to detect critical SCCs using 1,748 unstructured official documents on the HZMB from 2003 to 2018, which spans the period from project design to handover. The popularity trend analysis of texts enabled identifying the six most critical capabilities associated with each construction phase of planning, construction and handover. Thereafter, an ex-post capability evaluation map was developed by considering the popularity trend of capabilities and their relevance to different project phases. Industry practitioners would benefit from prior knowledge of SCCs and their dynamic impact on each project phase to prioritize initiating them adequately and appropriately, targeting value-enhanced-resilient supply chains in ex-ante decision-making of future prefabricated infrastructure development projects. Further, the text-mining research approach unveils to academia, an effective and novel mechanism to extract dynamic empirical clues from a large unstructured set of documents in construction SCC analysis research.

Keywords: *Hong Kong-Zhuhai-Macao bridge; Prefabricated construction; Supply chain resilience; Supply chain vulnerabilities; Topic over time modeling.*

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1. INTRODUCTION

Prefabricated construction techniques have enabled hitherto unattained innovations in safe, clean, highly efficient and advanced construction methods in the Hong Kong (HK) construction industry. However, the inherent supply chain complexities and fragmentations call for resilient supply chains by developing Supply Chain Capabilities (SCCs) that can help deal with consequential disruptions and boost project performance (Ekanayake *et al.,* 2021). The Hong Kong-Zhuhai-Macao Bridge (HZMB) is a milestone prefabricated infrastructure development project that recently raised the HK construction industry to new heights of international recognition. Significantly, the project received an award from the UK Institution of Civil Engineers for its achievements in project management and contribution to enhancing regional transportation networks. The HZMB being 55km long, is the longest bridge-cum-tunnel sea crossing in the world (Li, 2019).

The project was constructed in line with China's 13th Five-Year Plan, which aimed to create an economic hub in the Greater Bay Area (Li, 2019). The bridge is located at the Pearl River entrance and connects three regions of Hong Kong, Zhuhai, and Macao under the political system entitled: 'One Country, Two Systems'. Considering the project scope, the design and construction of the HZMB included three navigation channel bridges, 22.9km of marine viaducts, 6.7km of immersed highway tunnel and two artificial islands (Lu, 2020). Figure 1 depicts the coverage of this mega construction development.

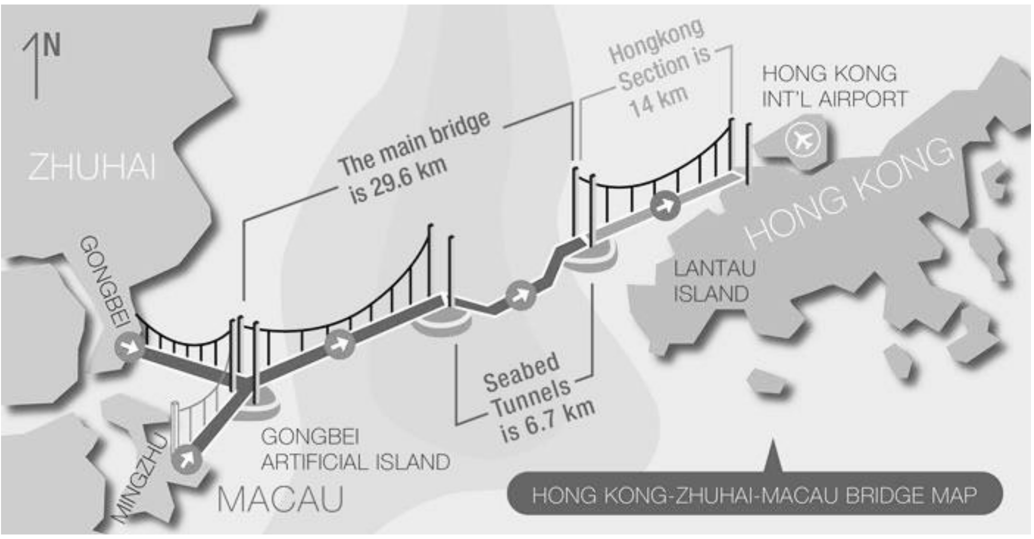


Figure 1: Coverage of the HZMB development (Source: www.ilikese.com, n.d.)

The project's specific location, challenging construction conditions, higher quality requirements, longer service life expected compared to the other similar projects (120 years) and significant safety concerns necessitated that it be developed on the basis of offsite factory-production, standardization and on-site assembly (Lu, 2020). As a result, the main bridge elements, including steel box girders, piers, pile caps, steel pylons and concrete-steel composite box-girders, were prefabricated in newly built prefabrication yards (Zeng *et al.,* 2018; Zhou *et al.,* 2018). The prefabricated components were transported through maritime routes using large pontoons and assembled using the horizontal piece-by-piece assembly method (Lu, 2020). With advanced prefabricated construction methods, the project could be completed safely, innovatively and economically in an environmentally friendly mode (Lu, 2020).

However, these innovative construction methods, advanced technology and equipment injected a new set of challenges that increased project supply chain complexities and vulnerabilities (Hu *et al.,* 2015). Manufacturing the prefabricated components required advanced technology and specific expensive equipment (Ming, 2017). As the components were heavy and bulky [i.e., 420,000 tons of box girders] (Lu, 2020), transportation and assembly became extremely challenging (Zhou *et al.,* 2018). Also, the logistics phase was severely disturbed by the weather conditions, marine waves, marine traffic, aviation height restrictions and safety (Zhou *et al.,* 2018). These added variables superimposed more challenges, which the project team had to cope carefully to ensure the success of this high-profile mega construction project.

In response, various capabilities were instilled in the supply chain process. These included supplier capacity development (Zeng *et al.,* 2018), modular product design (Lu, 2020), more advanced technology (Ming, 2017), meticulous coordination and enhanced collaboration (Zhou *et al.,* 2018), also deploying risk anticipation methods (Hu *et al.,* 2015). All these innovations and commitments unsurprisingly helped the project to achieve improved quality and safety while shortening the construction time compared to traditional construction approaches (Lu, 2020). However, Li (2019) argued that the risk analysis, risk mitigation and prevention measures that were used, could not handle all the challenges, while specific risk management strategies seemed lacking. This led to the project overrunning its timeline and the revised budget of RMB 127 billion, exceeding the allocation of RMB 72.7 billion (Li, 2019). Therefore, the case of HZMB provides a valuable opportunity to learn useful lessons from both successes and failures in developing resilient prefabricated construction supply chains.

On the other hand, there is a rising demand for a comprehensive understanding of SCCs targeting resilient construction supply chains (Zainal and Ingirige, 2018), while it has become more significant in the prefabricated construction subdomain (Ekanayake *et al.,* 2021). In response, Ekanayake *et al.* (2020) have identified the critical SCCs associated with prefabricated construction in HK through an expert opinion survey. Notably, the results of Ekanayake *et al.* (2020) were not tested using a more specific case study of an infrastructure development project. Also, the results were subjective and depended on respondents' quality (Yin, 2017). Further, it was based on static analysis; hence, it lacks the evidence to support the dynamics of SCCs throughout the project phases (Lin *et al.,* 2018). These limitations could be successfully overcome through text mining and case study research (Xue *et al.,* 2020). Topic modeling is a robust text-mining tool that detects the core commonalities among a pool of texts (Wang and McCallum, 2006). Among the topic modeling methods, Topic Over Time (TOT) modeling is considered to be more effective (Xue *et al.,* 2020) as it explores both the content of core concepts and the dynamic concept patterns (Wang and McCallum, 2006).

After considering all these merits, TOT modeling is regarded as appropriate to analyze the dynamics of SCCs using the project documents of this HZMB project. Further, adhering to this method enabled objective case analysis using a large, quantitative, credible and empirical dataset of official documents related to the selected case. Therefore, this study aimed to develop an ex-post SCC evaluation map by introducing TOT modeling as a novel method for SCC analysis, using a large set of unstructured project documents of the HZMB project. As a result of the analysis, the critical SCCs and their annual trend could be explored under each project stage of planning, construction, and handover based on the project timeline. Then, the results were appropriately mapped against project phases, and the ex-post SCC evaluation map was developed. The developed map is proposed as an SCCs initiation guide for project professionals. Further, the identified failure points in the project helped strengthen the discussion by pointing to other necessary capabilities of prefabricated construction projects. The forthcoming sections of this paper present the research methods used, results and consequential discussions, practical research implications, and the conclusions, including research limitations and suggested ways forward.

2. RESEARCH METHODS

2.1 DATA COLLECTION

Figure 2 presents the research data collection and analysis methods used and the flow of this study. As in Figure 2, the relevant data (official documents related to the HZMB) were collected from the Hong Kong Legislative Council's official website. This website is publicly accessible. The data were considered highly reliable since the government maintained the data on this website. Further, the search terms "Hong Kong-Zhuhai-Macao Bridge" and "HZMB" were used to download all the relevant documents. As downloaded, there were 1748 official documents spanning the HZMB construction project period between 2003 to 2018, which spanned over the planning, construction and handover phases.

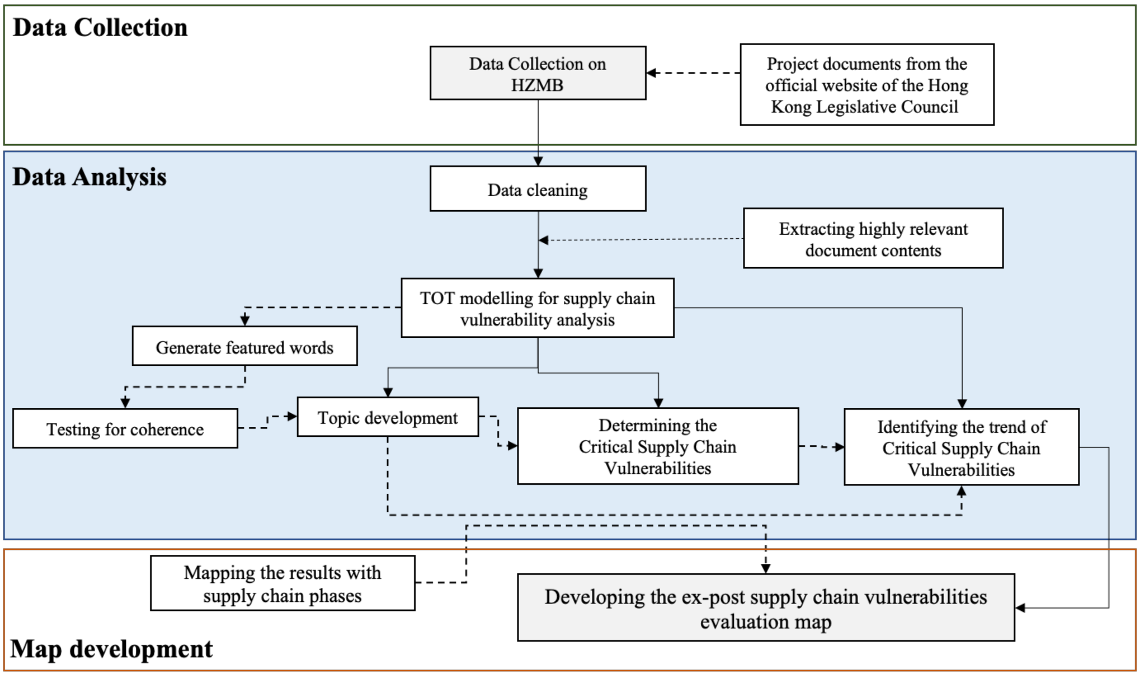
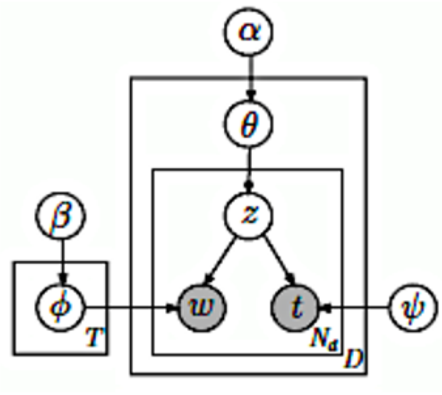


Figure 2: Research data collection, analysis and flow of this study

2.2 DATA ANALYSIS

Data cleaning was first done by extracting the contents from the raw data files using keywords related to SCCs, prefabricated construction and the HZMB to begin the research data analysis. The keywords associated with SCCs were extracted from the study of Ekanayake *et al.* (2020), since those terms were already empirically verified for the prefabricated construction domain in HK. Therefore, the data extracted through the cleaning process can be considered to be highly relevant for this specific study. Then, the primary analysis was conducted using the TOT modeling technique. Compared to other topic modeling techniques such as Latent Dirichlet Allocation (LDA), PLSA and probabilistic theory, Topic Over Time (TOT) modeling is considered to be a more effective technique (Xue *et al.,* 2020). This is because TOT captures the low-dimensional data structures, and also, TOT detects the structure's changes over time which is unavailable with the other topic modeling techniques (Wang and McCallum, 2006). Hence, TOT can facilitate more meaningful results considering both the content and the texts' timestamps (Wang and McCallum, 2006). All these advantages encouraged the authors to choose TOT modeling over other text mining techniques, to explore the texts and their distribution over timestamps associated with SCC analysis of the HZMB. Figure 3 further describes the TOT model used in Gibbs sampling (a commonly accepted model) (Wang and McCallum, 2006), which is also used in this current study.



Symbol	Description
T	Number of topics
D	Number of documents
V	Number of unique words
N_d	Number of word tokens in document d
θ_d	The multinomial distribution of topics specific to the document d
ϕ_z	The multinomial distribution of words specific to the topic z
ψ_z	The beta distribution of time specific to topic z
z_{di}	The topic associated with the ith token in the document d
ω_{di}	The ith token in the document d
t_{di}	The timestamp associated with the ith token in the document d

Figure 3: TOT model used in this study (Source: Wang and McCallum, 2006)

In TOT modeling, first, the timestamps were created for every word token. Then, following the study of Wang and McCallum (2006), each document's timestamp was counted by considering all the word timestamps in a document. The hyperparameters of α and β were kept as α = 50/T and β = 0.1 (Xue *et al.,* 2020) considering the model's simplicity (Wang and McCallum, 2006). Further, TF-IDF filtering was done prior to the modeling to enhance the texts' quality by removing frequent but meaningless texts. Finally, the model generated six SCC topics associated with the HZMB project, including 15 feature words with high relevant probabilities in each. Given the feature word list $V^{(z)}$, each topic's coherence [that measures the degree of logical consistency for text], $C(Z; V^{(z)})$ was calculated and tested using Equation 01, as suggested by Xue *et al.* (2020). In Equation 01, D(V) represents the document frequency; D(V_m, V_l) represents the number of documents that contain both feature words of V_m, V_l.

$$C(Z; V^{(z)}) = \sum_{m=2}^{15} \sum_{l=1}^{m-1} log \frac{D\left(v_m^{(z)}, v_l^{(z)}\right)+1}{D\left(v_l^{(z)}\right)} \qquad (01)$$

3. RESULTS AND DISCUSSION

3.1 CRITICAL SCCS ASSOCIATED WITH THE HZMB CONSTRUCTION AND THEIR TREND

Table 1 presents the six topics identified through TOT modeling, feature words, topic concepts, and coherence values. The authors assigned the topic concepts, considering the common themes underlying the topics (Xue *et al.,* 2020). These assigned topic concepts align with the associated feature words. Further, the TOT model was validated for its coherence and representativeness of the topics, following the method suggested by Mimno *et al.* (2011). Accordingly, the 6-topic TOT model of SCCs was regarded as the best valid model that interprets the project documents and evaluates critical SCCs. The developed six topic concepts are adaptability, anticipation, visibility, capacity, coordination and collaboration, and financial strength. These topics were considered as the critical SCCs employed during the HZMB construction. Figure 4 depicts the timestamps of these critical SCCs throughout the project duration (from 2003 to 2018). The planning phase was between 2003-2009, the construction phase was between 2010-2017, and the project was handed over in 2018.

Table 1: SCC topics developed through TOT modeling

Topic	Concept	Feature words	Average coherence
#0	Adaptability	technic; soon; improv; people; major; cost; commiss; plan; associ; fund; implement; traffic; infrastructure; transport; buffer	-49.0285
#1	Anticipation	transport; origin; direct; flow; connect; control; enhance; link; crossboundari; manag; monitor; feasibl; public; environment; urg	-57.9263
#2	Visibility	site; urg; build; marin; lead; environmentalimpactassess; live; track; estim; cooper; pearlriverdelta; develop; origin; safety; share	-73.9035
#3	Capacity	region; profession; meet; base; construct; conserve; train; strateg; facil; option; econom; land; promot; line; coordin	-66.4556
#4	Coordination and collaboration	coordin; oper; consult; highway; hksar; mainland; control; tunnel; pearlriverdelta; commun; progress; opportun; region; mainbridg; peopl	-63.9743
#5	Financial strength	competit; service; tuenmun; longterm; design; increase; base; process; feasibl; improv; estim; fund; flow; trade; demand	-66.7416

Adaptability [#0] was commonly applied in the project during the planning phase. This topic covers the ability to modify operations in response to disruptions. As the HZMB construction is new to the HK construction industry, proper *'technical*[5]*'* decision-making to deliver the project was mandatory (Lu, 2020). Therefore, the project has considered several alternative technologies during project *'planning'* and *'implementation'*. New prefabrication factories were established with advanced technology separately for tunnel element production, steel girder production, pile cap, and pier production.

Further, automated production lines, innovative connections between prefabricated segments, automatic cutting and bending methods utilizing robots were used (Lu, 2020) to enhance adaptability. As another adaptability measure, European technology was injected by outsourcing and adapting for the bridge deck paving work, blasting and asphalting (Lu, 2020). Indeed, especially produced pontoons were used to *'transport'* these heavy and lengthy segments (Hu *et al.,* 2015). Innovative prefabricated roof

[5] These italic words are the feature words associated with each topic concept.

modules were used to tackle airport height restrictions (Yau and Lok-kei, 2018). Building Information Modeling (BIM) based reporting tools were used throughout the project to enhance adaptability (Zhou *et al.,* 2018). Besides, simulation studies were undertaken to properly *'plan'* the project as most of the technology and approaches used were new (Hu *et al.,* 2015). Also, the schedules were developed by accommodating reasonable time *'buffers'*. Further, considering that the site is located in the white Dolphin protection zone (Li, 2019), the water breakers were designed to be environment friendly.

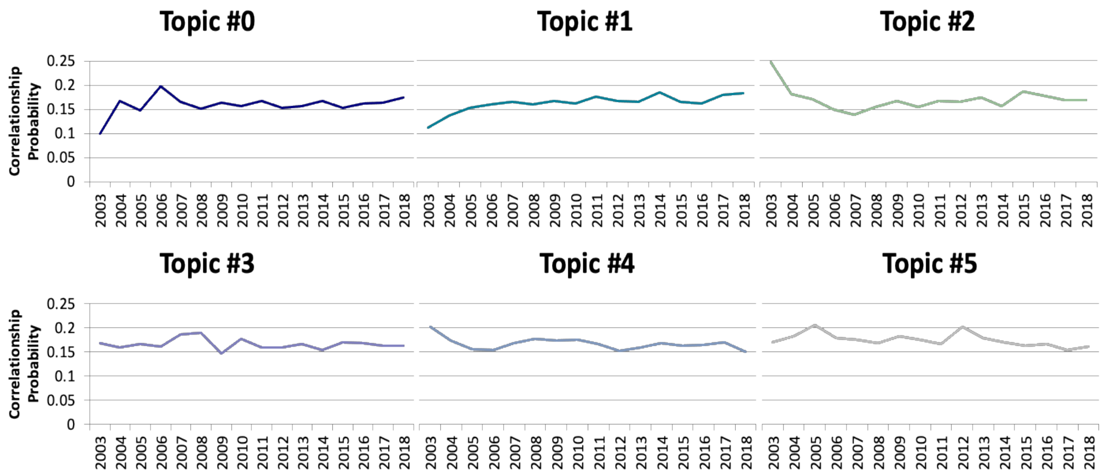


Figure 4: Topic trends developed through TOT modeling

Anticipation [#2] was also necessitated as inherent disruptions surrounded the project due to its challenging location. *'Controlling'* the prefabricated components during towing and installing was extremely difficult owing to high waves, strong currents and fickle weather. Hence, several observation stations were established, and frequent *'monitoring'* and predicting of hydraulic and hydrographic information were needed all the time (Hu *et al.,* 2015). Additionally, weather forecasting, and *'direction'* and velocity *'monitoring'* of wind and *'flow'* were deployed frequently to ensure smooth operation plans (Hu *et al.,* 2015). Further, risk prediction and mitigation through Monte-Carlo simulations were initiated as an anticipation measure (Li, 2019).

Visibility [#2] refers to having up-to-date knowledge of the *'site'* operations. As shown in Figure 4, the highest visibility was in the planning phase as all the project professionals were linked with the BIM planning platform. Hence, information *'sharing'* was up to date (Lu, 2020). More importantly, temporary governmental committees involving the central government and three local governments were established to enhance *'cooperation'* and cross-function integration at various locations (Hu *et al.,* 2018). The *'developed'* RFID and BIM integrated systems facilitated real-time data' *tracking'* and tracing while enabling risk control (Zhou *et al.,* 2018). Moreover, enhanced visibility could mitigate the vulnerabilities due to *'safety'* hazards during transportation and assembly with the use of early prediction and warning systems (Zhou *et al.,* 2018).

Capacity [#3] development was another great challenge that the project team undertook. Capacity should be available to undertake continuous project operation throughout the project duration, as seen in Figure 4. First, the project employed a responsible *'professional'* team, qualified contractors and suppliers throughout the supply chain (Zeng *et al.,* 2018). Second, alternative production *'options'* and *'strategies'* were utilized in three newly constructed factories to *'meet'* the project demand (Lu, 2020). Third, the outsourcing of special equipment and machinery was considered in manufacturing and assembly (Ming, 2017). Fourth, novel transportation methods were employed to avoid maritime traffic problems and safety hazards (Lu, 2020). Fifth, the horizontal piece by piece assembly method using floating cranes was deployed by mapping the assembly *'capacity'* (Lu, 2020). Sixth, the HZMB authority spent much time and money to improve the suppliers' production *'capacities'* and quality through technology support programs, *'training'*, and by allowing preferential prices (Zeng *et al.,* 2018). Last, an independent and capable consultant group was hired for quality inspection (Zeng *et al.,* 2018).

Collaboration and *'coordination'* [#4] are essential in prefabricated construction to avoid supply chain fragmentation issues (Ekanayake *et al.,* 2020). Therefore, the HZMB has maintained this capability throughout the project span by enabling better *'communication'* among the *'professionals'*. All the project information were updated to the BIM-based data center, and collaborative decision making was achieved (Zhou *et al.,* 2018). The data relating to the logistics and assembly phases were acquired through global positioning systems, sensors, sonar systems, RFID, and weather systems and transmitted immediately to the data center; while real-time element and *'progress'* monitoring system, command system and deep-water automatic element immersion and position adjustment system were used for enhanced data operability (Zhou *et al.,* 2018). Besides, several decision support systems were built to facilitate the *'opportunity'* of collaborative and timely decision making. The meteorological and hydrological forecasting system to manage transportation and assembly was also helpful in this regard (Hu *et al.,* 2015).

Financial strength [#5] is an important and commonly required capability in such a mega infrastructure development project. That is why the capability has marked two peaks in the planning (*'design'*) and construction phases (refer Figure 4). The project authority had to spend substantially on supplier capacity development (Zeng *et al.,* 2018). Manufacturing of the prefabricated components using advanced technology was costly. Further, outsourcing required special equipment and machinery, which were extremely expensive (Ming, 2017). The transportation of the prefabricated components due to the offsite construction required expensive methods (Lu, 2020). The assembly of those elements also required particular cranes and specific arrangements to accommodate these cranes, which was very costly (Lu, 2020). Therefore, supplementing and sustaining cash *'flow'* with government *'funds'* was highly necessitated in mega construction development projects. To compete with the market' *competition'*, the contractors involved in such projects need to consider their *'long-term'* capacity development (Zeng *et al.,* 2018).

3.2 THE EX-POST SCCS EVALUATION MAP AND ITS PRACTICAL IMPLICATIONS

The ex-post SCCs evaluation map was developed by incorporating the TOT modeling results (refer Figure 5). In Figure 5, the supply chain capabilities were located in each construction phase considering their trend and application levels derived from Figure 4. The slanting (up/down) lines [in Figure 5] that link the three construction phases indicate the increasing / decreasing patterns of each capability over the project duration as derived from Figure 4: correlational probabilities. The outcomes depicted in this map provides a managerial guide to the industry professionals to initiate SCCs appropriately in prefabricated construction projects. Using this map, the industry practitioners would benefit from prior knowledge of supply chain capabilities which is critical for infrastructure mega construction projects. The visualized dynamic impact on each project phase provides directions to prioritize implementing the critical SCCs adequately through appropriate capability development. For instance, as depicted in Figure 5, 'visibility' was highly required in the planning and construction phases compared to the handover stage. However, all these implications were based on project successes.

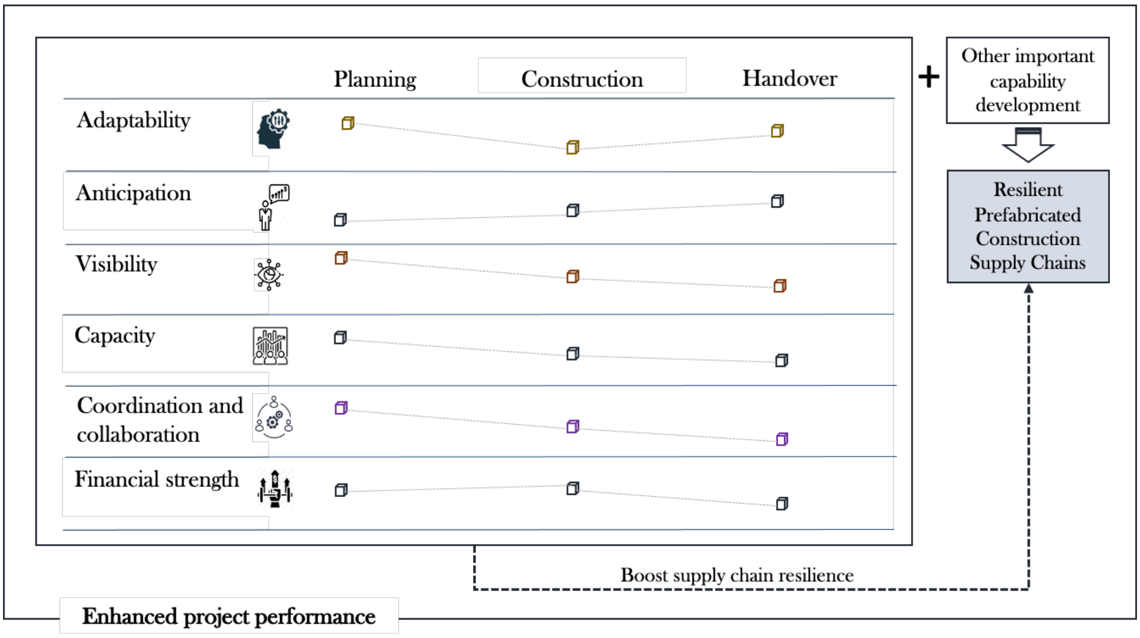


Figure 5: The ex-post SCC evaluation map

On the other hand, several failures should be indicated and analyzed to learn lessons from such a real-life case study. According to Li (2019), inadequate risk management is one of the limitations of this project. Also, transparent and decentralized decision-making must be adopted in other such projects to demarcate resilient supply chains. Other supply chain capabilities such as resourcefulness, flexibility, efficiency and dispersion would initiate more resilient aspects of prefabricated construction (Ekanayake *et al.,* 2020). More importantly, vertically integrated supply chains may solve some problems associated with supply chain fragmentation. Flexible supply chains with alternative/multimodal transportation channels would be more resilient than in the HZMB.

According to Hu *et al.* (2015), the HZMB project has partially achieved a reasonable level of smart construction site management. Collaborative, transparent and quick decision-making can only be achieved through smart construction site management; hence, essential in supply chain resilience. Installation of 3D laser scanners and high-density-high-precision 3D point cloud data would enhance real-time tracking and tracing of the data (Zhou *et al.,* 2018). The use of RFID, BIM, GIS and blockchain integrated platforms would boost collaboration, transparency, visibility, accountability and efficiency (Ekanayake *et al.,* 2020). Therefore, all these other essential capabilities must be developed to establish resilient prefabricated supply chains in infrastructure development projects, as illustrated in Figure 5. Ultimately, project performance would be enhanced through all these SCC initiatives.

However, the identified capabilities should also be appropriately mapped with relevant supply chain vulnerabilities that any project faces. As all construction projects are unique, no other forthcoming project can be exactly like the one in this case study. Similarly, the supply chain configuration of each project cannot be identical. However, as in other case study research, the findings may be adapted or progressively generalized here too, by considering the prefabrication supply chain specific capabilities for similar mega-infrastructure development projects. Moreover, although the present output is an ex-post decision-making map, improved ex-ante decision making is also enabled by this beneficial tool. Besides, the results are already validated through the findings of the current case-study. Therefore, the representative case choice, reliable information source, and the use of a large set of text documents in this study, add to the potential for progressive generalization.

More significantly, this is the first known study that enabled developing an SCC evaluation map based on the TOT modeling approach. Furthermore, this is the first known attempt to evaluate SCCs in infrastructure development projects focusing on increased resilience. Therefore, the novel research method employed, and the principal research outputs from this study significantly contribute to both construction and supply chain resilience research domains. The proposed research method could be initiated in other regions and/or projects where a large set of reliable project documents are available and also while considering the project-specific supply chain dynamics.

4. CONCLUSIONS, LIMITATIONS AND WAYS FORWARD

This study revealed the SCC dynamics underlying this high-profile HZMB mega-prefabricated infrastructure development project through the Topic Over Time modeling approach. Six critical topics of capabilities, namely, adaptability, anticipation, visibility, capacity, collaboration and coordination, and financial strength, were identified and presented, based on the popularity trend analysis of texts. Finally, a decision-making map was developed by considering the popularity trend of capabilities and their relevance to different project phases to help visualize the dynamic capability impact on the HZMB construction. The developed map represents both theoretical and practical underpinnings of the dynamics and outcomes. Hence, industry practitioners would benefit from having prior knowledge of SCCs and the relative levels of the needs for them, as well as their dynamics in each project phase, enabling them to prioritize appropriate improvements, targeting value-enhanced-resilient supply chains in forthcoming prefabricated infrastructure development projects. Although an ex-post map is developed in this case, this methodology be effectively applied in robust ex-ante decision making.

This paper also discussed some limitations associated with the HZMB project due to its inadequate risk management strategies. Accordingly, the need for other important SCCs (flexibility, robustness, efficiency and dispersion) to achieve resilience was explicated and proposed. More significantly, the text-mining approach adopted in this study unveiled and offered a novel but verified SCC analysis approach. Being the first SCC analysis study, which used the TOT modeling, this study directs academia towards an effective mechanism to extract empirical clues from a large unstructured set of documents in the construction domain. As a way forward, the developed SCC evaluation map could be further expanded and strengthened in further research, using several other case studies and/or more empirical data. Since the supply chain capabilities are jurisdiction and industry-specific, the developed model can be extended towards other jurisdiction-based studies and other industry-based studies. Hence, this map could be beneficially generalized for different industrial contexts. Furthermore, the TOT model may be beneficially verified through a 'sentiment analysis' approach in future research. Finally, this study unveils useful implications for construction research and practice.

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EFFECT OF SOCIAL AND ENVIRONMENTAL FACTORS ON EXPRESSWAY CONSTRUCTION IN SRI LANKA

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ABSTRACT

Expressway construction projects are one of the crucial infrastructure projects for a country. Hence, assessment of environmental and social implications prior to initiation of the expressway construction project is vital. Thus, the research aims to analyse effect of social and environmental factors on expressway construction in Sri Lanka. Initially a comprehensive literature review was done to discuss on expressway construction in Sri Lanka and environmental and social implications of expressway construction in global context. The study followed a qualitative approach. Hence, four expert interviews were carried out to explore more on the same context limiting to Sri Lanka. Experts were selected from only on-going expressway project in Sri Lanka, central expressway project. Moreover, collected data were analysed through manual content analysis.

The study findings highlighted viaduct construction, land acquisition and rock blasting as the major activities relating to environmental implications of the expressway construction projects. Thus, rational, logical, scientific, and technical selection of the routes is the most effective and efficient mean in minimizing adverse impacts. Hence planning of these activities should be done with due care by authorities only after proper feasibility studies. Further, major factors affecting social implications of the expressway construction have been identified as settlement, livelihood, public infrastructure and health and safety. Hence, resettlement action plans need to be updated to comply with the identified requirements through environmental and social factors.

Keywords: *Expressway construction; Social and environmental factors; Sri Lanka.*

1. INTRODUCTION

Development can be interpreted in various manners and has various aspects that are considerably different from each other (Amarasinghe, 2011). According to UN Documentation Research Guide (2020), development is a "multidimensional undertaking to achieve a higher quality of life for all people. Economic development, social development, and environmental protection are interdependent and mutually reinforcing components of sustainable development." Authors also stated that economic development is a well-recognized parameter through which a country's development can be measured and compared. It can be defined as "the process in which an economy grows or changes

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and become more advanced, especially when both economic and social conditions are improving" (UN documentation research guide, 2020).

Expressway infrastructure development typically requires major investments from government (Road Development Authority, 2020). In coping with the export of resources and associated regional growth, the government has set up various plans to accelerate road infrastructure development and improvement. In the Sri Lankan context road network (land base transport system) plays a predominant role in this discipline as it is the most widely used mean of transportation. (Road Development Authority, 2020), Sri Lankan Road network consists of three road classes namely Class A, Class B, and Class E. Altogether these three classes are known as national highways which has an approximate total length of 12,438.5km. Among them, Class E consists of expressways that have an approximate total length of 218km. It includes Southern Expressway (E 001), Outer Circular Expressway (E 002), Colombo-Katunayake Expressway (E 003), Andarawawe-Hambanthota Expressway (E 006). The latest expressway which is under construction is the Central Expressway Project (CEP).

Some of the legal provisions relating to expressway construction include Land Acquisition Act No 9 of 1950 and its subsequent amendments, the Land Development Ordinance (1935) and State Land Ordinance No 8 of 1947. Further, National Involuntary Resettlement Policy is considered as governing law for resettlements. Hence the expressway construction process embedded with legislative provisions is often affected by various social, environmental, economic, and time-related factors (Center for Sustainability, University of Sri Jayewardenepura, 2016).

Since expressway infrastructure usually has a long service life, the evaluation of investment alternatives and project selection requires tools and systematic methods. According to Surahyo and El-Diraby (2009), assessment of environmental and social implications prior to initiation of the expressway construction project is vital. Further, Goh and Yang (2013) stated that multiple factors such as physical, legal and political backgrounds may affect the assessment of environmental and social implications relating to expressway construction in a given country. Hence authors elaborated that the prediction and determination of a project's long-term socio-economic viability can be a precarious exercise. Therefore, it is not feasible to formulate common standards to meet the above challenges, especially in the field of assessment and mitigation of environmental and social impacts and implementation is still in the process of continuous development.

Hence the timely requirement has arisen in searching for social and environmental implications relating to expressway construction in Sri Lanka. Thus, the research aims to analyse effect of social and environmental factors on expressway construction in Sri Lanka.

2. LITERATURE REVIEW

2.1 EXPRESSWAY CONSTRUCTION IN SRI LANKA

Although Sri Lanka's Road density is higher than that of many developing countries, the standards and conditions of the road network are inadequate to meet the rapidly growing freight and passenger traffic. Most of the roads in the national highways network are still single and two-lane, more than 50% of the network has poor surface condition, and many portions are seriously congested (Asian Development Bank, 2018). These constraints limited the roads' contribution to the national development and economic growth, so the existing road infrastructure has to be improved and upgraded.

The expansion of the road network directly generates new markets and expands market opportunities not only for the goods market, but also for the factor market. The outcome of such expansion indirectly influences investment decisions, which then transform into industrial production, household income, and public revenue. Improvement in the quality and quantity of road networks reduces the travel time and associated costs, which directly influence the goods and factor markets through factor productivity. As pointed out by Goh and Yang (2013) the urban-rural connection roads provide market access opportunities to rural people and help them to diversify their income sources as they are linked with a greater variety of functional livelihood value chain systems.

2.2 ENVIRONMENTAL AND SOCIAL IMPLICATIONS OF EXPRESSWAY CONSTRUCTION

According to Surahyo and EL-Diraby (2009), the assessment of environmental and social factors associated with infrastructure construction is faced with several challenges such as lack of clear definitions, ambiguity in identifying relevant community requirements and improper planning. However, environmental implications can be discussed in detail.

2.2.1 Environmental Implications

Analyzing the environmental impacts of an infrastructure development project is a legislative requirement. That is mainly due to the vulnerability of the nature of the impacts. This is more serious regarding mega-scale infrastructure development projects such as expressways. Thus, environmental impact assessment together with environmental management and monitoring programs play significant roles in feasibility studies of such projects.

Ambient air quality, Noise, and vibration levels

Generally, the existing air quality of such areas in local context is within an acceptable range without any significant pollutions. However, in city areas like Mirigama and Kurunegala, and in the areas where the expressway meets highways, atmospheric conditions have been polluted to some far due to high vehicle movements.

Biological environment

According to the ecological survey of the project, the proposed expressway traverses through various natural, semi-natural and human-modified lands. However, it does not affect any national parks, sanctuaries, or declared wetlands.

The ecological survey which has covered a width of 100m road corridor reveals that there are 08 main terrestrial habitat/vegetation types and 02 inland aquatic/wetland habitat types in the affected area.

The road alignment will not hinder the permanent paths of animals significantly. But there can be some localised impacts due to the obstructions.

Anticipated environmental impacts of the proposed project

- Topography, geology, and soil

According to Dharmakeerthi and Wicramasinghe (2015), generally, above 44% of the soil has been faced some sort of degradation. In the considered scenario, soil erosion and sedimentation of soil in surrounding waterways are common as well as a critical impact. Blockages in the drainage network and silting of the nearby surface waterways are also possible. Also, air quality is affected while the transportation of soil particles by wind. Rockslides across the escarpment slope of the mountains at the road cuts is another severe issue.

- Hydrology and drainage

The major expected environmental impact is flooding, which can even destroy the construction. Also, floods cause embankment erosion and fill material stockpile erosion. According to the hazard profile of the country, floods are vulnerable to these areas during the Southwest monsoon season. Sedimentation at paddy fields and waterways is another result of floods.

- Biological environment

The most severe adverse impact on the biological environment occurs due to site clearances. There are road corridor clearances, larger area clearances at interchanges and clearances for access roads, site camps, material stores, and other temporary structures. These clearances cause the loss and fragmentation of organisms.

- Mitigation of ecological impacts

As the initial and most basic step, ROW should be designed by minimizing the impacts on sensitive areas as far as possible while maintaining an optimum balance with the cost. Providing animal overpasses and eco-ducts is also a successful design solution.

The spread of invasive alien species can be prevented by manual removal. Making the workforce aware of the threats is very important. Barricading the excavations to prevent animals from falling and sloping them to make escape easy should also be considered. According to Bakermans and Cuperus (2001) ecological compensation principle is a very productive approach for nature conservation during large-scale development projects.

2.2.2 Social Implications

According to Jani and Shukla (2018), social impacts can be defined as any public or private activities which change the organized living, working and behavioural patterns of any group of people. Analysing and evaluating the potential social impacts of a project is very much essential to ensure and enhance the living conditions of the inhabitants of the affected areas. Thus, a social impact assessment should highlight preventive, mitigate, managing and monitoring mechanisms against potential social impacts (Amarasinghe, 2011). A comprehensive overview of social impact dimensions namely settlements, land acquisition, livelihood and infrastructure (Gonathilaka and Zaman, 2016) has been done separately.

- Social impacts on settlements.

This need for land can result in the dislocation of the people living there. Affected communities who lose their places due to the projects, usually have deep-rooted cultural and social structures associated with those areas throughout a considerable period of time (Gouley and Nathan, 2017). Even in situations where people are not required to physically move, the project may still impact on their livelihoods or income generating activities, either temporarily or permanently or cause other social impacts that make settlements untenable. These processes are based on the National Involuntary Resettlement Policy (NIRP) which provides principles, rules, and norms to ensure a fair, equitable, and transparent resettlement process. (Gunatilleke, 2013)

- Impacts of land acquisition

Social impacts associated with land acquisition plays a significant role within the expressway construction. People who lose their lands will have to face various hardships such as landlessness, reduction of the profitable use of remaining lands, loss of paddy fields and unavailability of proper demarcation. However, the most critical issues arise with the acquisition of paddy lands as it reduces the availability of arable wetlands which directly affect the production of the country's staple food. Also, historical and ancestral values assigned with some lands create various issues. According to the findings of Syagga and Olima (1996) compulsory and involuntary land acquisition incurs far-reaching socio-economic impact on land consumers.

- Impacts on livelihood

Expressway construction has significant social impacts on livelihood and economic activities during both construction and operation phases. The most critical impact is the inability to continue economic activities after the relocation. It becomes worst with the loss of seasonal harvest from agriculture and earnings from agricultural labour. Livelihood is further threatened due to prolonged periods of construction and authorities' less attention towards the negative community impacts to resolve the issues within a reasonable period of time.

- Impacts on infrastructure

Recognising social impacts due to any infrastructure interventions is crucial to distinguish the direct and indirect impact on the community (Mteki *et al.,* 2017). Hence, appropriate arrangements should be made for the replacement of all community infrastructure and to ensure adequate access to essential public services.

Thus, environmental and social implications of expressway construction projects were discussed in detail.

3. RESEARCH METHODOLOGY

According to Kothari (2004) research methodology is the mechanism for systematic resolvent of research question. This chapter describes the approach and methodology adopted by the researcher to conduct the research. It justifies the research design together with data collection and analysing techniques. Further, it illustrates how the method has been designed in order to manage and direct the research to address the established research questions. Also, it discusses the mechanisms adopted to enhance the validity of the research.

Crossman (2020) argued that qualitative research is designed to synthesize the opinion survey. Qualitative analysis is an exploratory mechanism to uncover the patterns through the views of expertise in a particular area. Whereas quantitative analysis presents measurable and quantifiable data in numerical values. Thus, a qualitative approach has been used for the study as it requires opinion surveys on the context of expressway construction in Sri Lanka. Moreover, scarcity of projects relating to the context in Sri Lanka and ongoing pandemic situation led to continue study with available number of respondents. However, Table 1 indicates the profile of interviewees as follows.

Table 1: Profile of interview participants

Interviewee Code	Designation	Experience in expressway construction	Experience in construction industry
I1	Project Manager	9 years	22 years
I2	Project Engineer	7 years	19 years
I3	Project Engineer	6 years	16 years
I4	Project Engineer	6 years	15.5 years

Hence data collection was done through expert interviews with the participation of four experts relating to context who had more than 5 years' experience relating to expressway construction and more than 15 years of experience in the construction industry. Experts were selected from CEP stage II which is the only ongoing expressway construction project at the moment. Section 2 of CEP transverse through two administrative districts; namely, Gampaha in Western Province and Kurunegala in North-Western province. It traverses through 6 DS divisions of those districts. Section 2A: Ambepussa link road connects Gampaha and Kegalle districts and traverses through 2 DS divisions. (Road Development Authority, 2016). However, face to face interviews were done spending average of 45 minutes per interviewee. However, manual content analysis was used to analyse the qualitative data.

4. DATA ANAYSIS

4.1 ANALYSIS OF THE DATA COLLECTED THROUGH EXPERT INTERVIEWS

Expert interviews were conducted to have a deep insight into the subject matter and to investigate expert opinions on environmental and social aspects of expressway construction projects in Sri Lanka. The interview guideline has been designed based on factors identified through the literature under each aspect. Interviewees were asked to share their opinions on the context based on their own experience.

4.1.1 Environmental Implications

First part of the interview guideline consisted of analysing activities that creates major environmental implications within the context. Thus, interviewees were asked to discuss environmental impacts connected with major activities relating to expressway construction in detail.

According to interviewees I1, I3 and I4, when considering the rock blasting activities, the easiest way to minimize the environmental impact is to evade them as much as possible when selecting the trace. However, considering its less practicability for certain scenarios, few alternative mechanisms to minimize environmental impacts and can be taken into consideration as per the interviewees. Those are examining the possibilities to use the blasted rock materials for the expressway construction itself and to follow much effective health and safety procedures to minimise the impacts while blasting. Especially interviewee I1 and I4 mentioned having a proper communication between the site and the neighbourhood is crucial in rock blasting to minimise various accidents including deaths or injuries.

All interviewees highlighted that land acquisition and related procedures as key components in expressway construction project. Further I2 highlighted the involvement of certain political interventions during these processes. Also, all interviewees highlighted, experiencing public protests due to various issues relating to compensation procedures and acquisitions. Due to these circumstances, handing over of lands to contractor at schedule time periods had been delayed causing delay claims and time extensions as well. Further, interviewees mentioned that land acquisition process consumes more time requiring various documentation, particularly while acquiring private lands for public infrastructure development projects.

Phase II of CEP runs through paddy fields and marshy lands as well. According to Interviewees I2, I3 and I4, viaduct construction is taken place when the road trace goes through marshy lands, paddy fields and crosses over highways as an alternative for embankments which is complex than a typical embankment. Therefore, according to interviewees I2 and I4 this combination has to be designed very carefully by considering all the possible environmental data such as irrigation patterns, soil conditions, and weather conditions. Interviewees further mentioned about public protests occurred in relation to the circumstances. According to the findings of the interviewees, decisions were already taken to replace the embankments with viaducts after carefully considering the forwarded facts. Thus, based on the opinions of all interviewees, land acquisition, rock blasting and viaduct construction have been identified as most influential activities relating to environmental implications of the expressway projects.

4.1.2 Social Implications

Thereafter, under the part II of interview guideline, interviewees were further asked to discuss in detail about social implication factors relating to expressway construction projects named settlement, livelihood, public infrastructure and health and safety. Those factors were discussed thoroughly based on opinions of interviewees as follows.

- Settlement

According to interviewees I1, I2 and I4 implementation of the project led to a drastic change in social network in affected the community. Further I1 mentioned difficulties in attributing relevant socio-economic characteristics to the land-use changes. Also, Interviewee I3 said that settlement interconnects with cultural values, experience of cultural marginalized, exploitation of cultural monuments, loss of natural and cultural heritages, disruption of social network, changes in demographic structure of the community, social differentiation and inequality, social tension and violation. Hence the interviewee highlighted the importance of carefully planned strategies to ensure the smooth functioning of the community after the relocation.

Thus, adverse impacts on settlements should be considered to the fullest possible extent as per both I2 and I4. Also, any difficulties in addressing such requirements should be properly convinced to the resettling community to avoid public misunderstanding (I4). Hence all interviewees stressed that rational, logical, scientific and technical selection of the route for an expressway project is a must. Further as per all four interviewees, mitigating the inevitable negative social impacts of the projects in compliance with the relevant legal provisions as well as the internationally agreed standards and guidelines of redressing public grievances stemming from national development projects is another aspect to be prioritised. Thus, these aspects reinforce the need for successful resettlement plans.

- Livelihood

Interviewees expressed their opinions on livelihood depicting some key concerns; work at home environment or neighbourhood, disruption of daily living practice, recreation opportunity and facilities, aesthesis quality, physical quality of housing and availability of housing facilities. Further, Interviewees I2 and I3 pointed out variables such as poverty status, earning and employment opportunities and asset holding relating to social aspects.

Sustainably restoring livelihoods is a significant mitigation measure that should be adhered to (I1, 12 and I4). However, financial compensations are given to cover the loss of earnings during the period of resettlement and to cover the income from affected investments. Yet Interviewee I2 stated that the livelihood restoration has a much broader perspective beyond that. However, Interviewees I3 and I4 suggested that ability of affected community to adapt new surroundings highly depends on available infrastructure facilities.

- Public Infrastructure

Interviewees I2, I3 and I4 said that even though CEP is one of the major infrastructure development projects in country it may cause frequent damages to the existing infrastructure during its construction. Especially due to high traffic volume and frequent mobilization of heavy vehicles existing road networks may damage. Further as per interviewees I1 and I2, power transmission lines, telecommunication lines and water distribution lines can also disrupt due to certain construction requirements. Free and natural flow of waterways affect in places where expressway traverses through paddy lands and irrigation canals creating impacts on cultivation in highlands as well (I2). Nevertheless, noisy and dusty construction activities may interrupt calm and smooth functioning of community infrastructure facilities such as schools, temples, hospitals, hotels, religious centers, cemeteries, public parks and playgrounds (I1, I3 and I4).

- Public Safety and Health

The absence of proper precautionary measures causes serious health and safety issues for both inhabitants and the workforce in this type of huge construction projects (I1). Some of the associated activities such as frequent mobilization of heavy vehicles, explosive usage, deep cuts, and landfilling in mountainous sites bring life threats for workers and inhabitants (I2 and I3). Interviewee I3 mentioned that unauthorized and unsafe entrances and site visits may even cause serious accidents as CEP is a new experience for inhabitants.

People living within about 200m of the road corridor expose to polluted air and noise releasing from construction activities facing the risk of asthma development and lung function reductions (I4). Also, improper disposal of solid and liquid discharge from the site can directly contribute to contamination of water sources and the spread of diseases such as dengue providing rich breeding grounds around sites (I1 and I3). All interviewees pointed out significance of assuring public safety and health during both construction and operation phases, especially with greater care for higher population density areas. Strictly adhering to the security guidelines and assuring them with proper supervision is the best way to overcome health and safety issues (I2 and I4).

Social impact mitigation plays the most critical role in this project as it involves a significant amount of land acquisition which is occupied by individuals and institutions. However, overall project objectives can only be achieved with the proper restoration of affected local communities along with their social and environmental requirements. For that identified environmental and social implications relating to the context needs to be properly addressed.

5. CONCLUSIONS

The efficiency of the transport system has paramount importance concerning the country's economic and infrastructure development. Sri Lankan road network consists of expressways which have an approximate total length of 218km. Hence, expressway construction projects are critical due to their huge capital requirement, associated responsibility with the public money, the huge physical size of the project and occupation of large areas of land, social and environmental impacts, and externalities. However, expressway construction undoubtably consumes huge capital due to its environmental and social interferences.

The study findings highlighted viaduct construction, land acquisition and rock blasting as the major activities relating to environmental implications of the expressway construction projects. Thus, rational, logical, scientific, and technical selection of the routes is the most effective and efficient mean in minimizing adverse impacts. Hence planning of these activities should be done with due care by authorities only after proper feasibility studies. Further, major factors affecting social implications of the expressway construction have been identified as settlement, livelihood, public infrastructure and health and safety. Relocation plays a critical role in the expressway construction. However, land acquisition-related legislative enactments are not capable to address the broader social and environmental impacts of relocation such as income restoration and grievance redressing (Asian Development Bank, 1999). To mitigate the related issues, resettlement action plans need to be updated to comply with the identified requirements.

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ENERGY RETROFITS FOR IMPROVING ENERGY EFFICIENCY IN BUILDINGS: A REVIEW OF HVAC AND LIGHTING SYSTEMS

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ABSTRACT

It has been observed that inefficient buildings consume three to five times more energy than efficient buildings. Subsequently, improving the Energy Efficiency (EE) of existing buildings, which account for a significant portion of the energy consumption of the building sector, has become a top priority. Also, Heating, Ventilation, and Air Conditioning (HVAC) and lighting systems typically account for three-quarters of a building's energy consumption. Hence, focus on the energy efficiency improvements associated with these subsystems is entailed to optimise the energy use of buildings in comparison to other energy consumers. Energy Retrofit (ER) is defined as the main approach in improving the energy efficiency of buildings to achieve energy reduction goals. Nevertheless, there is a general lack of awareness regarding ER. Thus, the purpose of this article is to bridge this research gap by critically reviewing the applicable literature on ER. The paper first analysed the role of retrofits in buildings concerning optimising energy performance. The paper also discusses the implementation process of ER, which includes five steps viz. pre-retrofit survey, energy auditing, and performance assessment, identification of suitable and feasible retrofit options, site implementation and commissioning, and validation and verification. Further, different types of ER applicable to HVAC and lighting systems are discussed. In their endeavor to enhance the EE of existing buildings, practitioners could apply the findings of this study, as a basis to understand the available ER types and as a measure to gauge the efficiency of existing buildings, which will facilitate effective decision-making.

Keywords: *Building sector; Energy Retrofits (ER); Heating, Ventilation and Air Conditioning (HVAC); Lighting systems.*

1. INTRODUCTION

Over the past decades, limited energy sources and gradually increasing energy demands have created an inevitable energy crisis for all nations. If all nations continue with their present energy consumption pattern, demand for energy sources will be doubled in 2030 in comparison with its current level (Birol, 2007). Current predictions reveal that the building industry is responsible for a huge amount of energy consumption, whilst multiple buildings use a large amount of energy (Zuo *et al.,* 2012). Moreover, 29% of the global

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energy demand is derived from the building sector, and annually this percentage increases by 1% (Wu *et al.,* 2015). Buildings, demanding energy throughout their total lifecycle from their construction to demolition, and the operation phase are identified as an 80%-90% contributor to buildings' life cycle energy demand (Gamage and Lau, 2015). Further, many types of research reveal that the substitute rate of existing buildings by the new buildings is only around 1.0-3.0% per annum, whilst existing buildings consume a large amount of energy than newly constructed buildings.

Due to these reasons, mechanisms to enhance energy efficiency in existing buildings have become a vital concern even if energy efficiency techniques are to be incorporated and promoted for all newly constructed buildings and if upcoming buildings were to be constructed (Ma *et al.,* 2012). The authors further stated that incorporating energy efficiency techniques in newly constructed buildings will only influence their future energy demands and such an effort can only decrease future energy demands (while there is an energy crisis presenting in the current world). Hence, concerns on energy efficiency in existing buildings are crucial to coping with the timely enhancement of global energy demand and global energy crisis (Asadi *et al.,* 2012).

Total electrical energy consumption of buildings is mainly dependant on the operation of sub-level components such as Mechanical, Electrical, and Plumbing (MEP) systems integrated with the building (Zhao and Magoulès, 2012). According to U.S. Villar and Joutz (2006), in most buildings, the energy consumption of Heating, Ventilation and Air Conditioning (HVAC) systems make up 51% of total energy consumption, and lighting accounts for 25% of total energy consumption. At the same time, vertical transportation, pumps, and other equipment account for (5-10%) and (5-10%), respectively. As energy consumption of HVAC and lighting are combined, they are typically responsible for three-quarters of the building's energy utility. Hence, more than other energy consumers, it is usually vital to focus on energy-efficient improvements related to these subsystems to optimise the energy consumption of buildings (Zhao and Magoulès, 2012).

Whilst buildings are often open to energy-saving potentials, retrofitting plays an important role in reducing energy consumption by identifying energy-saving opportunities (Dascalaki and Santamouris, 2002). Retrofitting is recognised as a systematic process of investigating the energy-saving potential available in the existing buildings and perform necessary upgrades for energy efficiency improvements (Rysanek and Choudhary, 2013). Moreover, retrofitting actions focus more on optimising the energy efficiency of the existing building while complying with a pre-defined standard benchmark and in compliance with occupants' expectations on thermal, visual, air quality comforts (Dascalaki and Santamouris, 2002).

The energy use of buildings is projected to increase by 1.7% per annum until 2025, and the great potential for energy reduction in existing buildings can be achieved through the introduction of energy retrofit measures (Shen *et al.,* 2019). Hence, there is increasing pressure worldwide to retrofit existing buildings to have higher energy performance (Ruparathna *et al.,* 2016). Besides, the introduction and development of policies, regulations, building codes, (Palmer *et al.,* 2013), and sustainability protocols such as LEED imply that retrofitting of existing inefficient buildings is critical in meeting regulatory codes and standards (Kontokosta, 2016). Although the world is under pressure to retrofit existing buildings with higher energy performance, the adoption and implementation of ER are still relatively low. Hence, based on the critical review of the literature, the paper discusses ER implementation process, different ER measures, and different types of ER that could be useful in retrofitting HVAC and lighting systems of buildings.

2. RESEARCH METHODOLOGY

An extensive literature review was essential to solidify the research base by gathering prevailing knowledge in the research area. Hence, a comprehensive literature review is conducted to identify the role of ER in building to optimise energy performance, ER implementation process, and different types of ER that could be taken to retrofit HVAC and lighting systems. At the first stage, to limit the scope of the research, keywords search in the available search engines, 'Scopus', 'Google Scholar', 'Science direct' and 'Emerald'. Several keywords were applied in finding related publications. For example, the following keywords were used: 'ENERGY RETROFITS AND BUILDING SECTOR', 'ENERGY RETROFITTING PROCESS', 'ENERGY RETROFITS AND HVAC SYSTEM' and 'ENERGY RETROFITS AND LIGHTING SYSTEM'. Besides, conference proceedings, book chapters, commercial web pages, and publicly available publications were also reviewed to gain a broad understanding and evaluate the concept of ER. Altogether 60 peer-reviewed articles and commercial publications were reviewed. The search was conducted for the period from 2000-2020. Hsieh and Shannon (2005) stated that the content analysis method is the most used to interpret qualitative text data through systematic coding and patterns. Content analysis has been selected as the most suitable analysis method for this research. The scope of this research is to identify demand-side energy retrofit options for improving energy efficiency in buildings. Due to time constraints, this study is limited to HVAC and lighting systems among all identified MEP systems.

3. LITERATURE REVIEW

3.1 ENERGY AND BUILDINGS

In recent decades' energy has become an indispensable factor to run this world (Juan *et al.,* 2010). Zhao and Magoulès (2012) explained that a great deal of effort is ongoing to find methods for optimising world energy consumption and to reduce the sources, which are exerting more pressure on energy resources. The authors further stated that universally, demand for energy sources is derived from the main three sectors; i.e. (i) building sector, (ii) industrial sector, and (iii) transportation sector. Among these identified sectors, the building sector consumes a substantially large amount of energy throughout its whole lifecycle (Juan *et al.,* 2010).

Recently, due to increasing population growth and the upward forces for building services with enhanced user expectations on comfort levels, together with the increase in occupied time inside buildings have forced the building sector to consume energy at very high levels. This level of high energy consumption has exceeded that of industrial energy consumption and energy consumption for transportation. Studies by Zhao and Magoulès (2012) reveal that buildings demand energy throughout their whole life cycle but a comparatively large amount of energy consumption is recorded during its operation stage due to the operation and maintenance of a large number of MEP systems. It is identified that in most buildings energy consumption of the HVAC systems is 51% of total energy usage and the energy consumption of lighting systems is 25% of total energy consumption

(Ma *et al.,* 2012). The combination of both the energy consumption of HVAC and lighting systems is typically responsible for three-quarters of the total energy demand of buildings (Hendron, 2013).

Moreover, Ozturk (2013) indicated that the energy utilised by buildings is still highly inefficient and there are immense possibilities for energy performance improvement. The rising demand for energy-efficient buildings has led all nations to seriously consider exploring methods to optimise energy efficiency in buildings (Ouyang and Hokao, 2009). On another hand, it is identified that most buildings seem to welcome energy efficiency improvements, which can be achieved through incorporating ER (Hendron, 2013).

3.2 ROLE OF RETROFITS IN BUILDING TO OPTIMISE ENERGY PERFORMANCE

According to the Oxford English Dictionary [OED], (2017) "retrofitting" can be defined as "incorporate something with a system or feature which is not fitted during manufacture or to add a system component or system feature to any system or building that did not have it when firstly constructed". Further, retrofit is recognised as the process of renovating the systems and structure of buildings to reduce energy consumption for energy efficiency improvements (Alm *et al.,* 2005). Global researchers have proved that a reduction of 50-70 % can be achieved in the energy consumption of buildings by implementing ER measures (Ürge-Vorsatz and Herrero, 2012). However, every building has its unique aspect with different energy characteristics. Therefore, ER techniques and approaches that suit one building may not be suitable for another building (Chidiac *et al.,* 2011). Ma *et al.* (2012) identified that many interdependent factors such as geographic location, building type, size, age, occupancy schedule, sources of energy, national utility rate structure, operation, and maintenance procedures, building fabric, services, and systems comprised have influenced the process of selecting suitable ER measures. Accordingly, energy retrofitting a building is a complex job. Hence, it has to be performed as a well-organised step-by-step process (Ma *et al.,* 2012).

3.3 ENERGY RETROFITTING IMPLEMENTATION PROCESS

The ER process begins with a pre-retrofit survey. This phase focuses on setting scope and targets for the ER process and the entire operations that are to be carried out (Alm *et al.,* 2005). Moreover, in this phase, building owners will determine the required financial and physical resources to implement the project and to select an expertise service that will enable the company with the implementation of the entire retrofitting process (Department of Agriculture, Water and the Environment, 2010). The feasibility and success of the retrofitting process depend on the right understanding of problems identified during the building operation together with the main concerns of the occupants. Hence at this stage, a prerequisite of the pre-retrofit survey is to identify these necessities (Ma *et al.,* 2012).

The next stage of retrofitting process is inclusive of an energy audit and performance assessment (Ma *et al.,* 2012). The purpose of conducting an energy audit is for evaluating building energy trends, identifying building energy utility patterns, identifying areas with energy-saving potentials, and determining cost-effective and financially feasible energy conservation measures (International Performance Measurement and Verification Protocol [IPMVP], 2001). Further, diagnostics are also being conducted in this phase to identify the use of inefficient equipment in operations, improper control systems, operational conditions, occupant behaviours, and any malfunctions identified in the building operation (Alm *et al.,* 2005).

The third stage helps with identifying suitable and feasible retrofit options amongst available alternatives by considering energy models, economic analysis tools, and risk assessment methods. Energy Performance Benchmarking (EPB) helps to identify potential areas and possible amount of energy savings and quantitative performance assessment of retrofit alternatives in this phase and which may also require identifying the most beneficial retrofit option amongst multiple alternatives (IPMVP, 2001). Moreover, retrofit alternatives are also prioritised in this phase by considering energy-related and non-energy-related factors (Ma *et al.,* 2012).

According to the Australian Energy Performance Contracting Association (AEPCA) (2004), the fourth stage is known as the implementation and commissioning phase. Once the most suitable retrofit option is selected, it has to be implemented in the necessary locations. Then, Testing and Commissioning (T and C) need to be carried out against baselines provided by energy benchmarking, to ensure that retrofit measures keep the building and systems at an optimal level of energy efficiency (AEPCA, 2004).

The process of validation and verification is identified as the final stage of the ER process. Once the decision is made to implement the most suitable retrofit option it has to be well-tuned based on the results of energy audit and performance assessment, standard validation, and verification (Braun *et al.,* 2014). The authors further stated that various methods can be used to verify potential energy savings achieved through the retrofit implementation process. A post-occupancy survey is a prerequisite in this phase to verify building professionals and that occupants are satisfied with the overall retrofit process and its result (Ma *et al.,* 2012).

3.4 TYPES OF BUILDING ENERGY RETROFITS

As explained in the advanced energy retrofit guide (Hendron, 2013), energy retrofitting can be performed through three globally accepted approaches; i.e. (i) Existing Building Commissioning (EBC), (ii) Standard retrofit, and (iii) Deep retrofits.

The process of upgrading operational behaviours of buildings and the organisation and, implementation of building maintenance procedures is commonly referred to as EBC (Zazzara, 2004). The author further explained that EBC enables buildings to reduce up to 25% of their present energy consumption level. Optimising operation and maintenance procedures of buildings and MEP systems is the primary aspect of EBC (Sellers and Irvine, 2001). The author further states that "operations" focus on controlling and optimising the energy performance of equipment and systems installed in buildings. Meanwhile, "maintenance" focuses on periodical physical exercises that are carried out to ensure a continuous function or decline of equipment and systems.

Hendron (2013) has defined standard retrofitting as a systematic process that proposes component-level upgrades for systems and equipment to promote energy efficiency in building. The author further explains that standard retrofitting lets buildings achieve a 25-45% of reduction in the present energy consumption level of buildings.

Blush (2010) explains that deep retrofit measures focus on providing combined design proposals and procedures by considering the performance of the entire MEP systems.

Ma *et al.* (2012) explains that more than 45% of energy savings are achievable through deep retrofit implementations and that it requires a larger initial investment outlay.

All type of buildings has their unique requirements and opportunities for ER. Moreover, there are several energy-efficient retrofit measures available for every specific system. Hence, understanding and identifying those measures is crucial in implementing an effective retrofit procedure.

3.4 BUILDING ENERGY RETROFIT MEASURES

In general, ER technologies can be classified under three categories; i.e. (i) supply-side management, (ii) demand-side management, and (iii) occupants' behaviour management (Yu *et al.,* 2011). The process of providing alternative sources to enhance energy efficiency is known as supply-side management ERs. Demand-side management techniques focus on reducing the total energy demand of buildings to enhance energy efficiency (Nakagami, 1996). Further, the occupant's behaviour management measure fully focuses on promoting behavioural changes and user awareness to reduce building energy demands (Yu *et al.,* 2011). Ma *et al.* (2012) explain that there are plenty of retrofit technologies readily available for the industry. The scope of this research is narrowed to consider the demand-side management techniques focusing on HVAC and lighting systems. The combination of energy consumption of HVAC and lighting is typically responsible for three-quarters of a building's energy utility (Zhao and Magoulès, 2012). Hence, in comparison with other energy consumers, it is of importance to focus on energy-efficient improvements related to these subsystems to optimise the energy consumption of buildings (Zhao and Magoulès, 2012).

Retrofit measures applicable for HVAC

HVACs are the largest energy consumers in every building (Dessouky *et al.,* 2004). Therefore, retrofit improvements to enhance the energy performance of HVAC systems have a great impact in significantly reducing the energy requirements (Vakiloroaya *et al.,* 2014).

- Optimum Start-Stop Strategy

Optimum start-stop strategy is referred to as one of the main HVAC control strategies used to avoid unoccupied operations of HVAC (Rahman *et al.,* 2011). The authors further explain that optimum start/stop systems can help with detecting starting time early enough to turn on HVAC components at the optimum time to reach the indoor temperature setpoint at the initiation of scheduled occupancy. Further, this system can detect the optimum stop time of Air Handling Units (AHU) when the indoor air temperature is appropriate enough to maintain the comfort level till the end of the occupancy period (Korolija *et al.,* 2011). An optimum start-stop strategy can help to reduce the load on the equipment and helps with optimising the operation of the system and economising the hours to eliminate waste (Vakiloroaya *et al.,* 2014).

- Installing Variable Frequency Drives (VFD)

Miller *et al.* (2012) stated that most of the motors are designed to operate at a predetermined constant speed to provide continual constant output. However, many applications and work practices require variable speeds under different circumstances. Moreover, motor operating speed has a high influence on energy when used to run electric motors. On another hand, mostly HVACs are operated at part-load conditions. Therefore, during an HVAC operation, whilst HVACs are operating at part load conditions, electric motors operate at full load or at a constant speed, which can lead to energy inefficiencies. Hence, matching the output level or speed of electrical motors with the HVAC load condition can help with eliminating unnecessary energy wastages of electrical motors. Systems such as electric motors have a provision through VFDs to maintain energy efficiency by varying the speed of the electric motor based on the HVAC operational load conditions (Saidur *et al.,* 2012).

- Use of Thermal Storage Systems (TSS)

TSS are systems used to enable the shift of electricity usage of HVAC systems from peak hours to off-peak hours. TSS helps to avoid unnecessary peak-hour charges to help with reducing the burden posed by CEB where high charges are introduced during peak-hour utilities than off-peak or day-time utilities (İnall and Esen, 2004). TSS uses pre-cool water during off-peak hours and this chilled water is stored at low temperature (normally <200^{o}C) in an in-build sump. This could be used by HVACs during peak hours to produce cool air. Alternatively, TSS also uses pre-heated water during off-peak hours, and this hot water is stored (usually >200^{o}C) in an in-built insulated sump. This could be used by HVACs during peak hours to produce hot air (Kaygusuz, 2002). Moreover, TSS offers various advantages for conventional HVAC systems such as energy savings and capital cost savings, system operation improvements, system capacity extending and equipment size reduction (İnall and Esen, 2004).

- Free cooling application

The author further states that this technique is often identified as the economiser cycle (Yao and Wang, 2010). This system is used to reduce the workload that is carried out by HVAC systems by using the cooling capacity of the ambient environment (Yao *et al.,* 2004). Moreover, air from the outdoor environment could be used in this system as a cooling medium for indoor cooling instead of cool air supplied by HVACs if the ambient air is chilled enough to achieve an indoor temperature setpoint (Bulut and Aktacir, 2011). Two types of economizers could be used in the free cooling process; i.e. (i) airside economisers and (ii) waterside economisers (Florides *et al.,* 2002). Air-side economisers use the cooling capacity of ambient air directly to fulfil the requirements of indoor cooling. On the other hand, water-side economisers use ambient air to chill condenser water which circulates through the cooling tower (Yao and Wang, 2010). These systems also use a combination of both fresh and return air to fulfil a part of the indoor cooling requirement (Yao and Wang, 2010).

- Energy Recovery Ventilator (ERV)

ERVs are being used in HVACs to pre-condition ambient air intake by HVAC exhaust air through an energy transferring mechanism and pre-conditioned air is being used, as supply air intake of HVAC systems (Rasouli *et al.,* 2013). When ambient air is pre-conditioned through ERV at a certain temperature, the cooling load requirement of the HVAC system can be reduced and it can enable HVACs to consume a low amount of energy for indoor cooling (Zhang and Xiao, 2008).

- Demand Control Ventilation (DCV)

To comply with the cooling and any other requirement, the HVAC system which supplies cool air to the indoor environment has to be conditioned. Hence, it consumes a lot of energy to process it (Chao and Hu, 2004). As a result, a ventilation control system is required to avoid over-ventilation in HVAC operations, if not it may lead to a lot of energy wastages. DVCs can be used to overcome this, as DVC systems calculate the number of occupants considering the fresh air required for a person and based on this the fresh air supply could be controlled. (Wang, 2014). DVCs have enabled HVACs to reduce expenses incurred through unnecessary energy consumption when using ventilation processes that are not economical (Chao and Hu, 2004).

Retrofit measures applicable to lighting systems

Lighting systems are often recognised as the second-largest energy consumer in every type of building and often they also show significant influence on energy consumption patterns of HVACs (Bangali and Shaligram, 2012). Therefore, incorporating retrofit technologies for lighting systems has become a vital concern in promoting energy reductions in building energy (Chang *et al.,* 2012).

- Light Emitting Diode (LED) lighting

The use of LED lamps instead of any other type of lamp can introduce much potential to help reduce the electricity demand. This is because LED lamps utilise a very low amount of energy for their operation (Bing, 2012).

- Occupancy based control

The primary objective of occupancy-based lighting control is illuminating lighting systems only when indoor space is occupied (ElMaraghy *et al.,* 2017). Occupancy-based control systems have to install occupancy detection sensors along with Passive Infrared (PIR) and RF-Radar technologies in occupancy areas and integrating them with lighting control units (Ahn *et al.,* 2014). Further, these control units automatically switch on or switch off lighting systems based on the presence of indoor occupancy conditions (Sahoo, 2014).

- Task Lighting

Greater energy savings can be achieved through this technology, as the lighting power density of task lighting is lower and illumination can be provided to task lights only when and where it is required. Moreover, task lighting arrangements enhance safety and occupant satisfaction too (Dubois and Blomsterberg, 2011).

- Automatic lighting control system

An automatic lighting control system is a technology used to optimise the operating time of a lighting system to minimise the energy demand of lighting systems. Automatic lighting control systems are comprised of various devices to control the operating time of lamps based on, occupancy, working time, and presence of daylight such as occupancy sensor technologies, Passive Infrared (PIR), and ultrasonic sensors (Haq *et al.,* 2014).

- Daylight-linked lighting controls

Buildings that have the potential to allow daylight can enhance energy savings by integrating daylight-linked lighting controls and by using daylighting sources instead of artificial lighting sources whenever possible without any interruptions (Dubois and Blomsterberg, 2011). Daylight-linked controls help to light systems to switch on or off artificial light sources at an optimum level by considering the presence of daylight (Guo, 2010). Moreover, daylight-linked lighting controls are beneficial not only to ensure that artificial lights are turned off during daytime but also to control unnecessary illumination beyond the required level (Haq *et al.,* 2014).

- Lighting controlled by time scheduling

This system can automatically switch on and switch off lights based on pre-determined schedules (Flourentzou and Roulet, 2002). Since scheduling systems operate lighting units based on the time it is only feasible for areas where the times of occupancy can be accurately predicted (Diakaki *et al.,* 2008). Moreover, these technologies can facilitate automated commands to turn off the lights completely after occupancy and during weekends and public holidays (Flourentzou and Roulet, 2002).

3.5 RECOMMENDATIONS FOR IMPROVING BUILDING ENERGY RETROFITS

Retrofitting of existing buildings provides important opportunities for decreasing global energy consumption. Further, retrofitting of existing buildings is considered to be one of the key approaches to achieving sustainability in the built environment at a relatively low cost. Even though the adoption and implementation of building ER are still relatively low. Hence, academia could actively participate in educating, training, and motivating the use of the ER concept. Informational and inspiring seminars and publishing books are some tools that could be used to promote the application of building ERs. Awareness programs could be conducted by selecting representatives from the government and construction industry, for increasing understanding of how to effectively conduct a building retrofit to promote energy conservation and sustainability. Stakeholders in the construction industry should use the ER concept to formulate policies. The internal organisational policy could be reformed, redesigned, and reorganised to promote the building ER implementation in the construction industry (Bartiaux *et al.,* 2014). Further, governments should provide subsidies and other types of financial support to assist building developers and owners in achieving the applicable energy performance targets through implementing building ERs (Ma *et al.,* 2012; Achtnicht *et al.,* 2014). Further, it is beneficial to develop an action plan to incorporate ER literacy into undergraduate and post-graduate programs. Most courses provide an introductory level of knowledge. Nevertheless, their depth of coverage is insufficient to provide a comprehensive knowledge base for the practical application of building ERs. Therefore, reorganising mainstream education programs by combining concepts related to ERs into related subject areas provides students with tremendous opportunities to apply suitable building ER in the future.

4. CONCLUSIONS AND THE WAY FORWARD

This study provided a comprehensive overview of the ER concept. ER has been identified as one of the best opportunities to improve the EE of existing buildings, mainly through the modernisation or modification of building elements or systems. The paper also discusses the ER implementation process, which includes five steps viz. pre-survey, energy audit and performance evaluation, identification of suitable and feasible retrofit options, on-site implementation and commissioning, and validation and verification. Further, different ER measures such as EBC, standard retrofit, and deep retrofits that can be used to improve the EE of various building elements and building services have also been collected after reviewing articles related to the research area. Besides, the various types of ER-associated with HVAC system (i.e. Optimum start-stop strategy, installing VFD, use of TSS, use of the free cooling application, installing ERV and installing DCV) and lighting system (i.e. use of LED lighting, use of occupancy-based control, task lighting, automatic lighting control system, daylight-linked lighting controls, lighting controlled by time scheduling) were discussed to determine the most appropriate type of ER that could be adopted based on needs and context. The findings of this study can help industry practitioners to have a better understanding and have more clarity of the importance of ER, the ER implementation process, the possible ER measures and ER types applicable to HVAC, and lighting systems that can be beneficial to industry practitioners in their endeavour to improve the EE of their facilities. Further, research can be carried out to determine the ER types applicable to the Sri Lankan conditions.

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ENHANCING THE INTEGRATION OF SMART FEATURES IN COMMERCIAL BUILDINGS TO CONSERVE ENERGY: A FRAMEWORK

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ABSTRACT

The commercial building sector is classified as a highly energy-intensive category in Sri Lanka. Building practitioners adopt energy-saving mechanisms to minimise energy consumption. However, the integration of smart features plays a vital role in conserving energy in commercial buildings. However, Sri Lanka lags behind in the adoption of smart features when compared to other countries. To address this problem, this study aimed to develop a framework for the better integration of smart features to minimise the energy consumption of Sri Lankan commercial buildings. This research is carried out initially by literature review, and then research has been followed by case study. Data collected is analysed through manual content analysis and computer software with the aid of NVivo 12 software. Findings revealed that smart features are the new technologies evolved in commercial buildings to conserve energy. However, building practitioners faced several issues in integrating these features within the existing buildings. Limited knowledge of management, building owners and operators, high initial cost, and lack of workforce skill were identified as main barriers to integrating smart features in Sri Lankan commercial buildings. Moreover, this research identified the possible mechanisms for the better integration of smart features in commercial buildings. For better integration, it is required to plan it at the initial design stage of buildings, select reliable contractors, and raise awareness of management and client about smart features. Finally, a framework was developed for the better integration of smart features to minimise the energy consumption of Sri Lankan commercial buildings.

Keywords: *Commercial buildings; Energy conservation; Energy consumption; Smart features; Sri Lanka.*

1. INTRODUCTION

Global energy consumption has typically more than doubled in the last 40 years, and it is expected to increase by another 30% by 2040 (International Organisation for Standardization [ISO], 2018). Specifically, energy use in commercial buildings has increased in recent years (Anik *et al*., 2016; Central Intelligence Agency [CIA], 2019). Herein, reduce the energy consumption of commercial buildings, specifically existing buildings that account for a significant part of the building sector, has become a

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considerable priority (Fasna and Gunatilake, 2019; Kaygusuz, 2002). Similarly, in 2016, 39 percent of total energy was consumed by the Sri Lankan building sector (Vidanagama and Lokupitiya, 2018).

Smart buildings were introduced and widely utilised as the most suitable solution for high energy consumption (Madani *et al*., 2015; Nguyen and Aiello, 2013). On a similar note, smart buildings minimise energy consumption by 50 percent more than conventional buildings (Hojjati and Khodakarami, 2016; Brady and Abdellatif, 2017).

"Buildings that have advanced controls and sensors along with automation, communication, and analytic capabilities are known as smart buildings" (King and Perry, 2017, p. 22). Generally, this building automation becomes more attractive and feasible to potential residents by generating energy savings while meeting comfort needs (Arditi *et al*., 2015; Basnayake *et al*., 2015). In addition, smart buildings can connect with the power grid, a feature that is becoming increasingly important for the deployment of the response to utility demand (Sembroiz *et al*., 2019; Pathmasiri, 2010). Likewise, its features often include smart, automated, and adaptive management systems; indoor climate control systems; and energy efficiency (Gluszak *et al*., 2019).

As energy costs are one of the main drivers of business costs, reducing energy consumption leads to lower operating costs and improves organisations' profitability (Jayamaha, 2006; Dincer, 1999). Therefore, due to the forbidding energy situation, many countries focused more on energy conservation goals and strategies (Zhao and Magoules, 2012). Smart buildings emerge successfully and promptly in developed countries and certain developing countries as a solution for energy consumption (Verma *et al*., 2019).

Similarly, in Sri Lanka, the rate of commercial energy consumption was 21% compared to the other sectors (Ceylon Electricity Board [CEB], 2018). Also, Sri Lankan commercial buildings adopting several approaches to conserve energy (King and Perry, 2017). However, smart buildings are a relatively new concept and have only recently attracted the attention of researchers and industry experts as Sri Lanka lags behind in the adoption of new technology, as compared to other countries (Suriyarachchi *et al*., 2019). However, as a developing country, Sri Lanka should also be prepared to face the concept of a smart building (Fernando and Jayasena, 2008). Several studies concerning smart buildings in developed countries were conducted in different contexts. Despite these studies, in Sri Lanka, there is a need to investigate smart building implementation and smart feature integration as a solution for energy consumption. It is also essential to find suitable solutions and potential barriers to better implement smart features inside the building. Although several frameworks have been developed for developing countries, they cannot be fully adopted in Sri Lanka since such frameworks are context specified (Li *et al*., 2010). Meanwhile, challenges faced by the building practitioners in integrating the smart features and technologies are unique to Sri Lanka due to its economic scale and IT infrastructure (Atayero *et al*., 2016). Hence, this research aims to develop a framework for integrating smart features to minimise the energy consumption of Sri Lankan commercial buildings.

2. LITERATURE SYNTHESIS

2.1 STRATEGIES TO CONSERVE ENERGY IN BUILDINGS

Many countries focused more on energy conservation goals and strategies due to facing the grim energy situation (Zuo *et al*., 2012). Chwieduk (2003) opined that improving the building envelope, advancing heat and ventilation sources, introducing heat metering and automation, and improving other installed equipment are the traditional energy-saving measures.

Zou *et al*. (2018) identified that the design concept, technology, construction method, and soft measures are strategies to enhance building energy performance. On another note, Zavalani (2011) and Doukas *et al*. (2017) said several design stage fundamental decisions and solutions such as thermal performance of building envelope, building orientation, form, thermal mass, passive heating, cooling, ventilation, daylighting, selection of adequately sized energy-efficient individual energy-using devices, building management system (BMS), building automation or smart features have a significant impact on the commercial building's energy efficiency. Besides, adopting new technology and methods has also become popular among most researchers and practitioners as one of the most effective methods to optimise energy (Zou *et al*., 2018; Shabha, 2006; Zhou and Yang, 2018). Also, smart buildings integrate and account for intelligence, enterprise, control, and materials and construction as an entire building system, with adaptability, not reactivity, at the core, to meet the drivers for building progression: energy and efficiency, durability, and comfort and satisfaction (Buckman *et al*., 2014).

2.2 CHALLENGES AND BARRIERS IN IMPLEMENTING SMART FEATURES

Communication between the numerous components requires 'standardisation' and 'interoperability,' which are components of key issues in smart building technology development (Mammeri and Younus, 2018). Besides, the main barriers to the development of smart building technologies are scalability, cost, flexibility, and issues related to preventive maintenance (Woradechjumroen and Li, 2015). Moreover, the building owners have inadequate knowledge as function integrators of the cooperative advancements of incorporating various technologies due to the absence of a platform for abstracting, modelling, and validating new technologies that inhibit their adoption (Mammeri and Younus, 2018). Smart buildings can centralise security, access, and security systems control and monitoring, providing an increase to concern that those systems are the target of threats to cybersecurity (Ma *et al*., 2016). According to Ma *et al*. (2016), lack of customer awareness and workforce skillsets also affect smart technology proliferation. Another barrier to the prevalence of smart buildings is that building infrastructure requires a lengthy replacement sequence (Rana *et al*., 2018). According to Albino *et al*. (2015), another barrier to the proliferation of smart buildings is the lack of seamless interoperability among linked devices.

3. RESEARCH METHODOLOGY

In the first stage of research, a brief literature review was carried out to identify the energy consumption ways in commercial buildings, significant causes for high energy consumption, features of the smart building concept, and energy conservation feature in smart buildings through books, conference proceedings, internet, and journals. Since it is required to collect in-depth information from professionals involved in integrating smart features, which cannot be understood or experienced in numerical data and statistical analysis was needed. Therefore, a qualitative approach was carried out. The data collection was conducted to fulfil the study's aim through the semi-structured interviews under the case study research design. In Sri Lanka, the application of smart features are rare. Among such rare applications, commercial buildings mostly hold the place of applications in a global context. Besides, commercial buildings were considered as the most energy-consuming buildings requiring smart integration (Weng and Agarwal, 2012). Subsequently, according to Yin (2011), the case study is used where the researcher needs an in-depth investigation in a particular area and focused on understanding the full scope of the problem, not on quantifying the problem. Therefore, five commercial buildings were selected as cases to identify the issues related to smart features integration. Table 1 presents the detailed description of selected cases.

Table 1: Profile of the selected cases

Cases	**Building Information**					
	Type of Business	**Gross Floor Area (sq. ft)**	**Number of Floors**	**Building Operation**	**Number of Occupants**	**Expected Lifetime**
C1	Office	70,000	8	Since 2015	500	60 Years
C2	Commercial	260,000	11	Since 2008	1,200	65 Years
C3	Commercial	350,000	13	Since 2012	2,500	100 Years
C4	Office	500,000	32	Since 1985	3,000	50 Years
C5	Commercial	1,260,000	39x2	Since 1995	6,000	50 Years

Consequently, judgmental sampling was adopted to select the participants to conduct the semi-structured interviews. Judgmental sampling is a non-probability sampling technique in which sampling units are selected solely based on the researcher's knowledge and judgment (Westfall, 2008). Accordingly, selected cases had few professionals who have experience with smart integration. Therefore, due to the unavailability of professionals with adequate knowledge in smart applications and time constraints, the interviews are limited to one professional in each case. However, selected participants have reasonable experience in the field of study to respond to the questions to address the objectives of this study. Respondents' details are interpreted in Table 2.

Table 2: Profile of interview participants of selected cases

Cases	**Participant Code**	**Designation**	**Experience**
C1	P1	Facilities Manager	6 Years
C2	P2	Assistance Manager Engineer	10 Years
C3	P3	Facilities Manager	6 Years
C4	P4	Maintenance Engineer, Mechanical	20 Years
C5	P5	Former General Manager-Facilities Management	25 Years

Thereafter, the qualitative data collected was analysed using manual content analysis and computer software with the aid of NVivo 12 software.

4. RESEARCH FINDINGS AND DISCUSSION

4.1 CURRENT ENERGY SAVING MECHANISMS

In order to identify the energy-saving mechanisms to evaluate the level of energy consumption practised in the selected cases, participants of the selected cases were asked to comment on their current practices of energy-saving and mechanisms practised. Table 3 includes the summary of energy-saving mechanisms in selected cases.

Table 3: Summary of energy-saving mechanisms

Cases	C1	C2	C3	C4	C5
Thermal Performance of Building Envelope	✓				✓
Building Orientation, Form, and Thermal mass	✓	✓	✓	✓	✓
Passive Heating, Cooling, and Ventilation	✓		✓		✓
Daylighting	✓	✓	✓		✓
Properly Sized Energy-Using Devices		✓	✓	✓	✓
BMS Integration	✓	✓	✓		✓
Building Automation/Smart Features	✓	✓	✓	✓	✓

4.2 CURRENT LEVEL OF APPLICABILITY OF SMART FEATURES

To identify the current level of applicability of smart features in the selected cases, participants of selected cases were asked to comment on the smart features that are integrated within the buildings, which is tabulated in Table 4. In addition, the level of subsystem integration and measures practised in the industry to assess the efficiency of smart features can be used as measures to assess the applicability of smart features.

Table 4: Current smart feature practices

Cases	C1	C2	C3	C4	C5
Sensors	✓	✓	✓	✓	✓
Smart metering		✓	✓		✓
Smart lighting	✓	✓		✓	✓
Distributed generation, energy storage, and net metering	✓		✓		
Smart building energy management system		✓			✓
Smart grid and energy internet					
Smart HVAC technologies	✓	✓	✓	✓	✓
Predefined events (calendar events, emergency events, periodic events)	✓	✓	✓		✓

4.3 SUBSYSTEM INTEGRATION

A comprehensive literature review emphasised that smart features can integrate all the available systems in the building and are convenient for operation by better coordination among those systems. However, case study findings indicated a completely different indication of current industry practice regarding subsystem integration. The subsystems' availability and smart feature integration of selected five cases are illustrated in Figure 1.

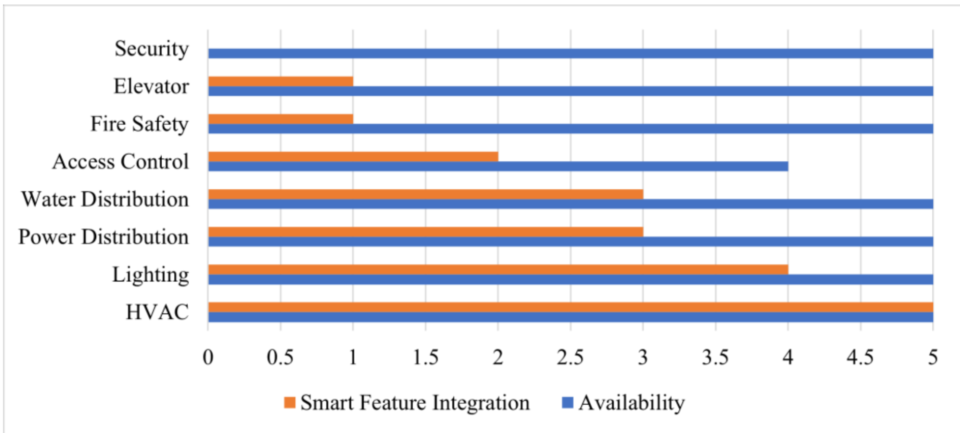


Figure 1: Subsystem availability and smart feature integration

All the selected cases have integrated with major seven systems, but they do not fully incorporate their subsystems with smart features for operation. In addition, it was found that HVAC, lighting, and power distribution are the main systems in the building and the focus of smart feature integration is more towards that.

When looking into integration, smart features are mainly used as a monitoring device and energy meter in most cases. It is evidenced that the capabilities of smart features are not fully utilised by building practitioners in commercial buildings. The level of integration of each system is illustrated in Figure 2.

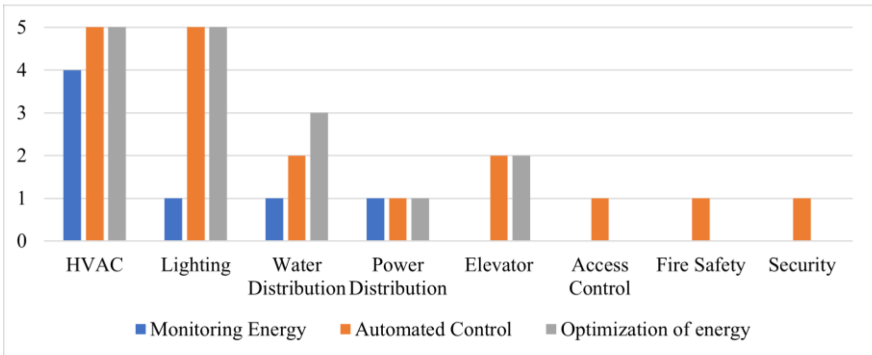


Figure 2: Level of smart feature integration

Concerning the findings, each case has a different level of subsystem integration to smart features. Mostly smart features are used to automatically control the subsystems rather than monitoring and optimise the energy. Although all the systems are integrated, only HVAC and lighting are used to a broader extent than other systems. According to the analysis, all the selected cases are clustered into three major groups based on subsystem integration as high, medium, and low, summarised in Table 5.

Table 5: Summary of subsystem integration

Level of Subsystem Integration	Cases	Building Type
High	C5	Commercial office
Medium	C1, C2, C3	Bank and Commercial
Low	C4	Bank

Concerning the findings, only HVAC and lighting are used to a broader extent than other systems in the Sri Lankan context. Further, findings revealed that there is no perfect smart feature practiced in the local context.

4.4 ENERGY EFFICIENCY ASSESSMENT

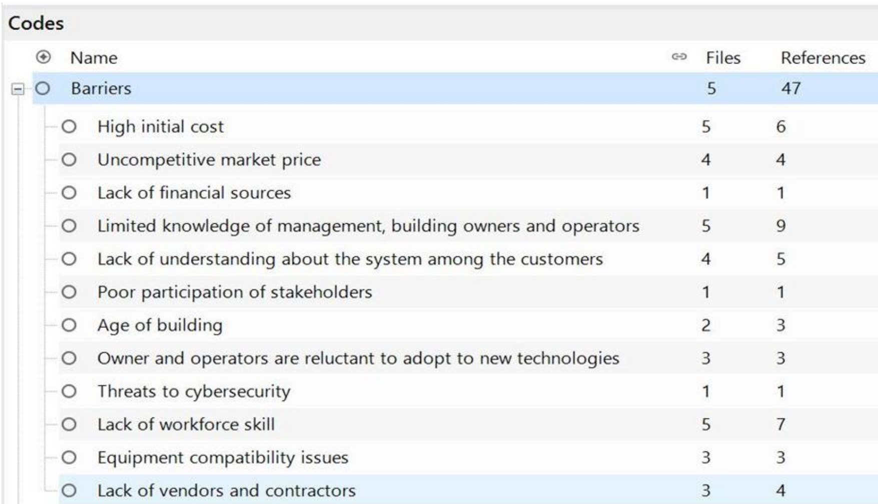
Based on the findings, it is evident that smart features save considerable energy compared to buildings that are not integrated with smart features. All cases integrate smart features mainly for energy-saving purposes. However, the energy-saving potential of smart features is not regularly checked by all the cases, as given in Table 6.

Table 6: Energy efficiency assessment practice

Cases	Assessment Frequency	Saving potential
C3	Annually	Save 50% of building energy consumption
C5	Monthly	Save 10 to 20% of building energy consumption
C2	Once at the initial stage	Save 20% of energy consumption
C1	Once at the initial stage	Save 10% of energy consumption
C4	Annually	Save 8 to 10% of energy consumption

4.5 BARRIERS TO IMPLEMENT SMART FEATURES

Barriers to implementing smart features efficiently in commercial buildings in Sri Lanka were evaluated using code-based content analysis. Interviewees were asked to comment on the barriers for integrating smart features, and their responses were analysed using code-based content analysis to collect the participant's perspective on the barriers. The results are illustrated in Figure 3.



Codes

Name	Files	References
Barriers	5	47
High initial cost	5	6
Uncompetitive market price	4	4
Lack of financial sources	1	1
Limited knowledge of management, building owners and operators	5	9
Lack of understanding about the system among the customers	4	5
Poor participation of stakeholders	1	1
Age of building	2	3
Owner and operators are reluctant to adopt to new technologies	3	3
Threats to cybersecurity	1	1
Lack of workforce skill	5	7
Equipment compatibility issues	3	3
Lack of vendors and contractors	3	4

Figure 3: Barriers for smart features integration

4.6 MECHANISMS FOR BETTER INTEGRATION OF SMART FEATURES

Strategies to enhance the performance of smart features towards efficient building operation in the Sri Lankan context were gathered through the participants' opinions and analysed, which are illustrated in Figure 4.

There are no specific studies that seem to have existed in the literature. However, analysis findings revealed that raising awareness of management and client, selecting reliable contractor, designing accordance with operation, assigning experienced operator, industrial cybersecurity standards, train operators and workforce, sufficient technical support, introducing building regulations, proper commissioning, selecting suitable vendor, pilot project, and continuous knowledge enhancement are the mechanisms proposed to mitigate the prevailing barriers.

Codes

Name	Files	References
Mechanisms	5	50
Raise awareness of management and client	3	5
Select reliable contractor	5	7
Design accordance with operation	5	8
Assign experience operator	3	3
Industrial cybersecurity standards	1	2
Train operators and workforce	5	8
Sufficient technical support	5	5
Introducing building regulations	2	3
Proper commissioning	2	2
Select suitable vendor	4	4
Pilot project	1	2
Continuous knowledge enhancement	3	4

Figure 4: Mechanisms for better integration of smart features

4.7 Discussion of Findings

The literature findings show that smart buildings are the current trend to conserve energy in commercial buildings. Similarly, according to case study findings, Sri Lankan commercial buildings are also in the stage of adopting new technologies, and smart features also be a part of it. All the participants emphasised that sensors and smart HVAC technologies are widely used in buildings to reduce energy consumption. In addition, smart lighting and predefined events are used as smart features. Moreover, smart metering is used to control energy consumption in commercial buildings.

In addition, the level of subsystem integration was checked in the selected cases. Smart features are integrated with several subsystems in commercial buildings. In addition, major subsystems that are commonly integrated into the buildings were identified, such as HVAC, lighting, security and access control, water distribution, power distribution, fire safety and an elevator (Aste *et al*., 2017; Doukas *et al*., 2007; Shaik *et al*., 2014). The case study findings emphasised that none of the cases integrates all available systems with smart features. Most building practitioners focused on HVAC and lighting rather than all the other systems.

Moreover, the level of subsystem integration is grouped into three groups as high, medium and low. Further, integrated systems are not fully utilised. Most of the cases are integrated with the smart features only to control the system automatically. Further, energy efficiency was assessed. Literature emphasised that energy saving is the most significant benefit which can be achieved through smart features integration. Furthermore, all the participants agreed that smart features save considerable energy compared to buildings that are not integrated with smart features. All cases integrate smart features mainly for energy-saving purposes.

Literature findings emphasised that there are several issues in integrating smart features within the buildings. In such context, case study findings highlighted that all the significant barriers identified in the literature greatly impact smart features integration. The uncompetitive market price for smart features, lack of financial sources, age of the building, owner and operators are reluctant to adapt to new technologies, and lack of vendors and contractors are identified as major barriers in addition to the literature findings. However, identified barriers have a huge role in the integration of smart features. Therefore, for the better integration of smart features, such barriers need to be mitigated.

4.8 FRAMEWORK FOR THE BETTER INTEGRATION OF SMART FEATURES IN COMMERCIAL BUILDINGS

In order to accomplish this aim, a framework was developed, as shown in Figure 5, from the overall findings of this research. The framework includes three models developed based on the level of subsystem integration with smart features.

Further, the barriers were linked with the models and revealed the reasons for the lack of integration of smart features with respect to the models. Moreover, the framework elaborates on the mechanisms that need to be used to overcome those aforementioned barriers to better integrate smart features in commercial buildings. Thus, the framework supports commercial building practitioners for the better integration of smart features towards energy conservation.

5. CONCLUSIONS

Different energy-saving mechanisms are practised in existing commercial buildings, and smart buildings are one of the current energy-saving mechanisms emerging in Sri Lankan commercial buildings. Through the research, it is evident that several commercial buildings practised smart features in buildings and conserve energy to a vast extent. However, it is evident that the integration of smart features in commercial buildings is not practised widely. Several barriers to integrating smart features in buildings have been identified in this research. Besides, identified barriers have a huge role in the integration of smart features. Therefore, for the better integration of smart features, those barriers need to be mitigated. Therefore, possible mechanisms were developed based on the opinions of industry practitioners. Arising awareness of management and client, selecting reliable contractor, designing accordance with operation, assigning experienced operator, industrial cybersecurity standards, training operators and workforce, sufficient technical support, introducing building regulations, proper commissioning, selecting suitable vendor, pilot project and continuous knowledge enhancement are the mechanisms proposed to mitigate the prevailing barriers. Finally, a framework was developed, and the framework supports commercial building practitioners for the better integration of smart features towards energy conservation. The findings of this report will help commercial building professionals in the industry to enhance the integration of smart features in Sri Lanka to conserve energy. Therefore, making aware of the subsystems that can be integrated with smart features and allowing better coordination among those systems and formulating possible mechanisms will allow better integration of smart features within the buildings.

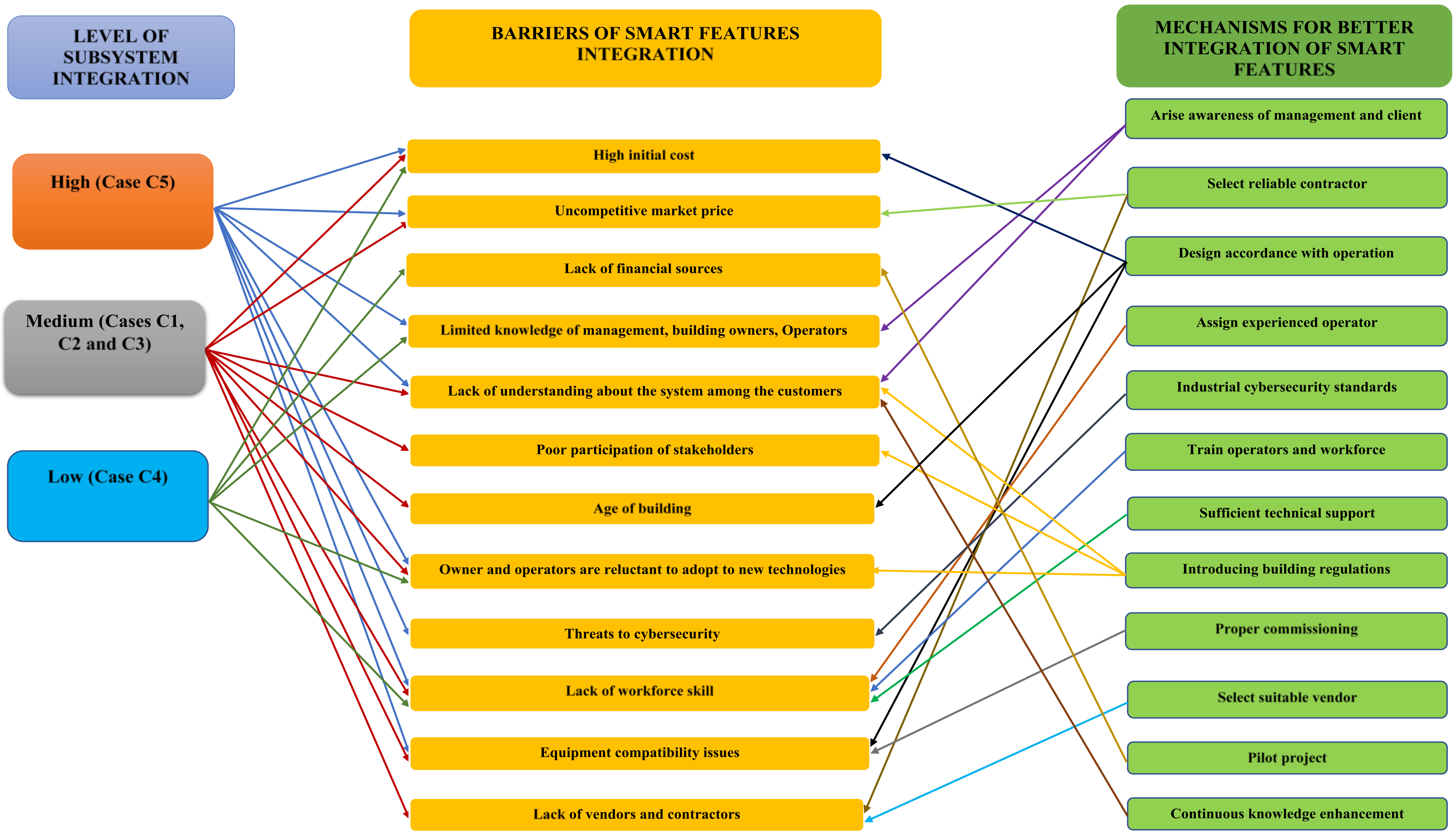


Figure 5: Framework for the better integration of smart features in commercial buildings

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ENHANCING VALUE ENGINEERING APPLICATION IN THE SRI LANKAN BUILDING CONSTRUCTION INDUSTRY: A FRAMEWORK

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ABSTRACT

The concept of value engineering (VE) is used to optimise the cost, time, quality, and functional performance toward achieving the best value for client money. However, the application of VE in construction industries is limited as there are differences in the use of the VE concept to developing economies, application of cost-oriented procurement systems, and lack of a practically applicable framework. In the local construction context, VE is practiced in an ad hoc manner. Therefore, the current study aimed to develop a framework including a tailored approach to enhance the VE application in the building construction industry. A qualitative approach was adapted to solicit views of twenty-two (22) construction professionals who involved in the six (6) high-rise building construction projects and practiced the VE concept. Views of professionals were synthesised using content analysis and finally developed a framework including a tailored VE approach. The findings conclude that cost and time as the main value criteria which motivate the VE application. Further, VE application in the construction industry is initiated mostly in the construction stages while professionals' preference is laid on the initial project phases. Consequently, the contractor change proposal was identified as the sound approach to deliver VE since motivations emerge during physical construction. Finally, a tailored VE approach was developed considering concept design, developed design, and construction stages with related VE motivations to enhance the VE application in the Sri Lankan building construction context in a simplified manner.

Keywords: *Building construction; Strategies; Value criteria; Value engineering.*

1. INTRODUCTION

Theoretically, Value Engineering (VE) is implemented as an innovative field for project performance optimisation (Chen and Su, 2017). Applying VE establishes a clear project objective and provides creative thinking for design improvement (Ahmed *et al*., 2016). Further, it contributes to reduces project cost by up to 26%, enhances operational performance by 40-50%, and upgrades product quality by 30-50% (Gudem *et al*., 2013). Tohidi (2011) stated that the VE process enhances ways to deal with resource shortages,

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minimise additional costs, and uses modern methods and practices. In addition, the VE application in the different stages of the construction works namely, feasibility study, design, construction, and maintenance throughout the life cycle generates optimum value (Shahhosseini *et al*., 2017). Reciprocally, Windapo (2013) stated the VE applies at any stage of the construction procedure since the generic requirement is to gain higher return through cost, time, and quality perspectives.

In the local context, the VE practices have not encouraged the theoretical aspects, practiced in an ad hoc manner without proper application of theoretical knowledge (Navarupan, 2004). Similarly, Senarathna (2013) stated that only a few instances had been reported on VE applications in the Sri Lankan context. Importantly, in several countries, there is a separate professional body; SAVE Local chapters or VE institutional bodies to establish the VE practices (Cheah and Ting, 2005). However, in the Sri Lankan construction industry, such requirement is not casted. Further, Sri Lankan VE practitioners consider VE as a cost-cutting mechanism initially used at the construction stage of a project, which is a common misconception on VE (Karunasena and Gamage, 2017). In addition, lack of client support, a misconception regarding the cost of implementation, lack of expert knowledge, unfamiliarity with the VE culture within public firms, and lack of construction framework and guidance to the practical application of the VE concept limits the VE application in Sri Lanka (Perera *et al*., 2003). Therefore, this study gives due consideration to facilitate construction professionals who work in building projects to identify value-enhancing gateways and simply understandable procedure to conduct VE study to enhance the application of VE practices in the Sri Lankan construction industry.

2. LITERATURE REVIEW

2.1 VALUE ENGINEERING CONCEPT

VE is considered an innovative and strategic approach used to achieve optimised value for money without reducing the quality, capabilities of operation, capabilities of maintenance, and aesthetic appearance (Othman, 2008; Yan *et al*., 2015). In addition, VE is considered as a subset of the Value Management (VM) process which focused on the technical process by translating built facility requirements using design and construction (Kelly *et al*., 2004). VM evolved through value analysis (VA), which caused the origination of the VE concept in the construction and industrial sectors (Shen and Liu, 2004). Further, the VM process can be illustrated in three stages as VA, VE, and value review (VR) respectively as illustrated in Figure 1.

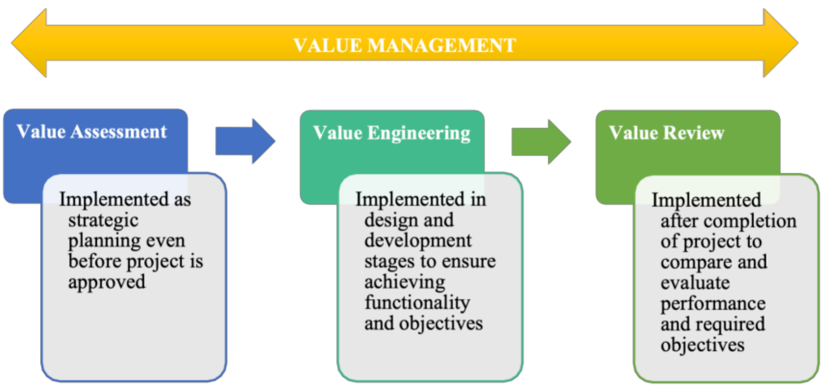


Figure 1: VM process (Adapted from Jaapar et al., 2012)

Table 1 illustrates the common VE job plans that apply in the construction industry.

Table 1: VE approaches in the global context

VE Approach	Description
Charette job plan	This is used primarily for function analysis on requirements of space to reasoning the client's brief. Considering the allocation of time this study can be enhanced with other problems concerned in the client's brief. This is not an expensive method of briefing the design team and providing solutions to their requirements effectively and in a shorter duration of two days
SAVE 40-hour Workshop	This job plan is conducted over five days. This job plan is considered a widely accepted formal approach comprised of three stages namely, pre-workshop stage, workshop stage, and post-workshop stage.
Contractor's change proposal	This job plan is a well-established form of carrying out the VM in the construction industry and projects.
VE audit	In this approach, the external VE team engaged in the project to identify VE proposals by reviewing the designs.

(Source: Kelly and Male, 2001)

Value attributes in VE concerned in the building construction industry evolved from the concept of the product to process as illustrates in Figure 2.

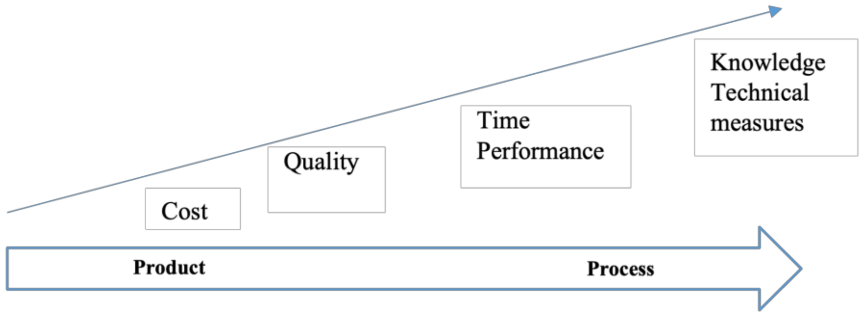


Figure 2: Value focus evolved over time (Adapted from: Dallas, 2006)

2.2 BARRIERS AND CHALLENGES FOR IMPLEMENTING VALUE ENGINEERING

According to Kosala and Karunasena (2015), one of the main objectives of Sri Lankan construction practitioners is to reduce the cost but not to enhance the value of the construction work. Thus, there is a requirement of redesigning due to the final design is mostly laid towards cost overruns (Perera *et al*., 2003). Other than the above poor perception of construction practitioners regarding the VE concept, the general application of VE to practical situations is restricted due to many reasons, which can be categorised as in Table 2.

Table 2: Challenges to implement VE in developing countries

Component	Specific factors contain
Obstructions of VE team	Lack of Client support Difficulties to implementation Misconception regarding the cost of implementation Less teamwork spirits
Obstructions of VE study	Lack of expert knowledge Overestimation of VE by stakeholders Reluctance to resource utilization efficiently Lack of construction framework and guidance to practical application Unfamiliarity with the VE culture within public firms
Difficulties of implementing VE	Use of procurement systems that are cost-oriented No willingness to apply VE The impression that VE is not a worthy application Conceptual provisions are inflexible Lack of support from the strategic management and government Lack of awareness of VE
Conceptual problems	Complicatedness and theoretical contents in VE Consider VE is not required when the project is designed by the best designers Unsoundness to allocate time for VE
Obstructions due to developing economies	VE is not being tallied with concepts of developing countries Lack of awareness and knowledge on methodology Insensitivity to take a risk and be creative

(Sources: Perera *et al.*, 2003; Cheah and Ting, 2005; Chen and Su, 2017)

2.3 VALUE ENGINEERING PRACTICE IN THE CONSTRUCTION INDUSTRY

Table 3 provides the international VE practices.

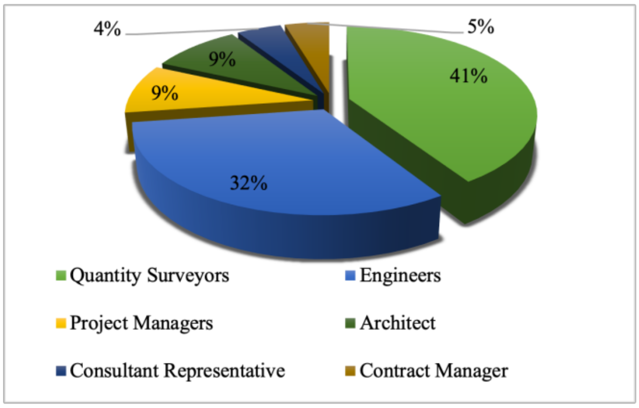
Table 3. The international practice of VE

Item	International practice
Objectives of VE studies	Existing and/or proposed projects or products related to both strategic and tactical problems
VE studies facilitator	Independent external or internal VE expert
VE studies timing	From the conceptual stage to completion of a project or product
Composition of VE team	Stakeholders relative and often many personnel are involved
The workshop-style of VE	Preferred continuous and concentrated workshops
Functional analysis	Purpose of clarifying client's requirements and to identify poor value by understanding the value system
Duration	Generally, takes only a few days

(Adapted from: Shen and Liu, 2004)

3. RESEARCH METHODS

In order to achieve the aim of this study, which is to develop a framework including a tailored approach to enhance the VE application in the Sri Lankan building construction context, a qualitative approach has been undertaken. Six (6) case studies have been conducted in high-rise building construction (above 4 storeys) projects where VE was applied within its project lifetime by giving the constraints of time and accessibility. All these identified cases were based on the traditional procurement methods. Subsequently, semi-structured interviews were conducted with the three or more respondents from each project from different professional disciplines. All together twenty-two (22) semi-structured interviews were conducted (identified as I01 to I22). Figure 3 demonstrates the professional profile and experience of interviewees.



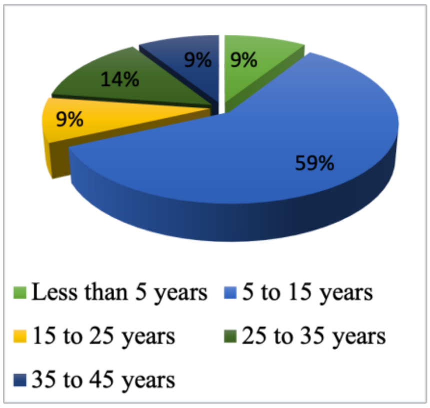


Figure 3: Profiles of professions and construction experience of interviewees

As seen in Figure 3, the majority of the respondents were Quantity Surveyors (41%) and Engineers (32%). In addition, most of the respondents had construction experience of around 5 to 15 years including VE practices.

Data analysis has been undertaken by using manual content analysis and NVivo 12 software. Ultimately, a framework has been developed including a tailored VE approach to enhance the VE application in the Sri Lankan building construction context through a comprehensive literature review and case study findings.

4. DATA ANALYSIS AND FINDINGS

4.1 DETAILS OF VE PROPOSALS

Table 4 shows the VE proposals that have been carried out within the selected cases. Nature, motivation, and achievements in terms of cost and time saving through the VE proposal in each project are drawn in Table 3.

According to the findings, identified VE proposals named PA1, PA3, PC3, PD1, PE3 were conducted with the main motivation of initial cost saving. In addition, PC1 and PC2 were considered the LCC concerned as major motivational factors. Further, VE proposals PA1, PA2, PA3, PB1, PE1, and PE2 were influenced to reduce the time consumption of the construction.

Table 4: Details of VE proposals

Case	Proposal Code	Motivation(s) for VE proposal	Description	Cost before	Cost after	Cost	Time
				Application of VE (US$ Mn)		Saving	
A	PA1	Initial cost-saving/ Contractor identified an opportunity to optimise project value	Replacement of natural marble and granite tiles with porcelain tiles	0.30	0.10	67%	√
	PA2	Reuse usage/ Contractor's familiarisation to the design	Use MFE Aluminium formwork system instead of traditional formwork	0.067	0.044	34%	√
	PA3	Cost-saving/ Enhance construction efficiency	Stainless steel handrail to mild steel handrail	0.51	0.35	32%	√
B	PB1	Time saving/ Space optimisation/Constructi on efficiency	Changing the vent pipe size from 150mm to 100mm	0.089	0.05	43%	√
C	PC1	LCC consideration/ New technologies	Replacement of traditional chiller system to Smart magnetic bearing chiller system	1.26	0.90	28.5%	-
	PC2	LCC consideration/ New technologies	Changing the electrical system - Power generation	This proposal was not implemented			
	PC3	Cost-saving/New technologies	Changing the interior decoration	This proposal was not implemented			
D	PD1	Cost-saving/New technologies	Changing the internal wall cladding thickness from 10mm to 8mm	1.72	1.20	10.98%	-
E	PE1	Optimise project Budget/Contractor identified opportunity to optimise project value	Use skim coat special finishing instead of granite cladding	0.74	0.26	65%	√
	PE2	Due to regulation requirements	Change the sprinkler system design according to the requirement	7.44	7.22	3%	√
	PE3	Initial cost-saving/ Construction efficiency	Electrical Aluminium cables instead of Copper cables	1.65	1.46	12%	×
F	PF1	Land restrictions/Due to adjacent constructions/ Unnecessary indirect cost in construction	Changing the piling foundation to raft foundation	0.31	0.22	31%	-

Interviewee I07 who stated that PB1 was motivated to implement excess time requirements due to constructability issues facilitated that statement. However, as identified through the VE proposal PF1, that it was not motivated to minimise the time for construction, but the VE proposal indirectly causes to reduce construction time consumption. Even though any of these selected cases were not motivated to increase quality, interviewee I18 stated that cheap material options could not be considered as VE proposals because they can influence quality reductions. In other terms, I19 stated VE could be used adhering to the regulations and standards related to the building construction to maintain the quality requirements.

4.2 VALUE ENGINEERING IN DIFFERENT PROJECT PHASES

Figures 4 and 5 demonstrate the project phases that applied the VE concept in the selected cases and the results of the interviews, respectively.

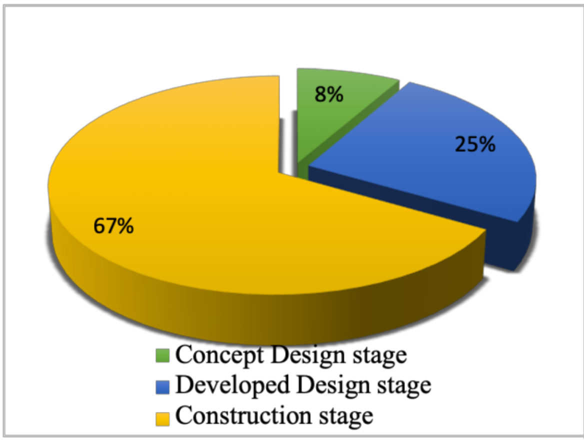


Figure 4: Project phases of VE applied

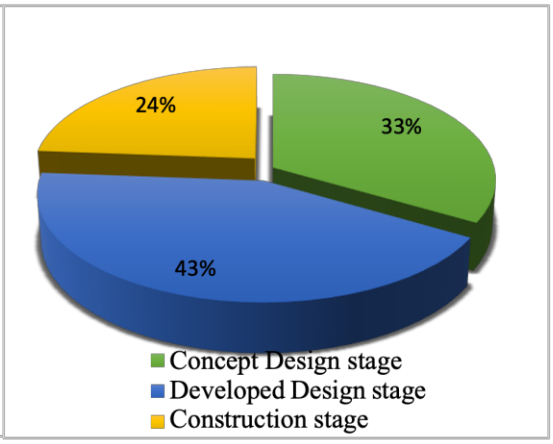


Figure 5: Preferred VE applicable phases

The majority of the VE proposals (67%) selected for the study carried out in the construction stage and 25% and 8% of VE proposals were applicable in the developing design stage and concept design stages, respectively. However, according to the views of respondents (44%), the developed design stage was identified as the most preferable project phase to apply VE proposals while the least preference (24%) was laid on the construction stage.

4.3 VALUE ENGINEERING APPROACHES IN THE LOCAL CONTEXT

Figures 6 and 7 demonstrate the VE approaches applied in the selected VE proposals and the results of the interviews, respectively.

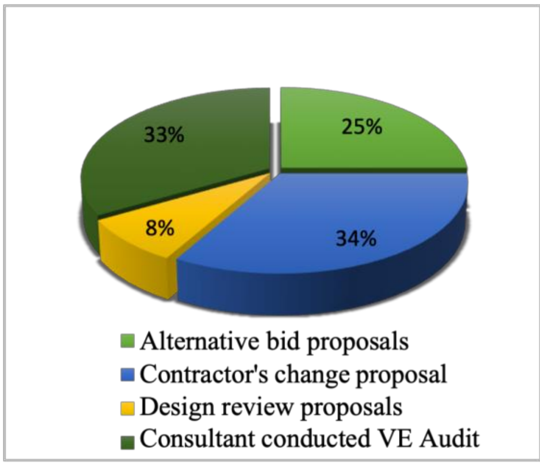


Figure 6: Applied VE approaches

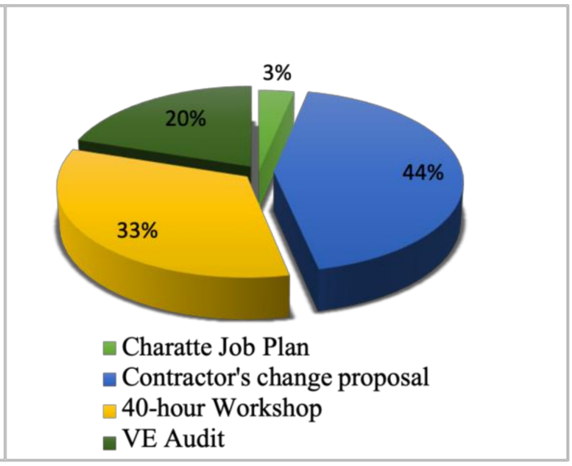


Figure 7: Preferred applicable VE approaches

According to the respondents, contractor's change proposals were most applicable (34%) and most preferable (44%) to the local construction industry. Most of the theoretical VE approaches were unaware of by the construction professionals. However, nearly half of the interviewees were aware of the VE workshop, and they recommended VE 40-hour workshop (33%) as one of the preferred approaches to the Sri Lankan construction industry. Above a quarter of the respondents stated, the risk resistance is very high in Sri Lanka due to the professionals' traditional thinking pattern. Therefore, implementing VE required considerably high force. Even though, selecting a preferred VE approach would be very obstructive within such background. Nevertheless, currently, the construction practice can easily implement the contractor's change proposal method. Following are the causations to the selection of the contractor's change proposal as the sound approach to deliver VE in the local construction context:

- Local construction is mostly cost concerned and when contracts identify any cost overrun within the project can use VE as a tool to reduce such budget overrun from another dimension.
- Generally, separate time is not allowed to practice VE.
- Consultancy services were not used to crave the optimum facilities required for the building constructions.

4.4 CHALLENGES AND STRATEGIES TO ENHANCE VALUE ENGINEERING APPLICATION IN SRI LANKA

Table 5 presents the specific challenges in implementing VE in project phases of selected cases.

Table 5: VE application challenges identified in each project phases

Project Phase	Challenges to applying VE
Strategic definition and preparation of client brief stages	The opinion of professionals is these changes are initial changes to the original design (I03, I06, I11, I15, I17)
Concept design stage	Generally, Architect does not agree to change their design (I02, I03, I07, I10, I19, I21)
	The client will not approve these value-adding opportunities while resisting to take risks (I01, I05, I11, I12, I16, I18, I20, I22)
Developed design stage	In some projects, bidders were called to submit alternative proposals, which has the potential of VE. Eventhough this is not conducted properly due to unethical practices (I07, I12, I13, I15, I16)
Construction stage	Contractor's do not tend to take the responsibility (I01, I10, I12, I14, I17)

Interviewees I09, I12, I18 and I22 expressed that in most of the building construction projects conducted in the Sri Lankan context, the main stakeholder or the client is a non-professional who does not aware about the tools and techniques that used to optimise the value of the construction facility.

According to the majority of the interviewees (36%), improve the awareness among construction professionals identified as the critical requirement to enhance the VE application in the Sri Lankan construction industry. Thereafter, most of the responses (32%) accept that initial insist through advantages of the VE practices as a secondly suitable way to enhance the VE approach. Then three strategies were identified which are enhance rules and regulations by the government, promote long-term benefits, and reviewing the design throughout design and construction stages as the third most important through the opinions of the professionals (27%). In addition, VE encouragement through current practices, enhance client end technology in the construction sector, ensure VE approaches not effecting time expansions, conducting brainstorming sessions, integrate separate VE team to construction projects, and introduce clear mechanism to reward parties who identify VE are also identified as the strategies to enhance VE application through findings.

4.5 DEVELOPMENT OF THE FRAMEWORK

The framework was developed to enhance the VE application in the Sri Lankan construction industry (see Figure 8). The framework identifies the motivations in the current construction industry and the most applicable project phases to implement VE due to the identified motivations or value criteria in this research study. Other than that, simplified tailored VE job plans were implemented using the analysis to enhance the construction professionals' attraction towards the standard VE practices. Moreover, barriers of VE application in standard and enhance focuses were addressed to mitigate with the suggestions. The framework was developed to distil the VE applications from a simplified perspective.

5. DISCUSSION

From the research findings, cost and time were identified as the main value criteria which were motivated the VE application. The results of Kim and Luu-Truong (2016) coincide with this finding. Though the quality aspect was not motivated by the VE application in the selected cases, interviewees stated that quality is a compulsory requirement. With a similar perspective, Dallas (2006) stated that quality performance is one of the value criteria which evolvedover the value focus in the construction industry. In terms of the application of VE proposals, literature identified in most of the circumstances VE is better to apply inthe initial project phases to obtain more benefits (Abidin and Pasquire, 2007). However, the research findings identified that interviewees mostly preferred to apply VE at the design stages because it minimises the changes that occurred to the design at later stages.

6. CONCLUSIONS

This research identified that the VE application in the local context is narrow to the standard VE practices. However, about the standard VE professionals were more or less knowledgeable due to conventional trends and conceptual problems in construction activities, professionals tend to informal VE practices. Therefore, the theoretical job plan is indirectly followed in an unstructured manner is the common feature identified from all the selected cases. Through this study identified the motivations in the current construction industry and the most applicable project phases to implement VE due to the identified motivations or value criteria.

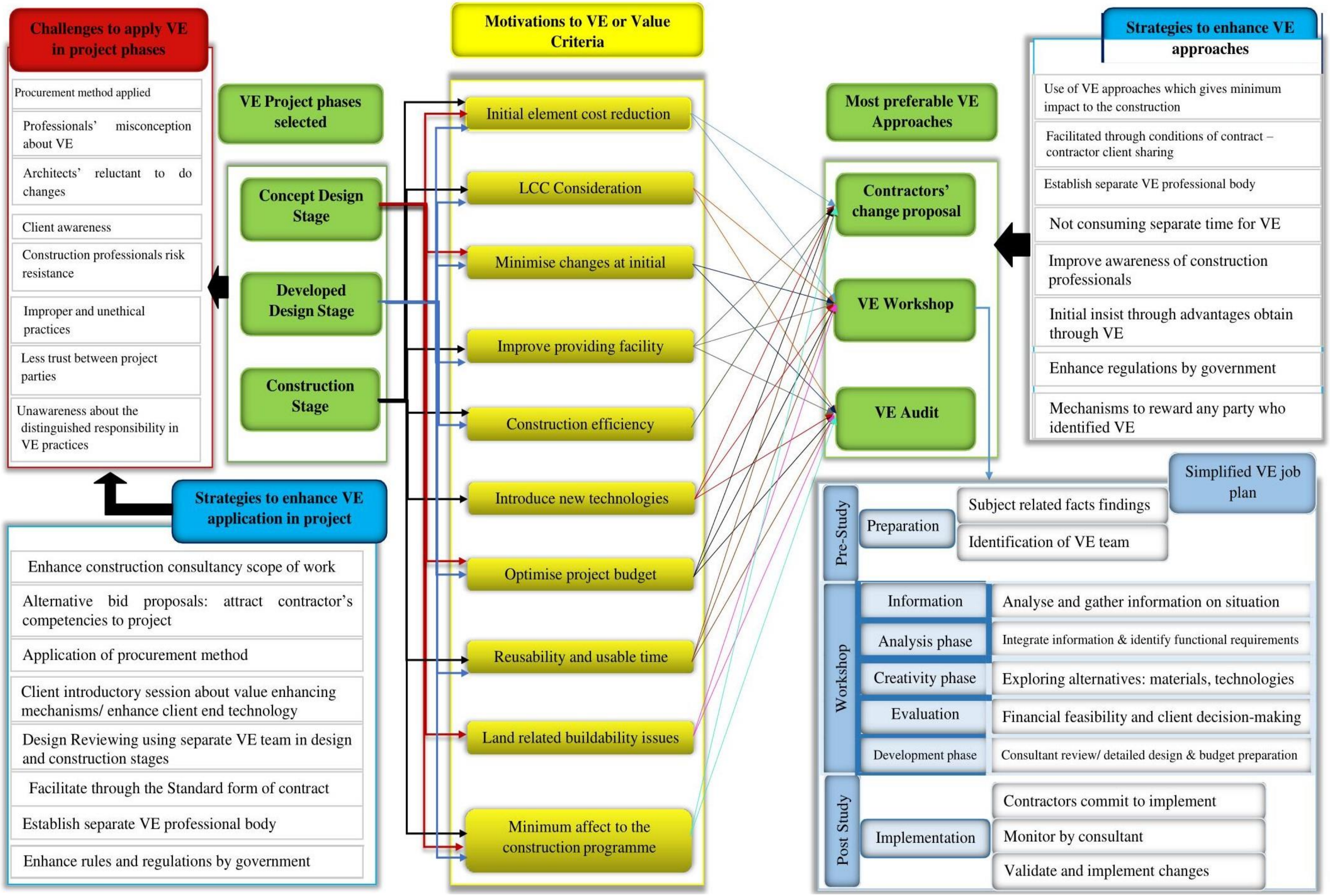


Figure 8: The framework to enhance the VE application in the Sri Lankan building construction context

Considering these VE motivations and attractions of the professionals above tailored VE approach were designed compared to the theoretical VE job plan. Further, this study recommends that they should take actions to enhance construction professional's knowledge on VE while minimising the misconceptions on the VE objectives by conducting knowledge transfer sessions. Currently, VE applications mostly can be seen in the construction industry, however, steps should be taken to promote the VE application in the design stages to minimise the changes and cost incurred to such changes due to VE applications through the national intervention.

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ENSURING HEALTH AND SAFETY IN PETROLEUM BUILT ENVIRONMENT: THE CASE OF SRI LANKA

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ABSTRACT

The petroleum-built environment is an important area of concern, which mainly includes refinery and storage facilities. Since its hazardous nature leading unexpected accidents and disasters, the safety of petroleum-built environment has become a vital requirement to eliminate the hazards associated with the petroleum process. However, a comprehensive study on safe handling of petroleum products in Sri Lanka is not reported so far. Hence, this study aimed at enhancing the health and safety in handling process of petroleum products in refinery and storage facilities. A comprehensive literature review was initially conducted on the petroleum products handling process, and national and international safety guidelines. Case study method was used since this study requires an in-depth investigation. Two prominent cases for refinery and storage facilities were studied to collect the data. Content analysis technique was used to analyse the data. The findings revealed that Factories Ordinance, National Fire Protection Association (NFPA) Guideline, Occupational Health and Safety Assessment Series (OHSAS) standard, and National Institute of Occupational Safety and Health (NIOSH) Guideline are commonly considered in ensuring health and safety of petroleum-built environment. Further, the chronic deceases in lungs and heart, cancers, high noise generation, unwillingness to use personal protective equipment (PPE), bowser and wagon accidents, fuel fire risk, pipeline leakages, and water and soil pollution were highlighted as common health and safety issues in refinery and storage. Finally, various strategies were proposed to overcome the identified health and safety issues ensuring the health and safety of petroleum-built environment.

Keywords: *Health and safety issues; Petroleum built environment; Refinery; Storage; Strategies.*

1. INTRODUCTION

Petroleum products are generated through ancient plants and animals that have been compressed beneath the surface of the earth. Petroleum gas (LPG), premium motor spirit (PMS), automotive gas oil (AGO), high power fuel oil (HPFO), dual purpose kerosene (DPK) and aviation turbine kerosene (ATK) are mainly introduced as petroleum products (Essoka *et al*., 2006). The process of petroleum industry is divided into exploration,

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extraction, refining, storage, transportation and marketing of the petroleum products (Amponsah and Opei, 2014). This study mainly focuses on petroleum built environment, which comprised of refinery and storage stages. Due to the complexity and the risk level in the process, human resource of the petroleum built environment needs special safety precautions (Stellman, 1998). Therefore, guidelines, standards and Acts are required for minimizing hazards and enhancing safety of the industry (Smith, 2013). Similarly, in Sri Lanka, petroleum built environment is one of the industries that has created various environmental damages, health and safety issues. For example, in 1995, the Orugodawaththa storage tanks were exploded due to terrorist attack and harmed the employees, environment and properties of the organization. The bowser accident at the Nellumdeniya station were contributed to major environmental and property damages (Ministry of Petroleum Industry, 2013). Even though, every country has their own national safety guidelines for the safe handling of petroleum products, many safety issues have been frequently reported in petroleum-built environment (Candreva *et al*., 2013). Moreover, majority of guidelines and standards are incapable of providing the adequate safety in petroleum-built environment covering the refinery and storage facilities in Sri Lanka (Samaratunga, 2013). Therefore, it is noteworthy necessity to develop a mechanism for ensuring health and safety of petroleum product handling process in refinery and storage facilities in Sri Lanka. Hence, the focus of this research paper is to investigate the existing health and safety guidelines, health and safety issues in the refinery and storage stages in order to propose strategies for ensuring health and safety in petroleum-built environment.

2. LITERATURE REVIEW

2.1 PETROLEUM PRODUCTS HANDLING PROCESS

Petroleum can be classified as heavy or light depends on gravity on each product. High Sulphur content (0.5% and above) is concerned as the sour and low amount of Sulphur is called as sweet (Łużny, 2011). Crude oil is converted into the different products at the refinery level (Ceylon Petroleum Corporation, 2013). Petroleum industry undergoes two major processes, such as upstream and downstream. Yang *et al*. (2016) mentioned that the upstream process refers the part of the oil industry involved with finding oil fields and bringing oil up from the ground. The downstream process includes refining of various products, storage petroleum products, the transportation and retailing of petroleum products (Ambituuni *et al*., 2013).

Considering the above, the downstream process related to petroleum-built environment was selected in this research, which consists of refinery and storage facilities of petroleum products. Crude oil is purified and treated substance which use to remove unusable substances in refinery while storage facilitates smooth out supply and demand discrepancies of petroleum products (Cheremisinoff, 2000).

2.2 NATIONAL AND INTERNATIONAL GUIDELINES AVAILABLE FOR HEALTH AND SAFETY IN PETROLEUM BUILT ENVIRONMENT

Edeskuty and Stewart (2013) highlighted three main issues in petroleum built environment, namely: health and safety issues, fire and explosions and environmental pollution. Moreover, authors mentioned that it is essential to establish guidelines and standards for safe handling petroleum products. Safety and health are ensured for safe handling of petroleum products by introducing proper Occupational Health and Safety Assessment Series (OHSAS) regulations. National Fire Protection Association (NFPA) is mainly based on preventing fire and safety issues in the handling of petroleum products. Further, National Institute of Occupational Safety and Health (NIOSH) standard is followed for preventing accidents, injuries and environmental issues (National Research Council, 2009). Functional Committee (2012) issued a permit for underground storage tanks and fittings of the storage tanks. Ravindran (2011) pointed out designing, construction, maintain of storage tanks. Workplace Law Group (2011) highlighted the requirements for the safe storage of used oil. Federal Road Safety Commission (FRSC) has established safety requirements and guidelines for articulated tanker operations in Nigeria that covers registration, licensing and emergency preparedness (Aroh *et al*., 2010). Festus *et al*. (2015) introduced petroleum licenses for filling stations.

In Sri Lanka, Petroleum Products Special Provisions Act No. 28 of 1961 basically govern the downstream petroleum industry. The regulation of the upstream petroleum industry is handled by the Petroleum Resources Act No. 26 of 2003 (Amaratunga, 2007). The safety issues in the refinery can be considered as a major area to develop a safety procedure for petroleum industry in Sri Lanka. The refinery unit of Sapugaskanda was established by Act No. 28 of 1961 and the unit distribute petroleum products throughout the island (Ceylon Petroleum Corporation, 2013). Ministry of Petroleum Industry (2013) described during refinery process, the organization is used various guidelines and standards for safe handling of petroleum products in petroleum industry namely, International Organisation for Standardisation (ISO) methods - ASTM D, OHSAS guidelines, Factories Ordinance No. 45 1942, NIOSH and NFPA. Factories Ordinance No. 45 1942, NIOSH, NFPA, Australian Standard and OSHAS 18001- 2007 guidelines are applied for enhancing safety in storage premises (Ministry of Petroleum Industry, 2013).

The conceptual framework summarizes the literature findings of the study as illustrated in Figure 1.

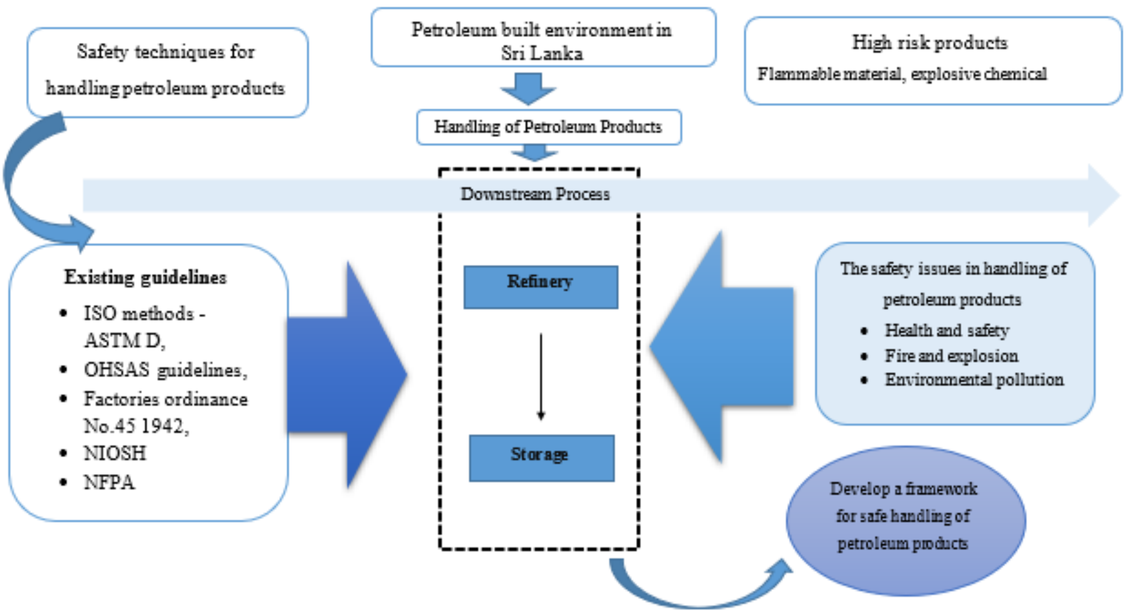

Figure 1: The conceptual framework

Framework depicts safety standards and guidelines for handling petroleum products and safety issues relating to downstream petroleum process in Sri Lanka including refinery and storage. As a key implication of the research, this framework will be further enhanced by proposing strategies for ensuring health and safety in petroleum-built environment in Sri Lanka.

The methodology adapted in this research is presented below.

3. RESEARCH METHODOLOGY

A comprehensive literature review was conducted on 04 major areas, such as categories of petroleum products, handling process of petroleum products, safety guidelines available for handling of petroleum products, and the process of handling petroleum products in Sri Lanka. Case study method was adopted under qualitative phenomenon because the research problem required an in-depth investigation. According to Yin (2014), the number of cases can be one to eight depending on the nature of the research. Accordingly, 02 cases were studied by adopting the multiple case study design, which were selected based on the stages of petroleum products handling process. "Handling process of petroleum products' was the unit of analysis of this study. Table 1 presents the profile of selected cases.

Table 1: Profile of selected cases

Case	Stage	Description
A	Refinery	Capacity - 50 000 barrels per stream day
		No. of employees - 1 100
		Location - Western province
B	Storage	Capacity - Supported by 11 bulk deposits and handles 12 petroleum products
		No. of employees - 3 000
		Location - Western province

Semi-structured interviews were conducted to investigate the existing safety guidelines, safety issues and to recognise probable strategies to ensure safety. Accordingly, 7 semi-structed interviews were conducted with grade A and grade B level employees in the petroleum industry particularly in refinery and storage facilities as presented in Table 2.

Table 2: Profile of interviewees

Case	Stage	Respondent Code	Designation	Years of Experience
A	Refinery	A1	Environment, Health and Safety (EHS) Supervisor	10
		A2	Safety Supervisor	21
		A3	Senior Operation Executive	15
B	Storage	B1	Fire and Safety Officer	16
		B2	Manager - Premises and Engineering	30
		B3	Maintenance Manager	10
		B4	Assistant Manager	32

The collected data were analysed by using content analysis technique. Within case analysis was used to analyse the data collected in each case. The key findings derived through case analysis are presented below.

4. RESEARCH FINDINGS AND ANALYSIS

Existing safety guidelines, standards and procedures, and safety issues were first determined under refinery and storage of petroleum products. Moreover, various strategies to overcome the identified issues were proposed accordingly.

4.1 CASE A - REFINERY

4.1.1 Existing Safety Guidelines, Standards and Procedures

EHS Supervisor (A1) stated that the organisation has implemented various safety guidelines to minimise safety issues and to enhance the overall health conditions of occupants. Senior Operations Executive (A3) further mentioned that the main aim of these guidelines and regulations is to safeguard the organisation and its' occupants against the fire risk. EHS Supervisor (A1) highlighted that *"ISO testing method checks oil samples before importing and transporting to the storage and retailing stations"*. All the interviewees in case A mentioned that Factories Ordinance No. 45 of 1942 is one of the regulations, which applicable for health and safety of employees in petroleum industry. ISO - ASTM D is involved as the main testing method for checking the quality of petroleum products. EHS Supervisor (A1) highlighted that *"NFPA guidelines are involved to prevent hazards and to enhance the overall safety of occupants of the refinery stage"*. Moreover, OHSAS standard and NIOSH guideline provides a better management system to achieve production goals, occupational health and safety targets, and economic objectives while enhancing the safety of refinery stage.

As a basic safety precautions of the refinery stage, every employee must wear hearing protections and safety glasses while they are working. Senior Operations Executive (A3) stated that it is essential to wear hearing protections especially in areas with high noise generation. Further, EHS Supervisor (A1) mentioned that *"safety glasses must be used when working on emery wheels, brushes, chipping or any other circumstances such as handling of hazardous chemicals"*. Other than that, respiratory protection considers as one of the high priorities. Senior Operations Executive (A3) buttressed that *"refinery process is occurred in a high temperature levels therefore, employees always need to cover their whole body by fire resistant dresses"*. Moreover, motor vehicles can enter to the refinery premises only with a vehicle permit. Especially, this permit issuing system is used to provide clearance and safety permits for hot works, electrical operations, and confined space operations to minimise potential hazards.

4.1.2 Safety Issues

According to EHS Supervisor (A1), *"chronic deceases in lungs and heart, and cancers can be identified as major health issues due to toxic vapours in the refinery premises. Stress related skin problems: dermal issues can be seen among employees who work for a long time in the refinery premises"*. As he further stated, toxic gaseous is a major cause for eye irritations. High noise generation causes for hearing losses for those who directly work with these hazardous conditions in refinery premises. Moreover, unwillingness to use PPE can also be considered as a major safety issue. Especially, bowser and wagons accidents can be identified as another common safety issue in the premises. Fuel fire, electrical wire short-circuits, pipeline leakage and environmental pollution: water and soil pollution can be commonly seen in refinery premises. Slips trips and falls issues are commonly occurred due to uneven surfaces and elevated working areas of the refinery premises.

4.2 CASE B - STORAGE

4.2.1 Existing Safety Guidelines, Standards and Procedures

Ceylon Petroleum Storage Terminal Ltd (CPSTL) safety rules and regulation is followed as one of the main guidelines of storage stage. Further, Factories Ordinance No. 45 of 1942 is also applied for this stage. To minimize the fire risk, NFPA Guidelines applicable for storage premises. Apart from that, National Electrical Code, National Fire Alarm and Signalling Code, and Guide for Fire and Explosion Investigations can be recognized as existing guidelines related to storage stage. Fire and Safety Officer (B1) stated that "*Australian standard involves ensuring products, services and systems safety, Also, we use a safety code for electrical installations under Australian standard"*. OSHAS 18001-2007 and NIOSH Guideline can also be recognized as guidelines which are currently using in storage stage.

Maintenance Manager (B3) mentioned that "*if employees want to do any welding or flame cutting work, they need to check previous welding work's flash point and also they must wear appropriate PPE. All the safety equipment including respiratory protections must be tested as a safety precaution. It is a must to wear PPEs (acid hood, rubber boots, face shields, fall-arrest equipment etc.) and non-flammable clothing when employees are engaging in maintenance and repairs such as cutting floor patches and repairing tank leaks*". Further to case respondents, fire extinguishers, fire hose reels and emergency cooling systems can be highlighted as safety precautions against fire risk. Especially, hot works are not allowed in storage area due to highly flammable nature of the process. Safety permit needs to be obtained to conduct the maintenance of floating roof. Floating roof and protecting rim seals are damaged due to weather conditions, therefore, obtaining a safety permit is a mandatory requirement. To safeguard the electrical risk, various types of electrical equipment enclosures are used such as totally enclosed weatherproof sparking, totally enclosed weatherproof non-sparking and intrinsically safe non-flameproof enclosures.

4.2.2 Safety Issues

Fire and Safety Officer (B1) and Maintenance Manager (B3) stated that *"health diseases, such as dermal issues, cancers and chronic in lungs and heart are common among bottom level employees due to the toxic vapour content in the petroleum products. High noise generation in pump house, inside the oil tanks and regarding maintenance of pipeline cause to hearing problems among employees"*. Moreover, vehicle accidents, unwillingness to wear PPE, fire risk, environmental pollution can be recognised as other common safety issues. Assistant Manager (B4) reported that *"a lot of fuel loaded vehicles are entered and exited in daily basis. Our company always gives the instruction for drivers, but we can observe a high accidents rate mostly inside and outside in our organisation*".

Tables 3 and 4 summarise the identified safety guidelines and standards, and health and safety issues in refinery and storage, respectively.

Table 3: Existing safety guidelines and standards

Existing Safety Guidelines, Standards	Stage of petroleum process	
	Refinery	Storage
ISO Testing: ISO -ASTM D	✓	
Factories Ordinance No. 45 of 1942	✓	✓
NFPA guidelines	✓	✓
OHSAS Standard	✓	✓
NIOSH Guideline	✓	✓
Ceylon Petroleum Storage Terminal Ltd (CPSTL): Safety Rules and Regulation		✓
National Electrical Code		✓
National Fire Alarm and Signalling Code		✓
Guide for Fire and Explosion Investigations		✓
Australian Code - Code for Electrical Installation		✓

Table 4: Health and safety issues of refinery and storage stages

Health and safety issue	Stage of petroleum process	
	Refinery	Storage
Chronic deceases in lungs and heart, and cancers	✓	✓
Toxic vapours in the premises	✓	
Stress related skin problems	✓	
High noise generation	✓	✓
Unwillingness to use PPE	✓	✓
Bowser and wagons accidents	✓	✓
Fuel fire risk	✓	✓
Electrical wire short-circuits	✓	
Pipeline leakage	✓	✓
Water and soil pollution	✓	✓
Slips trips and falls issues due to uneven surfaces and Elevated working areas	✓	
Leakages in underground oil tanks		✓

4.3 STRATEGIES TO OVERCOME IDENTIFIED HEALTH AND SAFETY ISSUES

In this step of the research attempts to explore the possible strategies to overcome the identified health and safety issues of refinery and storage stages. Moreover, interviewees suggested the following strategies not only to overcome the identified issues but also to enhance the overall health and safety condition of petroleum-built environment in Sri Lanka. Proposed strategies are summarised in Table 5.

Table 5: Strategies to overcome issues in petroleum built environment

Health and safety issue	**Strategies to overcome the health and safety issue**	**Case A**			**Case B**			
		A1	**A2**	**A3**	**B1**	**B2**	**B3**	**B4**
Chronic deceases in lungs and heart, and cancers	Designing job rotation		✓	✓			✓	
	Assigning limitations to working time	✓			✓			
	Arranging medical check-up				✓			
Toxic vapours in the premises	Designing job rotation	✓						
	Assigning limitations to working time	✓						
	Critically adhering to the Environmental Protection License (EPL)	✓						
	Measuring Volatile Organic Compound (VOC) level time to time	✓	✓			✓		
Stress related skin problems	Designing job rotation	✓			✓			
	Assigning limitations to working time	✓			✓			
	Arranging medical check-up	✓						
High noise generation	Designing job rotation			✓				✓
	Assigning limitations to working time	✓						
	Installing suitable sound insulation systems		✓				✓	
Unwillingness to use PPE	Enhancing knowledge regarding PPE		✓			✓		
	Conducting fit-tests		✓		✓			
	Inspecting and reporting about employees who are not properly wearing PPE							✓
Bowser and wagons accidents	Installing an in-vehicle monitoring system			✓		✓		
	Providing clear visual communication						✓	
Fuel fire risk	Establishing and monitoring of fire safety system		✓		✓			
	Collaborating with local fire emergency response community							✓
Electrical wire short-circuits	Conducting regular maintenance and inspection activities			✓			✓	

Health and safety issue	Strategies to overcome the health and safety issue	Case A			Case B			
		A1	A2	A3	B1	B2	B3	B4
Pipeline leakage	Conducting regular maintenance and inspection activities			✓			✓	
Water and soil pollution	Reducing spills		✓					
	Conducting proper actions for freshwater management	✓						✓
	Conducting awareness sessions for employees regarding water and soil pollution due to petroleum			✓				
Slips trips and falls issues due to uneven surfaces and elevated working areas	Displaying safety signs in hazardous areas		✓		✓			
	Installing safe lighting system in different working environments			✓				
	Familiarising the work environment for workers							✓
Leakages in underground oil tanks	Introducing new safety standards for fuel storages					✓		
	Conducting regular maintenance and inspection activities			✓			✓	

5. CONCLUSIONS

Due to its complexity and the high-risk level in nature, petroleum industry has become a hotspot for providing special precautions ensuring the health and safety of its employees, other occupants and general public. Similarly, in Sri Lanka, petroleum industry is one of the industries that has created various environmental damages, health and safety issues over the past years. Since, majority of guidelines and standards are incapable of providing the adequate safety in petroleum industry in Sri Lanka, it is worth to having a suitable health and safety guideline covering all the stages of petroleum products handling process. In developing a proper mechanism, this paper investigated the existing health and safety standards, regulations and guidelines, health and safety issues in the existing process, and strategies to overcome identified issues in refinery and storage stages. As derived through analysis, Factories Ordinance, NFPA Guideline, OHSAS standard, and NIOSH Guideline were highlighted as existing regulations and guidelines related to petroleum-built environment. Further, chronic deceases in lungs and heart, cancers, high noise generation, unwillingness to use PPE, bowser and wagon accidents, fuel fire risk, pipeline leakages, and water and soil pollution were recognised as common health and safety issues in both stages. Finally, the study was proposed probable strategies to overcome the identified health and safety issues in each stage in order to enhance the health and safety of petroleum-built environment. As the main implication, this study lays a way for approaching the betterment of health and safety in petroleum-built environment in Sri Lanka.

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HYDROFLUOROCARBON (HFC) MANAGEMENT FRAMEWORK FOR LOW CARBON INDUSTRIAL FACILITIES: MILK PROCESSING INDUSTRY IN SRI LANKA

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ABSTRACT

Milk processing industry consumes hydrofluorocarbon (HFC) at a great extent. Emission of HFC distresses the food security, water security and the future of healthy living beings. Thus, the purpose of this paper is to propose strategies to improve the HFC management practices in Sri Lankan milk processing industry. Case study method was involved under qualitative phenomenon. Thus, three case studies were selected based on the HFC handling process. Nine milk processing agencies representing three importers and distributors, three milk processors and three service providers were selected to collect the data. Case analysis technique was used for data analysis. Findings revealed that, lack of institutional and national level procedures, unstable governmental policies, and lack of technology have increased the unhealthy handling of HFC in milk processing industry in Sri Lanka. Initiating a national level mechanism for governing HFC importers and service providers, empowering inventers for creating sustainable applications over HFC use and improving awareness were identified as key strategies to eliminate the identified issues under organisational and national level. Accordingly, a framework was proposed, which provides a platform to investigate the status of HFC handling procedure of milk processing industry in Sri Lanka. Since there is a lack of national level concern on managing HFC use in milk processing industry, having a formal framework at national level to govern both national and institutional level procedures was determined as a vital step forward to be considered.

Keywords: *Hydrofluorocarbon; Hydrofluorocarbon management; Issues; Milk processing; Strategies.*

1. INTRODUCTION

Climate change and global warming are the most critical challenges faced by the whole world. The emission of greenhouse gases (GHGs) from industries has been affected for both climate change and global warming (Sumathipala, 2015). According to Sathiendrakumar (2003), carbon dioxide (CO_2), chlorofluorocarbons (CFC), carbon monoxide (CO), methane (CH_4) and nitrous oxide (N_2O) are considered as GHGs. Dunk

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(1999) stated that, CFC is the largest single contributor for ozone depletion, which has been developed instead of unpleasant sulphur dioxide and ammonia used in refrigeration compressors more than fifty years ago. HFC was originated as a replacement for both CFCs and HCFCs. According to a study by Mate *et al.* (2010), CFC and hydrochlorofluorocarbons (HCFC) had been depleted under the Montreal Protocol and thus, the demand for HFC has been increased across the globe. Among greenhouse gases (GHGs), HFC is used for various purposes in the milk processing industry including processing, cooling, chilling and freezing phases for keeping under acceptable environmental condition (O' Brien *et al*., 2014). Thus, thermal processing and clarification of raw milk, including container-filling phases have shown a high rate of HFC emissions. According to a study by Nutter *et al*. (2013), milk production industry contributes for generating 2.7% of GHGs emission globally while enforcing economies. Hence, it has become a grave challenge to reduce the emissions due to high HFC use in milk processing industry. Further, there is a trend of HFC emissions by 10% to 20% of carbon equivalent by 2050 because of its escalating demand (O' Brien *et al*., 2014).

However, very little attention has been paid on managing the HFC use in milk processing industry where no proper national and organisational level integrated mechanism was found for managing the current use of HFC. Hence, this research aims to explore the feasible strategies for managing HFC in milk processing industry. Accordingly, this paper presents a mechanism for managing the HFC use in milk processing industry emphasising the context of Sri Lanka through three objectives; HFC use and its management in milk processing industry, existing strategies, issues and strategies and national level enhancements to manage the HFC use in milk processing industry in Sri Lanka.

2. LITERATURE SYNTHESIS

2.1 HYDROCHLOROFLUOROCARBON EMISSION IN MILK PROCESSING INDUSTRY

According to a study by Hui *et al.* (2013), a large amount of HFC had been emitted when producing HCFCs. Further to authors, there is no specialised procedure which can be followed for monitoring and controlling HFC emission. As Velders *et al.* (2015) further stated, HFC production and consumption had been rapidly increased from 20% to 40% in China related to recent years. Apart from that, HFC mainly emits in food processing industry, fishing industry, poultry farms, milk processing industry, meat-processing industry and fire-fighting equipment production industry (Sumathipala, 2015). In milk processing industry, the HFC emission sources can be identified by referring to the way of using HFC based appliances in milk processing phases (Ulrich *et al*., 2013). Thus, the current use of HFC can be recognised during its importation, operation, maintenance and disposal stages. During the operational stage, HFC emissions can be occurred through different sources related to air conditioning and refrigeration phases of milk processing plants. According to a study by O' Brien *et al.* (2014), HFC is used for milk processing, cooling, chilling and freezing phases to keep the product under acceptable environmental conditions. Refrigerant losses from trucks and machines in the process can also be highlighted as the main HFC emitting sources of milk processing. Refrigerant leakages can be occurred during operations and standstill periods due to permeation through hoses and diffusion past fittings and seals (Zhan *et al*., 2014). Typically, raw milk is delivered by insulated refrigerated trucks with tanks from one or more farms to a processor.

Leakages of refrigerant can be occurred when milk is transported from one place to another through trucks (Ulrich *et al*., 2013). Further, refrigerant losses can be occurred through cold rooms and refrigerated warehouses, milk storage tanks and chillers at milk processing plants (Tang *et al*., 2017).

2.2 HFC EMISSION IN SRI LANKAN MILK PROCESSING INDUSTRY

According to Dayaratne and Gunawardana (2015), Sri Lanka contributes for emitting GHGs including HFCs related to many industrial sectors including milk processing industry. HFC usage has been increased over the years with respect to milk processing. According to a national survey on HFC use in Sri Lanka, there are seven main milk processing plants in the country, which mainly use HFC-134a based chilling tanks for the process (Sumathipala, 2015). Currently, Sri Lanka is about 15-20 percent self-sufficient with its milk products, though that level has been achieved mostly with imported milk powder. Total milk production in 2005 was an estimated 162 million litres, up 3 percent from the previous year, with approximately 13.6 million litres supplied by dairy cows. Of this growth, 98.9 million litres (47 percent) of local milk entered the formal market (Abeykoon *et al*., 2016). According to data gathered, the consumption of HFC has been increased from 496 tonnes in 2011 to 587 tonnes in 2014, an average annual growth rate of 6% (Sumathipala, 2015). HFC consumption is expected to continue to grow in next decade, by at least 40-50 tonnes and perhaps as much as 80-100 tonnes a year. However, no proper mechanism has been adapted yet at both national and organisational levels for managing HFCs in milk processing industry.

2.3 HFC MANAGEMENT PRACTICES

Various strategies have been applied across the globe to manage the HFC use. Denmark has used various climate and ozone friendly refrigeration technologies to reduce carbon emissions (Ciconkov, 2018). As stated by Liu *et al.* (2015), increased social consideration on achieving environmental goals and environmentally friendly technologies for appliances based on HFCs can be considered as other mechanisms. According to Velders *et al.* (2015), the Montreal Protocol was the first international agreement adapted to HFC management almost universally concerning any environmental matter. The Protocol was based on a proven, consistent, and well understood framework that allows the global community to greatly reduce greenhouse gases including HFC emissions while ensuring that consumers and businesses experience a smooth transition to newer, more sustainable products. Moreover, Kyoto Protocol was ratified by Japan in June 2002 which came into force since February 2005 and this protocol was an international and legally binding agreement to reduce greenhouse gases (GHGs) including HFCs emissions worldwide. A summary of practices, which have been introduced for managing HFC globally are presented in Table 1.

Accordingly, by considering the strategies and issues related to the HFC use across the globe, this study focuses on investigating the current status of HFC management practices in milk processing industry in Sri Lanka. Thus, the conceptual framework was firstly developed, which guided the authors to investigate the current strategies and issues of HFC management procedures in milk processing industry as illustrated in Figure 1.

As illustrated in Figure 1, The conceptual model is used as a basis to investigate the current status of HFC handling in milk processing industry in Sri Lanka. Thus, the national and organisational level directions were considered for establishing a proper integrated mechanism for HFC handling. Three aspects, such as, role of government, technology adaptation and value for business, which were identified through literature were initially considered at the national level. Main three stages of HFC handling; importation and transportation, operation and maintenance, and disposal were considered for investigating the current strategies and issues at the organisational level.

Table 1: Practices of HFC management

Source	Strategies
Montreal Protocol	Provisions introduced for shifting from HFCs, which has got high global warming potentials to alternatives
	Provides a proven, consistent, and well understood framework to greatly reduce GHGs including HFC
Kyoto Protocol	An international and legally binding agreement to reduce GHGs
	Introduced the mechanisms for reducing HFCs emissions
Clean Development Mechanism (CDM)	Global adoption of technologies has been introduced for reducing carbon emissions
The UNFCCC	Provides the guidelines for reporting emissions and meeting emission reductions targets

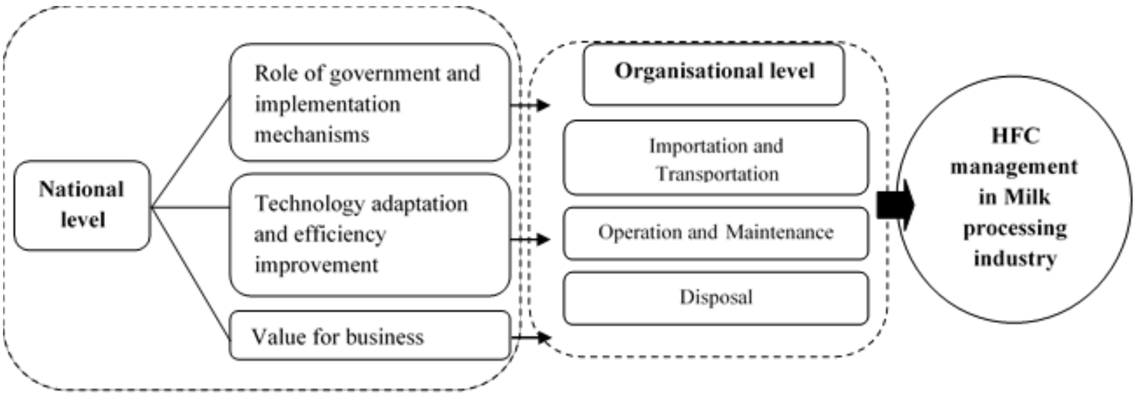

Figure 1: The conceptual framework

The research methodology adapted in this research is described below.

3. METHODOLOGY

Qualitative approach was involved to explore the existing issues and strategies for managing HFC in milk processing industry in Sri Lanka. Among the various research methods case study method was selected in this research because the research problem is required an in-depth investigation. Apart from that, case study approach is more appropriate to bringing an understanding of a complex issue or object and can extend experience or add strength to what is already known through previous research (Yin, 2014). As Yin (2014) stated, the number of cases can be one to eight depending on the nature of the research. Thus, three cases, which are based on the HFC handling process: (i) Importation and transportation, (ii) Operation and maintenance and (iii) Disposal, were selected. ‘Agency’ is considered as unit of analysis in each case. Thus, nine (09) agencies that have actively involved in HFC handling were selected to collect the data as shown in Table 2.

The collected data were analysed by using case analysis technique considering each individual case study as a separate study.

Table 2: Profile of case study interviewees

Case	Stages of HFC handling	Agency	Type	Designation	Years of experience
Case A	Importation and Transportation	A1	Importer and distributor	Transport and logistics manager	8 years
		A2	Importer and distributor	Supply chain manager	5 years
		A3	Importer and distributor	Transport and logistics manager	12 years
Case B	Operation and Use	B1	Milk processor	Supply chain director	10 years
				Engineering manager	5 years
				Mechanical engineer	4 years
		B2	Milk processor	Chief engineer	5 years
				Technical supervisor	6 years
				Technician	9 years
		B3	Milk processor	Engineering manager	5 years
				Mechanical engineer	6 years
				Technical supervisor	8 years
Case C	Maintenance and Disposal	C1	Service provider	Maintenance engineer	12 years
		C2	Service provider	Mechanical engineer	5 years
		C3	Service provider	Mechanical engineer	3 years

4. RESULTS AND DISCUSSION

The investigations were made into three key stages: (i) Importation and transportation, (ii) Operation and maintenance, and (iii) Disposal of HFC. The enhancements, which can be considered at national level were also proposed relating to three key constraints: (i) Role of government and implementation mechanisms, (ii) Technology adaptations and efficiency improvement and (iii) Value for business, for managing HFC use in milk processing industry. The case analysis and findings are presented under three headings: (i) Existing strategies, (ii) Issues and (iii) Proposed strategies, for managing HFC in milk processing industry in each case. As the next step, the national level strategies were also recognised under three constraints: (i) Role of government and implementation mechanisms, (ii) Technology adaptations and efficiency improvement and (iii) Value for business.

4.1 CASE ANALYSIS - CASE A (IMPORTATION AND TRANSPORTATION)

4.1.1 Existing Strategies

Case A has their own procedure to manage HFC operations. According to Transport and Logistics Manager *"according to organisation's regulations, importers should register and obtain the certificate and license for importing HFC. We are generally maintaining our certifications"*. Furthermore, having insurance coverage for purchasing the stock of cylinders and obtaining declaration from customs are other formal strategies used. In transportation, vehicles are labelled by using proper signage since it is a legal requirement. Further, daily mandatory checks are conducing on the leaks and repairs of transporting vehicles.

4.1.2 Issues

Absence of specific procedure for HFC importation and transportation was identified as a main issue in case A. This is further explained by Transportation and Logistics Manger as "*currently we are using a common procedure, but it is not specifically design for a milk processing industry*". Findings revealed that there is no national level mechanism or specific guideline for assisting and governing HFC handling organisations. Most importantly, organisations have faced difficulties due to the time-consuming procedure adapted by customs when releasing imported HFC. Not having enough space for storing before transportation and not considering safety and quality requirements for storing HFC are other issues found through case analysis.

4.1.3 Proposed Strategies

Introducing national level mechanism for governing HFC importers, and updated policies and standards relating to modern technologies are two essential strategies stated by experts in case A. Supply Chain Manager stated that "*existing policies and standards of HFC should be updated relating to different industries and modern technology*". As he further stated, training programs should be introduced for the custom officers to enhance the knowledge on HFC and to prevent delays.

4.2 CASE ANALYSIS - CASE B (OPERATION AND MAINTENANCE)

4.2.1 Existing Strategies

Involvement of service providers in the operation and use phase in terms of establishing agreements can be identified as a strategy. Continuous maintenance schedules and routine programmes can be followed to investigate the proper working condition of HFCs and to prevent fault with HFC based appliances. Further, organising technical programmes with the support of service providers to enhanced knowledge on operating procedures is another strategy as identified by Mechanical Engineer of case B. Further, automated systems used for getting readings and status on HFC working condition is used as a strategy of operation and maintenance stage.

4.2.2 Issues

Engineering Manager of case B identified that the difficulty in keeping the acceptable gas level within machines and risk of changing coolant level of air conditioning and refrigeration systems are main issues faced in operation and maintenance. Technician of case B stated another issue as, "*types of gases may be changed time to time according to the technology and our old gases such as CFCs have to be replaced into another gas, because of changing laws and technology*". HFC refilling process is also recognised as a critical issue when the composition of HFC had been changed through leaking and it is supported to create an unhealthy environment for raw milk and dairy products. Evaporation is another critical issue in operation and use of the HFC in milk processing plants.

4.2.3 Proposed Strategies

Conducting training programs for service providers, implementing a proper communication system and recruiting well experienced experts for detecting faults in

HFC handling can be introduced as strategies. Engineering Manager of case B3 mentioned that the service providers should be properly selected for system installation works and, the continuous inspections should be followed to ensure zero faults and leakages. Moreover, a proper maintenance procedure should be followed to ensure the operation of HFC based appliances.

4.3 CASE ANALYSIS - CASE C (DISPOSAL)

4.3.1 Existing Strategies

Maintenance Engineer of case C stated that "*we hold cylinder stock under our warehouse and normal temperature is maintained within them complying with the relevant safety rules, such as using a covered area as the warehouse and access should be limited for the safety name in few*". As Mechanical Engineer of case C further stated, applying explosive proof cabinets to store cylinders, installing all shelves within a covering space, storing in a locked cage are other strategies used. Mechanical Engineer of case C2 stated that "*normally HFCs are not disposed and empty cylinders are handed over to suppliers to get refilled*. Moreover, installation of combustible gas detectors and monitors for detecting leaks of cylinders can be highlighted as another strategy".

4.3.2 Issues

The disposal of HFC suffers a several issues in existing practice. Not having a proposer disposing mechanism for used cylinders and the risk of occurring short term and long-term diseases were the main issues identified in selected agencies. Maintenance Engineer of case C mentioned that "*beyond short term diseases, long terms diseases can be occurred because of handling HFC based cylinders and appliances can impact to our staff remembers*".

4.3.3 Proposed Strategies

Introducing updated and flexible methods to store HFC is one of strategies proposed. Awareness should be raised among the workers about the proper handling of HFC while loading, unloading and storing. Further, Mechanical Engineer of case C stated that "*new technology should be introduced for storing HFC to get maximum benefits through loading and unloading*". Proper use of personal protective equipment (PPE) should be a rule among the workers while handling HFC during disposal as suggested by the Maintenance Engineer of case C.

As the next stage, national level enhancements were also proposed based on case analysis.

4.4 NATIONAL LEVEL ENHANCEMENTS TO MANAGE HFC USE IN MILK PROCESSING INDUSTRY

Interviewees of cases were highlighted that organisational level strategies can be easily implemented because those factors are within their control. Even though, individual cases cannot control the factors regarding national level, interviewees of cases suggested enhancements regarding national level for handling HFC in milk processing industry in Sri Lanka. The key factors, such as role of government, implementation mechanism, technology, efficiency improvement and value for business, which represent a vital role in managing the HFC use in milk processing industry, were considered to enhance at national level.

4.4.1 Role of Government and Implementation Mechanism

Special attention of the government and the other regulatory bodies should be paid to empower the HFC management process. As stated by Supply Chain Manager of case A, "*updated policies and standards should be presented relevant to new technologies and common data base should be introduced and maintained to keep records of HFC use*". As stated by Maintenance Engineer of case C, there is a necessity of having a formal framework in line with updated policies and standards related to HFC based appliances. Supply Chain Director of case B1 further mentioned "*appointing a special team to provide the training programs for the HFC handling agencies is an important strategy to be established. Further, continuous auditing procedures should be followed to ensure the proper implementation of strategies*".

4.4.2 Technology Adaptation and Efficiency Improvements

Engineering Manager of the case B proposed "*new resources with technology should be introduced for the betterment of the field*". Further, HFC was the existing refrigerant, which showed a high use compared to other refrigerants. Thus, effectiveness and efficiency improvements of the HFC use can be considered in milk processing. Supply Chain Manager of case A stated "*new gases which are environmentally friendly, and more efficiency should be introduced*". Thus, inventors should be encouraged by providing facilities to improve the efficiency of HFC based appliances in milk processing. Hence, introducing updated technologies and adequate resources was recognised as a necessity at national level to establish a proper HFC management mechanism.

4.4.3 Value for Business

At present, low-cost procedures are followed by organisations to enhance the profit. Transport and Logistic manager of case A stated "*companies should be encouraged to follow environmentally friendly methods considering the social responsibility while seeking their own profits". Thus, encouraging companies for following environmentally friendly methods and social responsibility raising can be considered at national level*.

As the case study findings revealed, the handing process of HFC use in milk processing should have a due consideration in adopting national and organisational level strategies for its better management. Thus, a framework for managing the HFC use in milk processing industry was proposed based on the key findings of the research. The proposed framework is illustrated in Figure 2.

Figure 2 clearly displays the issues and strategies, which were derived through case analysis under three main stages: (i) Importation and transportation, (ii) Operation and maintenance and (iii) Disposal of HFC. Moreover, the factors related to national level aspects such as; role of government, technology adaptation and value for business were also presented which will govern the milk processing industry towards the better management of HFC.

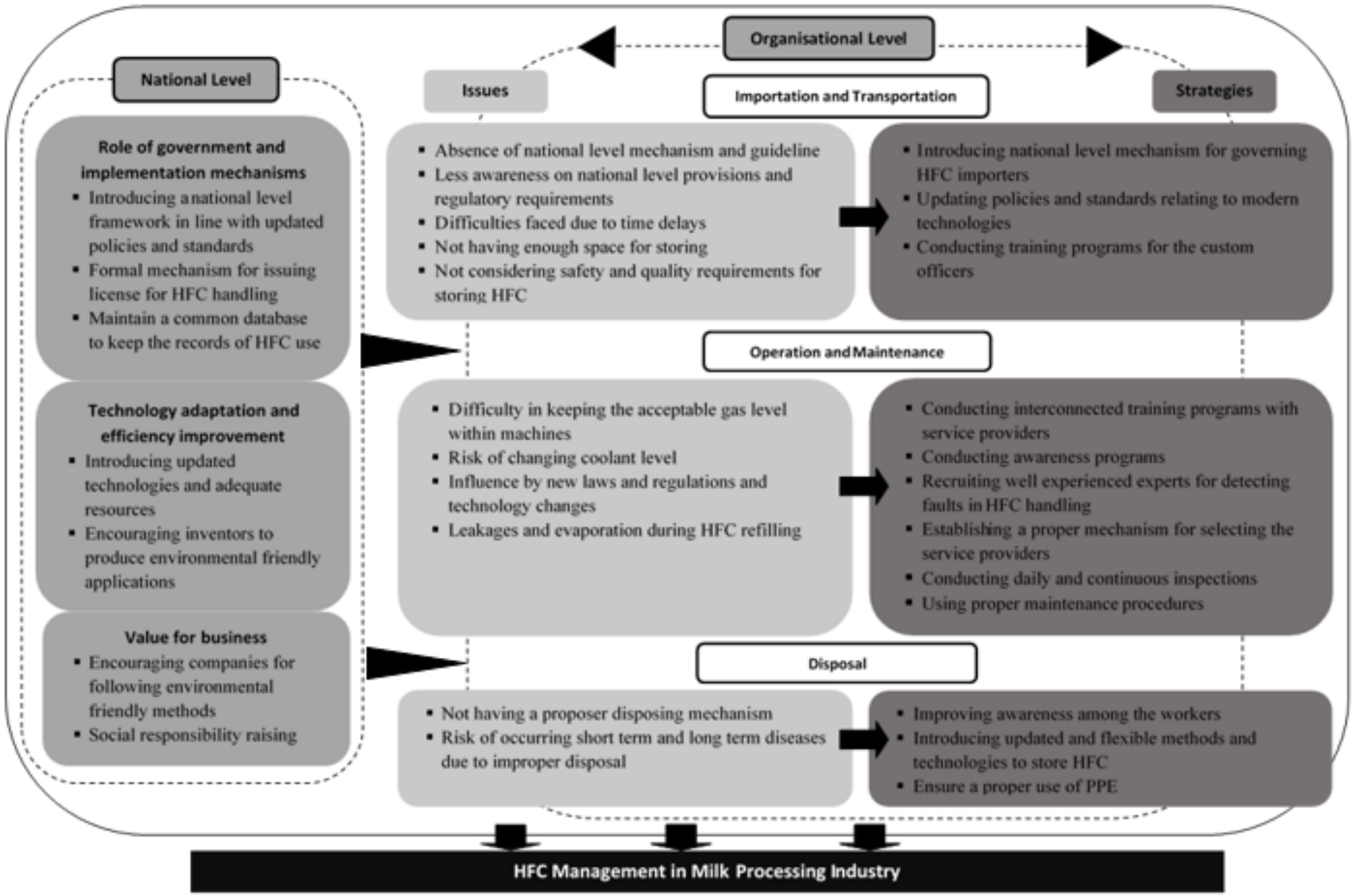

Figure 2: Framework for managing the HFC use in milk processing industry in Sri Lanka

5. CONCLUSIONS

Dairy industry has become one of critical sectors in country's economy. However, little attention has been paid up on managing the HFC use with respect to milk processing industry. The significance of study became obvious since the scholars stated the effect of the heavy use of HFC in milk processing industry for milk processing, cooling, chilling and freezing phases. Significantly, the issues in existing process were identified specially relating to HFC importation, transportation, operation and maintenance, and disposal. Introducing national level mechanism for governing HFC importers, conducting interconnected training programmes with service providers and introducing updated technologies to store HFC were suggested as strategies to overcome the identified barriers at organisational level. Apart from that, strategies, which are currently used in other countries, such as introducing climate and ozone friendly HFC technologies and increasing social consideration on HFC handling, were also identified as important strategies to adopt in Sri Lanka. Indeed, lack of national level concern has hindered the proper management of HFC use thus, having a formal framework at national level to govern both national and institutional level procedures was proposed. Further, the developed framework can be applied to establish a smooth and well scheduled HFC management procedure in milk processing industry in Sri Lanka.

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IDENTIFICATION OF SIGNIFICANT RISK FACTORS OF GUARANTEED MAXIMUM PRICE (GMP) CONTRACTS

A.D. Palihakkara[1] and B.A.K.S. Perera[2]

ABSTRACT

The construction industry is a risk-prone industry where projects are implemented in a dynamic environment with frequent exposure to various uncertainties. A construction contract is a document that allocates the risks associated with a construction project among the project stakeholders. Guaranteed Maximum Price (GMP) contracts have become popular as a project delivery method because they provide the client with a high degree of cost certainty through a fixed price cap that the contractor cannot exceed. However, most of the GMP projects are risky. Thus, the significant risk factors of GMP projects have to be identified to ensure their successful completion. This study, therefore, aimed to identify and rank the most significant risk factors present in GMP contracts. The study adopted a quantitative approach, which included a Delphi survey conducted in two rounds and a statistical analysis of the survey data. The most significant risk factors associated with GMP contracts were ranked according to their impact on the projects and their probability of occurrence (severity). Poorly defined scope of work and design changes were found to be the most significant risk factors associated with GMP contracts. The other significant risk factors of the projects are related to the scope of work, design, documentation, unfamiliarity with the GMP concept, agreed GMP value, and financial failures of the client and contractor.

Keywords: *Guaranteed Maximum Price (GMP) contracts; Risk ranking; Significant risks.*

1. INTRODUCTION

The construction industry is a risk-prone industry, with the projects inheriting risks and uncertainties from their initiation to completion (Chilumo *et al.,* 2020). The form of payment or type of contract used in a project has a significant impact on the risk allocation of the project (Osipova and Eriksson, 2011). Construction contracts are mainly of two types: fixed-price contracts and cost-reimbursement contracts (Eriksson *et al.,* 2017). A Guaranteed Maximum Price (GMP) contract is a hybrid arrangement of fixed-price and cost-reimbursement contracts (Boukendour and Bah, 2001).

Unlike conventional project delivery methods, the GMP mechanism has a high level of risks as the GMP level is decided before the completion of the design (Chan *et al.,* 2010a). Wong (2006) stated that GMP contracts are a viable option for sophisticated and capital-intensive construction projects with high technical and financial risks. Although GMP contracts have been adopted for a considerable time, not every project has been successful

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(Joseph, 2011). According to Rojas and Kell (2008), in the United States, nearly 75% of school projects and 80% of non-school projects procured using the GMP mechanism have exceeded their GMP values, thereby failing to reap the main benefit of the GMP mechanism. Several studies have been conducted on the various aspects of GMP contracts. Most of these studies have focussed on both GMP contracts and Target Cost Contracts (TCCs). However, literature on the significant risk factors associated with GMP contracts in terms of their impact on the project and probability of occurrence is scarce. Zimina *et al.* (2012) state GMP contracts are a form of TCCs in which the risks are shifted towards the contractor. Thus, the risk behaviour in GMP contracts is more complicated than in TCCs. Henceforth, this study aims at identifying and ranking risk factors specifically for GMP contracts.

2. LITERATURE REVIEW

2.1 GMP CONTRACTS

In a GMP contract, the contractor agrees to complete the project at a cost not exceeding a pre-agreed limit; thus, any cost overrun has to be borne by the contractor (Chan *et al.,* 2010a). The price ceiling under which the contractor has to deliver the agreed scope of work is called the Guaranteed Maximum Price (Anvuur and Kumaraswamy, 2010). If the work is completed below the GMP, the difference between the actual cost and the GMP has to be shared between the client and contractor according to a pre-agreed formula.

2.2 RISK FACTORS ASSOCIATED WITH GMP CONTRACTS

GMP contracts have been in place for a considerable period; nonetheless, project failures are still possible even with GMP contracts because of the high risks (Chan *et al.,* 2012). Therefore, risk factors of GMP contracts have to be identified. Table 1 illustrates the risk factors identified by past researchers.

Table 1: Risk factors of GMP contracts

Risk Factor	Researchers															
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Change in the scope of work	✓		✓			✓	✓	✓				✓	✓	✓		✓
Exchange rate variation	✓	✓							✓			✓				
Scope creep		✓												✓		
Incompleteness of the design at the time of inviting tenders	✓											✓		✓		✓
Poorly defined scope of work		✓					✓					✓		✓		
Acts of God				✓		✓			✓	✓		✓				✓
Inadequacy of the design									✓							
Buildability issues						✓			✓			✓				✓
Changes in government regulations				✓		✓			✓	✓		✓				✓
Inconsistencies in documents						✓										
Delayed payments				✓		✓						✓				✓
Design changes						✓		✓								

Risk Factor	Researchers															
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**
Variations													✓			
Defective designs				✓		✓										
Unforeseeable design development risks encountered during the tendering stage	✓							✓				✓		✓		✓
Overpayment by the client because the risks have been inflated by the contractor	✓			✓									✓			
Errors and omissions in the tender document	✓					✓			✓			✓	✓			✓
Delay in obtaining labour, material, and equipment				✓		✓		✓		✓		✓				✓
Delay in solving contractual issues				✓		✓						✓				
Inexperienced bidders		✓														
Difficulties in valuing revised contract prices						✓			✓			✓				✓
Financial failures of the client				✓		✓										
Financial failures of the contractor				✓		✓			✓							
Inclement weather						✓		✓	✓	✓		✓	✓			✓
Inexperienced contractors				✓		✓						✓				
Inflation				✓		✓		✓	✓			✓				✓
Failure to use a standard form of contract	✓			✓		✓						✓				
Possibility of compromising project quality				✓		✓						✓				✓
Subcontractor failures				✓		✓										
Third-party delays				✓		✓		✓		✓		✓				
Uneven cost sharing ratios					✓						✓	✓			✓	
Unforeseen ground conditions				✓		✓		✓	✓	✓		✓	✓			
Improper selection of the project team											✓		✓			
Unrealistic maximum price agreed in the contract												✓	✓			
Quantities of work done exceeding the estimated quantities												✓			✓	
Unfamiliarity with the GMP concept													✓			✓

A - Chan *et al.* (2011), B - Al-Ajmi and Makinde (2018), C - Olawale and Sun (2010), D - Ahmed *et al.* (1999), E - Broome and Perry (2002), F - Rahman and Kumaraswamy (2005), G - Fan and Greenwood (2004), H - Oztas and Okmen (2004), I - Environment Transport and Works Bureau (2005), J - Bing *et al.* (2005), K - Joseph (2011), L - Badenfelt (2008), M - Chan *et al.* (2014), N - Chan *et al.* (2010a), O - Rotimi *et al.* (2009), P - Chan *et al.* (2012)

As Table 1 shows, GMP contracts have many risk factors. According to Chan *et al.* (2010a), contractual risk factors in GMP contracts depend on four main factors: nature of the variations, quality and clarity of the tender documents, changes made to the project scope, and appropriateness of the GMP value. The authors stated that errors, omissions, and discrepancies in the contract and tender documents might contribute to conflicts and disputes between contracting parties. Most GMP contracts are concluded at a time when the designs have been completed only partially. Thus, important cost centres of the project scope may not be known at the time of inviting tenders, making it difficult to arrive at a realistic GMP value (Rotimi *et al.,* 2009) and leading to variations in the post-contract stage (Chan *et al.,* 2011). Furthermore, Davis Langdon and Seah Singapore (2004) stated deciding the GMP value with an incomplete design is risky for both the client and contractor. Olawale and Sun (2010) added that project scope changes would cause cost and time implications and that if not managed well, they would have a negative impact on the project cost and schedules.

When following the GMP approach, the client must ensure that qualified and well-experienced bidders are selected to bid. Otherwise, the project can be risky (Al-Ajmi and Makinde, 2018). Because GMP contracts are incentive-based contracts, inflation and exchange rate variations have a significant impact on the projects. According to Chan *et al.* (2010a), the fluctuation of material prices and varying market trends pertaining to building design are significant economic risk factors. All these risk factors will ultimately cause cost and time implications (Olawale and Sun, 2010). Because a large number of risk factors are associated with GMP contracts, the identification of the most significant factors among them is important for the successful completion of the projects.

2.3 IMPORTANCE OF IDENTIFYING THE SIGNIFICANT RISK FACTORS ASSOCIATED WITH GMP CONTRACTS

GMP contracting is a novel procurement strategy used by construction practitioners. GMP contracts are used in large-scale investments in which the client's risk has been lowered and the contractor's risk is inflated. Compared with conventional project delivery methods, the GMP mechanism has a high level of risk as the GMP level is decided before the completion of the design (Chan *et al.,* 2010a). Although GMP contracts have been used in practice for a considerable time, not every GMP project has become successful (Joseph C. H., 2011). The risk factors of GMP contracts have been identified to some extent by past studies. Nevertheless, most of these past studies have focused on GMP contracts and TCCs collectively. However, unlike TCCs, GMP contracts have only a gain-sharing mechanism. Therefore, the risk the contractor has to face in GMP contracts is high. Hence, conducting a separate risk identification and analysis in respect of GMP contracts will be appropriate due to the significant differences between TCCs and GMP contracts.

3. METHODOLOGY

Delphi technique is a data collection and analysing technique that employs multiple iterations to enable a selected set of respondents to reach a consensus on a subject through a series of questionnaire surveys (Hsu and Sandford, 2007). It was appropriate for this study because those who participated in the questionnaire surveys were experienced professionals capable of providing informed opinions (Nworie, 2011), who could quantify the risk factors and their impacts on the project (Hallowell and Gambatese, 2010). The data collection was conducted in two rounds of questionnaire surveys, a surveying research strategy was adopted as a part of the quantitative approach used. A quantitative approach enables the identification of statistical relationships among variables (Basias and Pollalis, 2018). Thus, the quantitative approach used in the study enabled the survey respondents to rank the most significant risk factors of GMP contracts statistically.

Delphi Round 1: Identification of the Significant Risk Factors of GMP Contracts

$$RII = \frac{\sum W_n}{N \times A} \quad (01)$$

Where RII = Relative Importance Index, W = Rating of each factor given by a respondent, n = Frequency of response, N = Total number of responses, and A = Highest weight.

According to Rooshdi *et al.* (2018), responses on a scale of 1 to 5 give RII values between 0 and 1. Factors with RII values between 1 to 0.8 are highly significant. Hence, through the first Delphi round, risk factors that had their RII exceeding 0.8 were identified.

Delphi Round 2: Identification of the Severity of the Significant Risk Factors of GMP Contracts using their Impact on the Project and Probability of Occurrence

$$S_j^i = \propto_j^i \beta_j^i \quad (02)$$

$$RS^i = \frac{\sum_{j=1}^{n} S_j^i}{n} \quad (03)$$

In Equations 02 and 03, n = number of responses, S_j^i = Evaluation of risk severity of the i^{th} risk factor by the j^{th} respondent, $\propto_j^i$ = Evaluation of the frequency level of risk occurrence by the j^{th} respondent, β_j^i= Evaluation of the significance of risk occurrence by the j^{th} respondent, and RS^i= Risk Severity Index of the i^{th} risk factor.

4. RESEARCH FINDINGS

4.1 DELPHI ROUND 1

During the first Delphi round, the respondents were asked to rate the significance of the identified risk factors of GMP contracts on a five-point Likert scale. Table 2 lists the risk factors that had an RII value exceeding 0.800 (highly significant risk factors). A Cronbach's alpha of 0.879, which exceeds the threshold value of 0.700, indicates that the inputs have high reliability and consistency (Aghimien *et al.,* 2020).

Table 2: Significant risk factors of GMP contracts

No.	Risk Factor	RII	SD
1	Poorly defined scope of work	0.900	0.726
2	Design changes	0.889	0.724
3	Changes in the scope of work	0.884	0.948
4	Unrealistic maximum price agreed in the contract	0.879	0.823
5	Defective design	0.874	0.819
6	Failure to complete the design before tenders are invited	0.862	0.928
7	Financial failures of the contractor	0.859	0.996
8	Errors and omissions in the tender document	0.855	0.820
9	Actual quantities of the work executed exceeding their estimated quantities	0.853	1.032
10	Failure to use a standard form of contract	0.850	0.937
11	Unfamiliarity with the GMP concept	0.849	0.895
12	Financial failures of the client	0.838	1.079

No.	Risk Factor	RII	SD
13	Unforeseeable risks associated with design development during the tendering stage	0.832	1.103
14	Scope creep	0.822	1.048
15	Inconsistencies in the documents	0.821	1.008
16	Inexperience of the contractors	0.816	1.024
17	Inadequacy of the design	0.805	0.911

Among the risk factors listed in Table 1, only 17 risk factors recorded RII values exceed 0.800, which are highly significant. The most significant risk factors have RII values ranging from 0.900 to 0.805. Among these most significant risk factors, seven are related to project scope or design. Risk factors such as 'Errors and omissions in the tender document', 'Failure to use a standard form of contract' and 'Inconsistencies in the documents' have higher RII values, suggesting that project scope and design and other relevant documents should be clear, precise, and well prepared; otherwise, the project may face a high level of risk. Financial failures of the client and the contractor are two prominent risk factors associated with GMP contracts. 'Unrealistic maximum price agreed in the contract' has the fourth highest RII value (0.879), indicating the importance of accurately calculating the GMP value. Thus, the whole concept of GMP contracts revolves around the GMP value, the most distinctive feature of GMP contracts.

4.2 DELPHI ROUND 2

4.2.1 Overall Severity of Significant Risk Factors

The second Delphi round was conducted to evaluate the significant risk factors of GMP contracts in relation to their impact on the project and probability of occurrence. The Severity Index (SI) of each risk factor was calculated based on its level of impact on the project and probability of occurrence. Table 3 illustrates the severity indices of the risk factors listed in their descending order of significance. The Cronbach's alpha of the data set in Table 3 was 0.857, suggesting that the results have high reliability and internal consistency.

Table 3: Severity of the significant risk factors

Code	Risk Factor	Impact	Probability	SI	Ranking
R1	Poorly defined scope of work	4.536	3.714	16.847	1
R2	Design changes	4.179	3.607	15.073	2
R3	Changes in the scope of work	4.321	3.429	14.816	3
R4	Inadequacy of the design	3.889	3.296	12.819	4
R5	Errors and omissions in the tender document	3.929	3.250	12.768	5
R6	Unforeseeable risks associated with design development during the tendering stage	3.778	3.148	11.893	6
R7	Scope creep	3.963	3.000	11.889	6
R8	Unfamiliarity with the GMP concept	3.654	3.154	11.524	8

Code	Risk Factor	Impact	Probability	SI	Ranking
R9	Actual quantities of the work executed exceeding their estimated quantities	3.857	2.964	11.434	9
R10	Inexperienced contractors	4.071	2.750	11.196	10
R11	Failure to complete the design before tenders are invited	3.964	2.821	11.185	11
R12	Defective design	4.038	2.731	11.028	12
R13	Inconsistencies in the documents	3.500	3.115	10.904	13
R14	Financial failures of the contractor	3.963	2.593	10.274	14
R15	Unrealistic maximum price agreed in the contract	4.143	2.429	10.061	15
R16	Financial failures of the client	4.222	2.370	10.008	16
R17	Failure to use a standard form of contract	3.370	2.815	9.487	17

The scatter diagram provided in Figure 1 was plotted using the impact and probability values listed in Table 3.

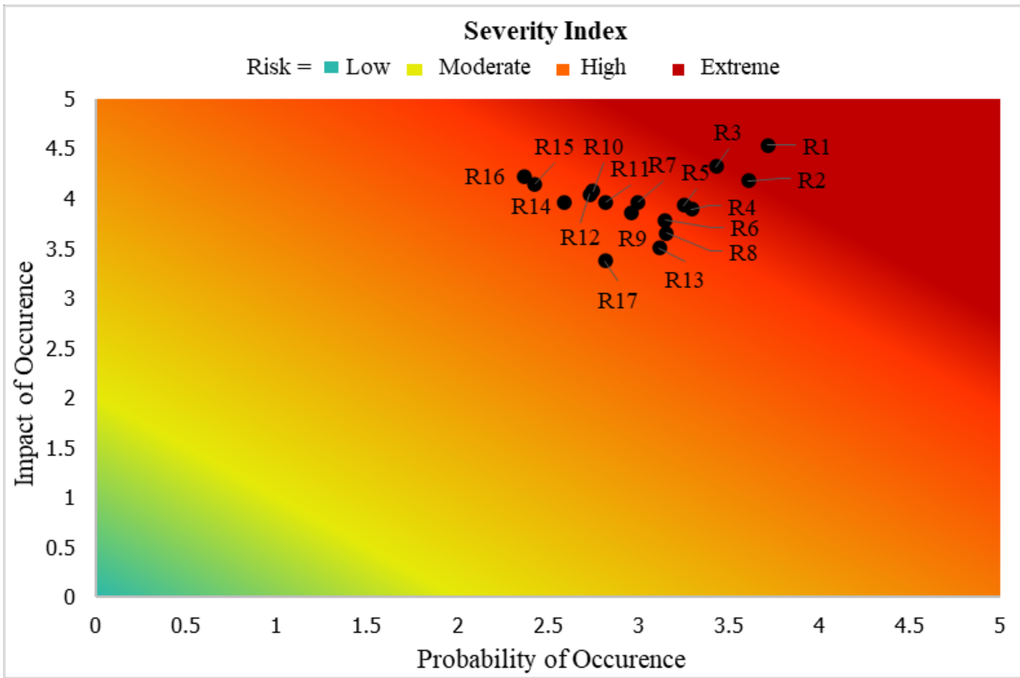

Figure 1: Risk impact probability matrix

R1 and R2 risk factors are in the red zone of the Impact Probability Matrix (Figure 1), indicating that the severity of each of the two risk factors is at an extremely high level. The severity indices of 'Poorly designed scope of work' (R1) and 'Design changes' (R2) are 16.847 and 15.073, respectively. The other 15 risk factors show a high level of severity and, therefore, are in the orange zone of the Impact Probability Matrix. The severity indices of these 15 risk factors fall in the 14.816-9.487 range. Thus, all of these 15 risk factors have a high level of risk. According to the rankings shown in Table 3, the most significant risk factors are related to the scope of work and design of the project.

4.2.2 The Severity of the Significant Risk Factors based on their Impact on the Project and Probability of Occurrence

As Table 3 shows, the impact and probability levels of the risk factors vary. None of the risk factors has a probability rating exceeding 4. The highest probability rating of 3.714 was for 'Poorly defined scope of work.' By contrast, seven of the risk factors have impact ratings exceeding 4. Furthermore, even though the risk factors such as 'Failure to complete the design before tenders are invited,' 'Inexperienced contractors,' 'Defective design' and 'Unrealistic maximum price agreed in the contract' have high levels of impact on a project, their probability of occurrence is low and therefore have received low rankings. One respondent opined that when the design is incomplete, no experienced and knowledgeable contractor would agree to the GMP value without seeking clarifications about the scope of work. Hence, the probability of occurrence of each of these risk factors will be low, although their impacts will be high if they ever occur. Another respondent stated that generally, in GMP projects, comprehensive information about the design is not available at the time of inviting tenders, which makes the clients prefer GMP contracts to other types of contracts, such as lump sum contracts, which require the design to be substantially completed at the time of inviting tenders. Hence, the probability of occurrence of these risk factors is high, and when they occur, their impacts on the projects will be high. According to Table 3, the probability of occurrence of a risk factor has a significant influence on its severity. For example, 'Financial failures of the client' has the third-highest impact value, although it is ranked lower with regard to severity because of its low probability of occurrence. The impact of 'Unforeseeable risks associated with design development during the tendering stage' is low, although it has a high ranking with regard to severity because of its high probability of occurrence. 'Failure to use a standard form of contract' has received a low ranking because the rights and obligations of the parties are stated clearly in a GMP contract making low the impact of the risk of not having a standard form of contract.

4.3 DISCUSSION

The most critical risk factors identified in the study are 'Poorly defined scope of work' and 'Design changes'. Most of the significant risk factors that were identified are connected to the scope of work and design. Considering their impact on a project, Chan *et al.* (2010a) suggested that 'Scope creep' and 'Poorly defined scope of work' might lead to a considerable number of GMP variations, ultimately making the project duration increase and project cost escalate. Fan and Greenwood (2004) expressed that in order to achieve their objectives, the client and contractor will express different opinions about common issues; thus, a poorly defined scope of work would promote disputes between the two parties.

Some of the significant risk factors, such as 'Errors and omissions in the tender document', 'Inconsistencies in the documents', and 'Failure to use a standard form of contract', were associated with documentation errors. According to Chan *et al.* (2010a), the quality/clarity of tender documents is a key contractual risk associated with GMP contracts because the fundamental tool used to allocate risks is the tender document. Ma and Beh (2011) identified the unavailability of a standard form of contract for GMP contracts as a major difficulty when allocating risks and responsibilities among the project players. According to Joseph (2011), unfamiliarity with the GMP concept may cause difficulties in setting the GMP value, monitoring the changes in the GMP value as the work progresses, and determining the profit-sharing formula.

Most of the previous studies on the risk factors associated with GMP contracts were conducted collectively on both TCC and GMP contracts. Furthermore, the literature that identifies the significant risk factors of GMP contracts has not addressed the severity of the risk factors in terms of their impact on the projects and probability of occurrence. The survey respondents accepted all the risk factors identified through the literature review. The study findings suggest that all of these risk factors are significant to some extent in GMP projects. Many of the past researchers found that the scope and design of the project might have a significant impact on anticipated risks, as revealed by this study as well. Joseph (2011) ranked the risk factors associated with TCCs and GMP contracts implemented in Hong Kong, and the findings are almost similar to the findings of this study. Five of the significant risk factors identified by Joseph (2011) were identified as significant in this study too. Moreover, Chan *et al.* (2010a) ranked the perceived risk factors of TCCs/GMP contracts in Hong Kong and identified changes in the scope of work and quality and clarity of tender documents as the two most significant risk factors present in the contracts. Chan *et al.* (2010b) ranked the key risk factors of TCCs/GMP contracts, and the results are considerably similar to the results of this study. Risk factors such as ‘Inexperienced contractors’, ‘Failure to use a standard form of contract’, and ‘Changes in the scope of work’ have been identified as significant risk factors by both studies. Risk factors such as the financial failures of the client and contractor have not been addressed in the previous studies on the risk factors in GMP contracts and TCCs. However, Ahmed *et al.* (1999) and Rahman and Kumaraswamy (2005) have addressed the impact of these two risk factors on the overall project irrespective of the type of contract employed. Nevertheless, the findings of this study reveal that financial failures of the client and contractors have a significant effect on the completion of GMP projects. The impact and probability of occurrence of each risk factor identified in this study may vary with project conditions and 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. Among the 44 risk factors identified through the literature review, 17 are of high significance, with their RII values exceeding 0.800. During the second round, all of these 17 risk factors were ranked based on their severity indices. Two of the risk factors, namely ‘Poorly defined scope of work’ and ‘Design changes’ obtained an extremely high severity level. The rest of the 15 risk factors had only a high severity level. The majority of the risk factors of high or extreme severity are related to project scope, design, and documentation. Furthermore, ‘Poorly defined scope of work’, ‘Design changes’, ‘Changes in the scope of work’, ‘Inexperienced contractors’, ‘Defective design’, ‘Unrealistic maximum price agreed in the contract’ and ‘Financial failures of the client’ have a high impact on the GMP process.

GMP contracts are suitable for projects that need early contractor involvement. It is strongly recommended that a clear and explicit definition of the scope of work be provided during the tendering stage. The project team should ensure that the design has been developed to a level that GMP contracts can handle and that bidders can quote their prices accurately. As the contractor’s risk is inflated in the GMP approach, the contractor needs to price the tender to correspond to the risks associated with the project. Moreover, issues due to changes made in the scope of work cause disputes between the parties to the contract; hence, the client and the contractor will have to agree on the types of events, such as the changes made to design development during the tendering stage, that will make it necessary to recalculate the GMP value. It is also important to decide early during project planning the stage at which the contractor has to get involved during design development and how the responsibilities pertaining to the design and engineering-related work are shared between the contractor and the client.

The primary outcome of this study is the identification of the most significant risk factors of GMP contracts. Thus, the study findings can be used as a reference when conducting further studies on the different aspects of GMP contracts. Moreover, the findings would help the successful implementation of worldwide GMP projects and overcome the challenges of adopting a novel contracting strategy like GMP contracts. Furthermore, the findings of the study were limited to the overall perspective of the client, contractor, and consultant, and the risks were ranked without considering a specific procurement type.

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IMPACT OF SPATIAL PLANNING FOR THE COST AND VALUE OPTIMIZATION IN BUILT ENVIRONMENT AGAINST NATURAL HAZARDS

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ABSTRACT

Spatial planning is managing the environmental, social and economic dimensions of development. Today the built environment suffers from a lot of natural hazards, resulted due to poor concentration over the environmental, social and economic aspects. Magnitudes and frequencies of these natural hazards has shifted from bad to worst in the recent past. Therefore, economic cost of these hazards has increased, and governments has been compelled to spend large amounts of public money to overcome these impacts on the built environment. Thus, in Sri Lankan context, these circumstances warrant the need to have a sustainable and realistic approach for the spatial planning in the built environment. Hence, the aim of this research was to enhance the cost and value efficiency in built environment against natural hazards through proper spatial planning in Sri Lankan context. Research was conducted mainly based on a questionnaire survey following the mixed research approach. Study identified the impact of poor spatial planning in the built environment in Sri Lankan context and study imparted set of guidelines to ensure effective spatial planning in the built environment in order to minimize the impact of adverse natural hazards. Finally, study concluded that, in order to establish a paradigm shift emphasizing the importance of effective spatial planning in the built environment, it is essential to have a clear understanding on natural process and other socio-economic concerns of the country.

Key words: *Built environment; Cost and value optimization; Spatial planning; Natural hazards.*

1. INTRODUCTION

"The earth does not belong to man, man belongs to the earth" (Seattle, 1855). Thus, being a part of the nature, human beings are forming relationships with the environment and fulfil their needs through environmental resources over million years. However, due to those informal relationships, human impact over the natural environment, social relations and economic impacts were shifted from bad to worst in the recent past (Mironowicz and Ryser, 2011). Therefore, researchers must find another appropriate dimension to build up the relationship between human development and natural environment. Spatial planning

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is monitoring and directing the economic, social, political and environmental dimensions of development (Acheampong, 2018). Furthermore, spatial planning is supporting to enhancing value for money in the built environment by offering maximum return on the investment and client can ensure that was worth the price that he has spent (Awodele *et al.,* 2017). Therefore, spatial planning can be defined as a key instrument for development which is balancing demands for development with the need to protect the environment to achieve social and economic objectives (Economic Commission for Europe, 2008).

However, in Sri Lankan context, number of development projects has failed due to lack of concern about the spatial planning specially in environmental aspects such as Kelani riverbank protection project, Ratnapura new city project, Hambanthota city development project and etc. Thus, the natural phenomenon needs to be identified, predicated and modeled during planning stages of any kind of development projects (Jayalath G. and Jayalath S., 2019). Then that will lead to minimize the unexpected costs of the projects and maximize the value for money. Moreover, in Sri Lankan context, no research has been carried out to emphasize the impact of spatial planning over cost of construction and value for money in built environment against natural hazards. Therefore, this research was conducted to enhance the cost and value efficiency in built environment against natural hazards through proper spatial planning in Sri Lankan context. To fulfil the aim of the research, research objectives were established as (1) To identify spatial planning ideologies and relationship with the phenomenon of nature, (2) To identify drawbacks of the built environment against natural hazards due to ineffective spatial planning in Sri Lanka, (3) Identify the effects of spatial planning to the construction cost and value for money in built environment, and finally (4) Formulate a spatial planning guideline to optimize the cost and to enhance the value of the built environment against natural hazards in Sri Lanka. Furthermore, the scope of this research is limited to discuss about the effects of spatial planning only for the economic and environmental aspects.

2. LITERATURE SYNTHESIS

Today, construction industry has direct and indirect impact on the environment in various ways (Enhassi *et al.*, 2014). Therefore, in Sri Lanka, number of development project failures can be investigated in the construction industry due to lack of knowledge on the environment and their natural phenomenon (Jayalath G. and Jayalath S., 2019). Therefore, that would be vital to discover viable solutions to avoid these circumstances while meeting demands for developments and to protect the nature. Moreover, spatial planning is extremely helpful to minimize exposure of people and built environment to natural hazards and to manage the long-term uninterrupted use of urban and rural lands (Sutanta *et al*., 2013). Thus, the spatial planning can be used to minimize impact of natural phenomenon on the built environment. Therefore, prior to that, there is a need to identify spatial planning ideologies and relationship with the phenomenon of nature.

2.1 SPATIAL PLANNING IDEOLOGIES

According to Economic Commission for Europe (2008), transformation of the space into a place which is more meaningful to humankind will achieve objectives such as reducing environmental damages, enhancing and preserving natural and cultural resources, developing energy resources while ensuring security, limiting the impact of natural hazards and improving relations between the city and the countryside successfully.

Development and Planning Commission (1999) identified the main characteristic of effective spatial planning as safeguarding people's rights, defending the natural system and using resources efficiently. Moreover, Bruin *et al.* (2013), identified some challenges in spatial planning such as demand for the space, facing to the traffic jam, environment-economy relationships, lifestyles and household needs and relationship between governments and individuals.

2.2 RELATIONSHIP OF SPATIAL PLANNING TO THE PHENOMENON OF NATURE

Most of the established ancient civilizations were destroyed from the earth due to the over-exploitation of environmental resources, massive resources depletion and unforeseen natural hazards (Scheffer and Janssen, 2004). Natural hazards cause loss of lives, livelihoods, properties and infrastructures worldwide annually (Perera *et al.,* 2019). According to Jayalath G. and Jayalath S. (2019), an active volcanic island in the Pacific Ocean is not a natural hazard because it does not take place in human habitats. Therefore, the issue is not with these natural processes at all but how humankind is going to build up and establish their habitats without adhering to natural phenomenon and spatial settings of the earth.

In the recent past, Sri Lanka has also experienced an increase in frequency of natural hazards and their impacts which are considerably affecting the economy and development projects (Ministry of Disaster Management, 2016). Landslides can be identified as one of the common natural hazards in Sri Lankan context which has adverse impacts to the human beings and built environment. However, according to the recent scientific literature, land slide is totally a natural process where solid mass lands will shape themselves by moving and flowing from one form to another (Landow, 2012). Landslides represents the natural transformation process where ecological system is trying to come back to their previous balance in terms of "natural balance phenomena" (Loucks and Wu, 1995). Therefore, wrong spatial settings of built environment find a landslide. In proper spatial planning, there are significant features related to the natural environment such as river morphology, evaluation of landforms and extremely helpful to minimize exposure of people and built environment to natural hazards and the vulnerabilities (Sutanta *et al.,* 2013). Thus, proper spatial planning can be used to minimize the impact of natural hazards by making better relationship with the natural phenomena.

2.3 DRAWBACKS DUE TO UNSUCCESSFUL SPATIAL PLANNING IN SRI LANKAN CONTEXT

There are some recent failures occurred in development projects in Sri Lanka caused due to disrespecting the relationship between spatial planning and phenomenon of nature. Among them, Miriyabedda and Aranayake landslides can be identified as the largest construction failures which were occurred due to poor spatial planning (Jayalath G. and Jayalath S., 2019).

2.3.1 Meeriyabedda Landslide

In summing up different causes for a landslide, the physical factors are amounting up to 40% while around 60% has been due to human related factors (Kaleel and Reeza, 2017). Thus, by implementing a comprehensive environmental impact assessment prior to the development project and by practicing proper spatial planning concepts, it will support to reduce the impact of landslides. Meeriyabedda landslide can be identified as the recent largest construction failure which occurred due to poor spatial planning in the Sri Lankan context which took more than 200 people and 150 houses buried alive on 29th of October 2014 (Jayalath G. and Jayalath S., 2019). Thus, it is essential to be aware on geomorphological processes and develop comprehensive environmental impact assessments through proper spatial planning for the development projects prior to beginning of these projects.

2.3.2 Aranayake Landslide

The landslide in Aranayake took place on 17th of May 2016 which buried parts of three villages namely Siripura, Elangapitiya and Pallebage and more than 100 people were dead and approximately 75 houses were destroyed (Jayalath G. and Jayalath S., 2019). In this case, Sri Lankan government allocated approximately USD 40,500 to recover the households that have been completely and partially destroyed (Perera *et al.,* 2018). Further author stated that, due to the landslide, 890 families were affected directly and indirectly. Finally, government concluded that, lack of awareness on environment and unplanned tea cultivation were the main contributing factors that increased the severity of the damage (Perera *et al.,* 2018).

2.3.3 Riverbank Protection Project - Kelani River

Throughout the last two decades number of large-scale engineering treatments were implemented to prevent the edge erosion of the Colombo-Hanwella low level road with the lack of understanding of fluvial morphological process of meandering Kelani River (Jayalath G. and Jayalath S., 2019). However, road edge was eroded continuously since this is a perfect natural process. Pre-cast concrete piles, steel sheet piles and finally the gabion retaining structures were used as the engineering treatments to prevent from such issues, but no one was successful as expected (Jayalath G. and Jayalath S., 2019). Therefore, due to the lack of knowledge on river morphology and poor environmental impact assessment, the government spent a large amount of money for precautions, yet the problem has not get resolved. However, river training is the most trending method of fluid engineering where the flow, being the main reason for bank and bed erosion, which is modified by inducing one or more large-scale secondary flows (Werdenberg *et al.,* 2014).

2.3.4 Ratnapura New City Project

Compared to old cities, modern attempts to artificially create new cities has been completely unsuccessful from human perspective (Alexander, 2017). Ratnapura new city, which was built to avoid frequent flooding issue, is one of the best examples for an unsuccessful new city made by the humankind in Sri Lanka. The reason for frequent flooding issue is not only due to the location of Ratnapura city which is located at the lower part of the Kalugaga basin, but also due to plenty of factors related to the urban population settlements and their behavior (Edirisooriya *et al.,* 2018). Accordingly, in the early 1980s the Sri Lankan government decided to shift the main city to a higher elevation near the original location of old city to avoid from major flooding every year. Due to the lack of impact of the new town development for the overall spatial configuration of the Ratnapura city, the new town becomes inactive and lack of functioning after the normal working hours of the government and private offices (Bandara *et al*., 2010). Therefore, the issue was not only an additional burden on municipal council to maintain an additional area that still does not have a substantial population and activities but also the original issue of flood and related hazards continuously recording with recurrent losses almost every year. Thus, to integrate the urban activities of new city, there should be substantial considerations of the environment, social and economic aspects to achieve the required degree of spatial planning. Otherwise, general public has to expect these kinds of environmental and economic failures due to poor adaptation of spatial planning.

Therefore, spatial planning will coordinate not only the social factors but also environmental factors to develop the local economy (Biesbroek *et al.*, 2009). Spatial planning aims to integrate different land-use functions and activities efficiently and effectively as possible for maximizing the benefits and profits at a given location (Partidario and Eggenberger, 2014). Therefore, the highest and best use concept also can be employed for this spatial planning system by considering not only about the land to be developed or left vacant but also what kind of improvement should be built (Boshoff, 2016). Therefore, according to Economic Commission for Europe (2008), by adopting effective spatial planning, there would be plenty of positive impacts on the cost of the construction projects and provides the best value for money.

3. RESEARCH METHOD

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). The first three objectives of this research required the collection of quantitative data. The final objective required the collection of qualitative data. Thus, for this study the mixed approach was used. Thus, in order to collect both quantitative and qualitative data, mixed approach was used for this research.

3.1 DATA COLLECTION METHOD

Primary data for the research was collected through a questionnaire survey. Generally, experienced construction professionals have adequate knowledge on the improper spatial planning and its effect over the built environment. Therefore, considering the available time constraints and often readily and easily available number of participants, convenience sampling method was used as the sampling technique for the questionnaire survey. Moreover, the latter part of questionnaire survey was focused to formulate a spatial planning guideline for the Sri Lankan built environment with the help of given set of international guidelines which were found from literature and attached to the questionnaire. Accordingly, data collected from the first part of the questionnaire were of quantitative nature and the latter part of the questionnaire mainly required the respondents to provide their opinions which were of qualitative nature. The questionnaire was distributed among sample of 42 experts in various professions.

3.2 DATA ANALYSIS METHOD

Quantitative data which were collected to identify effect of spatial planning to the construction cost and value for money were analyzed through SPSS statistical analysis software since SPSS is the most widely used program for statistical analysis in social science. Moreover, in order to analyze the statistical difference between mean and hypothesized value of the mean in the population, one sample t-test was used in quantitative analysis. Furthermore, the latter qualitative part of the questionnaire survey was analyzed by manual content analysis technique. Manual content analysis technique was used because of a lesser number of questions available to analysis.

4. DATA COLLECTION, ANALYSIS AND FINDINGS

4.1 RESPONDENT PROFILE

Out of 42 experts, 30 responses were received back. Therefore, overall response rate is approximately 72%. Summary of sample stratification based on their profession, work experience and engaged sectors were summarized in following Table 1.

Table 1: Summary of the sample stratification

Sample stratification	Category	Percentage
Profession	Quantity Surveyors	40% (12)
	Architects	23.4% (7)
	Engineers	36.6% (11)
Work experience	0-5 years	43.3% (13)
	5-10 years	30% (9)
	Over 10 years	26.7% (8)
Engaged sector	Residential sector	50% (15)
	Commercial sector	33% (10)
	Industrial sector	36% (11)
	All sectors	46% (14)

100% of the survey respondents stated that, they had experience on the unexpected or unplanned cost involvements during the construction and maintenance phases of construction projects and almost 70% of the respondents believed that the status and applicability of the spatial planning in Sri Lankan context is not adequate in order to minimize those unexpected or unplanned costs of construction projects.

4.2 IMPACT OF SPATIAL PLANNING TO THE COST AND VALUE FOR MONEY OF THE BUILT ENVIRONMENT

4.2.1 Impact of Spatial Planning to Cost of the Built Environment

Reduced economic life, impacts over natural environment, inconsistent government policies (bonds, taxes) and design and technical failures were the factors which were identified in literature synthesis that leads to unexpected costs during project lifetime. Table 2 presents the mean values of degree of influence on unexpected costs over built environment. In the questionnaire survey respondents were directed to rank the level of influence over each factor using following 1-5 Likert scale where, (1) represents lowest influence, (2) low influence, (3) medium influence, (4) high influence, and (5) highest influence.

Table 2: Mean values of degree of influence on unexpected costs over built environment

	Reduced economic life	Impact over natural environment	Inconsistent government policies	Design and technical failures
Mean	4.03	4.10	3.77	4.23

According to the mean values of above factors, except inconsistent government policies, all other factors have mean greater than 4.00 which means that, those factors have more than "high level of influence" towards the unexpected costs over built environment. One-sample t-test was used to compare these means and 4.00 is the hypothesis value which shows the "high level of influence". Improper environmental impact assessment, changes of the social behaviour/impacts, political influences, improper feasibility studies and inconsistent government policies were the causes of reduced economic life which shown in Figure 1.

Figure 1: Causes for the reduced economic life

Moreover, 100% of the survey respondents accepted that spatial planning makes an impact over these factors. Further they concluded that spatial planning can be integrated with the environmental, economic and social dimensions to minimize the impact over unexpected costs throughout the life cycle of the development projects.

4.2.2 Impact of Spatial Planning to the Value for Money of the Built Environment

The degree of influence of spatial planning over the factors revealed through the literature synthesis which can ensure value for money, were verified and ranked through the questionnaire survey and represented in Table 3. In the questionnaire survey respondents were directed to use the same 1-5 Likert scale above mentioned.

Table 3: Mean values of degree of influence on the value for money of the built environment

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**
Mean (how spatial planning effect on identified factors)	4.10	4.27	4.13	4.33	4.17	3.80	3.50	4.27	4.03	3.97
Mean (how those factors effect on value for money)	4.43	3.83	3.73	4.43	4.37	4.07	4.33	4.17	3.70	3.90
Average mean (both factors)	4.27	4.05	3.93	4.38	8.54	4.27	3.92	4.19	3.87	3.94

(1) Safeguard client right	(6) Ability to withstand natural disasters
(2) Defending natural system	(7) Construction time saving
(3) Efficient usage of natural resources	(8) Enhanced economic returns of the project
(4) Safeguard on investments	(9) Positive impact over the value of surrounding real estates
(5) Enhance economic life of the project	(10) Risks of disasters and its management

According to the degree of influence, factors having average mean value more than 4.00 can be considered as high influence factors on value for money in the built environment. One sample t-test was used to compare the means and 4.00 is the hypothesis value which shows the "high level of influence". Therefore, according to respondents' point of view, proper spatial planning can make high level of influence on ensuring the value for money of the built environment in Sri Lanka with effect of safeguarding client rights, defending natural system, safeguarding on investments, enhancing economic life of the project and enhancing economic returns of the project.

4.3 FORMULATION OF A SPATIAL PLANNING GUIDELINE OVER THE BUILT ENVIRONMENT IN THE SRI LANKAN CONTEXT

According to the findings of the literature synthesis and the results obtained from the questionnaire survey, it was concluded that, through establishing proper spatial planning mechanism over the built environment in the Sri Lankan context, it will be able to obtain social, economic and environmental benefits.

4.3.1 Causes for the Poor Spatial Planning in Sri Lankan Context

As per the findings of the study, causes for the poor spatial planning and their mean values of degree of agreement are presented in Table 4. In the questionnaire survey respondents were directed to rank the level of agreement over each cause of poor spatial planning using following 1-5 Likert scale where, (1) represents strongly disagree, (2) disagree, (3) neither agree nor disagree, (4) agree, and (5) strongly agree. These causes were identified to use as the basis to develop the spatial planning guideline to optimize the cost and to enhance the value of the built environment against natural hazards in Sri Lanka.

Table 4: Mean values of degree of influence on the causes for the poor spatial planning

	Lack of knowledge	Political issues and frequently changing government policies	Time consumption in planning stage	Poor relationship between government and individuals	Social aspect and convention al thinking pattern	Unavailability of proper platform to meet the professionals for decision making
Mean	3.63	4.20	3.93	4.20	3.97	4.13

According to the mean values of degree of agreement, causes for the poor spatial planning in Sri Lankan context can be summarized and ranked as follows.

1. Political issues including corruptions in government authorities and frequent changes in existing national policies
2. Poor relationship between government and individuals
3. Unavailability of proper platform to meet the professionals for decision making
4. Social aspect and conventional thinking pattern
5. Time consumption in planning stage of the construction projects
6. Lack of confidence and knowledge on spatial planning and lack of expert professionals and staff

4.3.2 Development of a Guideline for Modern Spatial Planning over Built Environment

Based on the findings of the literature synthesis and questionnaire survey, it was concluded that, role of spatial planning in the built environment and construction industry is far more important in cost and value optimization against natural hazards. Hence, there is a need to establish a proper spatial planning guideline which can be used to optimize the cost and to enhance the value of the built environment against natural hazards in Sri Lanka. They include the following steps.

- Understand the natural processes including geomorphologic settings of the project area during the planning stage of the project and analysis of findings of the feasibility study in a proper way
- Ensure maximum social return by the project, by understanding all-natural processes
- Identify the most optimum land for the development project by integrating the environmental, economic and social dimensions
- Identify the most desirable project for the landscape by considering the national economic development plan of the country
- Keep all stakeholders aware on the advantages of integrating an effective spatial planning within the planning stage
- Ensure better relationship between government and the client to reduce the time consumption during the planning stage
- Every planning related decision should be made by experienced and qualified professionals considering environmental concerns and economic value addition
- Develop a national policy through a transdisciplinary approach with the identification of objectives and their possibilities in order to establish a sustainable, economic and ecologically viable balance
- Government should establish the national policy through a transdisciplinary approach considering urban, suburban and rural areas separately by analysing the population growth aiming decentralization of the facilities while protecting the environment. Moreover, without stuck with the concept of urban and make sure that authorities do their duties in proper manner can be helpful to overcome the continuous urbanization.

5. CONCLUSIONS AND RECOMMENDATIONS

As per the literature survey findings and opinions received from the questionnaire survey respondents, there are number of drawbacks in some of the latest built environments in Sri Lankan context due to ineffective spatial planning. Thus, to overcome these circumstances and protect the environment while fulfilling human needs with enhanced value for money, spatial planning could be recommended as the best solution as per the findings of this research. Furthermore, spatial planning can be used to minimize the vulnerabilities of the natural hazards and other unexpected costs by understanding their ideologies and relationships of the phenomenon of nature.

Further, these findings revealed that, spatial planning makes high impact on the construction cost and the value for money in the built environment by up keeping the investments and client's rights of the project, enhancing the economic life and economic return of the project and defending natural eco system adjoining the built environment. Furthermore, findings of the study concluded that the existing spatial planning strategies are not adequate for the construction industry in Sri Lanka to cost and value optimization against natural hazards. Therefore, this study can be considered as a pilot study to evaluate the impact of spatial planning over the built environment with reference to cost and value optimization against natural hazards and recommend for better implementation of effective spatial planning in order to protect the environment while meeting human needs in built environment.

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INITIATING INDUSTRIAL SYMBIOSIS (IS) NETWORKS IN SRI LANKA: INSIGHTS FROM GLOBAL PROJECTS

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ABSTRACT

Industrial symbiosis (IS) is an ideal initiative for co-located industries to gain a competitive advantage through physical exchange of materials, energy, water, and by-products within a closed loop industrial system. IS has been created a considerable impact on the environmental and economic development through water savings, reduction of raw material extraction and carbon emissions reductions. As many developing countries are suffering from the environmental degradation due to industrial operations, initiating IS networks is vital to improve the business and environmental performance of industries. Since it is a novel concept, it is important to examine the insights from global IS projects to foresee the future challenges. Thus, in this study, PESTEL framework is employed to examine the impact of political, economic, social, technological, environmental and legal external factors on global IS projects. The secondary data collected from nine global IS projects were analysed using PESTEL analysis. The analysis clearly describes the several facets that could influence on industries deploying the IS networks, such as the pressure made by government, external parties, collective cost and environmental benefits, infrastructure sharing, social benefits, and influence made by laws and regulations. Accordingly, a PESTEL framework is developed, which provides a firm base to foresee the possible future changes, challenges and opportunities that can be effectively considered in strategic business decisions for deploying IS networks in Sri Lanka.

Keywords: *Framework; Global; Industrial Symbiosis (IS); Insights; PESTEL analysis.*

1. INTRODUCTION

Industrial symbiosis (IS) as an application of industrial ecology (IE), occurs at the inter-firm level as it includes exchange of resources among several organisations. According to Chertow (2000), IS engages the traditionally separate industries in a collective approach to gain competitive advantage through physical exchange of materials, energy, water, and by-products offered by geographic proximity. Since its emergence, the research scholars have interpreted this novel concept in various ways by tracking its development (Mallawarachchi *et al.,* 2020). As stated by Chertow and Ehrenfeld (2012), IS engages organisations from different sectors for achieving mutually favourable

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relations by reusing the waste and by-products in an innovative manner. Empirical studies reveal that a number of IS projects has been elevated across the globe amalgamating with the various IS theories and literature, which evidences how vital the application of IS towards achieving its ultimate outcomes. For an example, 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 (Tao *et al.,* 2019). Thus, IS has become a major business initiative in many countries all over the world.

Similarly, the concept of IS is an idyllic model to initiate the IS based industrial networks in Sri Lanka as it aims to improve the business and environmental performance of industries mainly through resource efficiency improvements. The industries, a main consumer of primary resources, have become the fastest growing component of the global resource use. However, shaping up the IS business among the local industries is still a challenge specially in developing countries like Sri Lanka. Industrial actors need to have effective and usable methods and tools to predict possible future changes, challenges and opportunities both in their own operations and in their business environments (Korreck, 2018). Based on the existing research, many fruitful insights can be found from global IS initiatives, which may facilitate the initiation of IS networks within the local context.

Thus, this paper focuses on examining the political, economic, social, technological, environmental and legal insights from global IS projects by employing the widely applied PESTEL framework. The localised industries may apply this framework to foresight the challenges and opportunities for IS initiatives within their industry operations as a main implication of this research.

2. LITERATURE REVIEW ON THE INITIATIVES OF INDUSTRIAL SYMBIOSIS

The concept of industrial symbiosis (IS) finds its origin in the field of industrial ecology (IE) (Baldassarre *et al.,* 2019). The world's concern on the importance of reducing the resource consumption has been resulted in developing various strategies and pathways. The concept of IS emerged in this regard by supporting the principles of IE, which has been increasingly grown over the few last decades due to its corporative benefits. Chertow and Ehrenfeld (2012) deliberated the improvement of the concept as a systematic approach for implementing the environmentally sound industrial systems. Further to authors, IS engages organisations from different sectors for achieving mutually favourable relations by reusing the waste and by-products in an innovative manner. Geographical proximity of the firms was concerned as a key for emerging IS (Chertow, 2007; Weerasinghe and Sandanayake, 2017).

Thus, a number of IS initiatives have been launched across the globe (European Commission, 2005; Tao *et al.,* 2019), expecting to achieve the sustainable benefits through the exchange of waste, wastewater and other resources. For example, the first model of IS was fully realized in the eco-industrial park (EIP) at Kalundborg, Denmark (Chertow, 2000). Moreover, at least sixty state-level industrial parks have been established in China during last decade, which account for a large proportion of the world's industrial parks (Liu *et al.,* 2018). Choctow Eco-industrial Park, USA, Qijiang Industrial Park, China, Songmudao Chemical Industrial Park, China are the other examples for IS projects initiated by aiming the exchange of wastewater (Carr, 1998; Van

Beers *et al.,* 2007; Li *et al.,* 2017; Zhang *et al.,* 2017). Boons *et al*. (2017) further stated that the decision could be influenced by various motives and institutional factors, such as level of trust, policies and regulations and social reasons, and incentives given by the individual industrial entities. Chertow (2007) clearly described that the key to IS for taking the advantage of synergetic possibilities is the geographical proximity of the firms, since it involves physical exchange of resources. However, Mirata and Emtairah (2005) noted that the symbiotic relationships could also happen in long distances and it can include the exchange of knowledge and utilisation of shared infrastructure.

As Chertow (2007) further stated, the efficient resource sharing, emission reduction and waste elimination may also help to reduce the cost and increase revenues as a collective advantage. As stated by Domenech *et al.* (2019), cost savings, CO_2 savings, water savings, reducing the landfilling of waste, eliminating hazardous waste and creating job opportunities are the key sustainable benefits that can be achieved though IS. As Domenech *et al.* (2019) further explained, IS also facilitates an environment for building new partnerships with other industries, accessing innovation, assisting to achieve environmental policy and company targets and satisfying the corporate social responsibility (CSR) requirements. Indeed, Ghali and Frayret (2019) mentioned that IS is primarily focusing on optimising the use of resources among the different industries for economic, environmental and social gains through a sustainable business. As stated by Morales *et al.* (2019), IS looks for optimising the material, energy and waste flows through an effective exchange in line with environmental and economic objectives. It is further supported by Maqbool *et al.* (2019) that optimisation achieved through efficiency gains, energy and carbon savings is a beginning for economically viable IS business coupling with the enhanced environmental performance.

Sri Lanka is facing a severe environmental challenge due to improper disposal of waste, extraction and utilization of non-renewable resources same as the other developing countries across the globe. Specially, the industries a main consumer of the primary resources, have become the fastest growing component of the global resource use. Besides, it has enriched the resource extraction and demand very rapidly. The extract and dump nature of the industrial systems has burdened the reuse of resources, in which the materials and energy are dumped in a linear flow after been used. Thus, the existing environmental degradation due to elevated freshwater utilisation, energy consumption, material extraction and waste disposal, can be overwhelmed through waste and by-products exchange.

Thus, understanding the current status of global IS business initiatives is vital to foresee the challenges and opportunities that can be affected on the local industry environment when moving towards IS. This study employs the PESTEL framework to determine the political, environmental, social, technological, economic and legal aspects from global IS projects, which may assist predicting the future challenges and opportunities for IS networks in Sri Lanka. The methodology adapted is described below.

3. RESEARCH METHODOLOGY

Since this paper aims to examine the insights of global IS projects, qualitative approach was selected. An in-depth investigation was conducted by selecting the existing IS projects in operation. As the most suitable method for selecting the published case studies over the considered period of time, desk review was selected to collect the published data.

Desk study is a quick and easy method for collecting data from existing sources. It reduces data collection time and adds to the accuracy of conclusion, since the data is collected from reliable published sources. Further, it forbids interviewee biasness and allows researchers to access to valuable information at little or no cost. Thus, the reliable data on IS projects were collected from the published sources. Accordingly, 09 published IS projects were finally chosen considering the research scope and availability of data. Data were collected from the journal articles, which have been published relating to the selected projects during the period of 1989 to 2019 as stated in Table 1.

Table 1: Profile of the selected projects

Project	Global IS projects	Article availability
Project A	Kalundborg, Denmark	Ehrenfeld and Gertler (1997); Chertow (2007); Domenech and Davies (2011); Zhang, *et al.* (2016); Zhang and Chai (2019)
Project B	Guitang Group IS Project, China	Zhu *et al.* (2007)
Project C	Kwinna Industrial Area, Australia	Van Beers *et al.* (2007)
Project D	Tianjin IS Project, China	Shi *et al.* (2010); Yu *et al.* (2014)
Project E	Gujiao Eco-industrial Park, China	Song *et al.* (2018)
Project F	Shandong Lubei, China	Zhang *et al.* (2015); Zhang *et al.* (2016); Zhang and Chai (2019)
Project G	Choctow Industrial Park, USA	Carr (1998); Domenech and Davies (2011)
Project H	Dunkirk IS Project, France	Morales *et al.* (2019)
Project I	Ulsan Eco-industrial Park, Korea	Park *et al.* (2019); Behera *et al.* (2012); Kim *et al.* (2018)

The data collected from selected projects were analysed using PESTEL framework since it is an ideal technique to identify external factors affecting IS projects and hence, to assess the viability of a new venture. PESTEL framework is briefly described below.

Political aspects: This includes the aspects, such as political and governmental pressure, trade policies, which could impact the industries deploying IS.

Economic aspects: This includes the factors influencing the economic performance of the industries that are deploying the IS business, such as fiscal and taxation policies, interest rates, input cost, waste treatment and discharge cost to name a few.

Social aspects: The influence made by the social environment, the stakeholders of the industries and communities on industries, such as behavioural patterns and cultural effects are considered.

Technological aspects: This includes the developments of technical aspects, such as use of new technologies, innovation, research and development and technical solutions, etc and their impact on the industries that are deploying IS.

Environmental aspects: This includes the ecological and environmental aspects, such as environmental impacts, resource utilisation, waste and energy management and other sustainable policies and their impact on the industries that are engaging in IS.

Legal aspects: This describes the legal aspects, such as, institutional, local and national level laws and regulations, which could impact the industries deploying IS.

Thus, by using the PESTEL analysis, the political, economic, social, technological, environmental and legal aspects of global IS initiatives were identified by synthesising the existing literature. The key findings derived through data analysis are presented below.

4. KEY RESEARCH FINDINGS

The analysis of secondary data collected from the global IS projects revealed several practices in relation to the business and operational environment. The global IS initiatives and practices were reviewed under the six areas of PESTEL analysis.

4.1 POLITICAL ASPECTS

The secondary data of IS projects clearly show that there is a pressure of political decision making in initiating IS concept. Specially, the political pressure through environmental protection agencies, non-government organisations, industrial associations and community leaders towards managing the environmental impacts caused due to industrial activities. Further, the lack of support by political parties can be recognised in both Projects E and G. The external pressure made by the political leaders as well as the environmental protection agencies on waste generators in Projects A and D can be highlighted.

> *There is a firm level concern in developing the new policies for dealing with environmental issues and waste management, which will be used in initiating the new synergetic opportunities reducing the external pressure (Project A)*

In Project C, all the industries together with Kwinna Industries Council started exchanging of resources due to increased government pressure to manage the air and water sheds and protect the sensitive marine environment. Furthermore, involvement of at least one government agency for authority is identified in few projects including Project H. In Project H, the local authorities have been involved for managing conflicts between industries, residents and environmental protection organisations. It is evident in Project G that the park is coordinated by the Industrial Park Authority, while an academic researcher has been appointed as the champion to drive the process through proper coordination of industries in Project I. Further, the involvement of government agencies has become a pressure, where the authority is owned by a government agency or private sector organisation limiting the decision-making ability of other actors of the network. For example, in the symbiotic network of Project F, the owner of the network has limited the decisions taken by other actors of the network.

Accordingly, 06 political insights were derived through review as; the lack of support by political parties (Projects E & G), the external pressure made by the political leaders and environmental protection agencies on waste generators (Projects A & D), increased government pressure to protect the environment (Projects F & H), involvement of at least one government agency for authority (Projects H), involvement of local authorities for managing conflicts between industries and community (Projects G & H) and limiting the decision-making ability of other actors of the network (Projects A, G & H).

4.2 ECONOMIC ASPECTS

There are number of economic aspects influencing the IS business worldwide. The competition between industries towards engaging with IS collaborations due to collective economic benefits is visible in most of the projects. Thus, several independent by-product exchanges have gradually evolved into a complex web of symbiotic interactions among five co-located companies and the local municipality in Projects A and D.

> *There has been a by-product exchange primarily begun with steam supply consisting seven main industries in Tianjin Economic-technological Development Area (TEDA) in China, which has been expanded to 81 symbiotic exchanges (Project D)*

Similarly, in Project B, industries have been collaborated to improve economic and environmental performance simultaneously. For an example, industries in Project A have reduced the waste disposal cost and transaction cost due to effective information sharing, while Project B has achieved cost reductions through sharing of updated information and easily established cooperative relationships. Indeed, industries have obtained various cost benefits through their collaborative engagement by adhering to the fiscal policies and incentives provided by the government.

> *The financial assistance given by the Ministry of Knowledge for conducting feasibility assessment of industries (Project I)*

> *Environmental and resource tax have been refined based on resource efficiency and emission reduction by the industries (Project E)*

On the other hand, consuming more time to achieve short-term and long-term collective benefits or the longer payback period is another economic factor influencing industries in IS networks. Further, the risk of long-term interdependence of industries also requires attention in IS business. It is evident in Project D that the modifications made by individual actors have led to discontinuous symbiotic exchanges over the time. Further, it has led to shortages of resources and price fluctuations of by-products.

> *The suspension of production of a food processing plant has led to the breakdown of IS exchanges associated with the firm. Furthermore, the price escalation of by-products, product unavailability within the park in long term (Project D)*

In summary, the competition between industries towards engaging with IS industrial collaborations (Projects A & D), collaborating to improve economic and environmental performance (Projects A, B, E & I), longer payback period to achieve short-term and long-term collective benefits (Projects A & D) and influence made by fiscal policies and incentives (Projects A & D) were recognised as the economic factors influencing IS networks.

4.3 SOCIAL ASPECTS

When discussing the social insights that have been influenced on industries in IS networks, the pressure made by social environment can be highlighted in many projects. For an example, the influence made by general public, community leaders and surrounding neighbours of the industrial park can be found in Projects C, E and G.

> *All the industries together with Kwinna Industries Council started exchanging of resources due to increased government and community pressure to protect the sensitive marine environment (Project C)*

Nevertheless, lack of trust on other partners and the difficulty in maintaining close relationship with other actors in long term are other influences made by industry stakeholders. Even though, the network began with mutual trust, projects have faced difficulty in maintaining close relationship with other actors in long term.

> *The industries in the network have faced trust over other partners belonging to the quality of by-products exchanged (Project F)*

> *The suspension of production of a food processing plant has led to the breakdown of IS exchanges associated with the firm (Project D)*

The generation of social benefits and contribution to enhance socio-economic development by the industries engaged in IS business is another social insight, which can be recognised in global IS projects. Considering the community needs over flooding and meeting, the quality of life can be identified in Projects G and H.

> *The symbiotic network has created job opportunities for public in which about 90-225 employees are currently working in the park (Project G)*

Thus, the influence made by general public, community leaders and surrounding neighbours (Projects C, E & G), lack of trust on other partners (Projects D & F), difficulty in maintaining close relationship with other actors (Project F), generating social benefits and community needs (Project G) and contribution to enhance socio-economic development (Projects G & H) were identified as social insights influencing IS networks.

4.4 TECHNOLOGICAL ASPECTS

The industries deploying the IS business have obtained various technological improvements and faced several challenges. Symbiotic exchanges have been developed by considering the availability of technology, benefits over investment and to be allowed under the existing laws in Project I. IS is an innovative business opportunity where it promotes sharing infrastructure and public utilities, while creating new business opportunities. The renovation and reuse of industrial complexes adhering to new technologies and innovative infrastructure designing strategies have motivated the industries to engage in IS business. Further, technical expertise and guidance provided by the government agencies are also visible in many IS projects.

> *Protection Bureau has played a leading role and provide technical expertise during the development (Project D)*

Further, industrial diversity is another innovative insight considered by the industries deploying IS business. As recognised in Projects A and C, diverse regional synergetic opportunities still appear within the network. Further, it has a possibility for expansion of the network.

> *Project H network is composed by 14 diverse firms, such as power plant, cement factory, steel industry, dust recycling company, agricultural market, etc while 41 diverse regional and industrial institutions are engaged in Project I (Project H, Project I)*

Accordingly, 06 technological insights influencing IS networks were recognised as; promotes sharing infrastructure and public utilities (Projects A, D & I), creating new business opportunities (Projects D & I), renovation and reuse of industrial complexes adhering to new technologies (Projects A & C), using innovative infrastructure designing strategies (Project C), technical expertise and guidance provided by the government agencies (Project D) and diverse regional synergetic opportunities (Projects A, C, H & I).

4.5 ENVIRONMENTAL ASPECTS

There are several environmental aspects influencing the industries that are engaging in the IS business. As aimed in IS collaborative business, the reduction of environmental issues has always been considered by many global IS projects.

In Project C, all the industries together with Kwinna Industries Council have started exchanging of resources in order to manage the resources, while protecting the sensitive marine environment. Further, in Projects A, D and E, industries are collectively engaged in generating environmental benefits, such as waste management, water management, energy management, reduction of environmental pollution and providing social benefits, to name a few. The IS network in Project F has been pre-planned by considering the reduction of the resource utilisation and waste.

> *The IS in Kalundborg has generated a significant environmental and economic gain through the reduction of waste within the process, which includes ground, surface and wastewater savings as well as the reduction of carbon emissions. The annual savings for the whole network is 15US$ millions. Further, it has generated over 310US$ of accumulated savings over the years (Project A)*

Further, the environmental liability of each industry in the IS network is visible as all the industries engaged in generating opportunities to reduce environmental impacts through waste sharing.

> *The partnership of IS in Project G has been promoted both tire recycling and the reuse of treated wastewater to fulfil the non-portable water needs of the co-located industries (Project G)*

Hence, collective engagement of industries in generating environmental benefits (Projects A, C, D & E), pre-planning of networks for reducing resource utilisation and waste discharge (Projects A & F) and assuring environmental liability of each industry (Project G) were identified as environmental insights, which can influence IS networks.

4.6 LEGAL ASPECTS

When discussing about the legal aspects influencing the industries deploying the IS business, the influence by new policies and regulations can be highly recognised. The legislations have a strong impact on waste disposal and recycling. For example, pressure made by new environmental regulations in China, which has been influenced on waste generators in Projects A and D can be highlighted.

> *The new environmental regulations in China have been influenced on waste generators engaged in IS business (Project D)*

Further, the influence made by the industrial development policies on industries in IS business can also be highlighted. For example, new industrial development policies and planning guidelines in China has been influenced on Project A. On the other hand, pricing and infrastructure designing strategies have been implemented in Project E to motivate the industries to engage in symbiotic development.

> *There was a planning procedure (a corporative plan) for initiating and developing IS network with a careful analysis of the design requirements and planning strategies to meet related necessities (Project A)*

The impact made by labour regulations is apparent in Project H. The feasibility investigation of the projects has been carried out under the premises of the existing laws in Project I.

In summary, 06 legal insights were derived through analysis as; the pressure made by new environmental regulations (Projects A & D), industrial development policies and planning guidelines (Projects A & H), impact made by labour regulations (Projects H & I), feasibility investigation of the projects under the premises of the existing laws (Projects D & I) and pricing and infrastructure designing strategies (Projects A & D). Figure 1 visualises the PESTEL insights for directing the industries towards initiating IS networks. The developed framework can be used in strategic business decision making for deploying the IS networks in Sri Lanka. Following the aim of this study, the key considerations that can be considered in deploying IS networks in Sri Lanka can be identified as follows:

- Setting amendments in national industrial policy and strategy for engaging the new and existing industries towards closed loop IS networks is important to be considered. Under this, sustainable industrial development guidelines can be introduced for initiating waste sharing networks as the industrial by-products by promoting environmentally friendly industrialization. On the other hand, industries may follow these guidelines effectively, if the provisions come into practice as a national policy driven guideline. However, no amendments have been taken place recently in the national policies relating to industries. For an example, many industries are located upstream and near riverbanks polluting the freshwater bodies due to the issues in Industries Citing Policy in Sri Lanka. Thus, it will be a greater challenge to begin IS initiatives along with the current policies and strategies in Sri Lanka.
- Further, since this requires a high initial investment by the industries involved, the willingness of the industries to engage in IS initiatives can be another challenge. Thus, incentivising the industries, introducing tax reductions, and providing lower utility rates for those who are willing to engage in the IS system are aspects to be considered.
- Establishing IS initiatives within the industrial parks in Sri Lanka with existing infrastructure facilities is another critical aspect. The current storage facilities, pipe networks and treatment technologies need major improvements and renovations, which must be facilitated by the government. Thus, designing or renovating new and existing industrial estates with innovating technologies, and facilitating public and infrastructure sharing possibilities will promote industries to be engaged in IS. This may create a network not only for sharing waste but also for exchanging the public infrastructure and technical expertise among the industries as a collective advantage.

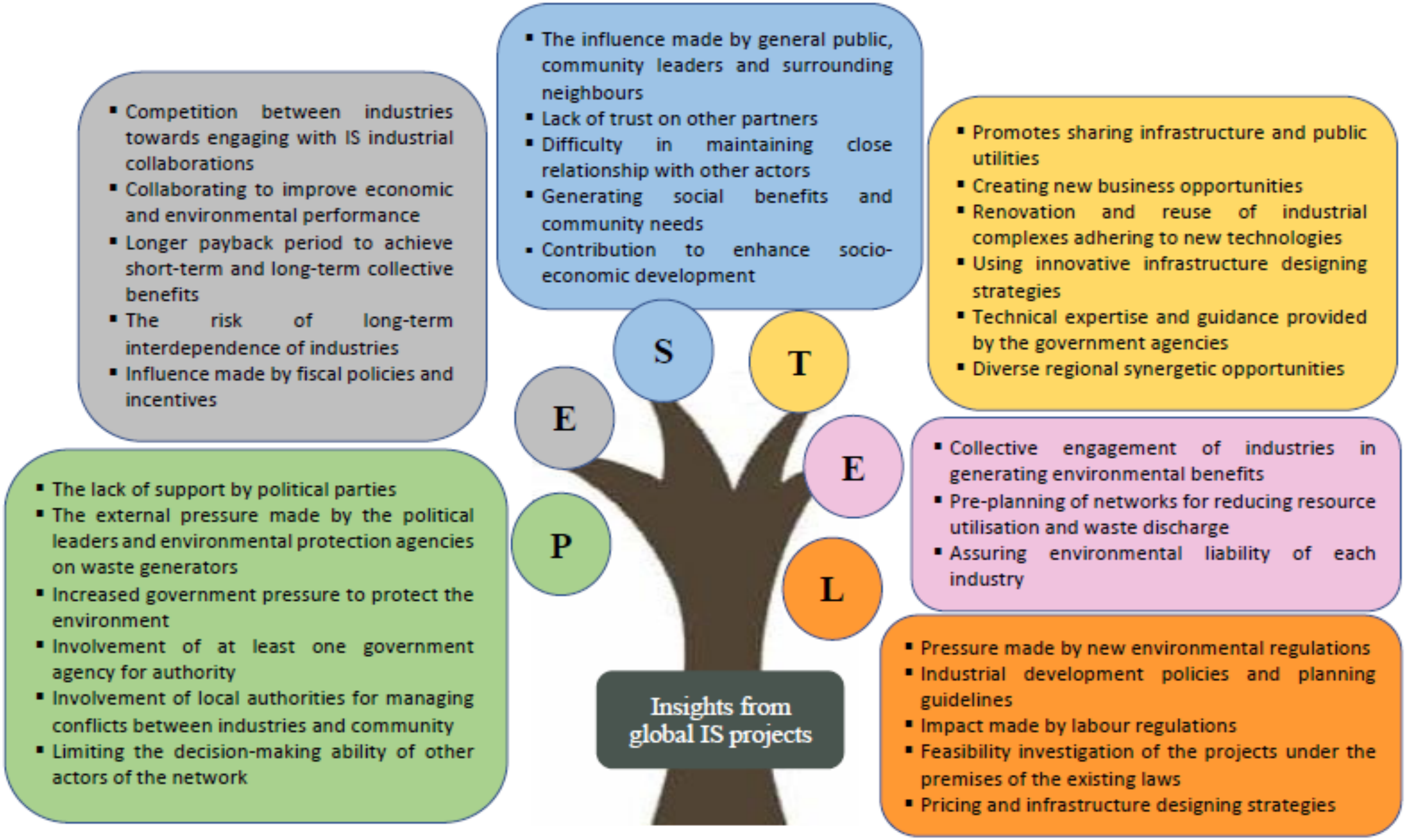

Figure 1: A PESTEL framework for deploying IS networks in Sri Lanka

5. CONCLUSIONS AND THE WAY FORWARD

This paper examines the political, economic, social, technological, environmental and legal insights from global IS projects for initiating IS business initiatives in local context by employing the widely applied PESTEL framework. IS is a collective engagement of co-located industries to gain competitive advantage through physical exchange of materials, energy, water, and by-products, which ultimately improve the business and environmental performance of industries through resource efficiency improvements. The existing environmental degradation due to elevated freshwater utilisation, energy consumption, material extraction and waste disposal of industries can be overwhelmed by directing the local industries towards IS business. The effort of this study was to foresee the challenges and opportunities that can be affected on the local industry environment when moving towards IS. Accordingly, many fruitful insights were derived from global IS projects, such as the pressure made by the government, external parties, collective cost and environmental benefits, infrastructure sharing, social benefits, influence made by laws and regulations, which can be effectively considered in strategic business decisions for deploying the IS business initiatives in Sri Lanka. Since this is an initial impetus to evaluate the challenges for initiating IS initiatives within the local context, the next stage of this research will be to develop an optimised waste (waste materials and wastewater) sharing model for effective resources utilisation of local IS initiatives within a circular nature targeting a high environmental and economic gain.

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KEY PERFORMANCE INDICATORS IN UPHOLDING SCOPE CREEP MANAGEMENT IN ROAD PROJECTS

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ABSTRACT

Scope creep has been a day-to-day occurrence in almost every major road project causing a considerable cost overrun with no early dimple. This paper offers a critical appraisal on the dominant causes behind scope creep in the road projects. A comprehensive literature survey was undertaken to explore the factors specifically contributing scope creep and various control measures that are adopted, among other purposes, in at least reducing the impact due to scope creep in the final delivery of road projects. The study included interviews with 15 experts to identify major issues and add their hands-on experience. A questionnaire survey was subsequently administered among 100 industrial personnel having a cost management background in order to evaluate the effectiveness of the key performance indicators (KPIs) in terms of taming scope creep. Results from the study showed that concomitant client instructions on additional features, unclear scope and incremental changes cause scope creep throughout the project. Among 53 KPIs identified, the most effective KPI that enables adequate control of scope creep in road projects is the cost efficiency ratio. The results enable comprehending the causes of scope creep and its resultant net effect on cost control.

Keywords: *Cost controlling techniques; Cost overrun; Key Performance Indicators (KPIs); Road projects; Scope creep.*

1. INTRODUCTION

Cost overruns are inevitable even in projects delivered well (Zwikael, 2009). Nivehithan (2017) revealed that cost overrun can even result in early cessation. Thus, it is necessary to implement cost control mechanisms to ensure no deviations. The study done by Malkanthi *et al*., (2017) has revealed that cost variance can be reduced as much as 50% through the use of appropriate cost control techniques. As such, most of the literature has focused on various cost control techniques for general application (Koushki *et al*., 2005). The effectiveness of a cost controlling technique will depend on the measure of its performance (Neely *et al.,* 2005). Performance measurement is to objectively reckon the efficiency and effectiveness of a given task. It allows making judgments against certain predetermined criteria (Neely *et al.,* 2005; Basheka and Tumutegyereize, 2011). KPIs are therefore essential in terms of finding the current status as well as the 'remaining balance'. Swan and Kyng (2004) contend that monitoring KPIs are critical in any project. Thoor

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and Ogunlana (2010), together with Humaidi and Said (2011), suggested that KPIs are helpful to compare the actual with estimated performance in terms of effectiveness. KPIs are outcomes from an industry-led self-improvement initiative rather than a top-down imposition from government (Kumaraswamy *et al*., 2017). In 30 mega infrastructure projects in India, road projects are found to have largest amount of time and cost overruns (Narayanan *et al.,* 2019). Among a host of reasons, scope creep, is exceptional in road projects in a way it is silently contributing cost overrun in long run. Most projects seem to sustain scope creep (Larson and Larson, 2009). A few researchers have attempted to gauge the effectiveness of KPI however no research is found in reference to their application in scope creep. Hence, the research problems considered in this paper are 'Is there any particular KPI that effectively works in taming scope creep in road projects?

This research aims to enhance awareness among the construction practitioners to successfully cope with scope creep that take place in road construction projects. The objectives encompassing this study are to, (1) identify the factors contributing scope creep resulting in cost and schedule overrun, (2) identify the various cost management functions and key performance indicators in the sphere of scope creep management, and (3) statistically measure the level of their effectiveness in taming cost overrun in road projects.

2. FACTORS CONTRIBUTING SCOPE CREEP

As such, many researchers have identified a gamut of factors that cause scope creep in road projects and the associated KPI and recommended for the adoption during the project execution stage (refer Table 1).

Table 1: Factors contributing to scope creep in road projects & KPIs

#	Author	Factors contributing scope creep in road projects	KPI recommended
1	Arditi *et al*. (1985)	Substitution of materials as a result of resource shortages	Net scope change (add and omit schedule)
2	Dlakwa and Cuplin (1990)	Unstable interest rates, too many temporary diversions than planned	Budgeted cost of work done
3	Hendrickson (1998)	Cascading effects due to less productivity	Lead time, productivity ratio
4	Larson and Larson (2009)	Change in specifications	Reduced timing, productivity ration, variation log
5	Smith and Love (2001)	Abortive work, lasts minute adjustments by the end user	Number of Rework approved
6	Smith and Love (2001)	Incremental design changes	Claims
7	Sonuga *et al*. (2002)	Change in elevations, sections and plans	Under measure added, variation log, EI instructions responded, design changes authenticated
8	Aibinu and Jagboro (2002)	Unexpected incremental price increases on daily basis	Cash flow yield

#	Author	Factors contributing scope creep in road projects	KPI recommended
9	Gurlen (2003)	Unintended directions	Approved varied work
10	Baloi and Price (2003)	fluctuation of exchange rates, sub surface works where the theoretical quantities exceed	Cash flow margin
11	Baloi and Price (2003)	Continuous design changes	Variation log, potential change notices approved,
12	Koushki and Kartam (2004)	Change in line, level and alignments, change in super elevation, change in specifications as to mix of asphalt, mix of concrete, type of soil	Site log book signed and confirmed, variation log
13	Koushki and Kartam (2004)	Plant idling	Mark up eroded
14	Hanna and Gunduz (2004)	Low labour productivity	Cost benefit ratio, productivity ratio
15	Chester and Hendrickson (2005)	Labour inefficiency, wrong estimate in quantities	Employer Instruction (EI) the cost of which is confirmed in principle
16	Koushki *et al*. (2005)	Verbal instructions at site level	Log notes confirmed, variation log
17	Iyer and Jha (2005)	High scope of temporary works, plant idling	Efficiency ratio, waiting time
18	Chester and Hendrickson (2005)	Labour inefficiency, plant idling	Contract rate vs. actual rate, productivity ratio
19	Cotton *et al.* (2005)	Labour inefficiency	Productivity ratio
20	Yahya and Boussabaine (2006)	Wastage of materials, labour, omitted works, missing items in the bill of quantities,	Abortive work schedule approved
21	Walsh *et al*. (2006)	Wrong method of resource handling, change in sequence of site operations	Cost performance index (CPI), schedule performance index
22	Dixon (2006)	additional functionalities	Return on investment
23	Berman (2006)	Low productivity	Productivity ratio
24	Walsh *et al*. (2006)	Wrong methods of resources handling	Amount of loss recovered
25	Yahya and Boussabaine (2006)	Change in the sequence of work and methods statement	Productivity ratio
26	Owens (2007)	Additional works in small quantities	Mean absolute deviation
27	Azhar *et al*. (2008)	Unstable costs of the manufacturing materials.	Cost target

#	Author	Factors contributing scope creep in road projects	KPI recommended
28	Ward and Chapman (2008)	Incremental change in the original scope of the work and its time impact	Schedule performance index (SPI),
29	Pewdum (2009)	Changes in source of supply of materials	Number of claims settled
30	Shane *et al*. (2009)	Idling of machinery	Cost limit
31	Turk (2010)	Ambiguous, vague scope fi work reticence could be a precursor to failure.	Variation log, Reduced preliminaries
32	Olawale and Sun (2010)	Design changes from time to time	Variation log
33	Fang and Ng (2011)	Wastage in handling materials	Approved Day Work Schedule
34	Jayalath (2011)	Original contract scope increased substantially, change in invert levels, change in mix proportions, change in intervals in joints, bases, thresholds etc.	Schedule variance
35	Jayalath (2011)	Changes in the method of execution	Actual cost of works performed
36	Wijekoon and Attanayake (2011)	Changes in end user requirements	Burn rate, variation log, omitted work schedule, day work schedule approved
37	Fang and Ng (2011)	Wastage during heavy usage of raw materials	Attendance fees settled
38	Jayalath (2011)	Deviation as to the methods of execution as planned. Slight changes allowed to the original project scope	Work certified to date, variation approved
39	Fang and Ng (2011)	Wastage, in the use of materials	Billing analysis
40	Jayalath (2011)	Additional functionalities	Return on investment
41	De Marco (2013)	Little changes to the planned base line, work scope and schedule	Claimed vs. approved (variations log)
42	Wijekoon and Attanayake (2013)	Low precision of the estimates, inaccurate site investigation,	Request for Information (RFI) responded, schedule for approved day work
43	De Marco (2013)	Changing the planned base line, work scope and schedule.	Variations
44	Shrestha (2014)	Last minute adjustments to project scope in order to rectify design errors	Budgeted cost of work performed

#	Author	Factors contributing scope creep in road projects	KPI recommended
45	Ghoddousi and Poorafshar (2015)	Plant idling, protracted delay in approval process	Number of variations finalized, Disputed amount vs. effective contract sum
46	Ghoddousi *et al*. (2015)	Works done on, trial and error basis	Productivity ratio, budgeted cost of work completed
47	Baek *et al.* (2016)	Incomplete drawings	Potential change notices (PCN) approved
48	Saidu and Shakantu (2016)	Large amount of materials wastage, labour inefficiency, concomitant changes in weather conditions, price increases	Standing time, budgeted cost of work completed
49	Kerzner (2017)	Additional features and functionalities	Cost variance
50	Veen *et al*. (2017)	Disruptive events due to a series of individual changes	Cost per km

The foregoing literature review essentially carries out the detailed elaboration of various factors contributing scope creep and key performance indicators as a set of quantifiable measurements used to gauge the overall long-term performance in taming scope creep.

3. RESEARCH METHODOLOGY

The study used the mixed research method. Mixed research approach being a combination of qualitative and quantitative approaches can overcome the weakness of the two approaches (Creswell, 2014). It can also enhance the rationality and consistency of the results of a study while enabling strong recommendations (Amaratunga *et al*., 2002). The study commenced with a detailed literature survey to identify the factors affecting cost overrun and cost controlling techniques and used semi structured expert interviews to collect the qualitative data required. 15 experts were selected using purposive sampling. Interview findings were transcribed and analysed using NVivo 11 code-based content analysis software and used to develop the questionnaire to evaluate the effectiveness. Interview findings were used to identify the most prevalent scope creep management tools in road projects. The profile of 15 interviewees are basically senior quantity surveyors with more than 20 years' experience working in road projects (refer Table 2).

Questionnaire surveys allow collection of data from a large number of respondents in a standard manner without any influence from the researcher (Bhattacherjee, 2012; MacDonald and Headlam, 2008). 100 project level quantity surveyors working in different capacities and authorities were selected using purposive sampling (refer Table 2). Questionnaires were despatched via email and the response rate was 84%.

The index of Mean Item Square (MIS) is the sum of the respondents' actual scores given by all the respondents as a proportion of the sum of all maximum possible scores on the 5-point scale. Weighting was assigned to each responses ranging from one to five for the responses of 'strongly disagree' to 'strongly agree' and 'Extremely unlikely' to 'Extremely likely', when expressed mathematically as given in Equation (01).

$$MIS = (1n1 + 2n2 + 3n3 + 4n4 + 5n5) / \Sigma N \qquad (01)$$

Where; n_1 = Number of respondents for extremely unlikely or strongly disagree; n_2 = Number of respondents for unlikely of disagree; n_3 = Number of respondents for neutral; n_4 = Number of respondents for likely or agree; n_5 = Number of respondents for extremely likely or strongly agree; N = Total number of respondents. After mathematical computations, the criteria are then ranked in descending order of their MIS (from the highest to the lowest).

Table 2: Profile of the questionnaire survey respondents

Work experience / **No. of years** / **Designation**	**11-15**	**16-20**	**21-25**	**Above 25**	**Total**
Senior QS	22	14	5	-	**41**
Chief QS	4	11	17	-	**32**
Cost Controller	-	-	6	-	**6**
Commercial Manager			2	-	**2**
Director	-		1	1	**2**
Managing Director				1	**1**
	26	**25**	**21**	**2**	**84**

4. RESEARCH FINDINGS AND DISCUSSION

48 authors revealed a gamut of reasons behind scope creep in road projects. The causes such as plant idling, wastage, incremental changes to design are of frequent occurrence. In the meantime, these scholars recommended nearly 50 tools that are adoptable at site level; broadly classifiable into three mail groups based on the function it serves, namely technical, contractual and commercial. Expert interviewees were requested to map, the first ten scope creep management tools as identified in the order of prevalence, in the literature to the real-life project scenario, together with their measurement scales, which are literally the KPIs in managing costs in road projects. Some tools were identified as being used rarely, some as being used commonly, and others as being used quite frequently. The most prevalent KPIs in managing scope creep are basically variation orders, potential change notices and day work schedules. The perception of 84 respondents who participated in the questionnaire survey was derived in a 5-point Likert scale in order to gauge the effectiveness of KPI (refer Table 3).

The functions ‘contract administration’ ‘earn value management and cost planning are the most effective functions in taming scope creep. The most effective tool of contract administration that gives the highest effectiveness in controlling scope creep is variation log. Net change in scope and potential change notice schedules ranked the second and third in terms of effectiveness respectively. ‘The highest number of KPIs, which is eleven have been identified for the cost management function, interim and final accounting. ‘Mark-up eroded’ and ‘billing analysis’ are the most significant KPIs among them. The KPI ‘cost performance index’ of the function ‘earn value management ‘obtained the highest MWR of 4.950 while the KPI ‘return on investment’ of the function; contingency management’ obtained the lowest MWR of 2.013. A mapping of the first ten KPIs with the highest ever ($\overline{x}$) values recorded in the questionnaire survey is presented in Table 3.

Table 3: Effectiveness of KPIs of each cost management tool

Pf	R	KPIs	$\bar{x}$	σX	R
Contract administration	1	Potential change notices (PCN) approved	4.568	0.856	1
		Net scope change (add and omit schedule)	3.965	0.829	2
		Claimed vs. approved (variations log)	3.850	0.783	3
		Site logbook signed and confirmed	3.560	0.820	4
		Request for information (RFI) responded	3.546	0.747	5
		Approved day work schedule	3.517	0.642	6
		Employer instruction (EI) the cost of which is confirmed in principle	3.442	0.531	7
		Number of rework approved	3.418	0.782	8
		Abortive work schedule approved	3.250	0.653	9
Earn value management	2	Cost performance index (CPI)	4.750	0.782	1
		Schedule performance index (SPI)	4.243	0.834	2
		Cost variance	3.943	0.734	3
		Schedule variance	3.759		4
		Budgeted cost of the work performed	3.724	0.750	5
		Actual cost of works performed	3.452	0.838	6
Cost planning	3	Cost per km	4.750	0.750	1
		Cost limit	4.439	0.820	2
		Cost target	4.129	0.765	3
Cash flow forecasting	4	Cash flow yield	4.320	0.735	1
		Cash flow margin	4.200	0.851	2
Cost value reconciliation	5	Over measure deducted	3.580	0.745	1
		Under measure added	4.002	0.869	2
Schedule perform variance	6	Productivity ratio	4.455	0.745	1
		Efficiency ratio	3.875	0.647	2
		Waiting time	3.900	0.836	3
		Lead time	3.745	0.829	4
		Standing time	3.410	0.683	5
Contingency management	7	Current ratio	2.760	0.870	1
		Burn rate	3.875	0.740	2
		Mean absolute deviation	3.743	0.622	3
Interim/final cost reporting	8	Mark up eroded	3.660	0.551	1
		Billing analysis	3.616	0.772	2
		Contract rate vs. actual rate	3.251	0.693	3
		Variations	3.875	0.781	4

Pf	R	KPIs	$\bar{x}$	σX	R
		Claims	3.799	0.832	5
		Timing of payments	3.560	0.734	6
		Number of variations finalized	3.416		7
		Disputed amount vs. effective contract sum	3.250	0.751	8
		Retention released	3.100	0.830	9
		Percentage of supplier account settled	2.856	0.759	10
		Attendance fees settled	2.564	0.821	11
		Amount of loss recovered	3.650	0.826	12
		Work certified to date	3.620	0.829	13
		Number of claims settled	3.555	0.787	14
Value engineering	9	Cost benefit ratio	3.479	0.827	1
		Advanced milestones	3.200	0.744	2
		Bonus for early completion	3.120	0.652	3
		Reduced preliminaries	3.340	0.531	4
		Enhanced functional value	3.247	0.782	5
		Reduced timing	3.233	0.643	6
Life cycle costing (LCC)	10	Value for money	3.082	0.782	1
		Return on investment	2.930	0.734	2
		Cost benefit ratio	2.884	0.735	3

Pf = Project function, σX = Standard deviation; $\bar{x}$ = Mean item score; R = Rank

5. CONCLUSIONS AND RECOMMENDATIONS

The results of the survey data analysis reveal that KPIs vary according to user's perspective. Further analysis displayed a substantial difference between scholars and practitioners' perceptions. However, ten indicators, the Mean Item Square for which was fallen within the 4 to 5 in the scale reported as being most useful. 'Contract management' is the most significant technique and its most important KPIs are Cost performance index (CPI), Cost per km and Potential change notices (PCN) approved. Experts concluded that most of the KPIs used are post contract lagging measures that do not provide the opening to make any adjustments. The most critical causes are client changes, unforeseen risk and unclear scope. The major effects are delays in project completion time and increasing cost of projects. Hence, it is imperative that a proper scope creep management tool is agreed upfront, constantly monitored and actions taken to avoid it changing in a way that exceed budget and the timescale. As an important contribution, a couple of prescriptions for mitigating the incidence of scope creep has been suggested. Further research could also be carried out to investigate in detail the cost impact of scope creep, in a quantifiable way.

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LEAN DESIGN MANAGEMENT PRACTICES ASSOCIATED WITH STAKEHOLDER MANAGEMENT DURING PRE-CONSTRUCTION STAGE IN SRI LANKA

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ABSTRACT

Lean Design Management (LDM) is a concept, which ensures efficiency and effectiveness of the design stage of a construction project to reduce uncertainty and improve the quality of the final product. Stakeholder Management (SM) is an effective approach for coordinating and managing stakeholders who involve with a construction project to ensure better relationships and reduce the complexity of the project. The integration of LDM and SM concepts together into the pre-construction phase provides a positive impact on the project performance. This paper aims to investigate the lean design management practices associated with stakeholder management in the pre-construction phase of construction projects in Sri Lanka. The research has used mixed method research approach to achieve the aforementioned aim. The research concluded that twenty-nine lean design management practices and eight stakeholder management practices can be integrated into the pre-construction phase in Sri Lanka. The findings further revealed that waste reduction, product performance enhancement, and functionality enhancement can be achieved by integrating LDM and SM practices together into the pre-construction phase in Sri Lanka.

Keywords: *Construction projects; Lean Design Management (LDM); Pre-construction phase; Sri Lanka; Stakeholder Management (SM).*

1. INTRODUCTION

The construction industry plays a major role in the social and economic development of a country (Ofori, 2015). Therefore, effective and efficient management of the pre-construction stage is an important task for the final output (Reifi and Emmitt, 2013). According to Dolage and Perera (2009), management of the pre-construction phase plays an important role in construction life cycle depend on challenges that occur during this phase. These challenges and issues that occur in the pre-construction stage affect the construction life cycle and efficiency and quality of the final output (Daluwatte and Ranasinghe, 2018). Lean Design Management (LDM) is a strategic management tool that the philosophy derived from the lean construction concept to communicate overcomes of the disorderly design process in construction (Mota *et al*., 2019). According to Bourne and Walker (2005), Stakeholder Management (SM) is considered as an effective approach for coordinating and managing stakeholders to keep a good relationship and reduce the complexity of the project.

The effective management of stakeholders on a project is an important area in the project management process (Jergeas *et al*., 2000). In the global context, LDM and lean practices have

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been evaluated through different studies. However, the relationship between SM and LDM in pre-construction phase has been studied only in few researches. Herrera *et al.* (2019) researched to evaluate the relationship between LDM principles and SM practices based on opinions of international experts during the pre-construction stage in Chile, Colombia, and Span. Moreover, that study was limited to investigate the relationships between Koskela's lean construction principles and SM practices during the pre-construction stage. However, there is a gap still not filled related to stakeholder management practices and LDM practices in the pre-construction phase when it comes to the Sri Lankan context. Therefore, the purpose of this paper is to investigate the twenty- nine lean design management practices associated with eight stakeholder management practices that can be used during the pre-construction phase of construction projects in Sri Lanka.

1.1 LEAN DESIGN MANAGEMENT PRACTICES (LDMP)

Lean design management simply describes the way of communicating how to overcome the disorderly design process in lean construction (Herrera *et al.*, 2019). Uusitalo *et al.* (2017) described that LDM concept is based on the lean construction concept, which focuses on two main values called minimising waste, and creating values. Furthermore, Kumar and Abuthakeer (2019) found that new practices, tools, and techniques are implementing to minimise the overcomes of the disorderly design process. Babalola *et al.* (2019) have elaborated lean practices that are applied in the present industry and categorised those practices into four basic categories based on their application in the industry.

Table 1 presents the lean design management tools and practices under four categories.

Table 1: Categories of lean design management tool and techniques

Categories	Lean Design Management Practices and Tools
Design and Engineering Practices	• Virtual Design Construction (VDC): (LDMP1) • Design Structure Matrix (DSM): (LDMP2) • Prefabrication and Modularisation: (LDMP3) • Detailed Briefing: (LDMP4) • Design Workshop or Big Room workshop: (LDMP5) • Integrated Project Delivery (IPD): (LDMP6) • Target Value Design (TVD): (LDMP7) • Standardisation: (LDMP8)
Planning and Control Practices	• Last Planner system (LPS): (LDMP9) • Work Structuring and Scheduling: (LDMP10) • Benchmarking: (LDMP11) • Location- Based Management (LBM): (LDMP12) • Six Sigma: (LDMP13) • Value Based Management/Value Streaming Mapping (VBM/VSM): (LDMP14) • Pull Scheduling/Planning: (LDMP15) • Reduce time: (LDMP16) • Simplify Steps: (LDMP17) • Increasing Flexibility: (LDMP18) • Focus on the Whole Process: (LDMP19) • Increase Transparency (LDMP20) • First run Study: (LDMP29)

Categories	Lean Design Management Practices and Tools
Construction and Site Management Practices	• Visualization tools/Management (VM): (LDMP21) • Teamwork and partnering: (LDMP22) • Total Quality Management (TQM): (LDMP23) • Kaizen: (LDMP24) • Conference management (CM): (LDMP25) • Kanban System: (LDMP26)
Health and Safety Management Practices	• Health and Safety Improvement Management: (LDMP27) • Plan of Conditions and Work Environment or Environmental Management System: (LDMP28)

Source: (Babalola *et al.,* 2019; Herrera *et al.,* 2019)

As elaborated in Table 1, LDM practices can be categorised based on areas of their possible implementation in the design, planning, and construction projects (Babalola *et al.*, 2019). Moreover, each LDM practices is used as strategic solutions to minimise wastage in different situations during the pre-construction stage. However, the identified twenty-nine (29) LDM practices were assessed whether those practices are applying when it comes to Sri Lankan construction projects during the pre-constriction stage.

1.2 STAKEHOLDER MANAGEMENT (SM)

As per Bourne and Walker (2005), stakeholder management is considered an effective approach for coordinating and managing stakeholders to keep a good relationship and reduce the complexity of the project. However, the involvement of stakeholders in the pre-construction stage is considered an important management practice that can provide better management through the whole process (Aapaoja *et al.,* 2013). Molwus *et al*. (2017) have stated that the SM concept is a critical element for the management of construction projects. The review on stakeholder management practices can be summarised under Table 2.

Table 2: Stakeholder management practices during pre-construction stage

Stakeholder Management Practices	Sources
Specialist designers are involved during the early stages of the project. (SM1)	(Knotten *et al*., 2016; Reifi and Emmitt, 2013)
The identification of requirements of the stakeholders: Identified special requirements, technical specifications. (SM2)	(Reifi and Emmitt, 2013; Herrera *et al*., 2019)
Builders are involved during the early stage of the project. (SM3)	(Knotten *et al*., 2016)
The participation of the employer during the early stage and their support to the other stakeholders. (SM4)	(Knotten *et al*., 2016)
The participant of the client during decision making and resolution of problems. (SM5)	(Salgin *et al*., 2016)
The involvement of the consultant party during legal and promissory conditions. (SM6)	(Chinyio and Olomolaiye, 2010)
The involvement of a consultant party during manage external and internal stakeholders who deal with Employer. (SM7)	(Franco and Picchi, 2016)
The design of the product and the construction process are carried out instantaneously. (SM8)	(Herrera *et al*., 2019)

As stated by the above SM practices, each SM practice is mainly applied in the construction industry to enhance the efficiency of stakeholder management procedure during the pre-construction stage. However, above eight (08) SM practices were assessed whether those practices are applying when it comes to Sri Lankan construction projects during the pre-constriction stage.

1.3 IMPORTANCE OF THE IMPLEMENTATION OF LDM AND SM INTO THE PRE-CONSTRUCTION STAGE

LDM is an important management strategy that increases the value of the final output of a construction project (Reifi and Emmitt, 2013). Improving the quality and the value of the project are other key benefits that can be gain through the LDM implementation (Mota *et al*., 2019). Furthermore, LDM is focusing on two main values called minimising waste and creating value to enhance the project performance during the pre-construction stage (Babalola *et al*., 2019). Moreover, LDM concept is being applied as a management strategy in construction projects to enhance project performance (Herera *et al*., 2019).

SM is another important activity that is being used to gain a mutual understanding of the objectives and expectations of all parties (Rajabul *et al*, 2015), Besides, delivering the success of the project is the main objective of SM in construction projects. Walt (2020) has identified SM as an important strategy because it addresses the whole project life cycle to create effective project relationships. Further, SM involves with developing the management planning, engaging and communicating with difficulties of a construction project to ensure the stakeholder expectation and project enhance performance (Walt, 2020).

When both management strategies are considered, only a few researchers discuss about the importance of implementation of both strategies. However, Herrera *et al*. (2019), have identified the importance of the implementation of LDM and SM during the pre-construction through their study. Increasing the final value of the project, reducing the cycle time, reducing the process variability, and increasing the efficiency of the process are the key importance that can achieve from the implementation of the LDM and SM together into the pre-construction stage (Herrera *et al*., 2019). Moreover, Herrera *et al*. (2019) found that LDM and SM are the key areas that affect project performance.

2. RESEARCH METHODOLOGY

The research was initiated with a comprehensive literature review which was included a broad perspective of LDM and SM concepts and their applications during the pre- construction stage. This research used a mixed-method approach as it consists of quantitative and qualitative research approaches. However, data collection was done through semi semi-structured interviews to investigate the level of awareness and importance of the LDMP and SMP in the Sri Lankan construction sector and appraise the relationship between LDMP and SMP in pre-construction phase of construction projects in Sri Lanka. The outcomes were evaluated by comparing with findings and validation through the literature survey to identify the suitability of the LDM practices and SM practices for the pre-construction stage of the Sri Lankan construction. Therefore, the content analysis was selected as the qualitative analysis method to investigate the current lean and stakeholder management practices at pre-construction stage. Finally, quantitative analysis was utilised for the identification of the relationship between lean construction principles and stakeholder management practices at pre-construction stage of the Sri Lankan construction industry.

3. RESEARCH FINDINGS

The semi-structured interviews were conducted with thirty-five (35) professionals who have experience in the pre-construction stage at Sri Lankan construction projects. Respondents were selected using snowball sampling technique. Tables 3 and 4 provide the summary of respondents contacted in data collection.

Table 3: Summary of respondent's profile

	Civil Engineers	Architects	Mechanical Engineers	Quantity Surveyors	Total Number of Respondents
Proportions of respondents	19	8	3	5	35
(%)	(54%)	(23%)	(9%)	(14%)	(100%)

Table 4: Working experience of the respondents

	0-5 Years	6-10 Years	11-15 Years	16-20 Years	21- 25 Years	More than 25 Years	Total number of Respondents
Proportions of respondents	7	14	6	2	1	4	35
(%)	21%	41%	18%	6%	3%	12%	100

3.1 RESEARCH FINDINGS

3.1.1 Awareness of LDM and SM Concepts at the Pre-construction Stage

Table 5 summarised the result of analytical data regarding the awareness of LDM concept and SM concept by the professional who involved in the construction industry and its implementation at the pre-construction stage in the Sri Lankan construction sector.

Table 5: Awareness of lean design management concept and stakeholder management concept

	LDM Concept	SM Concept
Number of respondents having awareness	32 (91%)	34 (97%)
Number of respondents with lack of awareness	3 (9%)	1 (3%)
Total number of respondents	**35 (100%)**	**35 (100%)**

As per the analytical data, 91% of respondents aware of LDM concept. However, 9% of respondents have some understanding despite a lack of experience regarding LDM concept. Furthermore, 91% of respondents aware of the SM concept. However, 3% of respondents have some understanding despite lack of experience regarding SM concept.

3.1.2 The Relationship between SM Practices and LDM Practices

To investigate the SM practices, their relationship with the twenty-nine (29) LDMP were investigated through semi-structured interviews. The opinion of 35 respondents was used to appraise whether the SM and LDM practices have a strong (complete) relationship, a partial relationship or relationship was non-existent.

The descriptive analysis was used as the analysis technique for this study. The mean value of the 35 respondent's answers was used to assess the relationships between these two variables.

$$Mean\ Value = \Sigma xi \div n \qquad (01)$$

According to the results, each relationship was assessed through the rules given in Table 6.

Table 6: Nature of the relationships

Mean Value	Nature of the Relationship
Mean Value = 0 - 0.5	Non-existing relationship
Mean Value = 0.50 - 1.50	Partial relationship
Mean Value = 1.50 - 2.00	Strong (Complete) relationship

There were 232 possible SM and LDMP relationships were assessed under this study. When these 232 possible were assessed during interviews, 55 possible had strong (Complete) relationships, 145 had partial relationships, and other 32 did not have any relationships. The number of total connections between SMP and LDMP were 200 (including both partial and strong relationships), which accounted for 86.21% of all potential relationships. In addition to that, when considering all potential relationships, 27.50% were complete relationships, and 72.50% were partial relationship. Figure 1 shows the number of LDMP that each of the SMP contributed to relationships.

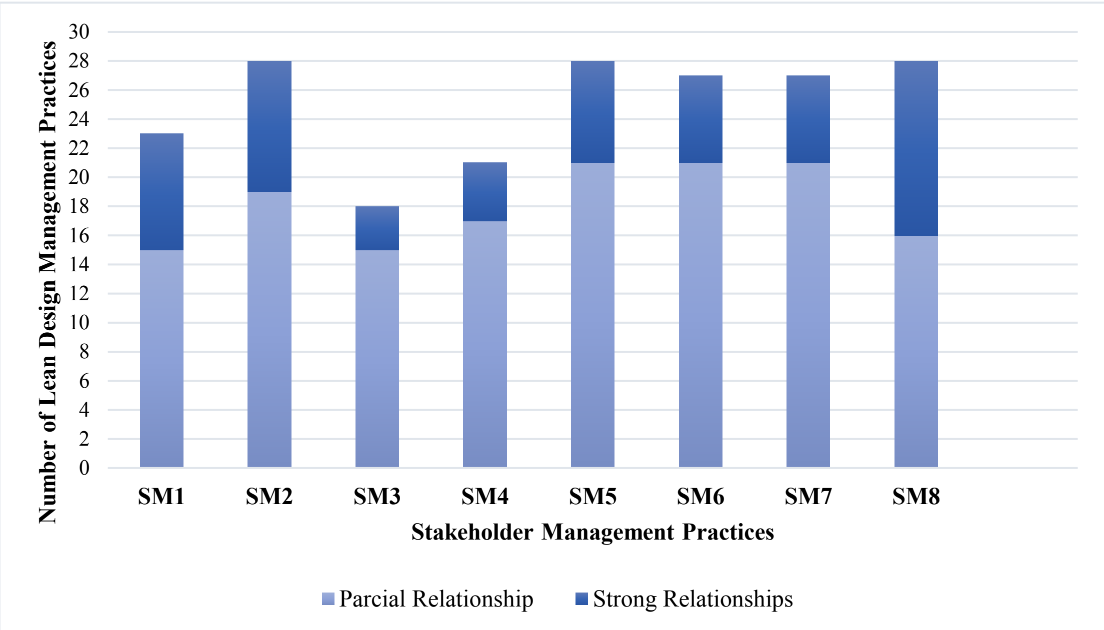

Figure 1: The number of LDMP that each of the SM practices contributed to relationships

On average SM practices were subjected to as a minimum 18 LDMP, and a maximum of 28 out of 29 LDMP that were assessed during the data collection procedure.

3.1.3 Complete Relationship between SM and LDM Practices

The judgement of 35 respondents regarding 232 possibles between these two variables was used to validate the relationship between LDM practices and SM practices. However, the mean value of those answers was used to establish the relationship between LDM and SM practices. As per the result of the analysis, there was a complete (strong) relationship for the 55 possible among 232 of total possible that had been assessed during the study. The association of 55 complete relationships was separated into eight SMP and it could be presented as the node diagram. Figure 2 shows the strong relationships between SMP and LDMP compactly as a node diagram.

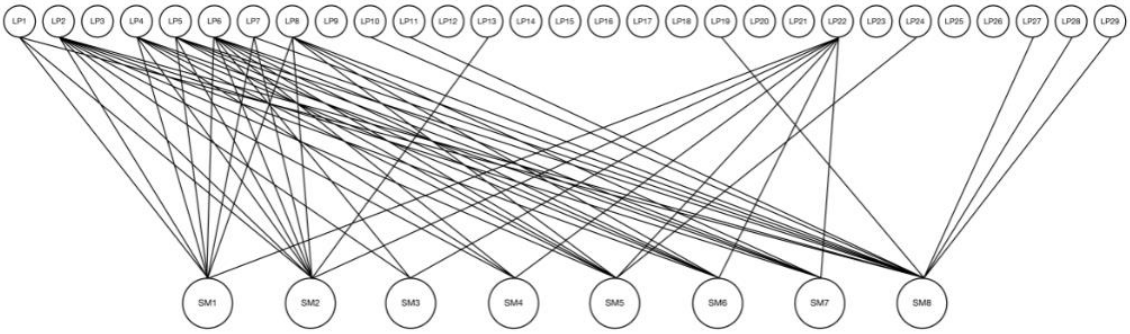

Figure 2: Strong (complete) relationships between SM practice and LDMP

On average, the involvement of builders during the early stage of the project (SM3) is the SMP that shows the least complete correlation with LDMP during the pre-construction stage. It has built up complete relationships with three LDMP namely Design Structure Matrix, Integrated Project Delivery, and Teamwork and Partnering. According to the study, the design of the product and the construction process are carried out instantaneously (SM8) is the SMP that has shown a complete relationship with more LDMP when comparing to other SM practice variables. SM8 had associated with twelve LDMP during the pre-constructions stage according to the node diagram. Virtual Design Construction, Design Structure Matrix, Design Workshop or Big Room workshop, Integrated Project Delivery, Target Value Design, Standardisation, Work Structuring and Scheduling, Benchmarking, Focus on the Whole Process, Health and Safety Improvement Management, Plan of Conditions and Work Environment or Environmental Management System, and First run Study were associated LDMP with SM8. When considering other SMP, SM6 and SM7 built up strong relationships with six same LDMP. In addition to that SM1, SM2, SM4, and SM5 build up complete relationships with eight, nine, four and seven LDMP.

3.1.4 Partial Relationship between SM and LDM Practices

145 partial relationships shown in the node diagram had been briefly described here based on each SMP that are applied pre-construction stage in Sri Lankan construction projects.

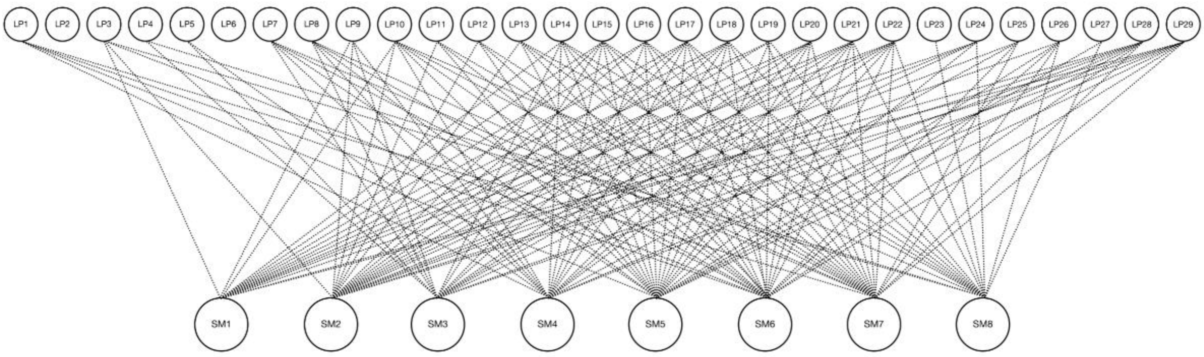

Figure 3: Partial relationship between LDMP and SMP

According to Figure 3, SM5, SM6, and SM7 are the SM practices that have shown partial relationship between more LDMP comparing other SM variables. These three variables are associated with 21 LDMP during the pre-construction stage. On average, SM1 and SM3 are the SM practices that shows the least partial correlation with LDMP during the pre-construction stage. These variables built up partial relationships with 15 LDMP. Furthermore, SM2, SM4 and SM8 build-up partial relationships consecutively 19, 17 and 16 LDMP.

3.1.5 Possibility of Implementation of LDMP into SM Practices at the Pre- construction Stage

The possibility of implementation of each LDMP into SM practices at the pre-construction stage could be assessed by using the outcomes from the descriptive analysis. Further, the possibility of implementation of LDMP could be assessed through two categories namely LDMP, which has a strong capability of implementation and LDMP, which has a partial capability with implementation. The probability was calculated considering both the partial and complete relationship that SMP built up with LDMP.

$$\textbf{P-value} = \frac{\textbf{Number of relationship associated with each LP}}{\textbf{Total relationship possible}}$$

Table 7 has comprised the probability of integrating LDMP into SM practices strongly and partially during the pre-construction stage.

Table 7: Probability of integrating LDMP into SM practices during the pre-construction stage

Lean Design Management Practice	Probability of implementation completely	Probability of implementation partially
Virtual Design Construction (VDC)	0.015	0.020
Design Structure Matrix (DSM)	0.040	
Prefabrication and Modularisation		0.025
Detailed Briefing	0.030	0.010
Design Workshop or Big Room workshop	0.030	0.010
Integrated Project Delivery (IPD))	0.040	
Target Value Design (TVD)	0.015	0.025
Standardisation	0.030	0.010
Last Planner System (LPS)		0.035
Work Structuring and Scheduling	0.005	0.020
Benchmarking	0.005	0.020
Location-Based Management (LBM)		0.025
Six Sigma	0.005	0.035
Value-Based Management/Value Streaming Mapping (VBM/VSM)		0.040
Pull Scheduling/Planning		0.035
Reduce time		0.040
Simplify Steps		0.040
Increasing Flexibility		0.030
Focus on the Whole Process	0.005	0.035
Increase Transparency		0.040
Visualization tools/Management (VM)		0.040
Teamwork and partnering	0.035	0.005
Total Quality Management (TQM)		0.025
Kaizen	0.005	0.020
Conference management (CM)		0.025

Lean Design Management Practice	Probability of implementation completely	Probability of implementation partially
Kanban System		0.010
Health and Safety Improvement Management	0.005	0.035
Plan of Conditions and Work Environment or Environmental Management System	0.005	0.035
First run Study	0.005	0.035

According to the probability values that have been presented in Table 7, majority of LDMP have more possibility to associate partial implementation with SM practices during the pre-construction stage in Sri Lankan construction projects rather than complete implementation. When the 29 LDMP were considered used for the research, there were 17 LDMP, which have the considerable capability of the partial or complete implementation with SM practices during the pre-construction stage at Sri Lankan construction projects. However, there is a considerable possibility for the implementation of LDMP with SM practices during the pre-construction stage.

3.1.6 Importance of Implementing LDMP with SM Practices during the Pre-construction Stage

Increasing the value and the quality of the design minimising errors, reducing unnecessary cost and time that is allocated to design procedure, providing flexibility for the design based on the requirement, increasing project coordination, identification of construction difficulties, and minimising them during pre-construction stage could be identified as the key benefits of integrating LDMP into SM. On the other hand, reducing the process variability, increasing the final product value through systematic consideration of client's requirement, reducing cycle time, reducing the non-value activities, increasing the process transparency, and continuous improvement process were identified as the other benefits that can be gained from the integration of LDMP into SMP during the pre-construction stage.

The respondents who have more experience with the construction industry emphasised that even if LDMP and SM are currently existing as management practices in Sri Lankan construction projects, the professionals do not have considerable knowledge on the implementation of those practices with construction projects. On the other hand, construction professionals reluctant to adopt the new concept that is coming to the Sri Lankan construction sector. Therefore, the professionals have a lack of experience and knowledge regarding new concepts that can provide considerable value to the construction sector. In summary, the majority of construction professionals have applied LDMP and SM practices during the pre-construction stage without knowing them as LDMP and SM practices due to a lack of theoretical knowledge that the professionals have. Therefore, the majority of the respondents described the importance of guiding professionals who involve with a construction project to enhance both theoretical and practical knowledge. However, according to the opinion of the respondents, it will be required to provide training regarding important management practices such as LDM and SM practices that have considerable capability to enhance the effectiveness and efficiency of the pre-construction process in the Sri Lankan construction sector.

4. CONCLUSIONS

In this study, 29 lean design management practices and eight (08) stakeholder management practices were identified under literature synthesis. These practices were assessed during the data collection procedure for achieving the aim of the research. However, due to time constraints, the scope of the research was limited to appraise the relationship between LDM practices and SM practices at pre-construction stage.

As per the viewpoint of experts, there is a 70% possibility of implementation of LDMP during the pre-construction stage and an 82% possibility of implementation of SM practices during the pre-construction stage when it comes to the Sri Lankan context. The implementation of LDMP during the pre-construction stage ensures the efficiency and effectiveness of a construction project by minimising waste and increasing the quality of a project. On the other hand, SMP provide a lower probability of developing the poor design through the better coordination of the stakeholders. Moreover, when considering the relationships between LDM and SM practices, there was a 61.64% possibility for integrating both variables during the pre-construction stage. These relationships have build-up under two categories called strong relationships and partial relationships. According to the results from the analysis, LDMP had a considerable possibility to create a partial relationship with SM practices rather than strong relationships.

When the Sri Lankan context is considered, numerous benefits can be gain through this implementation. Increasing value and the quality of the design, reducing unnecessary cost and time that is allocated to design procedure, providing flexibility for the design based on the requirement, and increasing project coordination were identified as main benefits of the implementation. Conversely, the implementation can influence the efficiency and effectiveness of the final output. However, though there is progressive earnest for implementing LDM into the pre-construction stage, the majority of construction professionals have a lack of awareness and poor earnestness with the implementation of LDM into the pre-construction stage. Therefore, the experts have focused on preparing the strategical process for implementing LDM into the pre-construction stage to increase productivity and minimise the complexity of the process in Sri Lankan construction projects.

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LIFE CYCLE COSTING IN CONSTRUCTION: CURRENT TRENDS AND EMERGING DIRECTIONS

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ABSTRACT

The current construction climate in the UK is moving forward with a much greater attention on cost certainty, sustainability and adoption of innovative technologies. The UK Construction Strategy 2025 provides a clear direction towards achieving such goals by 2025. Life Cycle Costing (LCC) is one of successful techniques for identifying the total cost of ownership in construction assets. Even though the technique has 50 years of history, the application and the diffusion of the technique within the construction domain is comparatively limited. Therefore, this study aims to investigate the evolution and current status of LCC within construction context through Bibliometric Analysis of journal publications indexed in Web of Science database (1970-2020). A series of Contents Analyses was performed and visualisation maps were generated via VOSviewer. The findings proved that LCC has been absorbed into construction in late 90's and there is a continuous rise in the global uptake from 2013 onwards. With limited budgets and growing demand for sustainability, an integrated methodology linking LCC, Life Cycle Assessment and Performance optimisation is apparently the way forward for LCC.

Keywords: *Life Cycle Costing; Construction; Bibliometric Analysis; New Directions.*

1. INTRODUCTION

The UK Government's strategic vision, 'Construction 2025' (Her Majesty's Government, 2013) emphasised the need for all construction companies to strive to meet the reduction of 'project time by 50%'; 'LCC by 33%' and 'emissions by 50%' by 2025. LCC has gained a positive momentum within the UK construction industry with the introduction of the above-mentioned targets. LCC is defined as the 'cost of an asset, or its parts throughout its life cycle, while fulfilling the performance requirements' (BS ISO 15686-5, 2017). The appropriateness of LCC in economic evaluation has been acknowledged within the literature. Cole and Sterner (2000) argue that the notion of LCC is generally recognised as a valuable approach for comparing alternative building designs, thereby enabling operational cost benefits to be evaluated against any initial cost increases. However, barriers have been attributed to the relatively low adoption rate of LCC, in spite of the number of advantages of the method. Lack of data, awareness of clients, methodology and standardised practices in relation to LCC have hampered quantity surveyors in its limited use. Even though the lack of standardisation of data

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from various companies is at the core of the issue, ISO 15686 standard exists for sustainability data for use in construction life cycle cost analysis. However, the users either do not follow the standard or feel that does not fully encompass the requirements to make full use of LCC.

Even though the technique LCC had featured in construction education over last 50 years, its application is seemingly very limited. Therefore this study aims to investigate the current trends and emerging directions of LCC.

2. LITERATURE REVIEW

2.1 LIFE CYCLE COSTING IN CONSTRUCTION

Life Cycle Costing (LCC) is a technique that is now perceived as a "driver" for construction change. It determines the total expenditure of a project by measuring and analysing the construction, maintenance and operational elements of an asset during the asset's through life (Dell'Isola and Kirk, 2003). LCC is mainly perceived in literature to predict cash flows and to provide an option appraisal, whilst allowing for the monitoring of costs and calculations of predicted future operational costs to an asset (Kelly and Hunter, 2009). The process involves the development of a plan, selection of LCC model, implementation of LCC model, recording and reviewing the results (Stanford University, 2005). LCC is a branch of Whole Life Costing (WLC) where WLC is defined as a systematic consideration of all relevant costs and revenues associated with the acquisition of an asset over a period of analysis as defined in the agreed scope (BS ISO 15686, 2017).

The current construction climate is in need of a robust methodology that would analyse the total cost of ownership of construction assets. Schneiderova-Heralova (2017) argues that the nature of construction industry itself is to aim for a lower acquisition cost. In a way, LCC could help to overcome this issue, with its perceived ability to enable a long-term assessment into the associated options to a building (Higham *et al*, 2015). In this respect, LCC allows better financial decisions to be made by considering all the relevant costs of an asset (Kelly and Hunter, 2009). Hence LCC is becoming a more dominant term within the current construction context (Kehily and Underwood, 2017). However, Bescherer (2005) and Kirkham (2014) explained that firms were only utilizing the initial cost of an asset, with very little consideration given to identifying the LCC of a project, leaving this issue to a "later date". Evidently the general pattern of costing in construction industry has primarily focused on CAPex (capital expenditure), ignoring the implications of OPex (Operational expenditure) (Ashworth *et al*, 2013).

The application of LCC in early stages of construction (pre-construction) will provide 70%-90% of cost certainty for OPex (Korpi and Ala-Risku, 2008), consequently reducing the risks (Boussabaine and Kirkham, 2008). LCC can therefore, significantly define the success of a project as it incorporates all the costs associated with the project through life. Literature further evidences the diverse applications of LCC including its ability to perform as a decision support tool (Meng and Harshaw, 2013; Gluch and Gustafsson, 2015; Minhas and Potdar, 2020), enhance sustainability (Caplehorn, 2012; Alaloul *et al,* 2021), and ensure value for money (Swaffield and McDonald, 2008). However, majority of research on LCC concerns tool modelling and development, and surprisingly few studies pay interest into how practitioners perceive the usefulness of the tools developed (Goh and Sun, 2016).

LCC integrates several mathematical calculations that help to identify the future costs (Flanagan *et al*, 2005). The methods, Annual Equivalent Cost; Net Present Value; Payback Method; Net Savings; Internal Rate of Return and Savings to Investment Ratio are quite common methods that are used within LCC (RICS, 2016). However, these calculations are perceived by many professionals to be complex and confusing (Kehily and Underwood, 2017), requiring expertise knowledge and have been associated with interoperability issues (Ive, 2006). The awareness of LCC is currently growing at an exponential rate. However, Olubodun *et al.* (2010) concluded that even though construction specialists were aware of the perceived benefits utilised by LCC, many were still reluctant to use the methodology. Fortune and Cox (2005) further stated that professionals have been slow to adopt LCC practices as a core tool for the estimations of early stage evaluations of a project. This issue of relatively low LCC implementation is noted as a current trend in literature, thereby the highlighting the need to assess the usability of LCC (Bull, 2015). Oduyemi *et al.* (2014) identified that lack of access and reliability of data, lack of standardisation and guidance documents and lack of awareness amongst construction clients as the key reasons for slow adoption of LCC within construction. Arguably, Perera *et al.* (2009) stated that although there are sufficient standards and tools available for undertaking the LCC, more attention is needed in training and understanding of the approach.

3. RESEARCH METHOD

Even though the demand for LCC within construction is noted, the real implementation of the technique within the practice is still limited. Literature underlines the benefits and challenges of LCC in construction however there is no clear reflection on the current status and directions of LCC. Hence, Bibliometric Analysis (Jonkers and Derrick, 2012) was used to understand the current status of the LCC and how the construction domain has acknowledged and reflected the term during the last 50 years. The journal publications on LCC available in the Web of Science database (Core Collection) have been accessed and data filtration and iteration processes were undertaken to identify the correct sample of literature. The data were analysed to understand the patterns, generate visualisation maps through Microsoft Excel 2016, Web of Science platform and VOSviewer software. The data collection was limited to Web of Science records.

4. DATA COLLECTION, ANALYSIS AND DISCUSSIONS

The data collection process followed a two staged approach. Firstly, the publications related to LCC within the field of Construction Engineering and Management during the last 50 years were retrieved. Secondly, the literature screening was undertaken to identify the relevant publications for this investigation.

4.1 LITERATURE RETRIEVAL

A list of publications available on Web of Science (Core Collection) in the area of Life Cycle Costing was retrieved on WoS platform. The term “Life cycle costing” was searched in all fields during the last 50 years (1970 - 2020). The total of 30,564 publications were retrieved belonging to the fields of Civil Engineering, Building Construction, Material Science, Transportation, Energy, Oil and Gas, Agriculture and other industries.

4.2 LITERATURE SCREENING PROCESS

As the study was focused on the current status of LCC within the field of Construction Engineering and Management, the filters ‘Building Construction’ and ‘Civil Engineering have been adopted. Due to the large number of publications the study was narrowed down to Journal articles only. This reduced the total number of journal publications to 2,912 (Civil - 2,053; Building - 859). The chronological development of publications related to LCC during the last 50 years have been plotted in Figure 1.

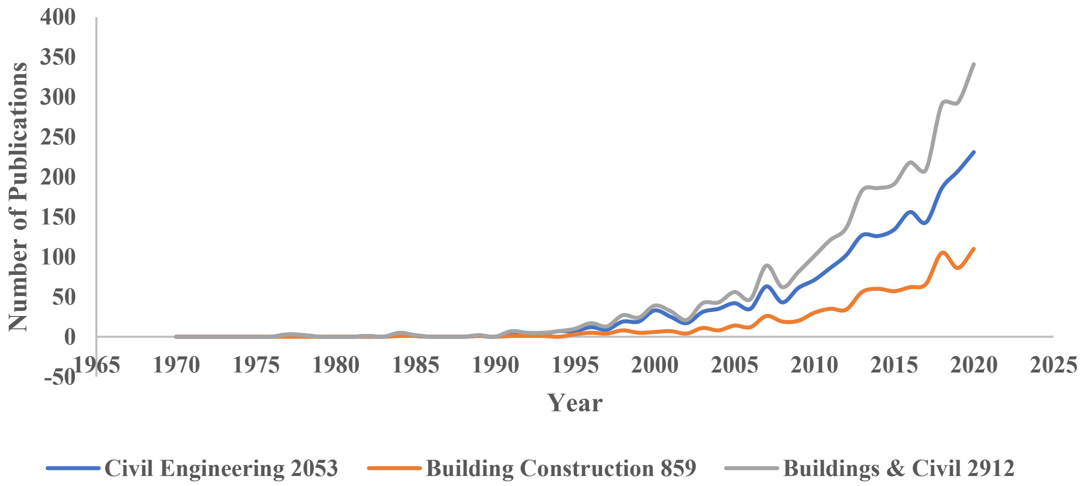

Figure 1: Chronological developments in LCC (number of journal publications)

The findings illustrate that the term "LCC" has first appeared in scientific literature in the early 70's and then a gradual rise in number of publications from early 90's. A sharp increase was observed since 2013. With reference to Ashworth (2004, p.29) chronological development in building economics, the term "cost in use" first entered into the UK Quantity Surveying practice in early 70's and the term "LCC" has been formally introduced in early 80's.

Having studied the pattern of publications, a positive increase in the number of publications related to LCC in construction context is noted from early 90's onwards. It can be assumed that due to the increased recognition given for the built environment discipline within higher education institutions, where it shifted from a purely traditional vocational focus to a more academic focus, provided more opportunities for research in built environment. In the UK, there was an increase in the number universities as majority of Polytechnics were upgraded into University Charter (post 92 universities). This upgraded institutional recognition enabled more opportunities and resources for research including more access to Government and Industry funding.

The emergence of integrated procurement approaches such as PPPs is another influential factor for the identified positive trend in LCC. The traditional relatively short term-based silo approach has been shifted to a more life cycle phase-wise integrated (Design and Build; Public Private Partnerships, Framework Arrangements) approaches, with improved client awareness on OPex considerations. On the other hand, the Government policies (Construction 2025, Procurement Policy, 10 Point Plan) also pushed-forward the LCC implementations within UK context. A positive uptake in LCC can be expected with the introduction of International Construction Measurement Standards, which provides a global consistency in presenting the LCC data.

4.3 GENERATING THE VISUALISATION MAPS

To provide an in-depth analysis of the current status of LCC within the construction context, four types of visualisation maps were generated via VOSviewer. In general, each circle of the map represents a term (node), and the size of the circle and font represent the activity of the term. The larger the circle and font size, the more active the term is in the field, and vice versa. The distance between any two terms in the diagram represents the degree of association between the two terms. The shorter the distance between the two terms, the stronger the correlation and vice versa (Van Eck and Waltman, 2020).

4.3.1 Co-occurrence Map Based on Text Data

The terms that are frequently apparent and their allied sub terms were identified by analysing the text data of the journal articles. This approach helps to detect any pattern of development in LCC (new terms, impactful terms etc). Total of 39,836 terms were created. However, having carefully examined the generated terms, the most relevant terms specific to LCC were further screened. As a result, a total of 216 appropriate terms were selected. In combining the criteria of "frequency of occurrence" and the "relevance" the most impactful terms are illustrated in Figure 2.

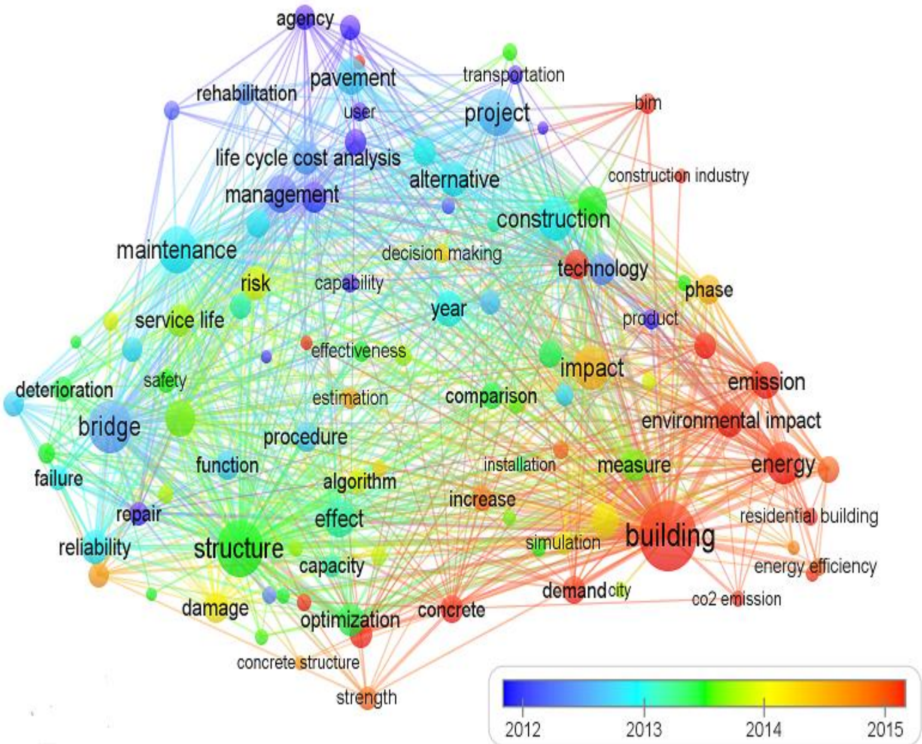

Figure 2: Co-occurrence of text data related to LCC

Civil Engineering represents an amalgamation of individual structures (roads, bridges, pavement etc) hence does not feature as a term in itself. However, the term 'Building' does appear on its own, hence is displayed as the most impactful term.

Having aligned those generated terms with the timeline (2012 - 2015) it is evident that the terms 'buildings', 'energy', 'technology', 'environment impact', 'CO_2 emission' etc (where coloured in red) appear as the recent trend in LCC. The term 'LCC' has been isolated from the visualisation map illustrated in Figure 2 and studied further to identify the terms that are directly linked with the LCC (Figure 3).

The findings evidenced that high number of publications in relation to LCC have been produced during the period of 2012-15. The recent applications of LCC can be seen in buildings, energy, and materials sectors and some strong development in technology also noted (coloured in red). Apparently, there is a very strong connection between LCC and "risk". In a way the visualisation map provides some valid information on the LCC application in product level (buildings, roads, bridges etc), and elemental level (structures, pavement etc) and sub-elemental levels (steel, concrete etc). Moreover, publications are well focused on through-life applications of LCC (design, construction, maintenance, operational, rehabilitation etc) and also on its usability in areas of alternative analysis, cost and energy efficiency and performance optimisations.

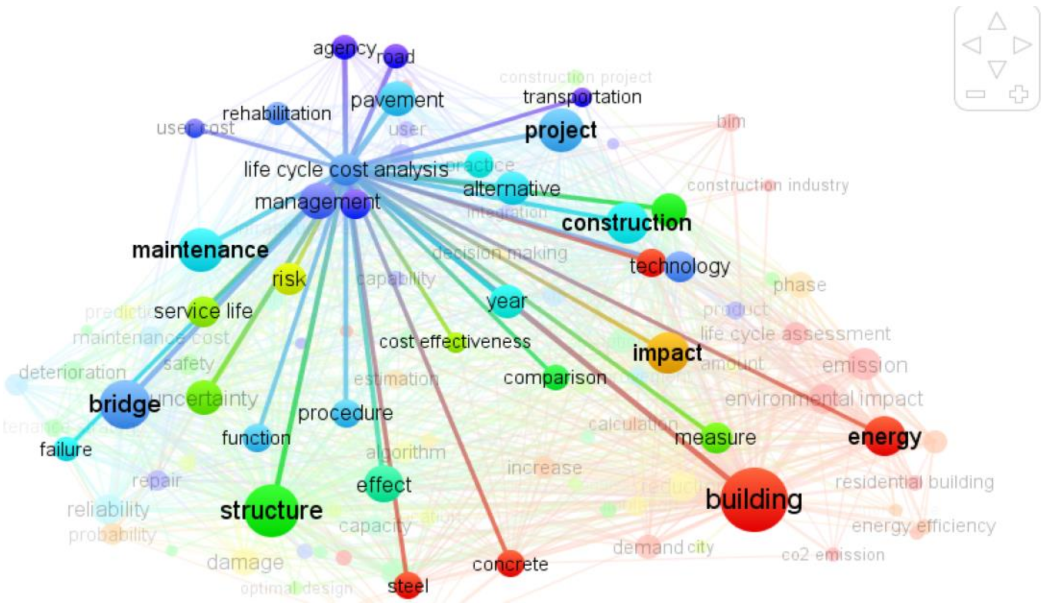

Figure 3: Terms directly connected with LCC

4.3.2 Co-occurrences Map Based on Keywords

The co-occurrence map of keywords was used to identify the top 10 keywords related to LCC (Figure 4). In fact the recent publications are moving towards the dimensions of sustainability, performance and integrated approaches like lifecycle assessment. The ‘design’, ‘optimisations’ and ‘reliability’ maintain strong links with the term LCC.

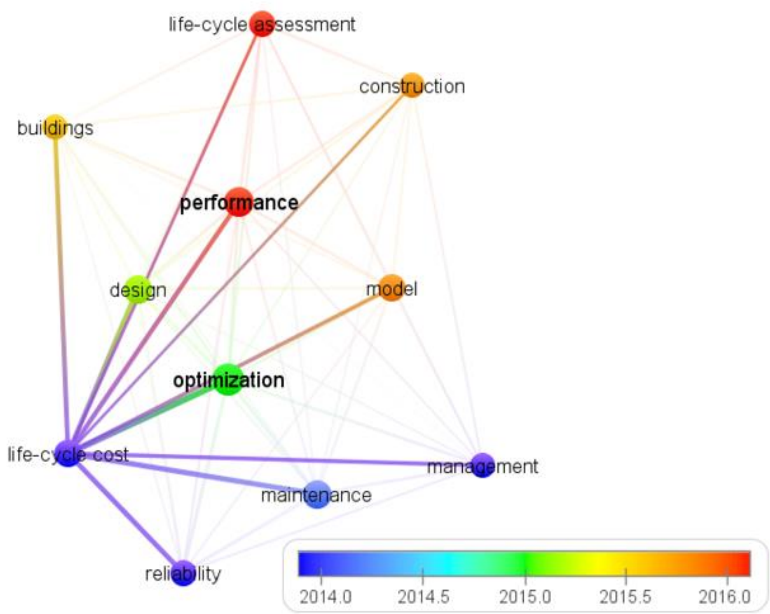

Figure 4: Co-occurrence map of keywords

This analysis also demonstrates that the term LCC has gained popularity since 2014 with its allied keywords ‘maintenance’, ‘management’ and ‘reliability’. Many research were aimed at understanding the maintenance and management aspects of LCC and also the reliability of the technique. During 2015, the application of LCC within buildings and construction is noted and sufficient attention was given in model developments. The recent past was more focused on integration and the performance. With the limited budgets and growing demand for sustainability, an integrated methodology linking LCC, life cycle assessment and performance optimisation seems to be a recent trend in LCC.

4.3.3 Co-occurrence Map Based on Country of Co-Authorship

Data analysis also identified the geographical spread of the publications. The visualisation map was generated for country of co-authorship by allowing a minimum number of documents of country into 10. Of the 82 countries, 40 met the threshold and findings are illustrated in Figure 5.

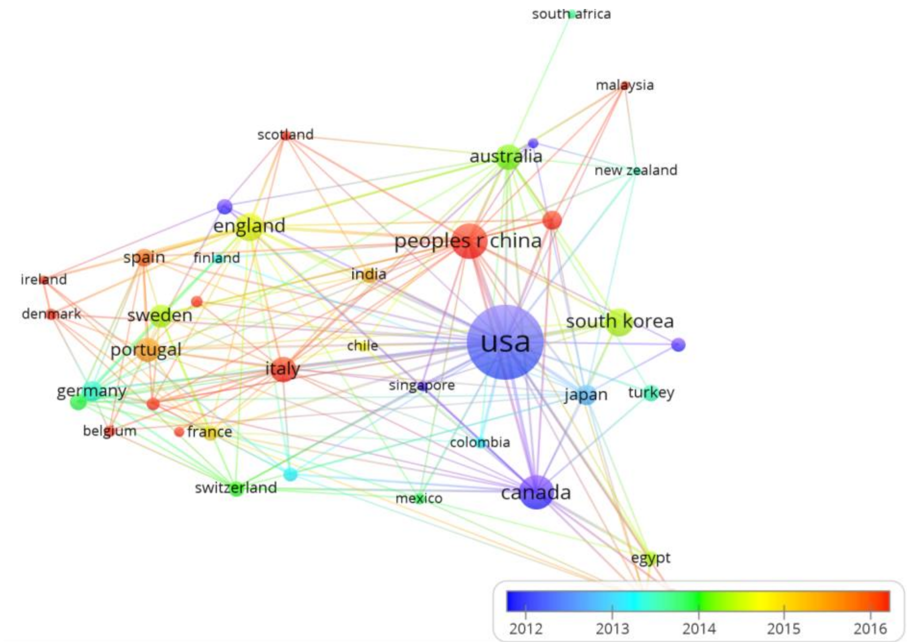

Figure 5: Country of co-authorships

Most publications appeared in the North American context (USA, Canada), followed by China and UK (England, Northern Ireland, Scotland, nothing from Wales). It was further noted there is a growing popularity of LCC in China and other EU countries (Italy, Span, Denmark, France, Belgium etc).

Being the country of origin for LCC, the USA has a recorded number of publications. In general, there is a continuous growth within North American context (including Canada). With a substantial increase in in built environment infrastructure and related higher education institutions, the People's Republic of China also produced a notable number of publications in LCC. Being a major research hub for built environment research, the UK (England, Ireland, Scotland, Wales) is placed in fourth position, and current trend in LCC is more visible in EU countries too. However, there is no clear evidence on the number of publications in other languages in relation to LCC, hence it is difficult to provide an overall conclusion in this regard.

4.3.4 Co-occurrence Map Based on Sources

The co-occurrences map of journals of the publications was also performed. Here minimum number of citations per source was limited into 5 as this will provide assured credibility of the publication. From a total of 229 sources (journals) 80 met the threshold, and findings are presented in Figures 6 and 7.

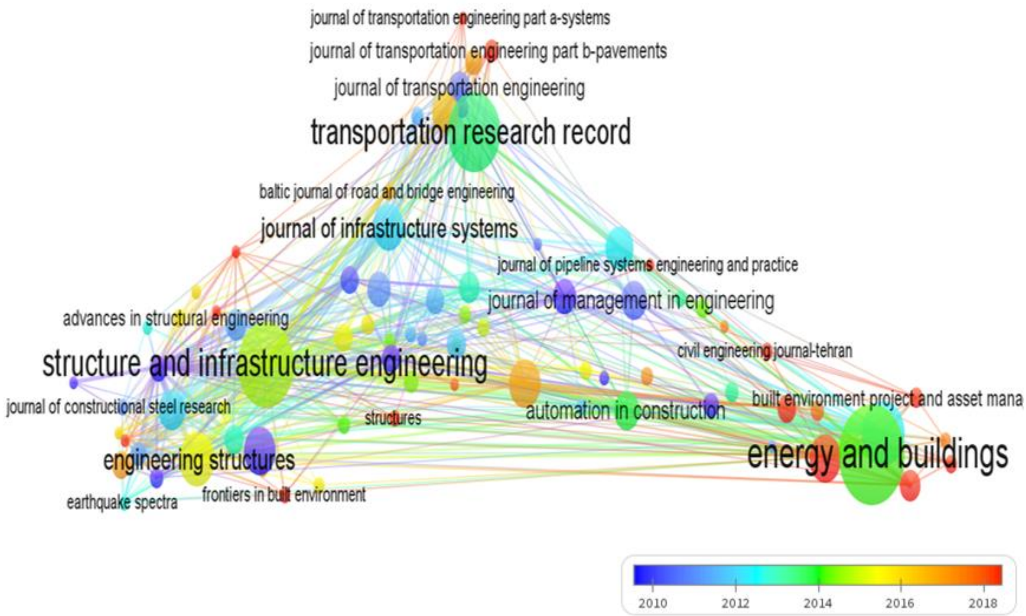

Figure 6: Co-occurrences of sources

The 80 sources were categorised under three main clusters; 'Buildings and Energy', 'Engineering and Infrastructure' and 'Transportation'. High number of publications appeared in the journals of 'Energy and Buildings' (214), 'Structure and Infrastructure Engineering' (156) and 'Transport and Research Record' (141). Majority of the recent publications (2018) appeared in the journals within the built environment disciplines. Therefore, the cluster 'Buildings and Energy' is enlarged and illustrated in Figure 7.

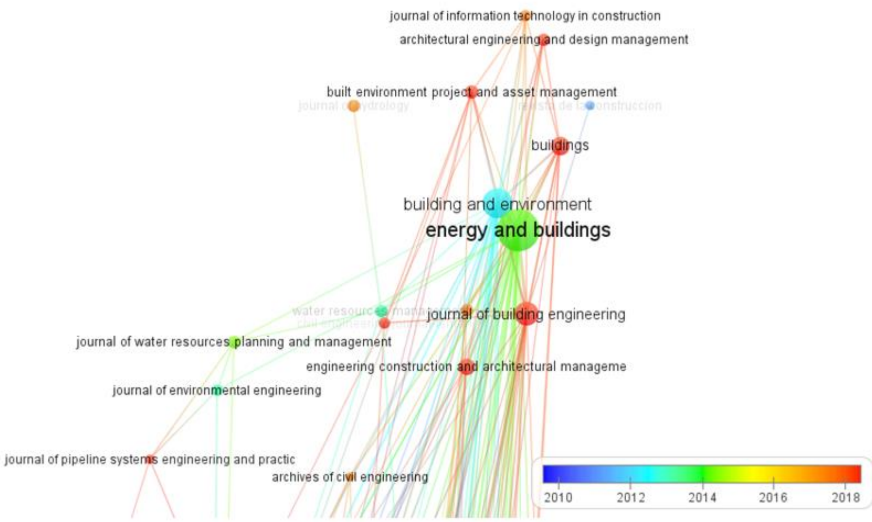

Figure 7: Sources of LCC publications within built environment discipline

Some of such journals are 'Buildings', 'Journal of Building Engineering', 'Architectural Engineering and Design Management', 'Engineering Construction and Architectural Management', 'Built Environment Project and Asset Management' entail most of the recent publications (2018 - nodes in red).

From the analysis of sources, it is evident that LCC in Civil Engineering and Buildings are still popular within Construction Engineering and Management discipline. However, the selective approach of Web of Science produces a curated collection of documents, and as a result some journals that are not indexed within the WoS may not have been selected, thereby omitting a large number of publications in the field.

5. CONCLUSIONS

The study focused on understanding the current status of LCC in construction context. Bibliometric analysis was performed by using the published materials on LCC over last 50 years. A gradual rise in number of publications since 1990, and by 2020 a sixfold increase is noted. In the UK context the Government mandate (Construction Strategy 2025) and new procurement approaches are seemingly the two of influential reasons for the underline popularity of LCC. With the introduction of International Construction Measurement Standards in 2017, which aims to provide global consistency in reporting LCC cost data, the technique gained much more attention in the global context. The findings demonstrate that there is still a significantly high focus for LCC within the construction domain. However, the attention has shifted from conventional LCC to more integrated approaches focusing on "Sustainability" including energy, zero carbon, waste management, circular economy etc. Moreover, the findings evidenced that the future direction of the LCC is more towards enhancing/optimising the performance of LCC while achieving the UN Sustainable Development Goals. Limitations of the study are acknowledged due to the fact that the data was gathered from a single database (WoS), hence further studies are needed for a more inclusive approach and analysis.

6. REFERENCES

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MANAGING CONCRETE WASTES BY IMPLEMENTING CONTEMPORARY CONSTRUCTION PRACTICES IN SRI LANKA

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ABSTRACT

Material waste is one of the main reasons for the client to suffer due to increments in unnecessary costs. Among all construction material wastes, concrete waste highly draws expenses to the project stakeholders. As a main component in construction, the volume of the concrete waste in Sri Lankan construction projects are considerably high, when comparing with the other material wastes. Currently, most of the countries are moving towards the sustainable developments while minimizing concrete waste. Therefore, applying traditional practices to minimize concrete waste have not been successful over the years. The aim of this research study is, to minimize concrete wastes by implementing contemporary practices that assists to reduce the project cost in Sri Lankan construction industry. In order to achieve the aim, comprehensive literature review, a questionnaire survey and semi-structured interviews were conducted to gather data in both qualitative and quantitative procedures. The empirical findings revealed that concrete waste has a positive relationship with the project cost. Same time, discovered the drivers and barriers that gains while implementing contemporary practices in Sri Lanka. Concrete recycling, precast elements, lean construction techniques, value engineering methods and few more other contemporary practices were identified that leads to minimize concrete waste. The results from the interviews found that many projects are willing to implement mentioned contemporary practices within their construction projects although there are few barriers. These findings deliver a valuable evidence to the practitioners with an in-depth understanding about the essential necessity of contemporary practices to construction projects.

Keywords: *Concrete waste; Construction industry; Contemporary practices; Drivers and barriers; Sri Lanka.*

1. INTRODUCTION

As a unique field, construction industry comprises of wide range of activities that includes the erection, repair, and demolition of all types of buildings and civil engineering structures. Generally, this industry embraces different types of construction activities that will be carried under namely by "Projects". Project represents a discrete piece of work with a clear start and finish dates, providing specified benefits at the accepted cost (Harris and McCaffer, 2005). To choreograph above mentioned construction activities the involvement of the stakeholders is essential, who are the ones that gain the benefits and have the interest in the final product, by taking part directly or indirectly to complete the project in a successful manner. In order to successfully complete the project, there is the most important factor called as 'Project Characteristics', which need to be considered by the stakeholders. In construction, there are

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three main project characteristics as Time aspects (speed construction), Cost aspects (level of price), and the Performance (quality of the final product), which are essential to be fulfilled in order to complete the project successfully.

Material, Labour, Plant and Machineries are the main inputs or the resources in the construction project. Both during the construction and demolition creates a large percentage of waste (Richardson *et al.*, 2010). Material waste has been recognized as a major problem in the construction industry. Construction Industry consumes relatively a large volume of material, which has been wasted due to various number of reasons. It can be due to labour attitude towards the material, labour arrangement, and lack of knowledge in reusing the material and the use of new techniques as; value engineering and lean construction techniques within the construction industry. Every year, most of the countries are send these material wastes to landfill instead of being reused and recycled for new construction. To go for the stated aims and targets, it is essential to maintain a proper management within the project for resource handling.

The problem arising out of this waste directly influences the project characteristics. Among this material waste, 'Wasting Concrete' take a great percentage that needs a significant attention. The cost relates to this concrete waste, directly creates an unnecessary expenditure for the Employer's budget. Concrete is used in many ways by most of the countries, which mainly acts as an alternative for the recycled aggregate in construction (Silva *et al.*, 2014). The main problem raised in the concrete waste directly relates to the human behaviour, their attitudes and as well as the arrangement of the work activity. Saunders and Wynn (2004) found that, the attitudes towards the waste minimization among labour and the other contracting parties in the construction is also an issue for this concrete waste. At the same time, Formoso *et al*., (2002) stated that the deviation in the dimensions of cast-in-place elements (slabs, columns, and beams) and also excessive thickness of slabs is one of the main issues that leads to form concrete waste. These issues are created mainly due to lack of constructability in structural elements, defects in formwork assembling process. Moreover, order additional allowance of concrete due to uncertainty of material consumption within the site, excessive dimensions of concrete foundations will also cause waste of concrete (Formoso *et al*., 2002). Kazaz *et al*., (2004) stated that, concrete waste generates at the production of poor-quality concrete with the use of extravagant raw materials. Dosho (2007) documented that, concrete waste accounts roughly 35 million tons per year of the total construction waste due to the demolition and other construction related activities.

Improper design coordination has a huge impact on concrete waste in the construction activities which tends to produce improper, incorrect or un-constructible designs (Zhen *et al*., 2002). Design change during the construction process is the significant cause of generating waste at the site which occurs due to attitudes of the designer, improperly identifying the client's requirements, and improper detailing of the documents (Kulatunga *et al*., 2006). Therefore, there is an allowance kept by the estimators for waste at the pre-construction stage of the construction process, but the actual amount gained at the time of execution of the activities are greater than the waste allowance which happens due to less attention and poor forecast on the construction activities at the pre contract stage.

Most of the countries are moving towards the concept of sustainable development while maintaining the balance between the built environments and protecting the natural environment. After wiping out the terrorism issue in 2009, there was a boom in the construction market where most of the projects are moving towards the vertical structures in Sri Lanka. Therefore, these projects are persuading to implement new technologies to minimize the construction waste while going for sustainable developments, which continue the developments without compromising the needs for future generation (Zuhairi *et al*., 2016).

In the past few years, a number of advancements improved in the entire concrete production together with the material recycling, mixture proportion and durability. Also, the new concrete technology is beginning with latest concrete types as, high performance concrete (HPC), ultra-high-performance concrete and geopolymer concrete which have more advantages when comparing with the standard concrete (Anon, 2010). Most of the construction projects tend to move to use prefabrication concrete elements within both residential and high-rise construction process which generates concrete waste within the site (Zhen *et al*., 2002). This prefabrication method has been used in the construction for many years which gives more positive benefits in terms of time saving, environmental performance, improve buildability and minimize concrete waste (Shen *et al*., 2008).

Both developed and developing countries such as Japan, USA, Turkey, and South Korea are the major ready-mix concrete (RMC) producers. Rather than using cast in-situ concrete, they use RMC within their construction projects. It increases the higher productivity, lower costs with higher profits, minimize wastages, increased client's satisfaction, improved competitiveness, and continuous quality development. Kazaz *et al*. (2004) reported that, the quality production of the ready-mix concrete will solve the problems arising when deficiencies in placing, curing and formwork for the cast in-situ concrete. Ready mix concrete plants ensure the quality of the concrete due to automatic operation compared to manually undertaking.

Current construction industry has focused on applying precast concrete instead of cast in-situ concrete because of a number of various advantages that include less wastage on-site, reduction in site labourers, less volume of building materials, site safety, quick erection, speed in construction and environmental friendliness.

Meanwhile, Sri Lanka is one of many developing countries the use of concrete is very high. Therefore, the construction industry is not very much familiar with new mechanisms / practices. Treloar *et al*. (2003) documented, a number of researchers have also highlighted, the potential benefits that can be gained by minimizing concrete waste, and also changing the attitudes towards the waste minimization helps to develop the construction process more effectively. The applicability of these practices to Sri Lankan construction industry need to study comprehensively. By reviewing the above, it assists to identify the gap within the research, where there are not any research articles, which address to implement contemporary practices to the context of Sri Lankan construction industry, which to minimize concrete waste towards reducing the project cost.

2. RESEARCH METHODOLOGY

The main aim of this research is to minimize concrete waste by implementing contemporary practices in Sri Lankan construction industry.

This research has adopted both qualitative and quantitative procedures as the methods to collect data from both the questionnaire survey and semi-structured interviews from industry experts to evaluate correlations of the factors whilst evaluating the same with the expert opinion. This has given a wider opportunity to ensure the researchers reached to the finest reasons behind the reluctance of contemporary concrete waste management tactics.

Table 1 provides the population and sampling used to gather data. Different disciplines of professions were covered from randomly selected construction projects in Sri Lanka to derive an outcome with content analysis.

Table 1: Population and sampling

Data Collection Method	Population	Sample
Questionnaires	Architect Civil Engineer Quantity Surveyor Project Manager Site Engineer	25
Interviews	Civil Engineer Quantity Surveyor Project Manager Batching plant operator Site Engineer	5

The questionnaire for this survey was prepared to collect both facts and opinions from the respondents. A web-based questionnaire was designed to collect the data required to test the hypotheses postulated for the study. It contained eight questions where the first four questions were allocated to collect the respondents' demographic data. The rest of the four questions are close ended questions that covered as Likert scale questions (Kulatunga *et al*., 2006). In order to cover the objectives of the research. Same time, few structured expert interviews had to carry out as face-to-face interviews using open-ended questionnaire technique, which prepared to investigate, the material waste in the Sri Lankan context and factors affecting concrete waste, involvement and current practices taken to minimize concrete waste, drivers and barriers occur when implementing contemporary practices in the Sri Lankan construction industry.

3. ANALYSIS

Correlations between sources of concrete waste, contemporary practices and barriers hindering the implementation of contemporary practices towards reducing the project cost have a positive relationship (refer Table 2).

Sources of concrete waste (s), Contemporary practices to reduce the concrete waste (c), Drivers and Barriers hindering the implementation of contemporary practices (b), Project cost (P).

Regression analysis was also applied to identify the impact on the project cost by the concrete waste, as well as by the drivers and barriers which discloses that the relationship between above mentioned (s), (c) and (b) has a positive impact on the project cost (P).

Observed findings showed that, the concrete component is highly used in building and infrastructure construction, and that is one of the major and the most critical element in the concrete structures. In one of a project Civil Engineer stated "there are numerous ways of wasting material at the construction sites by demolition, mixing or ordering excess quantity. Apart from these material waste, there are many ways that lead to generate concrete waste at the very beginning of the construction process". As he told, "mixing concrete manually by the laborers creates a massive waste of concrete. It generates excess quantity of concrete mixed without concern about the quantity required for a specific concrete work. Project manager in another project pointed out "poor coordination in design, procurement, poor material handling, at the time of operation are few causes of concrete waste in construction projects".

Table 2: Correlation coefficient

Correlations					
		avgs1	**avgc1**	**avgb1**	**DVP1**
avgs1	Pearson Correlation	1	.466**	.503**	.434**
	Sig. (2-tailed)		.000	.000	.001
	N	54	54	54	54
avgc1	Pearson Correlation	.466**	1	.370**	.298*
	Sig. (2-tailed)	.000		.006	.029
	N	54	54	54	54
avgb1	Pearson Correlation	.503**	.370**	1	.270*
	Sig. (2-tailed)	.000	.006		.048
	N	54	54	54	54
DVP1	Pearson Correlation	.434**	.298*	.270*	1
	Sig. (2-tailed)	.001	.029	.048	
	N	54	54	54	54

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

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

An Engineer from a leading project emphasized that, "sources of waste are directly or indirectly generated by the attitudes and perception of the labourers who involve in the construction projects". Design changes that create number of variations to the original scope of work, and also improper delivery methods and delivery schedules, improper coordination among the MEP and structural designers are some of highlighted situations that creates concrete waste in construction projects in Sri Lanka.

However, many stakeholders revealed that communication errors were one of the most critical causes to end up concrete in wastes, and apart from that, several causes create concrete waste within the construction activities in a project.

Concrete recycling, using precast concrete elements instead of cast-in-situ concrete, implementing 5S which is one of lean construction technique that used to reduce and to manage the material been wastes within the sites, implementing value engineering techniques such as; instead of traditional formwork, using system formwork method, implement post-tensioning technique which needs less concrete volume and few more other techniques currently implemented in some of the construction projects in Sri Lanka. Preparing the 'Material reconciliation report', which compares the difference between the store records and actual requirement of the materials, as the items in the bill of quantities (BOQ) are some contemporary practices that can implement to minimize the concrete waste. Apart from the above, practicing a waste management hierarchy and also conduct training programs and educate the labourers, other professional team members about the new practices and discuss the benefits gain by practicing them, and trying to use concrete recycling within the construction projects will directly affect to minimize concrete waste.

When considering and observing all the findings, the drivers and barriers that create while implementing these new techniques to minimize concrete waste can commonly be gathered to one place as follows:

Drivers:

- Improve the productivity, reduce unnecessary time and cost, and effectiveness of the material usage
- Reduce the reordering cost and other unnecessary expenses
- Improve the bottom line of the project and bring out the value to the final product
- Enhance the collaboration among the stakeholder in the project
- Increase more employment opportunities in the construction industry
- Changes to drawings will update automatically
- Saving the use of natural materials

Barriers:

- Reluctant to change their usual behaviours
- Affordability of the new machinery to the project made defensive attitudes among the professionals
- Lack of attitudes on workers regarding contemporary technologies
- Lack of confidence in the use of recycled concrete aggregates
- Lack of skilled persons to handle these new contemporary practices are a few barriers that hinder when implementing contemporary practice in Sri Lanka

Both drivers and barriers are states by the stakeholders who are currently employing in the construction industry.

At the same time, every interviewee agreed that implementing contemporary practices are appropriate to reduce the cost of the construction project and also, there are few practices implement currently within the construction projects in Sri Lanka to minimize concrete waste.

The results that analysed from both statistical and content analysis have confirmed that there is a relationship between concrete waste and the project cost in the Sri Lankan construction industry, which is unforeseen and happens out of the stakeholders' control.

When considering the experimental findings gathered and analysed above, it shows the barriers, which employ the contemporary practices in the Sri Lankan construction industry. The above results clearly illustrate the sources of concrete waste, contemporary practices and the drivers and barriers hindering the implementation of contemporary practices that have a positive relationship with the project cost that needs to be administer of being unnecessarily increasing.

4. DISCUSSION AND CONCLUSIONS

Construction industry is a complex industry which includes various types of activities carried out by interacting with different parties in various stages. Therefore, it tends to create numerous reasons and instances to generate concrete waste, which takes place out of their control. The amount of concrete wasted in Sri Lankan construction industry, is important when comparing with the other materials wasting from the construction projects in Sri Lanka, due to a number of various reasons. The generation of wasting concrete from the construction activities results in a huge problem due to the solid waste, when considering with the environment and the project cost aspects. Most of the journal articles and research papers reviews the effective ways to minimize concrete waste can by implementing new practices / techniques and concepts. The effective cost management enables the client, developers, facilitators and other stakeholders related to the project to achieve value for money by implementing modern technologies within the Sri Lankan construction industry. The study also revealed that there is a high degree of agreement between the Quantity Surveyors, Architects, and Civil Engineers on the advantages gain by applying new technologies for the minimization of concrete waste in the Sri Lankan construction industry. Therefore, the above findings will make a momentum to the industry practitioners to re-think about the concrete waste which represents how much they can minimize the waste at site levels contributing to sustainability.

The first objective of this research was to recognize the sources of concrete waste in construction projects. Therefore, the first objective of this research was achieved with the usage of literature synthesis and primary data collection survey. Identifying the factors that affect concrete waste through literature synthesis and preliminary survey were also used to prepare the questionnaire survey. The findings of the questionnaire survey were set with the statistical package of social sciences (SPSS) software to find out the relationship (whether it impacts or not) between the sources of concrete waste and the project cost. The literature synthesis showed there are few instances adhere concrete waste occurs during both design and construction process. The questionnaire survey findings revealed that, design changes at the mid of the construction, poor coordination among the stakeholders, improperly identify the client's requirements, ordering of excess quantity, attitudes towards the construction operations and material handling at the design and construction stages be the sources, that generate concrete waste which will directly impact to the project cost. The analysis clearly illustrates that, there is a relationship of the sources of waste with the project cost.

The second objective of this research was to find out the contemporary practices in minimizing the concrete waste, achieved by both literature synthesis and primary data collection. According to the literature findings, there are few contemporary practices that are implemented by other countries currently as computer aided software (BIM), value engineering techniques, concrete recycling, use of precast and prefabrication elements in construction. The results of the questionnaire survey was subjected to the statistical data analysis method (SPSS), which shows the views on new practices and currently implementing practices within Sri Lanka by the construction professional who are currently engaging with the construction activities. According to those results, it was found that use of precast and prefabrication elements in construction, use as ready-mix concrete instead of cast in-situ concrete, implement value engineering techniques within the projects currently in Sri Lanka. These findings were used to discover the relationship between practicing of new practices and the project cost. After, analysing all data statistically it was found that there is a positive relationship, which to reduce the project cost.

Discovering the barriers to overcome the concrete waste is another objective of this research to fulfil. This objective was achieved with the support of the literature and the primary data collection.

Both literature and the empirical findings revealed that, lack of skilled labourers, negative attitudes towards new practices, resistance to change from the conventional practices are few of barriers. The statistical data analysis method used to evaluate the relationship which took a positive way, where the barriers also affect to reduce the project cost by minimizing concrete waste.

The final objective of this research is to recommend appropriate approaches to minimize concrete waste by reducing the project cost, which achieved while analysing the findings. According to the results, there were few drivers, which drives the attitudes of the stakeholders towards the practicing of these current techniques towards minimizing concrete waste, but at the same time the barriers lead to act as defensive way when implementing these practices. When considering their opinions, considerable amount is there willing to implement contemporary practices within their projects. In Sri Lanka as a developing country, can recommend use of ready-mix concrete (RMC), precast elements, value engineering techniques and few other practices as most appropriate techniques to minimize concrete waste towards reducing the project cost.

Define abbreviations and acronyms the first time they are used. Do not use abbreviations in the titles unless unavoidable.

5. RECOMMENDATIONS AND IMPLICATIONS

This study covered several aspects related to reduction of concrete waste using contemporary practices, which will be beneficial to reduce the project cost. Therefore, the following recommendations will assist in implementing those contemporary practices / systems in the Sri Lankan construction industry to minimize concrete waste.

Educating professionals and all other parties engaged in the construction industry about contemporary practices by; arranging training programs, rewarding the persons who are willing to use contemporary practices within their contracting organizations.

Applying lean construction, concrete recycling, use of precast concrete elements, value engineering techniques with regard to minimizing concrete wastage and also to reduce other types of material waste such as cement and reinforcements.

Encouraging cooperation between the clients and all the other stakeholder who are part of the construction activities in a particular project by applying new methods, use computer aided software such as BIM, which leads to build up the collaboration among the stakeholders in the project.

Changing the negative attitudes towards the implementation of new practices among the labourers and the other professionals related to construction, by providing proper guidance, and explaining the advantages that gaining to the project by minimizing concrete waste.

When considering the above-mentioned recommendations, it is necessary to imply these contemporary practices within the Sri Lankan construction industry that leads to reduce the project cost, and also benefited to move towards the sustainable developments through protecting the environment.

6. LIMITATIONS

Evaluated contemporary practices are only to minimize concrete waste that generates from the construction projects. Time, Cost and Quality are the primary three keys in the construction project. Therefore, among those keys, this research study was endeavoured to evaluate environmental and cost related concerns related to concrete waste reduction which yet controlled by the stakeholders.

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OPERATIONAL ENERGY SAVING IN BUILDINGS: A COMPARISON OF GREEN VS CONVENTIONAL WALL

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ABSTRACT

The green wall concept has been introduced as one of the solutions to reduce energy demand for ventilation requirements while improving the natural vegetation in dense urban areas. Past studies revealed that the energy-saving of green walls can vary substantially, from 35% to 90% across countries such as United Kingdom (UK), Canada, Russia, Greece, China, Saudi Arabia, India, and Brazil. Given these differences in energy saving of green walls due to climatic conditions and other reasons, direct application of such findings to the Sri Lankan context is questionable. Therefore, this study aimed to assess the thermal performance of green wall applications in Sri Lanka through a case study analysis of an indirect green façade with a comparative conventional wall. The required data were extracted through on-site temperature measurements from different points of both the exterior and interior wall surfaces of each building in different time intervals per day for a period of fourteen days spanning from October to November. The analysis shows that the green walls contribute to 21% - 36% of temperature difference compared to the conventional wall. Eventually, this results in 0.06 kWh of energy-saving per m^2 of wall area, and thereby green walls contribute to the 80% energy saving for ventilation requirements. Hence, the study recommends that the use of green walls can be considered as one of the energy efficiency solutions while improving natural vegetation in tropical climatic cities and absorbing other benefits of green walls.

Keywords: *Energy cost saving; Green wall; Indirect green façade; Thermal performance.*

1. INTRODUCTION

In recent years, building designers have been searching for an effective way to enhance building energy efficiency in a sustainable manner (Pérez *et al*., 2014). Ottelé *et al*. (2011) identified that the integration of vegetation into the building is one of the retrofit technologies for energy efficiency in buildings relative to sustainable aspects. There are two main ways of integrating vegetation into the buildings: green roofs and green walls (Sheweka and Magdy, 2011). However, Dunnet and Kingsbury (2008) stated that most of the time, the green wall area could be twenty times bigger than the roof area of multi-storey buildings. Hence, it is evident that having green walls can have a more sustainable impact than the green roof in multi-storey buildings. Most of the researchers illustrated that the ability to reduce heat gain and to cool the atmosphere through evapotranspiration of green walls could reduce the energy consumption for ventilation and heating meanwhile, they reduce the operational cost of building (Wong *et al*., 2010; Ottele *et al*., 2011; Pérez *et al*., 2011; Susorova *et al.,* 2013; Susorova, 2015).

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Sri Lanka is gradually adapting to urban development by converting the natural vegetation into concrete buildings (Herath *et al*., 2018). The consequent natural vegetation depletion increases global warming (Pan and Chu, 2016). As a result of global warming, energy consumption increases to fulfil the requirement of human comfort (Sun *et al*., 2019). In the Sri Lankan context, more than 75% of electricity is used for ventilation and air conditioning purposes from the total energy consumption in a typical building (Geekiyanage and Ramachandra, 2018). In this context, the use of green walls can be considered as a solution to optimise the energy consumption in buildings in Sri Lanka. However, the application seems minimal, could be due to the reasons of lack of public awareness of the concept and its potential benefits, particularly about its contribution to energy saving, perception of higher initial and maintenance costs, possible aesthetic effects to the wall surface, and more time-consuming for the absorption of benefits (Jefas *et al*., 2012; Peiris, 2017; Rupasinghe and Halwatura, 2018).

Despite some of the global researchers such as Wong *et al*. (2010), Ottele *et al*. (2011), Pérez *et al.* (2011), Susorova *et al*. (2013), and Susorova (2015) have focused on potential energy cost-saving of green walls, the application of such research findings to the Sri Lankan context is questionable due to the geographical differences. Hence, this research aimed to assess the thermal performance of green walls through a comparison of a green wall with a comparative conventional wall of a residential facility and thereby establish the potential contribution made to savings in energy in the Sri Lankan context.

2. LITERATURE REVIEW

2.1 SIGNIFICANCE OF GREEN WALLS

Green walls refer to all types of vertical vegetation surfaces such as facades, walls, blind walls, and partition walls (Newton *et al*., 2007; Manso and Castro-Gomes, 2015). According to Dunnet and Kingsbury (2008), vertical vegetation can be climbing or hanging upward on the vertical surface or grow downward on the vertical surface. Green walls can be divided into two main categories as the green facade and living walls according to the method of construction (Köhler, 2008; Dunnet and Kingsbury, 2008). Green facades are further classified into direct and indirect green facades; based on a climbing plant directly attached to the wall and supported with structures such as steel cables or trellis respectively (Kohler, 2008). The living wall system is more complicated than the green façade system since it has prefabricated or pre-vegetated systems on a modular panel that contains growing media with balanced nutrients (Dunnet and Kingsbury, 2008).

When considering the construction cost of these green wall types, direct green facades are more cost-effective than indirect green façade and living walls due to the absence of support structure (Manso and Castro-Gomes, 2015). However, direct green facades comprise contribute to certain disadvantages, mainly, affecting the aesthetic appearance of the wall surface with the plant roots and collapsing of plant when further grows (Dunnet and Kingsbury, 2008). Manso and Castro-Gomes (2015) stated that indirect green facades and living walls are a solution to overcome those disadvantages of direct green facades. However, the construction cost of living walls is comparatively higher than indirect green facades.

The green wall concept has spread over the residential, office, commercial, and government buildings around the world with its numerous benefits (McCullough *et al*., 2018). In addition to the energy cost saving in green walls, it enhances the biodiversity in high-density urban areas with supporting foods and habitats for the animals (Lundholm, 2006), mitigates the urban heat island effect (Busato *et al*., 2014), and improve the air quality (Ottelé *et al*., 2010). Furthermore, Vox *et al*. (2018) stated that the green wall concept is mainly related to improving real estate value or rental value. Moreover, Ottele *et al*. (2011) identified that the green wall concept contributes to less external wall surface maintenance by absorbing the Ultra-Violet (UV) rays fallen onto the wall. However, the amount of benefits gained through the green walls depends on the green wall type, application, and the foliage thickness of the plant (Perez *et al*., 2011; Perini and Rosasco, 2013; Huang *et al*., 2019). Therefore, the study gives due consideration to those parameters in selecting the building for its energy assessment due to green walls.

2.2 ENERGY COST SAVING IN GREEN WALLS

The importance of green wall applications has become the forefront with the ability to reduce heat transfer between internal and external environments through plants (Susorova, 2015; Libessart and Kenai, 2018). Figure 1 shows the physical thermal process of the energy balance of the vegetated surface.

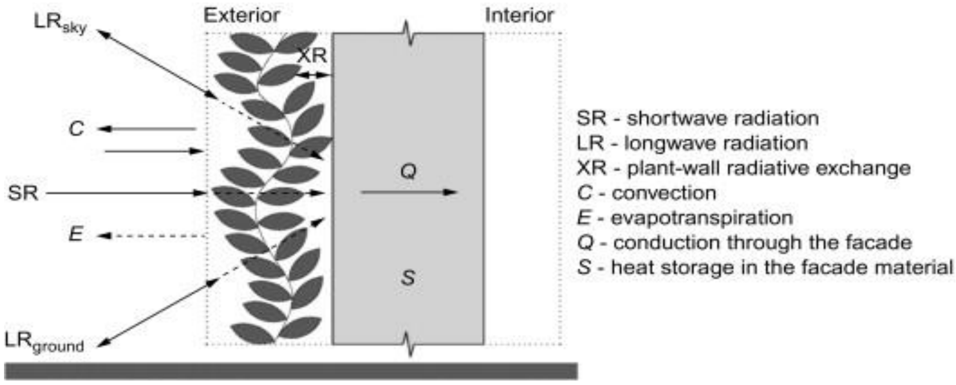

Figure 1: Energy balance of a vegetated façade (Source: Gates, 2003)

According to Larcher (2003) and Straube (2005), the thermal process of the energy balance of the vegetated surface can be listed as follows. Shortwave solar radiation is received by the building wall through the sun. Longwave radiation also exchanges between ground, sky, and surrounding surfaces. Then those radiations are absorbed by the walls and transferred back into the environment by convection or transferred to the building interior by conduction. Some amount of energy is stored in the wall material. The authors further derived the following equations for energy balance:

The energy balance of a conventional/bare wall (bw) is;

$$SR_{bw} + LR_{bw} + C_{bw} = Q_{bw} + S_{bw} \quad (01)$$

The energy balance of a vegetated wall (vw) is;

$$SR_{vw} + LR_{vw} + XR + C_{vw} = Q_{vw} + S_{vw} \quad (02)$$

The foregoing review evidences that the plant layer acts as an additional thermal insulation layer.

Gates (2003) stated that the study of energy balance and heat flows through a vegetated wall surface of a building is important to evaluate the thermal performance and potential energy saving of green walls.

Table 1 illustrates the findings of some studies that depict the heat flows through green walls.

Table 1: Heat flows through green walls

Type of Green Wall	Plant Species	Foliage thickness (cm)	Climate (Koppen classification)	Temperature reduction (^{0}C)		Source
				External wall	Internal wall	
Direct	*Parthenocissus tricuspidata*	25	Cfb	5.7	0.9	(Eumorfopoulou and Kontoleon, 2009)
Indirect	Climber plants	-	Af	4.36	-	(Wong *et al*., 2010)
Direct	*Hereda helix*	20		1.2	-	
Indirect	*Hereda helix, Vitis, Clematis, Jasminum, Pyracantha*	10	Cfb	2.7	-	(Perini *et al*., 2011)
Living wall	Evergreen species	10		5	-	
Indirect	*Wisteria sinensis*	20	Csa	15.8	-	(Pérez *et al*., 2011)
Direct	*Hereda helix*	10-45	Cfb	1.7 - 9.5	-	(Sternberg *et al*., 2011)
Direct	*Parthenocissus tricuspidata*	-	Dfa	7.9	2	(Susorova *et al*., 2013)
Living wall	Climber plants	-	Cfb	20.8	-	(Chen *et al*., 2013)

From the review of Table 1, it is evident that the heat flow through the green walls depends on various factors such as climate, green wall type, and vegetation type.

Furthermore, most researchers identified that the green walls significantly contribute to the energy saving of buildings through their ability to less heat flow through a building's external and internal wall surfaces.

Bass and Baskaran (2001) found that the implementation of green walls helps to reduce energy cooling load by 23%, energy for fans by 20%, and as a result that, annual energy consumption by 8%. Furthermore, Alexandri and Jones (2008) concluded that, if all possible facades covered with vegetations, energy saving can vary from 90% to 35% by conducting computational fluids dynamics simulation to main cities in the United Kingdom (UK), Canada, Russia, Greece, China, Saudi Arabia, India, and Brazil. These countries have different climatic conditions. Hence, the potential energy saving of green walls also depends on the climate.

Additionally, Wong *et al*. (2009) researched the variation of cooling load based on the foliage thickness of the green wall and showed that the 74% cooling load reduction in a building with a fully covered wall with the vegetation, 10% cooling load reduction in a wall with 50% covered with vegetation and rest 50% glazing and 32% cooling load reduction in fully covered vegetation on the fully glazed wall. Price (2010) developed a mathematical model to evaluate energy efficiency in low-rise buildings with an indirect green façade and found that building cooling load reduced by 28% in a temperate climate. Pan and Chu (2016) researched the energy savings of green walls in Hong Kong and demonstrated that green walls contribute to 16%

saving of the energy consumed for air conditioning in the months of August and September which are typical summer months.

3. RESEARCH METHODOLOGY

The study primarily used a quantitative approach where the required data were collected from preliminary survey and a comparative analysis. Initially, a preliminary survey was carried out into various sources such as site visits, internet, green wall suppliers, and green rating systems (GREEN^{SL} Rating System and LEED Certification) to identify green wall applications in Sri Lanka. Accordingly, forty-three (43) applications were identified through green wall suppliers (18), green rating systems (12), site visits (11), and internet surveys (6). The summary of identified cases is illustrated in Table 2 and further discussed in the following sections.

Table 2: Green wall application

Building	No	Green Wall Type			Application		
		Direct	Indirect	Living wall	External wall	Internal wall	Boundary wall
Hotel	15	8	5	2	4	1	10
Residential	10	2	6	2	6	2	2
Industrial	8	-	6	2	6	1	1
Office	7	-	7	-	6	-	1
Educational	2	1	1	-	2	-	-
Religious	1	-	1	-	1	-	-
Total	43	11	26	6	25	4	14

Among the 43 green wall cases, indirect green façade is the most used in Sri Lanka, compared to direct green facades and living walls. According to Perini and Rosasco (2013) and Huang *et al*. (2019), the application of green walls to the exterior walls of a building greatly contributes to the energy-saving of a building. Accordingly, it is evidenced that applications to external walls are significant in the Sri Lankan context. Furthermore, the amounts of energy savings gained from the green walls depend on the amount of the foliage thickness (Pérez *et al*., 2011). Hence, it was decided to select a building profile that contains an indirect green wall on the exterior wall surface of the building with significant foliage thickness to evaluate the thermal performance of the green wall effectively. From the 43 cases, only nine (9) cases were comprised of the green walls covering the entire building envelope. The remaining cases were limited to the boundary walls and internal walls (partition walls) of the buildings with less green wall coverage. Of the nine (09) buildings, due to the COVID 19 pandemic situation and related data accessibility and time constraints, it was possible to choose one case study of green walls. Furthermore, for this comparative study, there needs to be two buildings: with green walls and without green walls with similar physical properties which would influence the thermal performance and energy. Hence, when selecting the cases, due consideration was given to location, purpose, building shape, and size and thereby to ensure the reliability and accuracy of the research findings.

Based on aforementioned factors, a temple building (Religious) in Matara (5.95° N, 80.54° E, classified as tropical rainforest climate [Af], according to the Koppen climate classification), was selected as it contained buildings with both green walls and conventional walls in the same location.

Heat transfer through the conventional wall and green wall was calculated to evaluate the thermal performance of the indirect green façade. The ground floor walls of the green wall building were not covered with the climbing plant. Hence, the first and second floors of each building were selected to obtain the field measurements. An infrared thermometer and relative humidity meter were used to obtain the on-site temperature and relative humidity measurements. Measurements were taken for fourteen days scattered over the period from 21st October to 14th November in each building due to the time restrictions. The rays of the sun that fall on the external wall surface are not constant at every point. It changes due to the orientation of the building (North, South, West, East), the composition of the external wall, and surrounding buildings. Hence, to increase the accuracy of this study, temperature measurements were taken from different points on the first and second floors of each building. All measurements were taken from both the outer surface and inner surface of the walls. The intensity of solar radiation is not constant throughout the day. Therefore, to increase the reliability of the study, measurements were taken at five-time intervals per day (8.30a.m., 10.30a.m., 12.30p.m., 3.00p.m. and 5.00p.m.). Ultimately, the mean values of obtained measurements were considered to calculate the energy saving cost.

3.1 PROFILE OF THE SELECTED BUILDINGS

Both buildings selected for the study are rectangular in shape. Even though these buildings belong to the temple, they are used for residential purposes. The longitudinal sides of both buildings are oriented to the North and South directions. All sides of the building are fully exposed to the sunlight without obstructing from surrounding objects. An indirect green façade is present in one of these buildings. The plant is well grown around the wall surface of the building except for the south wall and the ground floor. *Thunbergia laurifolia* is the climbing plant used in this building. Average foliage thicknesses of north, east, and west wall surfaces are 45cm, 15cm, and 12cm, respectively. The support structure is made of one and a half-inch dia Galvanized Iron (GI) pipes and 3mm Polyethylene terephthalate (PET) wire. Table 3 illustrates the summary of both building profiles.

Table 3: Summary of building profiles

Description	Indirect Green Façade Building	Conventional Wall Building
Number of floors	3 floors with a rooftop	3 floors with a rooftop
Floor height	3.3m	3.3m
Exterior dimensions	Length - 22.6m Width - 9.75m	Length - 14.7m Width - 8.10m
GIFA per floor	210.74m^2	125.28m^2
Service life	3 years	4 years
A/C	-	-
Wall type	Block Wall	Block Wall
Wall thickness	150mm	150mm
Wall Finishing (Internal and External)	Plastering + Painting	Plastering + Painting
Window type	Louver Aluminum framed glazed windows	Louver Aluminum framed glazed windows
Door type	Louver Aluminum Door	Louver Aluminum Door

4. DATA COLLECTION AND ANALYSIS

4.1 THERMAL PERFORMANCE OF GREEN WALL

Based on the geometric mean temperature of each day, the average temperature difference between the external and internal surfaces of both conventional wall and green wall was calculated separately and the summary is presented in Table 4. The outer surface and inner surface are represented as O and I respectively.

Table 4: Summary of average temperature

Indirect Green Façade Building – Average Surface Temperature (^{0}C)												
Location	**North Wall**			**East Wall**			**West Wall**			**South Wall**		
	O	**I**	**O- I**	**O**	**I**	**O- I**	**O**	**I**	**O- I**	**O**	**I**	**O- I**
1st Floor	28.9	28.7	0.18	29.1	28.9	0.21	30.0	29.6	0.42	30.6	30.0	0.65
2nd Floor	28.9	28.8	0.16	29.1	28.9	0.22	29.7	29.4	0.28	30.6	29.9	0.70
Conventional Wall Building – Average Surface Temperature (^{0}C)												
1st Floor	30.1	29.3	0.77	30.6	29.4	1.18	30.8	29.8	0.98	30.5	29.6	0.87
2nd Floor	30.2	29.2	0.91	30.7	29.4	1.30	30.8	29.9	0.93	30.5	29.7	0.82

According to Table 4, in all points of location, a significantly higher temperature difference increment is observed in the conventional wall compared to the green wall. This temperature difference indicates the heat loss through the wall surface. Furthermore, the temperature behaviour of north, east, and west walls are approximately equal in indirect green façade buildings. However, temperature measurements of the south wall, which are not covered with the indirect green façade are considerably high and similar to the conventional wall building.

The following formula was used to calculate the heat transfer through the external wall surface of both building profiles.

$$\boldsymbol{Q} = \frac{\boldsymbol{K.A.\Delta\theta}}{\boldsymbol{L}} \tag{01}$$

Where, Q = Heat Transfer (W), $\boldsymbol{\Delta\theta}$ = Temperature Difference (^{0}C), L = Thickness of Surface (m), K = Thermal Conductivity (W/m^{0}C), A = Heat Transfer Area (m^2)

According to The Engineering Toolbox (2020), the thermal conductivity of the blocks was considered as 1.7 W/m^{0}C. Furthermore, 1m^2 of wall surface was considered in heat calculation.

Heat transfer calculations for wall surfaces of both buildings are shown in Table 5.

Table 5: Heat transfer calculations for green wall and conventional wall

Indirect Green Façade per m^2		
	First Floor (W)	Second Floor (W)
North wall	$Q = \frac{1.7 \times 1 \times 0.18}{0.15}$ = 2.04	$Q = \frac{1.7 \times 1 \times 0.16}{0.15}$ = 1.79
East Wall	$Q = \frac{1.7 \times 1 \times 0.21}{0.15}$ = 2.41	$Q = \frac{1.7 \times 1 \times 0.22}{0.15}$ = 2.50
West Wall	$Q = \frac{1.7 \times 1 \times 0.42}{0.15}$ = 4.76	$Q = \frac{1.7 \times 1 \times 0.28}{0.15}$ = 3.17
South Wall	$Q = \frac{1.7 \times 1 \times 0.65}{0.15}$ = 7.34	$Q = \frac{1.7 \times 1 \times 0.70}{0.15}$ = 7.92

Conventional Wall per m^2		
	First Floor (W)	Second Floor (W)
North wall	$Q = \frac{1.7 \times 1 \times 0.77}{0.15} = 8.68$	$Q = \frac{1.7 \times 1 \times 0.91}{0.15} = 10.35$
East Wall	$Q = \frac{1.7 \times 1 \times 1.18}{0.15} = 13.36$	$Q = \frac{1.7 \times 1 \times 1.30}{0.15} = 14.73$
West Wall	$Q = \frac{1.7 \times 1 \times 0.98}{0.15} = 11.16$	$Q = \frac{1.7 \times 1 \times 0.93}{0.15} = 10.57$
South Wall	$Q = \frac{1.7 \times 1 \times 0.87}{0.15} = 9.89$	$Q = \frac{1.7 \times 1 \times 0.82}{0.15} = 9.32$

According to the above calculations, conventional wall accounts for 88.06 W heat transfer per m^2 of wall area. However, the wall surfaces of the building which is having an indirect green façade account for 31.93 W per m^2. Generally, the building requires equivalent energy as the cooling energy for this transferred heat through the wall surface. As per Table 5, the conventional wall is responsible for an additional heat transfer of 56.13 W per m^2. Hence, the energy required for the cooling purposes of a building with an indirect green façade is relatively lower than the conventional wall building.

Table 6 presents the heat transfer and energy requirement through the selected conventional and green walls.

Table 6: Summary of heat transfer and energy requirement of conventional wall and green wall

	Green Façade Building	**Conventional Wall Building**
Heat transfer (W/m^2) per day	31.93	88.06
Energy requirement per month (kWh)	204.52	397.53

Green walls contribute to a reduction in heat transfer through the exterior and interior wall surfaces and the energy requirement of a building compared to the building with the conventional wall as evidenced in Table 6.

Using current unit rates published by the Ceylon Electricity Board (CEB) of Sri Lanka - 2020 for domestic buildings, monthly and annual energy costs for both buildings were calculated and presented in Table 7.

Table 7: Annual energy consumption of both buildings

Description	**Unit rate (LKR/kWh)**	**Amount (LKR)**	
		Indirect Green Façade Building (Energy consumption per month = 204.52 kWh)	**Conventional Wall Building (Energy consumption per month = 397.53 kWh)**
For first 60kW	7.85	471.00	471.00
For Next 30kW	10.00	300.00	300.00
For Next 30kW	27.75	832.50	832.50
For Next 60kW	32.00	1,920.00	1,920.00
For rest	45.00	1,103.40	9,788.85
Fixed		540.00	540.00
Total (Per Month) - Building		5,166.90	13,852.25
Total (Per Month) - Per m^2		24.20	92.05

Description	Unit rate (LKR/kWh)	Amount (LKR)	
		Indirect Green Façade Building (Energy consumption per month = 204.52 kWh)	**Conventional Wall Building (Energy consumption per month = 397.53 kWh)**
Total (Per Annum) - Building		62,002.80	166,228.20
Total (Per Annum) - Per m^2		290.39	1140.65

According to Table 7, the energy cost per m^2 of a wall area in a green wall building is Rs. 290.39 per annum while the same for the conventional wall is Rs. 1140.65 per annum. Hence, the green wall building shows Rs. 850.26 cost-saving per m^2 than the conventional wall per annum. In other words, indirect green façade building shows 80% of energy cost-saving than the conventional wall building.

5. DISCUSSIONS

Green walls contribute to saving the energy requirement for cooling and ventilation purposes of buildings via maintaining the building's internal temperature (Susorova, 2015; Libessart and Kenai, 2018). It is due to the less heat transfer through the external wall surface with the presence of green walls. The data retrieved through the case study analysis of the current study also supports the above statement.

Moreover, Sternberg *et al*. (2011) stated that, during the daytime, the exterior façade surface temperature is reduced by a 1-9^{0}C due to vegetation on the wall surface than the wall without vegetation layer. Similarly, as per Table 5, the exterior surface temperature of the green wall is always lesser than the conventional wall's external surface temperature. However, there was no such high difference in temperature reduction between the green wall and conventional wall observed in this study. The difference was limited to 0.8^{0}C - 1.5^{0}C. The reason for this dissimilarity could be due to the use of green wall type and the climate difference between the two studies. Sternberg *et al*. (2011) conducted a study regarding the direct green façade on Cfb climate (Reference to Koppen Climate Classification) and this study focused on indirect green façade on Af climate. However, Wong *et al*. (2010) conducted a study on indirect green façade on Af climatic condition and showed that the temperature reduction of 4.36^{0}C of external wall surface, which is having a vegetation layer. Hence, it is evidenced that the thermal performance of green walls not only depends on the green wall type and the climate. There seem other reasons such as façade orientation, foliage thickness, and vegetation type which could contribute to the different degrees of temperature difference.

In agreement with that, Pérez *et al*. (2011) depicted that the thermal performance of green walls varies with the foliage thickness and the orientation of the façade. As per Table 4, a lower average surface temperature difference of 0.16^{0}C is shown by the north wall with 45cm of average foliage thickness. West wall has a less average foliage thickness compared to other sides and shows a high surface temperature difference of 0.42^{0}C. This proved that the plant layer in the exterior wall surface of green walls provides an additional insulation layer and helps to reduce heat conduction through the exterior façade. Therefore, the literature findings were proved further by the case study analysis.

Furthermore, the analysis results indicate that the indirect green façade building accounts for 80% of energy cost-saving than the conventional wall building. This supports the finding in previous studies Alexandri and Jones (2008). Alexandri and Jones (2008) concluded that, if all possible facades are covered with vegetation, energy saving can vary from 90% to 35%. Moreover, Pan and Chu (2016) stated that green walls contribute to saving 16% of the energy consumed for air conditioning in hot and wet summer seasons in Hong Kong. However, this figure has been derived by considering the seasonal changes are in Hong Kong while no such seasonal changes are visible in Sri Lanka. Hence, the energy-saving percentage is considerably less than the findings of the current study. This further shows that the potential energy saving of green walls depends on the climatic conditions.

6. CONCLUSIONS

In this study, a comparative analysis of the thermal performance of green walls and conventional walls was performed to determine the energy-saving contribution of green walls. From the study findings, it was apparent that all common building types: commercial, residential, and office have incorporated with the most popular indirect green façade type in Sri Lanka. Direct green facades are mostly applied to the boundary walls in the hotel buildings with the intention of aesthetic appearance. Energy cost saving for cooling and ventilation purposes of buildings via maintaining the building's internal temperature is a significant benefit of green walls. The current study found that the significant temperature difference increment in the conventional wall compared to the indirect green façade and thereby indirect green façade building accounts for 80% of energy cost-saving than the conventional wall building. Hence, it is expected that the findings of the study would convince the public of the awareness and perceptions about the energy-saving cost benefits of green walls and thereby enhance its application in the Sri Lankan context.

This study has limited its focus only to energy aspect of the most used type of green wall, indirect green façade type in Sri Lanka. However, there are other types of less commonly used green walls and green walls offer benefits beyond energy saving. Therefore, it is recommended that these aspects need to be evaluated comprehensively for effective implementation of green walls and to absorb its optimum potential.

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OPTIMISING VALUE DURING CONSTRUCTION SCHEDULE ACCELERATION

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ABSTRACT

Construction Schedule Acceleration (CSA) can affect not just the time but many other project aspects. During a CSA, there can be many impacts having significant effects on the project value. Previous studies have highlighted the importance of considering quality, productivity and functionality at a CSA along with cost and time. The aim of this research is, therefore, to investigate how value can be optimised during a CSA process. A qualitative research approach was adopted. Altogether, ten semi-structured interviews were conducted. The interview data were transcribed and analysed using a manually performed content analysis.

This study has revealed types of CSA based on the purpose (delay minimising purpose or non-delay minimising purpose) and the party who initiates it. Cost, quality, functionality, productivity and profitability were identified as main value considerations during a CSA other than time. Applicability of value management (VM) job plan stages and Earned Value Management (EVM) indicators during different CSA stages to optimise value were also found. Finally, these findings were mapped in a framework to show how VM and EVM concepts could be used in enhancing value during a CSA. The framework conceptualises the relationship between "value" and CSA and how it varies upon distinct parties of a construction project during different stages and types of CSA. The proposed framework can be used as a guidance for optimising the value during the stages of a CSA.

Keywords: *Construction schedule acceleration (CSA); Productivity; Scheduling; Value; Value management.*

1. INTRODUCTION

A proper construction schedule is useful for stakeholders to plan the timing and sequence of project operations, calculate project completion date, predict and calculate the cash flow and evaluate the effect of changes (Mubarak, 2015). Even though, a typical project schedule is developed using existing methods based on the assumption of complete knowledge of project parameters, uncertainties in construction can affect the schedule during a project (Bruni *et al*., 2011). Those uncertainties can lead to project delays and can adversely affect the project success in terms of time, cost and quality (Theivendran and Gunathilake, 2015). In order to overcome delays and prevent contractors from making decisions based on a schedule consisted with inbuilt errors, certain alterations are necessary for the "As-Planned schedule" (Baldwin and Bordoli, 2014; Theivendran and Gunathilake, 2015). Construction schedule altering methods are considered as corrections to the "as built schedule" and can include alterations for key contract dates, logic links, constrains, activity durations and sequence of activities

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(Baldwin and Bordoli, 2014). Eventhough there are few schedule alteration techniques, "construction schedule acceleration" stands as one of the most commonly used techniques.

CSA is mainly aimed at increasing the speed of a project and can occur due to instructions of owners' or contractors' own intiatives (Mubarak, 2015). CSA can affect not just the time but many other project aspects as well and hence, requires proper coordination among all project stakeholders. As highlighted by Thomas (2000), around 20-45 % of labour efficiency losses have been observed due to disruption of normal utilization of resources which can occur during a CSA. Theivendran and Gunathilake (2015) also highlight additional costs, productivity problems, quality issues, conflicts, coordination problems and abortive works as possible problems faced due to CSA. Hence, it appears that there can be many impacts during a CSA that can have significant effects on the project value (Haddadia *et al.,* 2016; Mubarak, 2015).

In a construction project, "value" is a much broader concept than just reducing the cost and its meaning could differ from one person to another depending upon their objectives (Karunasena and Gamage, 2011). In order to measure and enhance the value of a construction project, value techniques such as Earn Value Management (EVM) and Value Management (VM) are commonly used.

Past researchers have proposed different approaches for schedule acceleration. For instance, Moselhi and Esfahan (2013) have proposed a multi attributed decision-making environment to produce an executable plan for a schedule acceleration by considering cost and several other factors. Moreover, Thomas (2000) has proposed a tool for measuring the inefficiency of an accelerating process. In the Sri Lankan context, Theivendran and Gunathilake (2015) have revealed impacts of schedule acceleration and strategies to overcome those negative impacts. Similarly, previous studies have highlighted that cost should not be regarded as the only consideration during a CSA (see Mubarak, 2015) and noted the importance of considering other factors such as quality, productivity and functionality that affect the value during a CSA. This research, therefore, is aimed at investigating how value can be optimised during a CSA process. Herein, the paper first focuses on identifying and critically reviewing the concepts and types of CSA, impacts on project value during CSA and applicability of value techniques during CSA. It then goes on to discuss findings in relation to the value considerations along the CSA process and the suitability of applying value techniques to ensure optimum value during a CSA. Finally, based on the findings of this study a framework is proposed that can be used to ensure optimum value during a CSA.

2. LITERATURE REVIEW

2.1 CONCEPTS AND TYPES OF CSA

Construction delay, which is a recurring problem, has an adverse effect on time, cost and quality which are the three bases of golden triangle in construction projects (Mahamid, 2017; Theivendran and Gunathilake, 2015). Accordingly, CSA is often used to increase the speed in construction projects. Mubarak (2015) has defined project acceleration as shortening the normal duration of the project without reducing the original scope. Thomas (2000) described the acceleration as having more work to perform in the same period of time or having a shorter period of time to perform the same amount of work or combination of these two methods.

Acceleration can be categorised as "planned acceleration" (which is done before commencing the project) and "unplanned acceleration" (which takes place during the construction phase as a reactive approach once a delay has been identified or due to project scope change) (Noyce and Hanna, 1998). Methods of conducting a CSA under either of the aforementioned approaches can also be divided into two, namely "schedule crashing" and "fast tracking". Here, "schedule crashing" is the process of shortening the durations of certain tasks (Bowen, 2015). On the other hand, "fast tracking" is where certain tasks are carried out parallelly rather than doing them in sequence (Bowen, 2015). For example, this may involve starting the construction phase of a project while its design is still under development (Mubarak, 2010). Thus, it is clear from the above discussions that CSA can be mainly divided into two as "unplanned" and "planned" based on the when the decision to undertake CSA has been taken and each type can be carried out either by "schedule crashing" or "fast tracking". This can be summarised as shown in Figure 1.

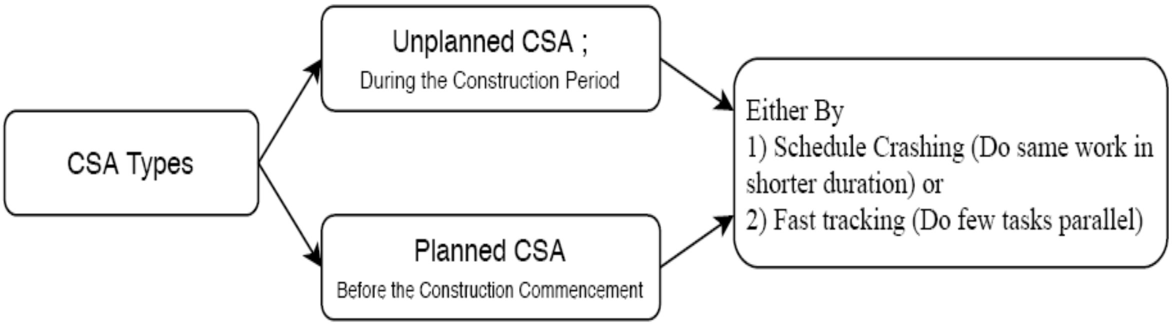

Figure 1: Types of CSA

2.2 IMPACT ON VALUE DURING A CSA

"Value" has been described as the ratio between functionality (quality) and cost. In other words, the optimum functionality and quality at the lowest possible cost leads to enhanced value (Ashworth and Hogg, 2000). The concept of value is highly subjective and can differ based on different perspectives of stakeholders as well as during different phases of a project (for e.g., refer Perez, *et al.,* 2010). Even though CSA can clearly impact on construction project value, the behaviour of value expectations during a CSA, have still not been investigated in existing literature.

"Cost" can be considered as a main element of "value". Cost impacts of CSA will vary upon the method of CSA (i.e., schedule crashing and fast tracking) used. In fast tracking, where certain tasks are carried out in parallel without doing them subsequently, the level of effort remains same and hence, the direct costs may not change (Bowen, 2015; Kuehn, 2006). However, schedule crashing can increase the direct costs on most occasions as it involves in assigning additional technologies and resources to tasks to get them done earlier than scheduled (Kuehn, 2006; Mubarak, 2015). However, financing excessively for certain activities may reduce the productivity and efficiency due to site congestion and tiredness of workers and some activities which require decision making and creative skills should not be accelerated much (Kuehn, 2006; Mubarak, 2015). Hence, Mubarak (2015) has suggested that acceleration decisions should take into consideration factors other than cost to ensure value.

Construction industry is often criticised for its poor levels of performance compared to other industries. According to Tangen (2002), "performance" is an umbrella term, which is inclusive of profitability, productivity as well as quality. "Productivity", which can be defined as the ratio between input and output, also has a strong relationship towards value creation. Tangen (2002) has further stated that once productivity is connected with its financial connotations, it is termed as "profitability". During a CSA, disruptions to the normal utilization of resources are common. For example, Hanna *et al.* (2005) note that labour productivity can decrease as a result of more working hours. Similarly, Theivendran and Gunathilake (2015) have identified productivity and quality issues as negative impacts during CSA. From all these findings it can be concluded that CSA process has an impact on overall performance of the project and therefore the factors related to performance, namely "productivity", "profitability" and "quality", will be impacted.

"Functionality" is considered as a main success criterion of any construction project and also it has been mentioned that, once the functionality of a project becomes low, the project life cycle will also come to an end (Nguyen *et al*., 2004; Kelly, *et al.,* 2015). Accordingly, sustaining the functionality of the project even during a value adding activity is of critical importance as well (Norton and McElligott as cited in Ashworth and Hogg, 2000).

Hence, from the literature review, cost, quality, functionality, productivity and profitability could be identified as main value considerations other than time during a CSA.

2.2.1 Applicability of Value Techniques during a CSA

There are numerous value techniques available and among them Value Management and Earned Value Management are the significant techniques related to construction industry (Ashworth and Hogg, 2000; Karunasena and Gamage, 2011; Kliniotou, 2004). The following sections discuss these two techniques, which have been considered in this study.

Value Management (VM) has been defined by Male (2002) as a proactive approach which solves problems and discloses the client value system by analysing time, cost and quality. VM has also been highlighted as a more beneficial tool for clients as it fulfils clients' needs and demands, which are of paramount importance in a construction project (Perera, *et al.,* 2011). Kelly and Male (1993) has indicated that VM can be adopted from initial stages to completion. VM has been recognised as a proactive approach which solves problems and disclose the client value system by analysing time, cost and quality which are all factors highly impacted during a CSA (Male, 2002; Mubarak, 2015;). Ashworth and Hogg (2000) has mentioned five stages in a VM process as follows;

- Information gathering - Collect required information, functional and process analysis may assist.
- Brainstorming session - Innovative and creative ideas on the subject are considered.
- Idea evaluation - Selection of the best choice/option as raised in previous steps, the selection should be based on the subject and the situation.
- Development - Study further on the selected choice / option to determine whether to confirm or not.
- Implementation - Plan for implementation is presented to client representatives

However, a gap remains on exploring possibilities of aforementioned VM stages to optimise value during CSA.

Earned Value Management (EVM) can be considered as a tool for project performance which compares the actual work with planned work in monetary terms only (Anondho, 2017; Dissanayake, 2010). Raby (2000) has highligted the uses of EVM as facilitating a uniform unit of measure for project progress and providing a sound basis for the analysis of cost performance. In terms of project management, EVM can be considered as an efficient and well-known tool which assists in making managerial decisions at a construction site (Czemplik, 2014). Specific parameters and indicators that are used to reflect costs and progress from actual and planned perspectives in EVM are summerised in Table 1 (Baldwin and Bordoli, 2014; Czarnigowska, 2008; Tzaveas, 2010);

Table 1: Indicators and parameters of EVM

Indicator / Parameter	**Formula** (Source: Baldwin and Bordoli, 2014)	**Description** (Sources: Czarnigowska, 2008; Tzaveas, 2010)
Schedule Variance (SV)	= BCWP - BCWS	Difference between the actual progress and the planned progress
Schedule Performance Index (SPI)	= BCWP / BCWS	Ratio between the actual progress and the planned progress, if below 1, then considered as a delay.
Cost Variance (CV)	= ACWP - BCWP	Deviation between planned and actual cost of works done
Cost Performance Index (CPI)	= BCWP / ACWP	Ratio between planned and actual cost of works done, if below 1, then considered as a cost over-run
Estimate At Completion (EAC)	=ACWP + {(BAC-BCWP)/PF}	Based on the current progress, estimates the cost at completion
To Complete Performance Index (TCPI)	$\frac{\text{BAC}-\text{BCWP}}{\text{BAC}-\text{ACWP}}$	Ratio between the value of work left and the balance money left from the budget.

Legend:
BCWP = Budgeted Cost of Work Performed (Earn Value)
BCWS = Budgeted Cost of Work Scheduled
ACWP = Actual Cost of Work Performed
BAC = Budget At Completion
PF = Project Factor (Factor differs from project's behaviour)

Even though there are value techniques such as VM and EVM used in the construction industry the applicability of those techniques particularly during a CSA has not been investigated in the existing literature. Thus, the next stages of this study attempt to address this gap.

3. RESEARCH METHOD

Respondents' opinions on value concepts and their knowledge about any possibilities of using value techniques such as VM and EVM at a CSA environment are subjective. Considering the highly subjective nature of the opinions on the phenomenon being investigated a qualitative approach was adopted for this research. Considering that CSA is a highly practical phenomenon, expert interviews were carried out to collect in-depth insights from construction professionals on the value considerations and applicability of VM and EVM during a CSA. Semi-structured interviews were used with open ended questions allowing respondents to elaborate more when answering. Construction project professionals such as project managers, planning engineers and quantity surveyors from both client and contractor parties, who have been actively involved in CSA related activities were selected as respondents for the expert interviews. Employing convenience sampling technique, altogether ten experts having more than 5 years of construction industry experience were selected. Experts from the Contractor's side have been coded from "EC1" to "EC5" while the rest of the respondents of Client's side were given a code from "EE1" to "EE5". Details of selected respondents are given in Table 2.

Table 2: Details of expert interview respondents

Respondent Code	Contractor/ Employer	Professional background	Experience
EC1	Contractor	Project manager	22 years
EC2		Civil Engineer / Project Manager	14 years
EC3		Project Manager	10 years
EC4		Quantity Surveyor	10 years
EC5		Project Manager	8 years
EE1	Consultant (Employer's representative)	Quantity Surveyor / Director	25 years
EE2		Civil Engineer / Director	20 years
EE3		Quantity Surveyor / Project manager	8 years
EE4		Resident Engineer	8 years
EE5		Civil Engineer	7 years

The collected qualitative data from the expert interviews were analysed methodically using manual content analysis.

4. FINDINGS AND DISCUSSION

This section presents the findings from the expert interviews in terms of CSA types, value considerations along the CSA process and the applicability of VM and EVM during a CSA process.

4.1 TYPES OF CSA

According to Figure 1, CSA can be categorised as “planned CSA” and “un-planned CSA”. The expert interview findings revealed that “un-planned CSA” could be further sub-divided based on the reason for acceleration as a delay minimising technique or a non-delay minimising technique.

As a delay minimising technique: Either contractor (To prevent from liquidated damages) or client (Client representative may order the contractor to accelerate) may initiate CSA when they realize that the project is going at a delay. The party who is responsible for the delay will bear the cost.

As a non-delay minimising technique: Mainly, initiated by clients. The client requires accelerating the project to complete the project earlier than previously expected to gain business benefits. However, the contractor may also initiate this type of technique to accelerate a project when sharing resources among several projects. The party who initiates the acceleration will typically bear the cost. Not commonly found.

The above findings on types of CSA were highlighted by most of the expert interviewees and those types can be summarised as shown in Figure 2.

Majority of the respondents agreed that “unplanned CSA” is more common as a delay minimising technique with planned acceleration not being practiced much in the local context. Among the types of un-planned acceleration, types A and B were found to be more common.

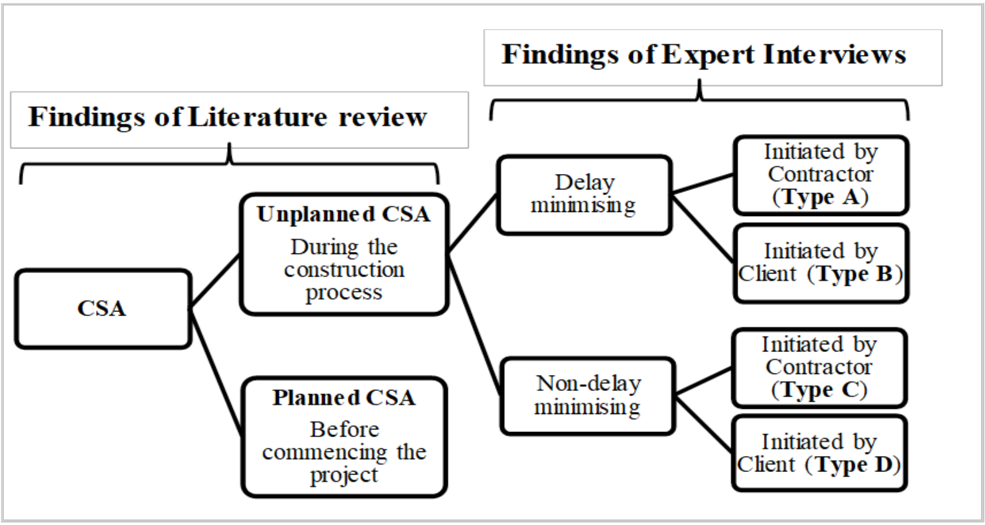

Figure 2: Types of CSA

Most of the expert interviewees stated that it is not possible to carry out a CSA process in a methodical manner due to practical constraints such as client's sudden instructions to accelerate certain activities or the entire project and lack of commitment of the professionals to plan the acceleration properly. However, the findings revealed that the CSA process could be broadly categorized into three phases as decision-making stage, detailed planning stage and physical CSA stage. Hence the following sections go on to present the findings in relation to value considerations and the applicability of VM and EVM during each of these three stages separately.

4.2 DECISION MAKING STAGE

This stage mainly involves the deciding whether to accelerate the project or not. At this stage, respondents from both client and contractor have mentioned that they are not giving much concern to cost during a delay minimizing CSA. For instance, EC1 commented "… *if the acceleration is initiated by the Contractor itself in order to recover a delay, cost will not be considered much*…" During a delay minimising CSA, profitability and productivity were found to be key value considerations for contractors during this stage. Cost appears to be a major value consideration only during non-delay minimising CSAs, which are initiated by contractors. On the hand, respondents from client's side highlighted functionality and quality as main value considerations when deciding whether or not to accelerate a project.

When exploring the applicability of the main VM steps during the decision-making stage of CSA process, it appears that out of the identified main steps in a VM job plan, mainly information gathering and evaluation were applicable. Based upon the expert interviews, main information required for a decision to accelerate was "comparison between as-planned and actual progress". However, respondents such as EE1 and EE2 were firmly convinced that contractors do not follow the as-planned construction schedule. Similarly, EC1 also noted *"…only the date of completion is taken into account. But if the consultants and employers are strict, as-planned schedule will be taken into consideration to a certain extent…"*. Besides this, procuring limitations, resource requirements and availability, cash flows, and contractual provisions were also important information needed prior to taking a decision to accelerate. EC1 particularly highlighted the importance of being aware of procurement and resource limitations by adding, *"…in order to accelerate, some materials needed to be imported and it will take months of time. So, in that type of a situation, acceleration decision will not be worthwhile…"*.

Applicability of the identified EVM indicators; namely SV, CV, TCIP, BAC and EAC, in assisting making the decision to accelerate was also inquired. Interview findings revealed that EVM was not a useful value technique for planned CSA as typically the decision to accelerate had to be taken before actual construction and hence, there is no comparison of actual construction progress with the planned schedule. However, EC5 noted that a derived form of BAC and EAC were sometimes used to get an idea about the cost and the time of completion to assist in decision-making. For un-planned CSA, EVM indicators such as SV, CV and EAC were useful to compare as-planned and actual progress.

4.3 DETAILED PLANNING STAGE

After taking the CSA decision, next stage is to prepare a detailed plan for the CSA. Respondents noted that considerations such as (1) which activities are to be accelerated, (2) up to which extent they should be accelerated, and (3) the method of acceleration of each activity were often determined at this stage.

For both contractors and clients, "productivity" appears to be a main value consideration during this stage. In addition, from the client's point of view, "functionality" and "quality" are also main value considerations during this stage. However, when a planned CSA (which takes place before commencing the project) is considered, "cost" and "profitability" also become important as considering these factors in early stages can positively impact the ultimate goals. Besides these, respondents also highlighted that doing activities in an accelerated manner can lead to safety issues and added that particular attention should also be given to safety during the detailed planning and physical CSA stages.

"Information gathering" (i.e., the first stage of VM job plan) was again found to be relevant during this detailed planning stage as well. In addition to the information identified as important in decision making stage (such as comparison between planned and actual progress, cash flows, procuring schedules, contractual provisions and resource requirements), other information identified as essential to this particular stage included BOQ, specifications, quality standards and "look ahead schedules of previous months". EC3 also added that labour histograms can be a significant element under resource requirement schedules.

According to the expert interviewees, brainstorming for creative solutions was another useful VM stage, applicable during this CSA stage. Respondents mentioned that creative ideas such as substituting of prefabricated materials instead of conventional materials and initiating creative project management strategies were obtained from brainstorming during CSA activities. However, respondents also highlighted the importance of ensuring the initial scope and functionality of the project when taking such creative ideas on board.

If there are more than one method to accelerate a particular task, such options must be evaluated in terms of cost and time. Basis of evaluating options depend on the purpose of CSA. As stated by EC1, *"...If the main purpose is earning profit, the option with the highest profit will be preferred and if the purpose is just to shorten the duration of the project most practical option will be selected. That's the option with less risk to complete...* According to EE4, cost benefit analysis, which is also a value technique, could assist in such evaluations as it allows all the negative and positive impacts in addition to acceleration costs to be taken into consideration. Respondents also noted the importance of contractors making collaborative decisions together with consultants and client, especially if there is a change to the design or major preliminary work in order to conduct the acceleration. According to EE3, a summary including all the considered options can be presented to the client at this stage in a simple, understandable manner for approval.

With regard to the identified EVM indicators, respondents agreed that SV and EAC can be used to ascertain "up to which extent those selected activities should be accelerated". EC5, who was a respondent from a contractor organization, highlighted that in instances where acceleration is done to address a delay taken place due to contractor's own fault, they only considered the aforementioned EVM indicators and did not consider any cost related EVM indicators. However, the respondents agreed that other EVM indicators were also used at least to a certain extent when cost and time were both critical during a CSA. In general, it can be concluded that all the identified EVM indicators are applicable in obtaining the optimum value during the detailed planning stage of CSA.

4.4 PHYSICAL CSA STAGE

This stage involves the actual physical implementation of the CSA. From the contractor's perspective, "productivity", "cost" and "profitability" were highlighted as main value considerations. EC1 and EE2 both highlighted that the expected progress or the productivity can be affected during a CSA by labour inefficiencies and material shortages. "Functionality" and "quality" were identified as main value considerations from the client's point of view. As highlighted by EC2, quality issues can arise during a CSA due to inabilities to recruit skilled laborers and to supply quality material to fulfil excessive demand within the time constraints. Additionally, interviewees also emphasised the importance of safety and environmental considerations which can enhance corporate reputation during physical CSA stage.

4.5 FRAMEWORK TO OBTAIN OPTIMUM VALUE DURING CSA

Figure 3 presents the framework developed to ensure optimum value during a CSA. CSA process has been presented divided into the three main stages identified; namely decision making, detailed planning and physical CSA. In each stage, applicable VM and EVM techniques to achieve optimum value are presented. Since the priority given by the parties for value considerations differ along the three stages as mentioned in sections 4.2, 4.3 and 4.5, those value considerations are included for each stage in their priority order. The process flows and information flows are separately indicated in the framework to improve clarity. The proposed framework is more suitable for unplanned accelerations which are decided after the project commencement date with the aim of minimizing a delay (i.e., Types A and B). The framework will be particularly useful for contractors to obtain optimum value during a CSA. "Value" from the Contractor's perspective can be optimized by giving more concern to the prioritized value considerations in each stage of CSA and by following the steps of VM process and using some EVM indicators as illustrated in the framework.

5. DISCUSSION AND CONCLUSIONS

CSA is about completing a project or a particular activity of a project before the scheduled date or the date in which that task would have been completed at its normal pace. Two main CSA types were identified as "planned CSA" and "unplanned CSA". Unplanned CSA has been further divided into four based on the purpose (i.e., delay minimizing or non-delay minimizing) and the party who initiates it. However, unplanned delay minimizing CSA types (Types A and B) appear to be more common in the local context.

The literature review identified cost, quality, functionality, productivity and profitability as main value considerations other than time affected during a CSA. Perez *et al.* (2010) stated that "value" is not only generated by the client and can vary from the stakeholders' point of view.

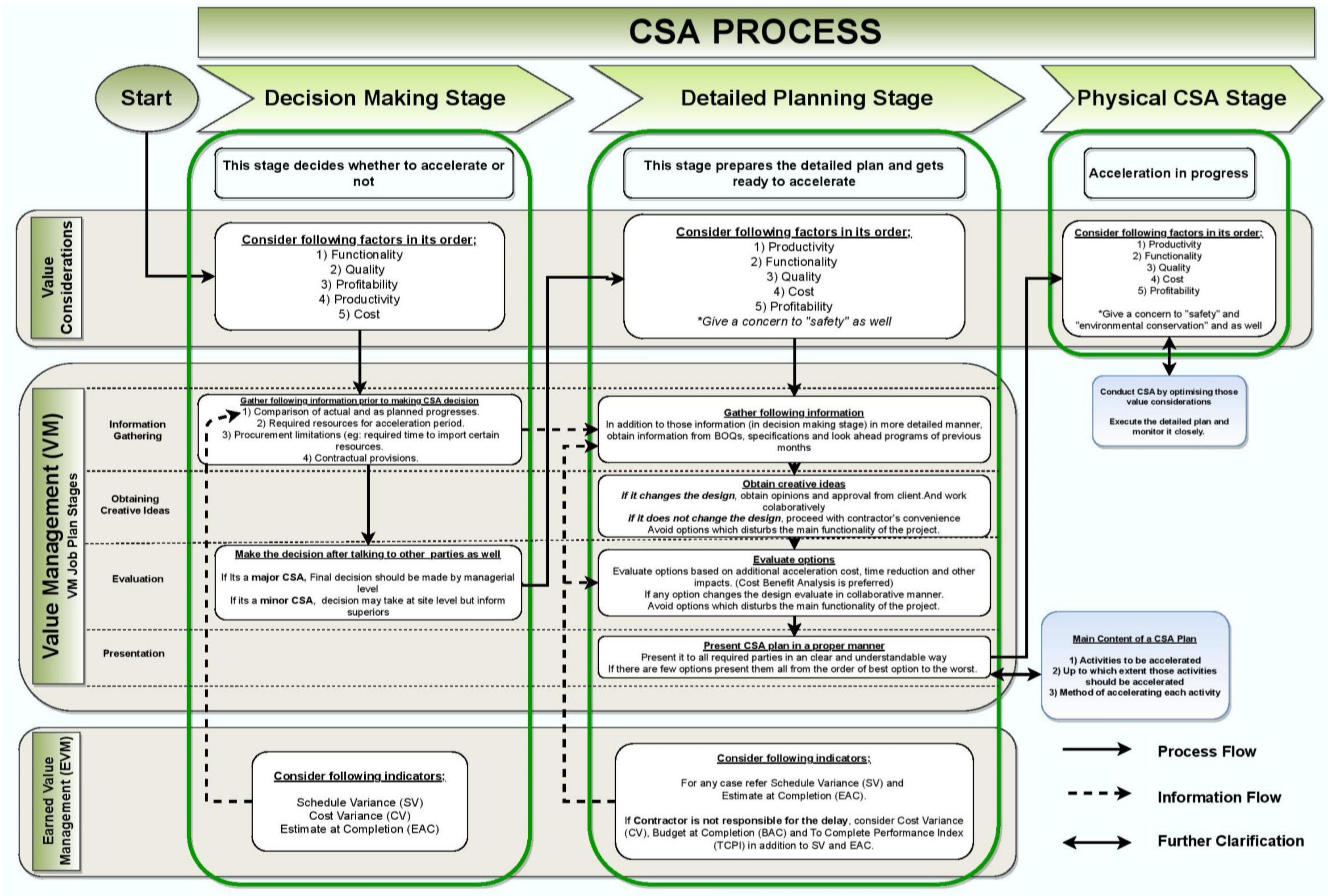

Figure 3: Framework to obtain optimum value during CSA

This was also supported by expert interview findings where it was found that value expectations differ between client and contractor during a CSA. Additionally, it was found that the value considerations can vary based on the type and stage of CSA as well. For instance, while "cost" was a main value consideration for the entire CSA process, "quality" and "functionality" have become major concerns during decision making stage.

The applicability of VM and EVM during the two initial stages of CSA were highlighted. Particularly to the decision-making stage, information gathering and evaluation steps of a VM job plan was applicable and SV, CV and EAC were the applicable EVM indicators to that stage. Detailed planning stage can be assisted by information gathering, brainstorming, evaluation and presentation stages of VM job plan while obtaining certain information from EVM indicators namely SV, EAC, CV, TCPI and BAC. Further, two characteristics of a VM job plan namely "working in a collaborative manner" and "not disturbing to the main functionality of the project" have proven to be required at decision making stage and detailed plan preparation stage of a CSA. The findings were used to develop a framework to ensure optimum value during a CSA.

In order to obtain the optimum value during a CSA and to smoothen the CSA process, certain recommendations would be useful for the industry such as monitoring the construction progress properly, communicating effectively, maintaining the main functionalities of the project (during a CSA) and replacing conventional methods of construction with modern technological methods. This study has paved paths to further studies namely to investigate the applicability of Cost Benefit Analysis (CBA) for a planned CSA and to study the strategies to enhance productivity during the physical CSA stage.

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POTENTIAL OF INTERNET OF THINGS (IOT) IN THE CONSTRUCTION INDUSTRY

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ABSTRACT

The introduction of the Internet of Things (IoT) in the manufacturing industry changed the trajectory to Industrial Revolution 4.0. Accordingly, it consists of various technologies, where the IoT is the basis of this revolution. However, there is an increasing gap between traditional Construction and digitalised data-driven Construction. In such context, the adoption of IoT applications in construction projects shall increase the productivity and better performance of construction activities. Consequently, IoT concepts, developments, applications, and potential benefits of IoT in the construction industry need to be acknowledged by industry practitioners before the implementation can take place. Hence, the purpose of this research is to outline such needs, thus provide an understanding on the potential of the IoT in the construction industry. Subsequently, a comprehensive literature synthesis revealed the expression IoT is best understood as a metaphor that encapsulates the immersion of almost anything and everything within the communications and connectivity space. The development is at an embryonic stage of development but proliferating in measuring, tracking, modelling, and prediction stages such as smart wearables, sensors attached to the structures and machinery, IoT linked Building information modelling (BIM) models, usage of drones. As a result, potential benefits are entertained by the construction industry practitioners towards sustainability. Ultimately, the study provides a starting point for raising awareness to facilitate and implement IoT applications in construction projects. In the absence of empirical literature on the implementation of the IoT paradigm in general, this paper presents a valuable contribution to the growing body of knowledge.

Keywords: *Automation; Bottlenecks; Construction industry; Internet of Things (IoT); Smart controls.*

1. INTRODUCTION

A telescope was invented after more than two hundred years, from the invention of the printing press in the 14th century (Kodithuwaku, 2019). However, Kodithuwaku (2019) emphasises that today, Things being invented within months, where time gaps between inventions are being shortened. In line with this development, the Internet of Things is an area of innovation and growth (Vermesan and Friess, 2013). The development of the IoT concept would change lifestyles and enhance the industry's performance (Suriyarachchi *et al*., 2019). As a result, the construction industry will follow such rapid technological enhancements around the world.

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The IoT is massively significant to the built environment (Oesterreich and Teuteberg, 2016). Jones (2017) insisted that carpenters, welders, and painters on the worksite might not discuss the IoT in casual conversation. However, a growing number of industry-leading contractors and builders are using IoT devices to monitor equipment, machinery, and workers to make better decisions in real time. Consequently, there are 367 IoT-related projects identified worldwide, whereas industrial-related is 265, and IoT-related building projects are 193 (Lueth, 2019).

2. RESEARCH PROBLEM

Triax (2018) identified that the construction industry regularly suffers from bottlenecks, slowing down dramatically without supervisors knowing that is even happening. In the case of one company, where they lost $4 million by labourers spending too much time waiting for the lift. Installing a second lift on day one would have cost them just $1 million, which is the solution provided by an IoT device at the end of the day. The company could have adopted such a solution on the initial day if they had such technology to identify. Hence, that would not have had such a severe impact on their project (Triax, 2018).

Consequently, many countries are developing their IoT network in Construction. Therefore, the use of IoT applications and the potential of such applications in Construction need to be acknowledged by the Construction industry, as the industry will become ever more complicated in the future (Mahmud *et al*., 2018). In such a time, if there is no system for facilitation of the work involved, the construction sector must take account of the expansion of the IoT network; otherwise, the construction sector will be left behind by other industries.

Besides, IoT in a fledgeling stage, with a limited number of experts operating somewhat in isolation and offering single-point solutions; for instance, publications identified and the main focus of research undertaken to be in the technical areas of smart buildings, construction safety, and optimisation and simulation (Ghosh *et al*., 2020). Hence, a broader picture of applications needs to be outlined. Additionally, researches were conducted on the adoption of IoT specifically to several geographical construction contexts. Despite those restrictions, there was a necessity to bring the overall applications and benefits of IoT to the construction industry. Nevertheless, the benefits of IoT applications in the construction industry are still not clear (Chen *et al*., 2019). Therefore, the subject of the enquiry undertaken was to examine the applications of the IoT in global context; thus, this study aimed to illustrate the potential of IoT in the construction industry by addressing the IoT concepts, present applications, development categories, and benefits associated with it.

3. RESEARCH METHOD

To achieve the aim, this paper intends to bring in literature analysis and arguments on the following themes:

1. The concepts and current development categories of IoT identified in the global construction industry
2. IoT applications practised in the global construction industry
3. The potential benefits achieved from IoT applications in several construction contexts.

The literature was searched based on unconstrained and unstructured iterative queries to explore the potential of IoT in the construction industry (Eiris and Gheisari, 2017). Accordingly, information from the peer-reviewed conference, journal papers, reports, forums, and dissertations were obtained from leading academic databases were examined such as Google Scholar, Web of Science, Science Direct/Scopus, EBSCOhost, IEEE Xplore, CuminCAD, JSTOR (Loyola, 2018). The generic descriptors "Internet of Things", "Construction 4.0", "Smart", and "Digital" were used to find relevant information in the construction field of study (Senanayake *et al.*, 2020). The sources were slightly extended through a selective snowball method, as the need to deepen the review in complementary topics arose (Loyola, 2018). Besides, as decisions regarding inclusion and exclusion remain relatively subjective, this research is mainly focused upon an in-depth investigation of literature sources. Accordingly, the selected papers were subjected to manual thematic analysis to develop findings against the developed themes. However, this study is limited to the sources which are readily available from databases. Consequently, IoT concepts, present applications, development categories, and benefits associated with it in the construction industry in the global construction context were outlined.

4. INTERNET OF THINGS (IOT)

The International Telecommunication Union (ITU, 2012) defined IoT as "A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies" (p. 6). Specifically, IoT is identified as a system of 'Things' using the Internet or a private network to connect and communicate with each other (Censis, 2019). In particular, 'Things' are stipulated as 'smart devices' connected to a network and communicate among each other with minimum human engagement (Phuoc *et al*., 2009). The basic idea is that objects of day-to-day life can be equipped with the detection, sensing, networking, and processing capabilities that enable them to communicate over the Internet with each other and with other devices and services to achieve a common goal (Dooley *et al*., 2017). In such context, the IoT allows people and Things to be connected anytime, anyplace, with anything and anyone, ideally using any path/network and any service (Balte *et al*., 2015). The system enables acquiring, processing, and reacting to real-world data in real-time (Lan *et al*., 2019).

4.1 DEVELOPMENT CATEGORIES

Presently, millions of IoT devices are communicating with each other. In addition, such devices tend to be negotiating, interacting, measuring, and responding with the least human involvement. Husain (2017) identified the development of IoT in three waves.

4.1.1 First Wave: Measuring and Tracking

Husain (2017) recognised that people are currently in the midst of the first wave of IoT. There are wearables and gadgets implemented to measure pulse rate and track day-to-day work activities, predict the circadian rhythm and automatically trigger the alarm if people fall asleep, and alarm in case of intruders in private places (Husain, 2017).

4.1.2 Second Wave: Modelling and Predicting

There are circumstances identified where data captured from the first wave of devices were used by devices to model the environment, their behaviour, and the behaviour of other systems to predict the future. Some systems include delivery drones, self-driving trucks and tractors, and increasingly sophisticated factory and warehouse bots that use vision to detect objects and sort products and packages (Husain, 2017).

4.1.3 Third Wave: Fully Autonomous Devices

IoT's maximum potential will be recognised in the third wave, where there will be federated network intelligence powering cognitive, fully autonomous devices. In such context, the humans who built such devices will not experience the reality of it. For instance, algorithms that empower fleets of hundreds of thousands of autonomous drones carry out an ever-increasing range of functions for their human owners (Husain, 2017).

5. PRESENT APPLICATIONS OF IOT IN THE GLOBAL CONSTRUCTION INDUSTRY

A new and fast-emerging shift in networking and communications is the IoT. Several contractors have already implemented IoT applications for both production and delivery of services in the construction industry to maximise their opportunities (Atayero *et al*., 2016). Accordingly, several applications were identified below.

5.1 MEASURING AND TRACKING APPLICATIONS

In such context, Mehata *et al*. (2019) identified IoT- Designed smart wearable devices, such as bands and helmets, using different types of sensors to help track workers' health and safety. The devices are designed with the help of IoT, which detects any worker's fall and sends alert messages for emergency help. Besides, employees are frequently tracked and alert about adverse health problems, such as pulse rate and temperature (Ding *et al*., 2013).

In another context, abnormal changes in the underground water table, change in shape, load on external lateral support, and degree of sloping of supporting structural components are indications before structural failure. Such changes inevitably go beyond safety limits and potentially lead to structural failures. IoT real-time monitoring solutions are developed to detect and analyse such abnormal changes and issue appropriate warning signals to take remedial actions on time (Lam *et al*., 2017). Therefore, evacuation time would still be adequate to avoid accidents and casualties. Similarly, the IoT system was used to monitor a retaining wall movement in Shenzhen, China. Measurable cracks, in particular retaining walls and cracks created by differential settlement in the adjacent buildings, were identified in real-time. Subsequently, data showed a night-time surge in the rising level of the underground water table detected on the side of the retaining wall. The findings revealed that the drainage system experienced a significant leakage (Lam *et al*., 2017).

Bottaccioli *et al*. (2017) found a different scenario that the IoT system will represent the buildings' energy usage accounted for in real-time. Therefore, energy consumption monitoring improves energy efficiency, decreases waste, and is favourable to sustainable development (Wan *et al*., 2010).

On the other hand, green building is a reasonable assurance for sustainable growth. The Green building concept achieves its goals by using the IoT technology and cloud computing with the green building energy efficiency standards (Zhao *et al*., 2013). In such context, IoT carries out the overall environmental monitoring, provides supervision, managing, and data processing (Wang *et al*., 2017).

Nair (2020) mentioned the most intelligent building in the world called "The EDGE", which has 28,000 sensors installed under the IoT network. Such sensors collect property data and user data with the goal of increased user friendly.

Zhou and Ding (2017) pointed out the scenario of the twin tunnel project across Yangtze River, where during the transport of materials in 25m depth of tunnel hole, the hazard energy restriction alarming scenario has occurred at the bottom. The gate crane driver at the top could not be able to see the circumstance at the bottom. The Radio-frequency identification (RFID) sensors on workers' helmets and sensors around this dangerous area triggered the warning. Accordingly, the regional workers were able to leave the hoisting field.

5.2 MODELLING AND PREDICTING APPLICATIONS

In contrast, IoT technology influences the concrete production market. IoT based services for mounted batching plants can improve the consistency of concrete quality, connected logistics, and predictive maintenance (Walther, 2018). The batching plant is fitted with sensors such as weighing sensors and flowmeters to handle such measurements (Rasmussen and Beliatis, 2019). In such context, weighing sensors monitor the mixing of all aggregates and measure the weight of each aggregate. The flowmeter calculates the water rate in kg/sec to the batch to maintain the appropriate mix of gravel and cement in the receipt.

In another case, the developed BIM model is available for steel bridge construction, which is directly linked with IoT for real-time data simulation for Construction (Zhang *et al*., 2016). Such encouragement facilitating dynamic interactions and real-time responses among designers, builders, transit providers, and maintainers. Therefore, the integration of the value chain between stakeholders is possible, and the project's success is achieved (Ding *et al*., 2018).

In contrast, the type of precast components, the fabrication method of such components, the comprehensive construction process, cost, and quality of the completed steel bridge can be identified by attaching IoT labels on precast components (Zhong *et al*., 2015). Accordingly, steel-bridge performance can be monitored remotely in the construction stage. Thereafter, Big data analytics further evaluates sensor data into the decision-making model. Thereupon, the steel bridge can be predictively and proactively maintained (Ding *et al*., 2018).

KOMATSU introduced smart Construction, which links everything present on the site dynamically under IoT and allows 3D formation (Sategna *et al*., 2019). Furthermore, IoT applications are involved in using drones to conduct surveys high precisely and real-time observation of changing topography of worksites.

Kuenze *et al*. (2016) addressed, IoT system addresses all steps of the supply system, from asphalt batching to compaction of asphalt. Moreover, asphalt temperature can be regulated by temperature sensors in the truck at any time. The information from embedded sensors on asphalt plants and pavers allows for a just-in-time schedule of asphalt delivery services, thereby decreasing the number of dump trucks to be delivered at the site (Sategna *et al*., 2019).

In another case, a contractor used swing stages to do external work on a high-rise building to get the job done. All the subcontractors required to access the stations, and the supervisors complained about not having enough stations and not being available at the time necessary. The work was slowed down accordingly. Later it is identified, with the support of IoT sensors attached to each platform, the supervisors on his smartphone were able to figure out where the lifts were and whether one was available instantly (Triax, 2018).

5.3 FULLY AUTONOMOUS APPLICATIONS

Wu *et al*. (2018) found a situation on the application of IoT in a utility tunnel in Xiamen city, China. The project includes surrounding dust monitoring systems, automatic sprinkler dust falling control systems, and site temperature monitoring systems based on real-time metrological data. Hence, the tunnel operation and maintenance are visualised by data provided by IoT sensors (Bottaccioli *et al*., 2017). Data control of the dust is related to the spray dust reduction system. If the air quality is not up to standard, the device will issue a warning on the BIM model and open the spray dust control system automatically in the respective region (Teizer *et al*., 2017). Besides, BIM and IoT technologies often have essential applications such as limited space detection and gate management; thus, the gate can be controlled and operated remotely. Correspondingly, the gate can be automatically monitored and connected to the network to ensure better protection inside the utility tunnel (Patti and Acquaviva, 2016).

In another case, Smart contracts can remove the need for an authorised third party to administer a contract in an autonomous state by integrating BIM and the IoT. As a result, IoT will manage payment procedures with actual work progress. Afterward, the central iContract platform will evaluate all data against the agreed contract clause and enforce the terms accordingly (AIQS, 2019).

Therefore, seems to be numerous applications were identified by authors in measuring, tracking, modelling, and predicting waves that would have a significant impact on the construction industry. Besides, it seems the industry will reach more tremendous potential in the full autonomous wave.

6. THE POTENTIAL BENEFITS OF IOT IN THE CONSTRUCTION INDUSTRY

The construction industry value chain is profoundly affected by collaboration with major contractors to low-level suppliers. Besides, Construction projects are site-based and complex, requiring a higher-level management process (Oesterreich and Teuteberg, 2016). In such context, the emergence of the IoT makes a significant impact and brings several benefits for the projects and people involved. Accordingly, several authors identified consequences that emphasise the potential of IoT. Such consequences are recognised below.

6.1 UP-TO-DATE INFORMATION FOR BETTER DECISION MAKING

The IoT network consists of intelligent devices that are installed around the worksite, connected to vehicles, materials, and attached to workers (Bucchiarone *et al*., 2019). Besides, the IoT application handles all incoming information and provides supervisors with up-to-date information and alerts for particular events such as the system stops working and the process stage is completed, thereby allowing them to make suitable decisions (Piccialli *et al*., 2020).

6.2 IMPROVED PROJECTS HANDLING WITH MINIMUM HUMAN EFFORT

Construction sites of megaprojects have various workflows, according to the size and type of the project. In such context, a challenging task is to plan and organise such complex projects (Clough *et al*., 2000). Further, the lack of adequate digital and precise data requires a permanent project manager at a physical presence. Hence, IoT Network helps project managers to control several construction sites remotely at various locations simultaneously and to intervene quickly to adjust their activity to the effects of real-time data (I. Lee and Lee, 2015).

6.3 MINIMISED PROJECT DELAY BY TAKEN PREVENTIVE MEASURES

Typically, the construction site is not prepared to face abnormal weather situations, and preventive mechanisms are not in place (Mohammed *et al*., 2014). Hence, the status of such a situation leads to the loss of money and downtime delays in the construction process. However, the IoT network's usage promptly alerts such bad weather by interacting with the meteorological station. Therefore, countermeasures can be taken on time (Wu *et al*., 2018).

6.4 REMOTE OPERATION OF ACTIVITIES IN WORKSITE

According to Burger (2017), if machines are remotely connected, instructions can be given from a long distance. Therefore, human resources can be removed from hazardous places. Besides, Nordin (2016) elaborated on such a situation with drones, that a machine easily identifiable by drone is eligible to obtain commands and operate alone under surveillance areas.

6.5 IMPROVED SUPPLY CHAIN MANAGEMENT

Through IoT, the system could measure the available stock by the RFID labels attached to materials. Therefore, the system will automatically produce alerts to maintain available stock (Burger, 2017). The RFID tags installed on the commodities inform about the adequacy of the item temperature, handling impact, damage level, and expiry period (Macaulay *et al*., 2015).

6.6 MAINTENANCE OF MACHINERY AND EQUIPMENT PROMPTLY

Maintenance of machinery is necessary to prevent additional expenses due to severe damage. The IoT allows sending information on the current state of tools and equipment in real-time to repair or maintain needs (Burger, 2017). According to Levy (2017), heavy-duty construction machines are equipped with sensors, where such sensors can detect the required maintenance from range, such as temperature fluctuations and increased vibrations.

6.7 ENERGY, FUEL, AND POWER SAVINGS

Unmaintained energy and fuel usage will lead to wastage and affect the project cost. Through the approach of IoT, information about the usage of electricity, gas, generator fuel can be obtained from the building (EEI *et al*., 2011). Additionally, the use of tools and equipment will be controlled for fuel-saving requirements (ITU, 2015).

6.8 IMPROVED TRANSIT MANAGEMENT (TIME-SAVING)

According to Cunha (2014), selecting inappropriate transit routes would lead to significant fuel usage and delay in the supply chain. Hence, sensors act as general packet radio service (GPRS) will provide operators with data about the most efficient and quick transit lines through the Internet of Things (Sategna *et al*., 2019).

6.9 SECURITY CONTROL OF THE SITE

There is a possibility for material theft at the site if the storage units are not adequately supervised (Said and Rayes, 2010). However, with the help of IoT, any material theft is easily solved using IoT labels since these sensors inform the current location of such materials (Macagnano *et al*., 2014). Furthermore, the IoT-developed security device known as August Smart Lock, which operates over Wi-Fi networks. This unit is placed at doors and provides control over doors through mobile devices. Moreover, such a device scans every object pass through doors and triggers an alarm when there are threats (Macaulay *et al*., 2015).

6.10 HUMAN RESOURCE MANAGEMENT

Firms need to make sure that employees work effectively and efficiently under considerations of third-party safety, obligations of the contract, and rules of the firm (Loosemore *et al*., 2003). Through the IoT application, sensors attached to the employees' uniform are enabled to notify the supervisor of their presence, abilities, and credentials for the task and the time they spend on particular activities (Häikiö *et al*., 2020). Furthermore, such data from IoT used for human resource development and payment procedures (Cunha, 2014).

6.11 ENVIRONMENTAL MONITORING

Libelium (2012) identified there are devices developed with the concept of IoT to monitor environmental aspects. Such devices consist, a remote-control sensor capable of monitoring fire, flood threats, and air pollution. Subsequently, they interact with relevant protocols to take preventive measures.

6.12 HEALTH MONITORING OF STRUCTURES

Libelium (2012) reported that the IoT is used for the building's health and safety by installing sensors on structures sensitive enough to detect vibrations, cracks, and defects in building components.

6.13 WASTE MANAGEMENT

A smart waste management scheme was launched as an IoT solution using infrared sensors, microprocessors, and remote accessories (Zeinab and Elmustafa, 2017). The particular program ensures that the garbage is removed automatically when the waste hits full. The condition will be reported to relevant authorities for necessary action if the trash has not been removed for a while.

6.14 ECONOMIC BENEFIT

IoT increases interconnectivity among people and Things. Hence, it drives the economy much higher and provides more wealth (Manyika and Roxburgh, 2011).

6.15 IDENTIFICATION OF FLAWS IN CONSTRUCTION PHASES

In the use of IoT, potential weaknesses can be identified at all stages of the construction process by gathering, assimilating, and connecting data of all operations at the worksite (Sategna *et al*., 2019).

6.16 NEW OPPORTUNITIES AND SOLUTIONS

In the future of Construction, everything will be connected at the site (Yuanyuan *et al*., 2006). Data arising from such environments will be available on cloud platforms to further develop integrated services and solutions for different project stages (Bottaccioli *et al*., 2017).

6.17 OTHER KEY BENEFITS

Accordingly, Yuqiang *et al*. (2010) identified, the purpose of such advancement enables all Things to be interpreted and remotely controlled and integrated with the Internet into a more intelligent system of life and development. Hence, the system can solve technical problems in industries, improve work management, enhance resource utilisation, and improve the relationship between humans and nature (Chao-sheng, 2012). Furthermore, key benefits are summarised in Table 1.

Table 1: Benefits from IoT

Benefit	Description
Efficiency	Better use of time; speed up processes
Productivity	Identify and eliminate process errors
Profitability	Cost savings and increased productivity leads to increased profitability
Compliance	New and more effective ways to monitor and report compliance requirements
Safety	People exposed to less hazardous environments
Society	Monitoring for health and social care
Environment	Maintenance of pollution levels, air quality, flooding alerts
Innovation	New products and service opportunities or new markets
Business Intelligence	Allowing the gathering of data to make better decisions to benefit the organisation

(Source: Censis, 2019)

Therefore, it seems to be those potential benefits of IoT would bring greater sustainability through better utilisation of resources and improvements to the construction industry. Hence, it will lead to strategic, structural & cultural transformations towards the new normal.

7. CONCLUSIONS AND WAY FORWARD

This study uncovers and identifies, and assesses the IoT concepts, applications, and potential in the construction industry by bringing literal identification from significant authors. Accordingly, the concept of "IoT" seems to be widely adopted, with three features: the live-time tracking of "Things" conducted actively by different types of sensors; linking such smart objects to a worldwide network through widespread internet technologies and utilising such technologies to develop smart "Things" controls. However, the development of IoT applications is still in the measuring, tracking, and modelling stage out of its maximum potential of autonomous applications. It is further evidenced by the identification of several present applications of IoT in the global construction industry. Moreover, significant benefits identified from such prospective scenarios emphasise IoT's potential impact in the construction industry. Besides, it is an indication that many have adopted the technology and put it into practice.

In addition, there are potential benefits of applying IoT in construction projects addressed through different contexts of applications. Hence, it emphasises the IoT has the potential to solve the problems utilisation of resources and improve the working methods incorporated in the construction industry. Consequently, the overall potential of IoT has been established. Accordingly, industry practitioners and internal, external stakeholders should develop innovative attitudes and flexibility to adopt new practices; thus, this study can achieve maximum benefit. Additionally, this new creation of explicit knowledge of this study shall be acknowledged by professional institutions to raise awareness in the construction industry. The government agencies, stakeholders and policymakers shall refer to this study to get the point of reference in directing the IoT's adoption smoothly in the construction sector.

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PROBLEMS AND RELATED CAUSES OF PUBLIC PROCUREMENT PROCESS TO ACHIEVE SUSTAINABILITY IN DEVELOPING COUNTRIES

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ABSTRACT

Public Procurement Process (PP Process) in construction industry has identified as integral part to achieve sustainability in developing countries. Sustainability links with the social, environmental, and economic indicators. The PP Process contributes largely to the budget of developing nations. However, existing PP Processes of developing countries have shown lagging features to achieve sustainability due to a number of problems. Further, the depth and gravity of the problems depend on the impact of root causes throughout the activities and stages of procurement lifecycle of a project. Hence, this paper aims to identify the problems and related root causes during the various activities in the stages of PP Process to achieve sustainability in construction projects in developing countries.

In order to achieve the aim, this study started with a comprehensive literature review to identify the stages, activities, problems and related root causes in PP Process to achieve sustainability. Subsequently, interviews with 14 subject matter experts were carried out to identify and verify the stages, activities, problems and related root causes to achieve sustainability in PP Process in developing countries. The data were analysed using manual content analysis. The findings of the study identified 10 problems and 22 root causes that affect the 39 activities in 05 stages of PP process in project procurement lifecycle in construction industry. The outcome of this paper will be beneficial to relevant authorities, funding agencies and policy makers in taking necessary steps to update the existing guidelines, bidding documents, procedures and protocols to address the identified problems and root causes to achieve sustainability of developing countries.

Keywords: *Construction industry; Developing countries; Problems and root causes; Public procurement process; Sustainability.*

1. INTRODUCTION

Sustainability is defined as processes and related actions that focus on the present moment and keeping things above a certain level throughout the identified period of time to fulfil

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the needs of future generation (World Commission on Environment and Development, 1987; White, 2012). According to World Bank (2016), construction industry shall be considered as an integral part, which provides major contribution to achieve sustainability. Further, World Bank (2016) stated that Public Procurement Process (PP Process) in construction industry continuously evolves as a tool to achieve sustainability and Sustainable Development Goals (SDG). Procurement plays a predominant role not only in public sector, but also in private sector to achieve the sustainability (Love *et al*., 2010). Further, the public procurement considers as a largest sector that influence the sustainability when compared with private sector (Hawkins *et al*., 2011). World Bank (2016) defined public procurement as a process that implements a series of activities to acquire goods, works and services for government institutions in most appropriate manner. According to Jones (2007), works represent major part of the government expenditure, with compared with goods and services. Further, Albano *et al.*, (2013) categorised the construction activities of the procurement process as works.

The activities of the PP Process in construction industry implement in line with the stages of the project lifecycle (Royal Institute of British Architectures [RIBA], 2007). The primary objective of the PP Process in construction industry denotes as fulfilment of stakeholder satisfaction in line with strategic objectives of the country (Office of Government Commerce, 2008; Ministry of Finance, 2019). Eurodad (2009) found that the impact of the PP Process in construction industry is significant in developing countries than developed countries. Further, Organisation for Economic Co-operation and Development (OECD, 2009) and Silva *et al*. (2017) added that the contribution of the PP Process in construction industry in developed countries vary between 08% to 25% of the Gross Domestic Product (GDP) at global scenario, whereas around 30% in developing countries (Preuss and Walker, 2011; United Nations Environmental Management Group, 2012).

However, Ayopo *et al*. (2016) found that existing PP Process in construction industry in developing nations has failed to deliver necessary infrastructure requirements to achieve sustainable development and sustainability due to number of prevailing problems. Further, the depth and breadth of problems depend on number of root causes (Rahman and Kumaraswamy, 2004). Accordingly, stakeholders of the PP Process strive to prevent and overcome the problems by addressing the root causes to achieve the sustainability (Thai, 2016). Although a number of studies are available to identify and determine the problems and root causes of the PP Process in general, a limited number of studies have investigated the problems and root causes in construction industry in developing countries. Further, there is a lack of studies that address the problems and root causes of PP Process in construction industry in developing countries to achieve the sustainability.

Thus, the identification of problems and root causes in PP Process to achieve sustainability along each stage of the project lifecycle in the construction industry is vital to propose the solutions and remedial measures to attain sustainable development. Therefore, this paper aims to identify the problems and related root causes of the PP Process in construction industry in the developing countries to achieve sustainability.

2. LITERATURE REVIEW

The PP Process facilitates to fulfil the stakeholder satisfaction in line with strategic objectives of the country (Ministry of Finance, 2019). However, Chimwani *et al*. (2014)

emphasised that prevailing problems of the PP Process in construction industry in developing nations negatively affect the sustainable development of the country. Further, Ayopo *et al*. (2016) explored root causes influencing to the problems of the PP Process.

Walker and Brammer (2009) highlighted that the existing problems of the PP Process can be addressed by integrating innovative improvements of construction industry to achieve the sustainability. Furthermore, World Bank (2016) has pointed out that contemporary versions of the PP Process facilitate to upgrade the living standards of the community as per the current global needs. Thus, the PP Process can be upgraded by addressing prevailing problems and providing solutions to the root causes.

The following sections review the stages and activities of PP Process, prevailing problems and related root causes of the PP Process in construction industry to achieve sustainability.

2.1 STAGES AND ACTIVITIES OF PP PROCESS IN CONSTRUCTION INDUSTRY

Crowder (2015) stated that the public procurement in construction industry comprised with the number of activities and stages. RIBA (2007) developed framework for construction industry with five (05) stages of Preparation, Design, Pre-construction, Construction, and Use. However, World Bank (2018) has emphasised that the number of stages and activities of the PP Process in construction industry differ and depend on the nature and complexity of the project lifecycle. Further, activities of the PP Process have been identified as continuous processes with number of stages that initiate from preparation stage to post completion stage (Dzuke and Naude, 2017).

Office of Government Commerce (2007) divided PP Process into seventeen (17) stages, starting from the needs assessment up to the disposal throughout the project lifecycle. Further, RIBA (2013) divided this into eight (08) stages from the stage of 'strategic definition' up to the stage of 'in use'. World Bank (2018) has specified seven (07) key stages of the PP Process from the strategic development stage to the end of management of contract. Turin (1973) identified four (04) stages of the project such as Conceptual, Planning, Execution, and Termination with number of activities. However, Hillebrandt (1984) divided project procurement lifecycle into three (03) stages of discovery, development and delivery. National Procurement Agency (2006) divided procurement process in construction industry under two (02) stages of pre contract and post contract. According to Chimwani *et al*. (2014), it was revealed that different number of stages and activities are referred by different authors. However, majority of the construction project's procurement lifecycle divided into five (05) key stages; i.e. (a) Preparation, (b) Design, (c) Pre-construction, (d) Construction, and (e) Use (RIBA, 2007).

International Federation of Consulting Engineers (FIDIC, 2017) and World Bank (2016, 2018) have provided guidelines and directions for the activities in PP Process in construction industry in global context. Further, National Procurement Agency (2006); Ministry of Finance (2017); Construction Industry Development Authority (CIDA, 2018) have provided guidelines and directions to govern construction projects and their activities for the Sri Lanka as a developing country. Accordingly, the activities of the PP Process throughout project lifecycle identified by various authors and institutions were summarised into 50 activities (10 activities under each stage) of the project procurement lifecycle. This list was presented to the experts during the empirical investigation and evaluated the suitability and relevancy to developing countries context. (Refer findings section for further information).

2.2 PROBLEMS IN PP PROCESS IN CONSTRUCTION INDUSTRY

Raymond (2008) noted that poor procurement practices and prevalent problems of the PP Process as major reasons hindering the economic growth of a country. Further, Ayopo *et al*. (2016) emphasised that no matter whether it is in developing or developed country, widespread of problems can be seen in the PP Process in construction industry. Ayopo *et al*. (2016) identified the challenges face in effective implementation of activities in the PP Process as the prevailing problems in construction industry. Dubois and Gadde (2002) and Decarolis and Palumbo (2015) explored the problems of the PP Process that are prevailing in construction industry as late delivery, risk and cost overrun and low efficiency. Further, Raymond (2008) added that fraud, corruption and risk overrun as the problems in PP Process. Furthermore, Walker and Brammer (2009) pointed out that not meeting the required quality and standard, outdated technology, and ignoring the Value for Money (VFM) as some other related issues. Schiele and McCue (2006) and Ameyaw *et al*., (2012) added that ignoring the analysis of externalities as another problem. Moreover, Jones (2007), World Bank and Asian Development Bank (2012), Ameyaw *et al*. (2012), and Naude (2017) revealed that deliverables not fit for purpose and fraud and corruption as some other leading problems in the PP Process.

However, risk of the problems of the PP Process in construction industry defers due to the inherent complexity in construction project (Rahman and Kumaraswamy, 2004; Thai, 2011). Moreover, Naude (2017) mentioned that gravity of the problem defers from one country to another country. However, Ayopo *et al*., (2016) emphasised that the problems of the PP Process in construction industry in developing nations are in similar nature. Accordingly, comprehensive literature revealed 10 problems affect the PP Process in construction industry as shown in Table 1.

Table 1: Problems in PP process in construction industry

No	Description of the problem	Authors referred
P.1	Deliverables not fit for purpose	3, 4, 8, 9, 13, 14
P.2	Late delivery	1, 12, 15, 16
P.3	Cost overrun	1, 12, 15, 16
P.4	Risk overrun	1, 12, 15, 16
P.5	Low efficiency	1, 9, 11, 12
P.6	Not up to the required quality and standards	6, 9, 10, 11
P.7	Outdated technology	6, 9, 10, 11
P.8	Not identified the costs for the damages of social and environment	2, 4, 8
P.9	Not considered the value for money (VFM) in the process	6, 7, 9
P.10	Fraud and corruption	3, 5, 8, 9, 14,

1. Dubois and Gadde (2002), 2. Schiele and McCue (2006), 3. Jones (2007), 4. OECD (2007), 5. Raymond (2008), 6. Walker and Brammer (2009), 7. Dawson *et al*. (2011), 8. Ameyaw *et al*. (2012), 9. World Bank and Asian Development Bank (2012), 10. Amemba *et al*. (2013), 11. Adhikari (2015), 12. Decarolis and Palumbo (2015), 13. Ayopo *et al*. (2016), 14. Naude (2017), 15. Gyawali *et al*. (2018), 16. Bhuvaneswaran (2019)

Literature explored 10 problems affecting the PP Process in construction industry. The next section critically reviews the root causes behind those problems in PP Process in construction industry.

2.3 ROOT CAUSES BEHIND THE PROBLEMS OF THE PP PROCESS IN CONSTRUCTION INDUSTRY

Chimwani *et al*. (2014) explored factors and root causes influencing to generate and create problems in PP Process in construction industry. Further, Ayopo *et al*. (2016) identified root causes as issues that affect the problems in the PP Process. Thai (2011, 2016) found root causes affect the problems in the PP Process and summarised the key root causes as lack of interrelation and communication between the parties and authorities and lack of available information to take procurement decision. Schiele and McCue (2006) and OECD (2007) revealed number of root causes that affect the problems of the PP Process as lack of integrity and transparency, communication issues, negative attitude, and inadequate knowledge and transferring of knowledge. Subsequently, Ameyaw *et al*. (2012), and Albano *et al*. (2013) elaborated the root causes that identified by Schiele and McCue in 2006 and OECD in 2007. Raymond (2008) emphasised that lack of planning, information and capacity as root causes affect the problems of PP Process. Lacy *et al*. (2009) revealed that unavailability of procurement strategy and legislative framework, outdated documentation, and lack of audit as root causes affect to the problems of PP Process. World Bank and Asian Development Bank (2012) highlighted similar root causes and additionally pointed out the negative affect of the behaviour of the policy and decision makers. Furthermore, Albano *et al*. (2013) explored that lack of innovative approaches increase the gravity of the problems in the PP Process. Moreover, Ayopo *et al*. (2016) identified variations and change orders for the stages and activities of procurement lifecycle increase the gravity of the problem of the PP Process. Accordingly, comprehensive literature revealed 22 number of root causes of the PP Process in construction industry and summarised in Table 2.

Table 2: Root causes in PP Process in construction industry

No	Description of the Root cause	Authors referred
1.	Lack of documentation	2, 4, 8, 9
2.	Lack of interrelation and communication among team members	2, 4, 8, 9
3.	Lack of interrelation and communication between relevant institutions	2, 4, 8, 9
4.	Negative attitude of the officers & stakeholders	2, 3, 6
5.	Inadequate knowledge of the officers & stakeholders	3, 4, 6, 6, 9
6.	Lack of knowledge transferring to the officers & stakeholders	3, 4, 6, 6, 9
7.	Unavailability of single institution for strategic and regulatory matters	2, 4
8.	Unavailability of legislative framework for PP Process	2, 4
9.	Negligence, mistakes & errors in PP Process	4, 8
10.	Insufficient capacity of implementing institution	2, 4
11.	Lack of integrity in PP Process	2, 4
12.	Lack of transparency in PP Process	2, 4
13.	Inadequate review, monitoring, & follow-up actions	4, 5

No	Description of the Root cause	Authors referred
14.	Lack of identification of feasibility aspects & lack of consideration on feasibility outcomes	1, 7, 8
15.	Lack of attention on unforeseeable physical conditions	4
16.	Lack of linkage with long term national plan	2
17.	Uncertainty on project funds	2, 8,
18.	Absence of updated procedures of protocols	2, 3, 8, 9
19.	Unnecessary time consumption due to lack of attention to critical path	3, 4
20.	Consideration of only traditional elements of Time, Cost, & Quality	4, 9
21.	Inadequate real-time technical & performance audit	2, 5
22.	Insufficient transfer of lessons learned from previous stage and projects	2, 5

1. Nakamura (2004), 2. OECD (2007, 2009), 3. Rajaram *et al*. (2010), 4. Thai (2011), 5. World Bank and Asian Development Bank (2012), 6. Moe and Päivärinta (2013), 7. Lu *et al*. (2015), 8. Ayopo *et al*. (2016), 9. Naude (2017)

The literature explored activities, stages, problems, root causes that affect the PP Process in construction industry. Accordingly, in next section discusses research approach, method, and data collection techniques that used to achieve the aim of this paper.

3. METHODOLOGY

The study used qualitative research approach to identify the activities, stages, problems, root causes affect the PP Process in construction industry in order sustainability in PP Process. A comprehensive literature review was carried out using journals, books, conference articles, report and official websites to identify the activities, stages, problems, root causes affect the PP Process in construction projects. Subsequently, in-depth interviews with 14 subject matter experts were carried to investigate the suitability and relevancy of literature review findings to developing countries context. The profile of 14 experts were given in Table 3.

Table 3: Profile of experts

Entity	Profile	Designation of Expertise	Experience
World Bank (WB) Funded Project 1	R1	Project Director	36 years
	R2	Deputy Project Director	32 years
	R3	Procurement Specialist	15 years
World Bank (WB) Funded Project 2	R4	Project Director	37 years
	R5	Deputy Project Director	24 years
	R6	Procurement Specialist	16 years
Asian Development Bank Funded (ADB) Project	R7	Project Director	40 years
	R8	Deputy Project Director	31 years
	R9	Procurement Specialist	18 years
Industry Experts	R10	Procurement Specialist (WB)	40 years
	R11	Procurement Consultant (WB)	37 years
	R12	Procurement Consultant (ADB)	42 years
	R13	Representative of Contractor	15 years
	R14	Representative of Consultant	15 years

The data collected through interviews were then transcribed and analysed using manual content analysis. The research findings are presented below.

4. RESEARCH FINDINGS AND DISCUSSION

The research findings are presented below under different sections related to activities, stages, root causes and problems of PP Process in construction industry in developing countries.

4.1 THE STAGES AND ACTIVITIES OF THE PP PROCESS IN SRI LANKAN CONSTRUCTION INDUSTRY

The stages of PP Process in construction industry are divided into the five categories as (a) Preparation, (b) Design, (c) Pre-construction, (d) Construction, and (e) Use in line with the RIBA Plan of Work (2007). Further, the literature review revealed 50 activities of the PP Process throughout project procurement lifecycle by representing 10 activities in each stage. During the expert interviews, 50 activities identified through the review was refined to 39 activities to suit to the developing countries with the experience in Sri Lankan context as presented in Table 4.

All the experts agreed with the 05 stages identified from the literature. However, the experts suggested to refine and revise the activities in each stage to suit the developing country and Sri Lanka context. Accordingly, 10 activities explored in literature for each stage of the PP Process refined and verified to 09 activities at the Preparation Stage, 05 activities at the Design Stage, 08 activities at the Pre-Construction Stage, 08 activities at the Construction Stage, and 09 activities at the Use Stage. Hence, the 50 activities at the 05 stages refined and reduced to 39 activities to suit to the requirements of Sri Lankan construction industry and to ensure the applicability to the developing countries. Further, experts agreed with the majority of the activities and some activities were re-worded and changed to suit to the Sri Lankan context. However, some activities were fully revised by the experts.

Table 4: Stages and activities of the PP Process in construction industry in developing countries

Stages and Activities Identified from Literature	Expert Comment	Stages and Activities Verified after Expert Interviews
Activities in Public Procurement Process (Preparation Stage)		
1. Identification of needs of the stakeholders	Agreed	1. Identification of needs of the stakeholders
2. Establishment of team and identification of scope	Reworded	2. Establishment of project team and define & develop scope of the project
3. Develop procurement brief including aim and objectives	Agreed	3. Development of procurement brief including aim and objectives
4. Preparation of feasibility study, EIA*, SIA* & RAP*	Reworded	4. Feasibility study and initial clearances
5. Identification of associate risks	Agreed	5. Identification of associate risks
6. Development of output-based design brief	Reworded	6. Development of output-based concept design
7. Assessment of options, alternative arrangement	Agreed	7. Assessment of options & alternative arrangements
8. Outline the specification & preliminary cost plan	Agreed	8. Outline the specification & preliminary cost plan

Stages and Activities Identified from Literature	Expert Comment	Stages and Activities Verified after Expert Interviews
9. Identification of procurement method	Refined	9. Identification of procurement strategy
10. Documentation	Deleted	*As documentation is mandatory requirement at the end of each activity*
Activities in Public Procurement Process (Design Stage)		
1. Review concept design, draft contractual document & definition of assignment	Reworded	1. Review scope of the project & concept design and decision on use internal experts
2. Review the availability of funds, procurement route & balance activities	Reworded	2. Review the availability of resources and cost plan
3. Appointment of procurement committee	Reworded	3. Appointment of PC* for determination of consultancy firm
4. Identification of procurement time schedule	Agreed	4. Identification of procurement time schedule
5. Preparation, review, approve, & issue EOI*, RFP* document 6. Evaluation of EOI* & identification of shortlist 7. Issue RFP* documents 8. Preproposal meeting, clarification, & addenda 9. Closing, evaluation, determination of consultancy firm 10. Appeal procedure & award of consultancy contract	Merged 5 to 10	5. Selection of consultant for design, procurement & contract management
Activities in Public Procurement Process (Pre-Construction Stage)		
1. Review the contractual document & detailed definition of assignment	Agreed Refined	1. Ensure availability of resources & initial clearances
2. Identification of balance activities & confirmation of availability of funds	Agreed Reworded	2. Determination of activities to select the civil works contractor
3. Appointment of PC* & TEC*	Agreed Reworded	3. Appointment of PC* & TEC* for determination of civil works contractor
4. Identification of procurement time schedule	Agreed	4. Identification of procurement time schedule
5. Preparation, approve, & issue pre-qualification/ bid document	Agreed	5. Preparation, approve, & issue pre-qualification/ bid document
6. Evaluation and approve pre-qualified bidder	Agreed	6. Evaluation and approve pre-qualified bidder
7. Issue bid documents 8. Pre bid meeting, clarification, & addenda	Merged 7 & 8	7. Issue bid documents, pre bid meeting, clarification, & responds
9. Closing, evaluation, determination, & appeal procedure 10. Award the civil works contract	Merged 9 & 10	8. Closing, evaluation, determination and sign the contract agreement
Activities in Public Procurement Process (Construction Stage)		
1. Appointment of project management team	Agreed	1. Appointment of contract management team
2. Review the contract document, bonds & insurance	Agreed	2. Review the contract document, bonds & insurance
3. Identification of balance activities & confirmation of availability of resources	Reworded	3. Determination of activities to implement the civil works contract
4. Update the programme and resources 5. Progress monitor, review & approve site works, variations & claims	Merged 4 & 5	4. Progress monitor, review & approve site works, variations & claims
6. Issue addendum and variation orders	Agreed	5. Issue addendum and variation orders

Stages and Activities Identified from Literature	Expert Comment	Stages and Activities Verified after Expert Interviews
7. Documentation for completion of project	Agreed	6. Documentation for completion of project
8. Review state at completion & arrange final discharge 9. Arrangement for release guarantees & retention	Merged 8 & 9	7. Arrangement for release guarantees & retention
10. Provisions for arbitrations and remaining disputes	Agreed	8. Provisions for arbitrations and remaining disputes
Public Procurement Process (Use Stage)		
1. Review the agreement for operation and maintenance	Agreed	1. Review the agreements for operation and maintenance
2. Identification of balance activities & confirmation	Reworded	2. Determination of activities and resources for operation & maintenance and update programme
3. Conduct trainings for trainers (TOT) 4. Documentation for lessons learned	Merged 3 & 4	3. Conduct TOT and documentation for lessons learned
5. Ensure performance of the assignment and documentation are in order	Agreed Reworded	4. Ensure performance of the activities of operation & maintenance
6. Preparation programme for close-out	Reworded	5. Preparation programme for close-out by the consultant, contractor and project team
7. Clearance from all the parties for programme for closeout	Agreed	6. Clearance from all the parties for programme for closeout
8. Release guarantees & liabilities	Agreed	7. Release guarantees & liabilities
9. Demobilisation of team	Reworded	8. Demobilisation of resources and teams (Contract & Project)
10. Disposal (reuse or recycle)	Agreed	9. Disposal (reuse or recycle)

**EIA- Environmental Impact Assessment; SIA- Social Impact Assessment; RAP- Resettlement Action Plan; EOI- Expression of Interest; RFP- Request for Proposal; PC- Procurement Committee; TEC- Technical Evaluation Committee*

4.2 THE PROBLEMS IN PP PROCESS IN CONSTRUCTION INDUSTRY

The literature reveals 10 problems of the PP Process (refer Table 1) in construction industry, which negatively affect to achieve the sustainability. During the interviews, the experts agreed with the identified problems and mentioned that those 10 problems are applicable to the Sri Lankan context and other developing countries similar to Sri Lanka. Further, R10 mentioned that low efficiency is a general term, however, low efficiency of the end product or final output is a problem in PP Process in construction industry to achieve the sustainability. Based on the expert opinion, the wording of the problem number P.5 was refined as low efficiency of final output. Furthermore, R12 highlighted that efficient works and deliverables shall link with the aim and objective of the sustainable development, if not that will be wasting of resources of the PP Process. Further, R11 and R12 said that '*how can we say not to identify cost for damages of social and environment and not to consider the value for money (VFM) in the process?*'. Further to them, the social and environment aspects, and the VFM considered with less attention throughout the activities of the PP Process in construction industry. Hence, the experts added 'lack of attention on the damages to the society and environment' and 'less attention to consideration of value for money' as the problems to achieve the sustainability in developing country. Hence, the problems in PP Process in construction industry to achieve sustainability in developing countries can be summarised as below:

1. Deliverables not fit for purpose
2. Late delivery
3. Cost overruns
4. Risk overruns
5. Low efficiency of final output
6. Not up to the required quality and standards
7. Outdated technology
8. Lack of a social and environmental cost valuation
9. Less attention to VFM
10. Fraud and corruption

4.3 THE ROOT CAUSES OF PP PROCESS IN CONSTRUCTION INDUSTRY

The expert interviews refined and verified the root causes of the PP Process identified through the literature review that have impact to the problems to ensure the applicability to the developing countries and Sri Lankan context. Accordingly, all the experts agreed with the 22 root causes identified in the review and pointed out that all the root causes have impact to the problems in all the stages of the PP Process in construction industry and enhance the risk to achieve the aim and objectives of sustainable development. Hence, identified 22 number of root causes from the literature review are same to the number of root causes refined and verified through the preliminary study. However, the wordings of root causes updated as per the opinions of the experts to suit to the Sri Lankan context. Accordingly, experts of the preliminary study verified 22 number of root causes affect the problems of the PP Process to the Sri Lankan context as a developing country and listed below:

1. Lack of documentation
2. Lack of interrelation and communication among team members
3. Lack of interrelation and communication between relevant institutions
4. Negative attitude of the officers & stakeholders
5. Inadequate knowledge of the officers & stakeholders
6. Lack of knowledge transferring to the officers & stakeholders
7. Unavailability of single institution for strategic and regulatory matters of the PP Process
8. Unavailability of legislative framework for PP Process
9. Negligence, mistakes & errors in PP Process
10. Insufficient capacity of implementing institution
11. Lack of integrity in PP Process
12. Lack of transparency in PP Process
13. Inadequate review, monitoring, & follow-up actions
14. Lack of identification of feasibility aspects & feasibility outcomes
15. Lack of attention on unforeseeable physical conditions
16. Lack of linkage with long term national plan
17. Uncertainty on project funds
18. Absence of updated procedures of protocols
19. Unnecessary time consumption due to lack of attention to critical path
20. Consideration of only traditional management elements of Time, Cost, & Quality
21. Inadequate real-time technical & performance audit
22. Insufficient transfer of lessons learned from previous stage and projects

5. CONCLUSIONS AND WAY FORWARD

This paper aimed to identify the problems and related root causes of the PP Process in construction industry for the developing countries to achieve sustainability throughout activities and stages of the project procurement lifecycle. A comprehensive literature review revealed 10 problems and 22 root causes affected PP Process throughout construction lifecycle that includes 50 activities in 05 stages in global construction industry. Interviews with the experts in Sri Lanka refined and summarised 10 problems and 22 root causes affecting PP Process throughout the 39 activities and 05 stages of the PP Process in construction industry in the developing countries. This paper has presented the findings of a preliminary investigation of a PhD study programme. Accordingly, these findings will be used to propose the remedial measures to minimise the negative impact of the root causes to the problems, and then to minimise the negative impact of problems to the activities in each stage of the PP Process in construction industry during the next stage of the PhD research study. Hence, as a way forward, the impact and relationship between the root causes to the problem, and problem to the activities will be determined. Consequently, the study will propose remedial measures for smooth implementation of the activities of the PP Process to achieve the sustainability in construction industry. The conceptual model developed to establish the aforementioned relationship is shown in Figure 1.

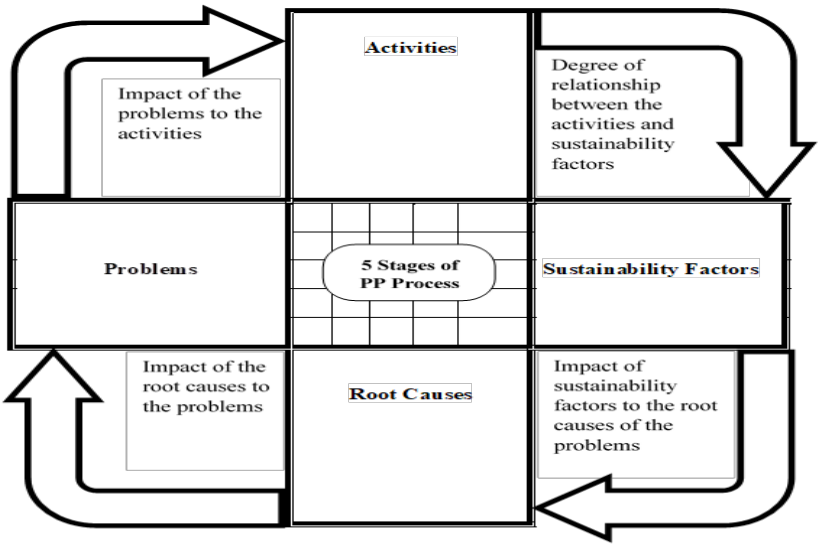

Figure 1: Conceptual model for sustainable PP process

The paper outcomes and the final outcomes of this study will be benefited to the relevant authorities of developing countries, funding agencies, development partners, and policy and decision makers in taking necessary steps to update the existing guidelines, bidding documents, procedures and protocols to achieve the sustainability.

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PROMOTING STAKEHOLDER COLLABORATION IN ADOPTING CIRCULAR ECONOMY PRINCIPLES FOR SUSTAINABLE CONSTRUCTION

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ABSTRACT

Circular Economy (CE) has been recognised as one of the most comprehensive way of attaining sustainable development, which considers every aspect; social, technical, economic and environmental, of sustainable development. For a building construction project that aims to achieve circularity, collaboration of project stakeholders both within vertical horizontal supply chains is vital. This research project establishes importance of such collaboration and proposes methodology to identify stakeholders responsible for attaining circularity in projects through collaboration between such stakeholders. This paper reports of the key literature findings of this on-going research. The key findings from the current paper are establishing importance of stakeholder collaborations to achieve circular buildings and potential of blockchain technology in this regard.

Keywords: *Blockchain; Circular economy; Sustainable construction; Stakeholder management.*

1. INTRODUCTION

The industrial production till now has been mostly in linear model i.e., of take, make and dispose of resources, which has given an extraordinary growth but it has come with significant wastage in terms of resources and other negative externalities in environment as by-products. EMF (2012) has defined circular economy as restorative and regenerative process, where the utility of any product, resources is optimised and used to its highest value and 'end of life' is replaced with restoration, while adapting renewable energy sources during the process. It is the process of designing out waste through its biological and technical cycles, while maintaining certain economical value at every stage of cycle (EMF, 2015). In other words, the resources loop in circular economy are closed in order to minimise waste through reuse and recycle. Also, using optimum amount of resources

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in the production process is termed as ‘narrowing the loop’ and designing long lasting reusable products is termed as ‘slowing the loop’ (Bocken *et al*., 2016).

While the focus of circular economy (CE) is to minimise resources input and waste out of industrial system, its adaption in construction industry seems very important. The construction sector utilises significant amount of resources, accounting to 40% of materials consumed in global economy (Leising *et al.*, 2018). Whereas, only 20% - 30% of the materials are reused or recycled at the end of life of buildings (EMF, 2014; Leising, *et al.*, 2018). It should be noticed that the adapting the complete reuse concept is practically unachievable as there is end of life on various productions using materials, which better be demolished than reused, not to exclude buildings, which typically having 50-70 years of functional lifespan, but most of them are demolished within 20-30 years as they do not meet the users need (Munaro *et al.*, 2020). Current scenario, thus, suggests the importance of CE in construction.

CE adaption in construction industry comes with its own complications. In case of medium lived products, the materials after repeated maintenance and reuse to possible extent or ‘end of life’ are taken back by the manufacturer for recycling, but in case of constructed buildings it is tough due to longer life cycle and lower salvage value (Adams *et al*., 2017). Currently, CE in construction is about recycling construction and demolition waste, but the adaption of CE in real terms would be from reuse of the materials and resources, which requires the attention from design phase. Buildings should be designed in such a way that its reusability and value is preserved till end of life (Adams *et al*., 2017). In addition to that, for making a close, narrow and slow loop of materials flow of any building, requires the integration of material supply chain to whole of life cycle of building, where every actor has responsibilities towards circularity (Leising *et al.*, 2018). In other words, the construction value chain has to be integrated into the life cycle of building through circular business models, so that closed loop can be attained and every actor makes some gains during the process and sustain the economy (Hossain *et al.*, 2020; Munaro *et al*., 2020). To follow and execute these processes requires collaboration between all the stakeholders involved during life cycle of the project such as designers, manufacturers, contractors, demolition companies and recycling companies (Leising *et al.*, 2018). Achieving collaboration among these stakeholders thus can be considered key for adaption of CE in construction.

Looking into the issues regarding collaboration studied by Adams *et al.* (2017) with stakeholders in UK, provides industry insights about lack of awareness among the stakeholders regarding circular economy (CE), including clients who should be leaders in this process. Study found that, subcontractors were less aware than others and demolishers mentioned that designers do not practice design for reuse concept. The study, in addition to raising awareness, suggests developing a strong financial case for reuse through collaboration of stakeholders, where parties less benefited in process such as designers could be motivated through financial incentives. Similar suggestions have been made by Hossain *et al*. (2020) for sustainable business model innovation with circular value chains evolving around stakeholder collaboration. Hence how to achieve collaboration among stakeholders for a close, narrow and slow loop of CE remains the main research question. This paper aims to first understand the circular economy concepts and thereby, highlight the importance of stakeholder collaboration in circular economy adaption for sustainable construction through a literature survey.

2. CIRCULAR ECONOMY CONCEPTS FOR SUSTAINABLE CONSTRUCTION

As the name suggests, circular economy is the economy, where materials, products and energy are intended to flow in a circular path and make a closed loop, which is very different approach than of current linear economy of “take, make and dispose”. In linear economy, resources are extracted, products are manufactured and disposed after use at the end of product life. Whereas, in circular economy the practice would be to keep off from disposing, through reuse, remanufacture and recycle. The key objective behind circular economy is to minimise the virgin resource extraction. The current ideas of circular economy have been derived from various ideas in previous decades and this one. For this study, information about those ideas has been obtained from work of Weigend Rodríguez *et al*. (2020) and reports from “Ellen Macarthur Foundation” (EMF) (EMF, 2012, 2015), and has been briefly described in this section.

The circular economy concept can be dated back to 1966, when Boulding (1966) explained the idea of “spaceman economy”, comparing earth with a resource and pollution constraint spaceship, where humans have to live and meet their needs within a ‘cyclical ecological system’. It is an example of circular economy, in contrast linear economy has been termed as “cowboy economy” i.e., considering the earth as endless plain with unlimited resources. In linear economy, resource consumption and production is considered as success, but in a resource constraint world, production and consumption should be lessened and the extent and quality of the capital stock (nature and human) should be a measure of success of economy (Boulding, 1966).

Another concept relevant to circular economy is ‘performance economy’ proposed by Stahel (1982), where emphasis has been given onto extending the product-life rather than replacing with another short lived product. It undertakes activities such as reuse, repair, reconditioning and recycling for product-life extension. This would largely reduce the extraction of resources and waste from used products (Stahel, 1982). In this system, the flow of products would be in a circle between the manufacturer and a consumer, and later would rather be called a user who utilises the services and pays for performance rather than for the product itself. Doing so, the service provider is obliged to provide quality service, and the product-life extension process is more labour-intensive work than resource intensive, which would lead to growth in jobs as well (Stahel, 2010).

The concept of ‘Industrial Ecology’ is also much related to circular economy. It was firstly proposed by Frosch and Gallopoulos (1989), which is about orientation of manufacturing systems as a biological ecosystem. As in a biological system, where there is a circular flow of nutrients from plants to animals and again back to plants, in industrial ecosystem, waste (by products) from manufacturing in one industry can be raw materials for other industry. Also in the production process, the energy and resources are optimised and waste are minimised in order to align with biological ways (Frosch and Gallopoulos, 1989). In addition to that, industrial ecology concept has also been used to compare the industrial economy to the ecosystem that supports it, in terms of the carrying capacity of the ecosystem. The deterioration technological society is causing to the ecosystem, for extraction of resources and sinks that has been used to dump those wastes (Reid and Thomas, 2002).

Another influence on circular economy is by the concept ‘regenerative design’, coined by Lyle (1994). It is about making our production process regenerative, i.e., the processes themselves would replace or renew the sources of energy and materials consumed (EMF, 2012; Weigend Rodríguez *et al.,* 2020). Lyle suggested use of renewable energy sources, and keeping waste within the environment capacity, which would be restored back in environment without ecological damages (Weigend Rodríguez *et al.*, 2020).

The next concept influencing circular economy is termed as 'Biomimicry,' which was defined by Benyus (2002) as a field of study about nature's ideas and to imitate nature's ideas in design and processes to solve our personal, societal, business and technological challenges. Biomimicry can be obtained through three principles, namely - nature as model (imitating nature's model), nature as measure (using nature as standard to measure sustainability), and nature as mentor (value nature on what it offers to learn from, not extract) (EMF, 2012).

Lovins *et al.* (1999) have proposed another concept which influences circular economy. They have termed it 'Natural Capitalism', which mentions that the economy itself is embedded in the natural environment and produces value from it. That makes the environment, natural capital the largest capital of our economy. So, current capitalistic economy should value the natural capital to generate sustainable benefits, both for present and future generations. The process as such can be performed by adapting four main practices in our economy; (1) manufacturing system should upgrade to reduce the consumption of resources in large scale, which in turn can produce more benefits than while consuming more resources and overcome the initial capital investment of the enterprise for upgrade, (2) manufacturing system should adapt the biological model where there is no waste generation, waste are either composted or reutilized as resources for another manufacturing unit, (3) business models should change from consuming to using model, where user pays for the leasing of services rather than buying of product, which ensures the flow of product and resources, (4) business should reinvest in restoring and expanding natural capital, which ultimately would be of some business value to the enterprise itself (Lovins *et al.*, 1999).

Then there is 'cradle to cradle (C2C)' concept of zero waste with goal of attaining closed loop cycles of material flow. The cycles have to be regenerative and powered by renewable energies (McDonough *et al.*, 2003). Other methods of improving efficiency of production being adapted, in one way or another depletes resources. In other hand, C2C design concept perceives 'biological metabolism' to develop a 'technical metabolism" process, and both processes are kept in mind, while designing products to maintain their value at different use cycles (EMF, 2012; Weigend Rodríguez *et al.*, 2020). The main principles of C2C; (1) Waste equals food of imitating biological metabolism concept (2) Use current solar income of adapting 100% renewable energy sources (3) Celebrate diversity of adapting to local ecology for setting out niche production systems, encapsulates many past ideas of ecology promoting economic ideas (McDonough *et al.* 2003). The aim of C2C concept is a step ahead of others as it aims to develop a system, where production processes have positive effect on ecology health and abundance (Braungart *et al.*, 2007).

Finally, the newest significant influence to CE is by concept of 'Blue Economy' by Pauli (2010). This concept is based on principle of open-source movement, where various innovative business models, mainly small-scale businesses best suited to the local system and production would be adapted. and economy would be sustained in that locality. Such economic practices will also focus on enhancing well-being through mindful living, in harmony with nature (Pauli, 2010). The concept is a challenge to current economic model of continuous growth and promotes the integration of various known processes for utilising resources in a cascading system, to optimise use and minimise waste to the extent possible (Pauli, 2011; Weigend Rodríguez *et al.,* 2020).

The current discourse on circular economy is led by 'Ellen Macarthur Foundation' (EMF), and defines it as a system, where the production process is 'restorative or regenerative by design' (see Figure 1). For that C2C would determine the technical and biological cycles and aim to keep products, components, and materials at their highest utility and value at every use cycle (EMF, 2015). The EMF's ideas for CE principles are comprehensive and is influenced by most of the ideas discussed earlier. Based on different ideas EMF has developed three principles and an outline for circular economy, which has been taken from EMF report of 2015. The three main principles include; (1) Utilise only renewable energy sources, if not possible then use efficient technologies, dematerialise utility when possible, consume as less natural stocks as possible, instead enhance natural capital by encouraging flow of nutrients in biological system, (2) Design products for circularity i.e. reuse, remanufacturing, refurbishing, cascading and recycling to keep materials flow in circular loop, maintaining their highest utility at all times, either through biological and technical cycles, (3) Work to reduce the damaging impacts of production system through designing out the negative externalities. EMF has also suggested a framework for attaining circular economy termed as "ReSOLVE". The framework is generalisation of various working strategies into six one-word actions- regenerate, share, optimise, loop, virtualise and exchange; most of which has been already discussed previously in other concepts influencing CE.

The main objective behind all these concepts is about attaining sustainability in our development activities and same is applied for construction. Moreover, construction being a significant sector in terms of resource and energy consumptions, working to achieve circular economy in construction industry is vital for executing sustainable construction projects.

The sustainable construction practices till now have largely been associated to energy use and energy efficiency. The focus is on constructing sustainable buildings, but the circular economy (CE) concept suggests us to attain circularity in buildings i.e. circular buildings (Leising *et al.*, 2018). Many other researches also have focused on recycling of construction and demolition waste without much attention to other aspects of CE such as design and reuse (Adams *et al*., 2017). CE approach for circularity in buildings considers whole of life cycle during design phase and seeks to adapt different ownership models for building materials, where building act as a material bank (Lacy, 2015). Circular buildings have also been simply defined as designed, planned built, operated, maintained, and deconstructed in manner consistent with CE principles (Pomponi and Moncaster, 2017). Report by ARUP in 2016 suggests adapting "Resolve" framework by Ellen Macarthur Foundation for adapting circular economy in construction. It suggests considering 7S model of building layers, which includes layers namely system, site, structure, skin, services, space and stuff, and decide our strategies for each layer to have a clear techniques of attaining circularity (Zimmann *et al.,* 2016).

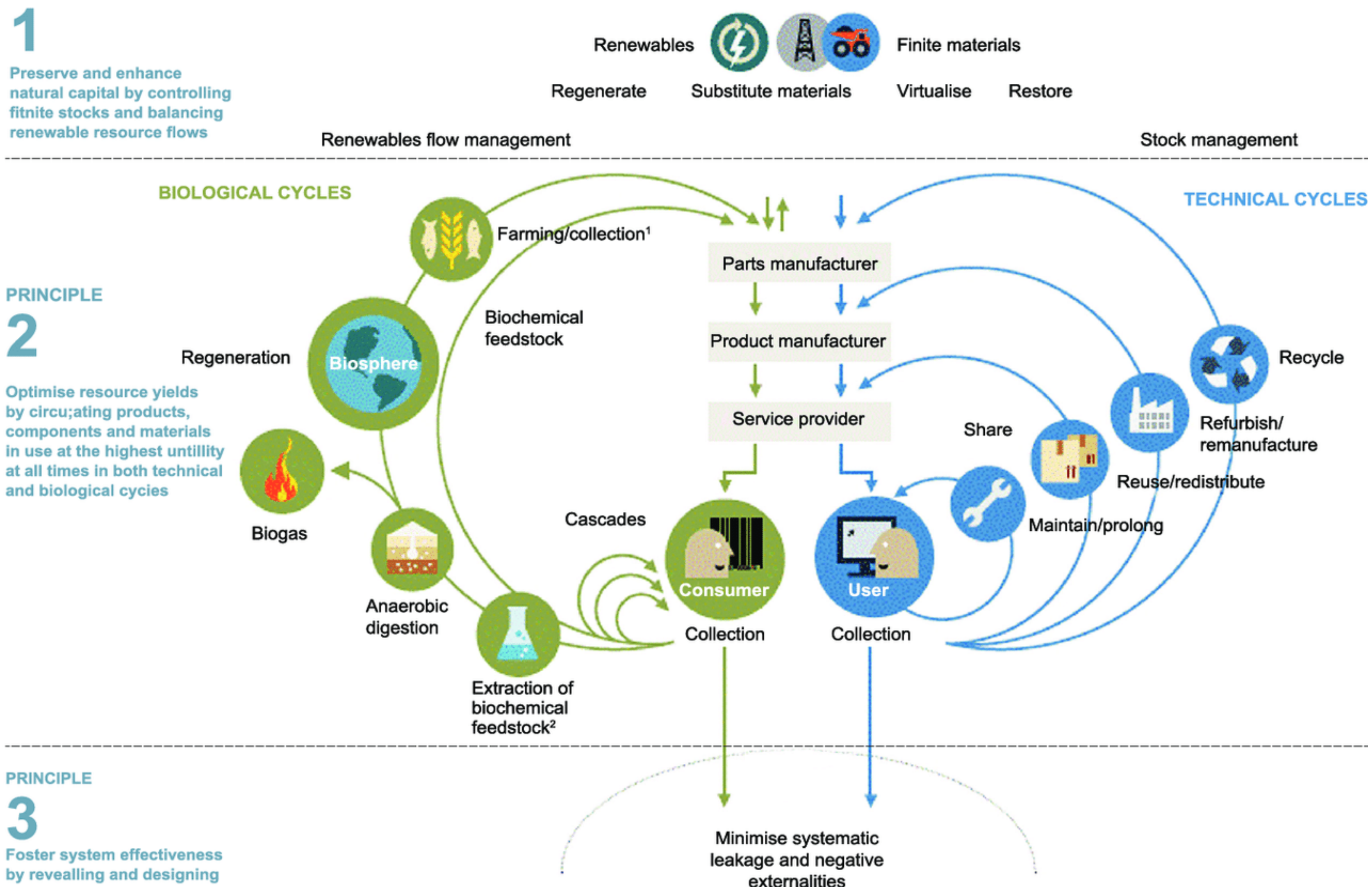

Figure 1: Principles and outline of circular economy (Source: EMF, 2015)

In order to integrate life cycle analysis and material flow, the materials and resources flowing throughout the lifecycle of the building should be considered, i.e., whole of life cycle supply chain (Leising *et al.*, 2018). For flow materials in such supply chain, it is necessary that all the stakeholders belonging to the stages of lifecycle; such as business owners, service providers, designers, contractors, demolition companies' users, government agencies, etc. would have to collaborate (Hossain *et al.*, 2020; Leising *et al.*, 2018; Zimmann *et al*., 2016). Such collaboration is required to develop a common platform for identification of possible business partners, information sharing and developing business models for sharing or flow of materials (Górecki *et al.,* 2019; Hossain *et al.,* 2020). The whole of built environment comprising of various businesses can act as industrial symbiosis network for supply chain collaboration (Herczeg *et al.*, 2018), which is discussed from stakeholder management perspective next.

3. STAKEHOLDER COLLABORATION FOR CIRCULAR BUILDING

As the importance of collaboration has been realised, it makes sense that for a project of constructing circular building to be successful by attaining circularity, the supply chain actors would be important stakeholders and a project organisation must collaborate with such stakeholders to achieve project's objectives. This section starts with the discussions around basic concepts and techniques of stakeholder management in construction, followed by application of those techniques to prove the relevancy of stakeholder collaboration as an integral part of stakeholder management in circular building project.

3.1 STAKEHOLDER COLLABORATION IN CONSTRUCTION

Stakeholders for any project are people, community and organisations, who affect or are affected by project activities, and are required to be managed to prevent from impacting project performance. Different stakeholders have their different interests, and level of impact one stakeholder can cause is different than of others, thus requires different responses from project organisation (Chinyio and Olomolaiye, 2010). Newcombe (2003) suggests similar range for stakeholders, comprising of parties not just involved in project activities, but also parties, who have investment or interest in organisation. For a construction project, list of stakeholders might include the ones working in the project, financers, end users, general public, government agencies, media and so on (Chinyio and Olomolaiye, 2010). Different ways of classifying stakeholders have been proposed by different authors. Classifying into direct and indirect stakeholders is one of them (Project Management Institute, 2016; Smith and Love, 2004). Direct stakeholders have been described as those directly involved in the execution of the project, whereas indirect stakeholders are not directly involved, but influence execution of the project. This approach basically categorises project sponsors, project team and suppliers as direct stakeholders, whereas general public, governmental and non-governmental agencies, media etc. fall under indirect stakeholder category. The needs and requirements of direct project stakeholders will often be detailed in the contract documents, mainly specifications of the construction project (Project Management Institute, 2016). The stakeholders might also be classified as external and internal stakeholders, where internal type corresponds to the direct ones and external corresponds to indirect stakeholders discussed earlier (Atkin and Skitmore, 2008). There are other classification categories, which are also more or less similar to the ones discussed earlier in the paragraph.

Stakeholders are required to be managed to minimise negative impacts they can cause and ensure that they do not obstruct achieving project goals. It is also required that the organisation keep good terms with stakeholders, who are constituent for project completion and maintain support of these parties by balancing their interests, as the impacts from stakeholders are both positive and negative (Chinyio and Olomolaiye, 2010). Stakeholder management in most of the construction projects seem to adapt processes, which are generally similar. The process includes identification of stakeholders; gathering information about stakeholders; assessing the information to determine interests, level of influence, urgency of stakeholders; determining priority for stakeholders through power/interest matrix (Newcombe, 2003) and determine strategies through cooperative/threatening matrix (Savage *et al.*, 1991); decide the actions required to manage each stakeholder; and finally take actions based on the decisions made (Yang and Shen, 2015). Determining priority helps to guide actions on what degree of importance one stakeholder should be given, and to what level their interests be fulfilled (Newcombe, 2003). In addition to that, Savage *et al.* (1991) suggest a matrix to set strategies for stakeholder management based on the level of cooperative or threatening, stakeholders could be towards the organisation or its goals (see Figure 2).

		Potential for Threat to organization/goals	
		High	Low
Potential for cooperation with organization/goals	High	Stakeholder Type: MIXED BLESSING Strategy: COLLABORATE	Stakeholder Type: SUPPORTIVE Strategy: INCLUDE
	Low	Stakeholder Type: NONSUPPORTIVE Strategy: DEFEND	Stakeholder Type: MARGINAL Strategy: MONITOR

Figure 2: Stakeholder matrix for different strategies

Based on the matrix an organisation would be able to determine its strategy of collaborate, involve, defend and monitor depending upon the stakeholder type of mixed blessing, supportive, non-supportive and marginal, respectively to above mentioned strategies. This matrix is much relatable to a circular building project scenario and thus would be further discussed in context of such projects in following sub-section.

3.2 STAKEHOLDER COLLABORATION FOR CIRCULAR BUILDING

Any construction projects for circular buildings, would set its prime goal as attaining circularity and support transition into circular economy. As per discussion so far, it has become almost obvious that every such project would have certain suppliers of materials and buyers of surplus in another construction or demolition project, in addition to the new material manufacturers. Along with such parties, experts for sustainability and circularity hired by either owner or contractor would also be stakeholder for circular building project.

Stakeholder management in these projects would have to be done with emphasis on circularity goals along with the other conventional project objectives. The steps as described under previous heading of stakeholder management would be followed where stakeholders are identified, prioritised, strategies are developed, and actions are taken (Yang and Shen, 2015). While developing strategies through cooperate-threaten stakeholder matrix for a circular building project, and comparing with project scenario, end users of buildings, materials suppliers and circularity experts can be categorised as "mixed blessing" type stakeholders.

In context of current conceptual phase of CE, materials manufacturers might have various clients and would be supplying materials to various other conventional projects making a sound profit. In order to manufacture reusable construction materials, it is important that share ideas and their technology to manufacture niche items, and while doing that also ensure their profit during the process. Long term collaboration is also necessary to implement concept of material banks. Collaboration for long term growth should be prioritised against quick benefits of linear economy. If using old reusable materials, it is important that parties involved in deconstruction of source building are collaborated beforehand to have design inputs in current project, based on the materials available to reuse. Manufacturers and suppliers opting towards linearity is a negative impact to circularity objectives.

End users on the other hand might invest on linear building, mainly due to lack of awareness (and unwillingness) about long term benefits of life cycle cost of circular buildings and reluctance towards reusable products. So, they must be ensured about the financial benefits and quality of circular buildings through collaboration from the conceptual phase and providing them a feeling of satisfaction and ownership about the investment they would be making on the project.

In addition to flow of materials and promote awareness, collaborative working methods has been suggested for innovation in various fields, be that in general (Roberts and Bradley 1991), or specifically in construction (Xue *et al.*, 2018). For designing a building to be built with materials obtained from deconstruction and design to easily disassemble in future, and create a unique product requires innovation. With limit in expertise in this area and lagging of communication or miscommunication between clients and designers would complicate the design process and output may not be as desired, which may not fulfil our circularity criteria or become might become difficult to execute the design at site. Both would hinder the project's circularity goals.

Furthermore, stakeholder collaboration has been argued as vital for multi-sector innovation, which comprises of changes in different aspects of technical, social, economic, political, behavioural and biophysical environments (Bunn Michele *et al.*, 2002). Implementing circular economy also demands changes in practices in different branches of construction industry. From change in design techniques, to way services are utilised and conduct business would be changed while transitioning to circular economy and will require collaboration with different organisational stakeholders and stakeholders within the project organisation as well. Thus, for a circular building project, stakeholder collaboration becomes integral part of stakeholder management. Collaboration would be necessary in both vertical project organisation and horizontal supply chain of materials. The key ideas discussed in above section with the stakeholders are depicted in Figure 3.

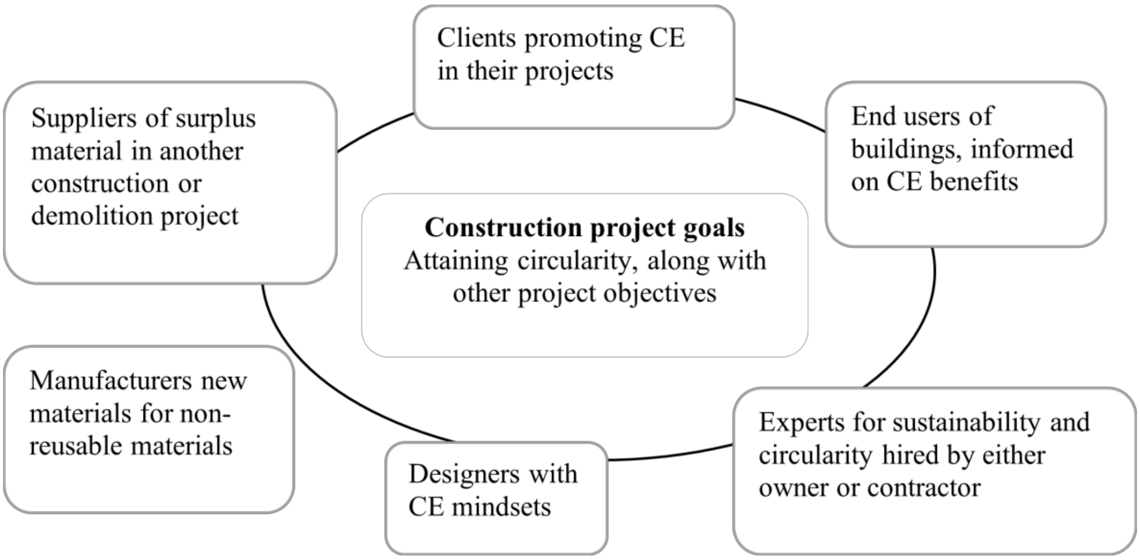

Figure 3: Importance of stakeholder collaboration for circular buildings

Blockchain is a disruptive technology that has attracted significant interest in several industries including construction industry in recent times. Blockchain comprises of a decentralised distributed ledger, which could be shared between all participants in a trusted environment without the need for a third party. It offers transaction traceability, transparency, and security, together with verification and validation processes on recording transactions. Blockchain is seen as a potential platform to connect all construction project stakeholders to achieve circular buildings and close the loop.

4. CONCLUSIONS AND WAY FORWARD WITH BLOCKCHAIN TECHNOLOGY

As circular economy is a promising solution to current scenario of resource and energy depletion and extreme carbon emissions, it can be a way to attain sustainable development and leave a better future for coming generations. So, transitioning into such system could be one of the top sustainability objectives. Construction sector being significant consumer of resources and energy, is a major player of this transition.

The circular economy practices in any sector is currently in initial stages. The undergoing works mainly focuses on transitioning from linear to circular economy The key findings from the current paper are establishing importance of stakeholder collaborations to achieve circular buildings. Such collaboration is required to develop a common platform for identification of possible business partners, information sharing and developing business models for sharing or flow of materials. In terms of material flows, need to track the reuse of materials, keep record of sources of materials and smooth transfer of material ownerships are also insisting on a common platform for large scale value chain actors' collaboration. Potential for blockchain technology to create such circular economy in construction will be explored in the next phase of this research.

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PSYCHOSOCIAL HAZARDS AND RISKS IN THE CONSTRUCTION INDUSTRY IN NEW SOUTH WALES, AUSTRALIA

Negar Rezaeian[1], Liyaning Tang[2] and Mary Hardie[3]

ABSTRACT

The construction industry faces many challenges, one of which is the difficult to define psychosocial influences. The construction sector has highly demanding employment conditions, long working hours and sometimes unfeasible terms of project execution. Psychosocial influences represent emotional as well as physiological characteristics which impact the immediate environment. Some construction personnel face psychosocial problems that can lead to depression or suicide. The research conducted in this paper focuses on the psychosocial status of personnel working in construction companies, in New South Wales (NSW), Australia. A questionnaire survey was conducted to investigate the psychosocial hazards observed in the construction industry in NSW. Practitioners in two private construction companies and one government department having construction project management experience in NSW were involved in the survey. The data analysis indicates that most workers experienced being pressured to stay back and work long hours. This led to workers being 'very frequently' tired. Regarding bullying, Respondents reported that the frequency of they experienced 'exclusion or isolation from workplace activities' was 'monthly'. Being 'Subjects of gossip or false, malicious rumours' was reported as happening 'weekly' and 'Humiliation through gestures, sarcasm, criticism or insults' was said to happen 'almost daily'. This study's findings indicate that construction projects could have unaddressed psychosocial hazards and risks, each of which may be a potential factor for accidents and occupational and psychological injuries. The data displayed from this research could help understand psychosocial hazards. Spreading awareness on the issue can hopefully be a step towards improving the mental health of construction workers while decreasing the overall suicide rate.

Keywords: *Australia; Construction industry; Mental health; New South Wales; Psychosocial hazards.*

1. INTRODUCTION

Construction is probably one of the oldest occupations in history. However, it still presents a formidable challenge to health and safety experts with its lengthy background. Despite concerted efforts and significant workplace health and safety improvements, the construction industry remains one of the most hazardous sectors with serious injuries.

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Builders often deal with diverse environmental factors and engage in monotonous and stressful jobs (Boatman *et al.*, 2012). Many employment circumstances are itinerant and unreliable, making it easier to lay off workers at short notice (European Social Partners, 2007). The sector also has demanding work tasks, long working hours and sometimes unfeasible implementation terms (Beswick *et al.*, 2007). Such features can have a significant effect on the physical and emotional well-being of the builders. A major study found that work-related stresses could lead to health problems among construction workers (Wang *et al.*, 2017). To fully understand their effect on safety and well-being, it is essential to assess the impact of psychosocial stressors and psychosocial risk factors (PRFs) that help mitigate work-place accidents, avoid illness and enhance profitability (Boschman *et al.*, 2013). Psychosocial influences, as the word implies, reflect emotional and physiological features and the immediate environment. The International Labour Office defines psychosocial factors related to work as 'employment and career experience,' the essence of duties, organisational conditions and skills of workers, preferences, culture, personal extra-work issues that may affect security, job performance and job satisfaction through understanding and experience' (Burki, 2018).

This research aimed to examine factors related to NSW psychosocial and mental well-being conditions in the construction industry. The paper started with a literature review. The research methodology was then explained that how the research was conducted and data was collected. The results of the data analysis were discussed in the following section. Last but not least, limitations of the research and recommendations for future work were presented at the end of the paper.

2. LITARATURE REVIEW

2.1 DEFINITION OF PSYCHOSOCIAL HAZARDS AND RISKS

Stress as a construct has been clarified across many different schools of thinking. Job dissatisfaction can be characterised as mental and physiological reactions to workers' responsibilities. These reactions are psychological (cognitive, physiological, and emotional), these reactions may lead to poor health of workers. Stress is captured as a response, which captures psychological, physiological and emotional aspects of the job. All vital aspects of human health include the workplace, climate, and job nature (Marmot and Wilkinson, 2006).

The International Labour Organization (ILO) mentioned psychosocial risks could include worker relationships, job description, content, labour management and organisation. In various academic writings, emotional exhaustion is defined as physical, mental and emotional deprivation due to long-term commitment to adverse or traumatic conditions for workers. Such interactions are forms of interaction that impact workers' well-being (Schaufeli and Greenglass, 2001).

2.2 PSYCHOSOCIAL HAZARD AND RISK FACTORS IN CONSTRUCTION

Psychosocial hazard and risk factors are characterised by work outcomes like financial, execution factors (Beswick *et al.*, 2007); as well as positions in the company such as under-use of jobs or unchanged activity (Goldenhar *et al.*, 1998). Environmental implications such as unusual turnover of employees and inadequate communication because of the transitional nature of construction may also affect work outcomes. (Lunt *et al.*, 2008).

In the construction industry, psychosocial problems may be caused by tight deadlines, lack of knowledge, or adverse working climate. The workplace can also pose unknown hazards for construction practices, new products, and chemicals. The transition to subcontracting and specialisation (including multiple influences in the same workplace) shifts existing balances. A proper description of occupational mental well-being is essential to recognise possible hazards.

2.2.1 Finance-related Issues

Workers can be influenced by financial expenditure to support their families and themselves. One study found that the most significant stressor is financial difficulties. They influence a worker's performance and consequently, their psychological state (Glasscock *et al.*, 2006). Building workers (especially in developing countries) have low pay, wage payment delays, and unpaid overtime (Safe Work Australia, 2011).

2.2.2 Long Working Hours

Builders start working earlier than other workers (Dong, 2005). They also have higher chances of multiple jobs and constantly changing jobs. The positive link between long hours, irregular schedules and work injuries was established. This partnership kept after controlling for confounders. Such results suggest that long hours and unpredictable schedules influence employee psychology and damage employee health (Dong, 2005). Long working hours of up to 13 hours or even longer can lead a worker to physical and mental exhaustion (Safe Work Australia, 2011), primarily when working under severe climatic conditions such as extreme heat or extreme cold (Bust and Gibb, 2006). Exhaustion affects a construction worker's psychological well-being.

Overtime-related pressure and exhaustion can affect the worker's ability to remain healthy in the workplace. Longer hours do not necessarily mean higher output. Labour hours are counterproductive above a particular "full production" and can even reduce efficiency. Dong's 2005 research was conducted to identify working hours and schedules for a nationally representative U.S. construction worker (Dong, 2005).

2.2.3 Workplace Conditions

Poor workplace conditions in some countries can cause psychological worker health problems. Research by Arboleda and Abraham (2004) found that construction workers forced to work under poor physical conditions experienced considerably more discomfort, affecting their OH&S status. In the Gulf Cooperation Council (GCC) nations, Sonmez *et al.* (2011) researched human rights and health disparities among construction workers. They found that inhuman working and living conditions created severe health and safety problems. Weak working conditions include lack of hygiene and lack of construction site operation.

2.2.4 Work Stress and Work Overload

Bernaards *et al.* (2006) evaluated the correlation between physically and mentally conditions in a Dutch population. In the sedentary workforce, the "dose-response correlation between strenuous physical activity and poor general health" was found to be most vital. Another result showed that hard leisure physical exercise once or twice a week has a lower risk of long-term absenteeism, such as more than 21 days or three weeks. It was concluded that a sedentary population benefited more from extreme recreation than non-sedentary employees and that the potential of physical activity to avoid possible psychological and physical health issues, as well as long-term absenteeism may be beneficial among employees.

2.2.5 Shift Rotation

Van Amelsvoort *et al.* (2004) studied the differences between three-shift workers' psychological well-being and their work-family tensions. Results suggested that a backwards-looking schedule is related to a greater need for rehabilitation and poor overall health. The authors concluded that optimising shift-work plans in terms of shift rotation appears to be a promising solution to minimising the detrimental effects of shift work. The study was based on a Maastricht cohort study, where N=12,095 respondents, 95 employees, and 681 employees were working in three shifts, retroactive rotating jobs. (Van Amelsvoort *et al.,* 2004).

2.2.6 Relations with Workmates

Social-psychological factors include a welcoming workforce and worker relationships (e.g., "team spirit" and "good working relationship"), The latter is "much more important for productivity". Construction workers are engaged with a crew or project for a limited period. Staff who were clustered in crews and got along well had more substantial safety records (Kazaz and Ulubeyli, 2007).

2.2.7 Cultural Adjustment

Loosemore *et al.* (2010) examined the nature of cultural diversity on Australian building sites and their impact on workers. Findings found that most respondents had a reasonable degree of intercultural interaction with other cultural groups. However, ethnic identities are based on friendship groups for most operatives, and many workers do not try to connect outside their ethnic culture.

3. RESEARCH METHODOLOGY

After identifying these psychosocial hazards and risk factors in the construction industry, a questionnaire survey was conducted with practitioners from two private construction companies and one government department having construction project management experience in NSW. Research ethic approval was granted before the data collection started. Only those people who gave their informed consent were included in the project. If they decided to not participate, they could withdraw from the project at any time without giving a reason and they had the option of withdrawing their data up to point of publication. Around two hundred responds were collected. After manually checking the complement situation of those responds, 100 valid responds were selected to do the data analysis. Respondents included project managers (employers), contractors, experts and consultants, and workers. Table 1 presents the percentage of respondents.

Table 1. Percentage of respondents

Respondents	Percentage
Project managers	5%
Contractor managers	20%
Experts and consultants	25%
Workers	50%

4. DATA ANALYSIS AND DISCUSSIONS

Data were analysed and clustered by the frequency. Figure 1 presented items that concerned the various aspects of the current job. The results showed that most of respondents did not have a choice in deciding what they do at work, but they have a say in their own work speed. Some of the time, respondents have some say over the way they get the job done.

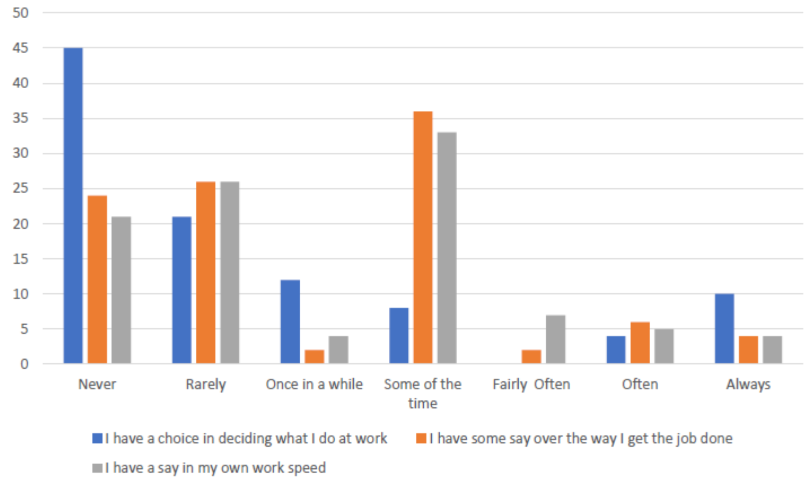

Figure 1: Items that concern various aspects of their current job

Figure 2 provided data on workers who have been pressured in their current job. 'I am pressured to work long hours' can be seen highest at 'Often' (56). 'I have unachievable deadlines' and 'I have unrealistic time pressures' can both be seen reaching their maximum at 'Some of the time' (63, 57, respectively), with 'I have to neglect some tasks because I have too much to do' being highest at 'Once in a while' (69). The results suggested that most workers are 'Often' pressured to work long hours with unachievable deadlines. This can cause high stress levels due to lack of sleep and less free time performing hobbies. If workers are always pressured to work long hours, then the stress levels will continue to rise and thus lead to depression overtime.

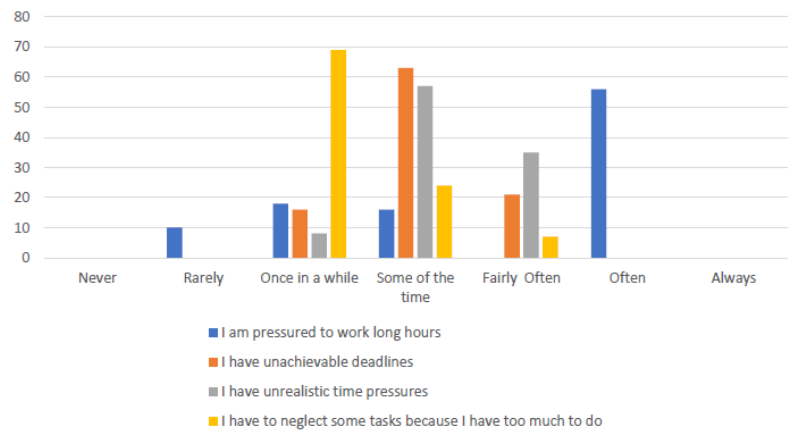

Figure 2: Items concern the amount of time pressure have in their current job

The data from Figure 3 outlined the support that a worker receives from a co-worker. 'I can rely on my co-workers to help me out with a work problem' and 'If the work gets difficult, my co-workers will help me' can be seen to be highest at 'Some of the time'

(59, 42, respectively). This indicated that although co-workers cannot be helpful all the time, but some of the time workers can help each other at work. However, 'I get the help and support I need from my co-workers' and 'My co-workers are willing to listen to my work-related problems' reach their greatest at 'Once in a while' (37, 39, respectively). This indicated that construction workers normally could only hold their feelings to themselves without mental support from co-workers. This increased the chance of mental issues if problems keep building up.

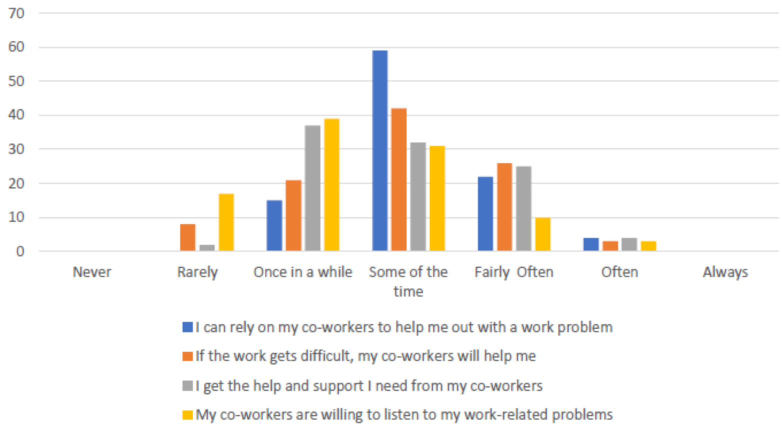

Figure 3: Support received from co-workers.

Figure 4 presented the relationship of a worker and their supervisor. 'I feel that my supervisor values my contributions to this organisation' reaches its highest at 'Some of the time' (41). However, 'My supervisor gives me sufficient credit for my hard work' peaks at 'Once in a while' (47), while 'My supervisor encourages me in my work with praise and thanks' is also highest at 'Some of the time' (48). This indicates that workers may need more praise and credits recognized from their supervisor when completing hard tasks in order to encourage them in continuous work.

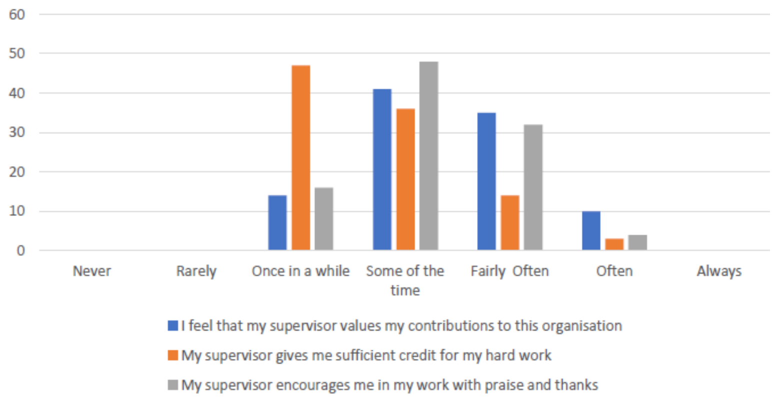

Figure 4: Relationship with supervisor

Figure 5 showed the various relationship conflicts within a workgroup. 'Processes are applied consistently in your workgroup' reaches a maximum of 64 at 'Often', while 'Processes are free from bias in your workgroup' reaches a maximum of 58 at 'Fairly Often'. This indicates that works on sites can be consistent and good for experienced workers to finish their job within the required quality and time. 'Employees in your workgroup are able to express their views and feelings during those processes' and 'Processes are based on accurate information about your workgroup' both peak at

'Always' (75, 66, respectively). This indicates the consistent results with the other relationship conflicts within a workgroup. Because works on sites are consistent, work processes are transparent to workers, and they can have a say in their work.

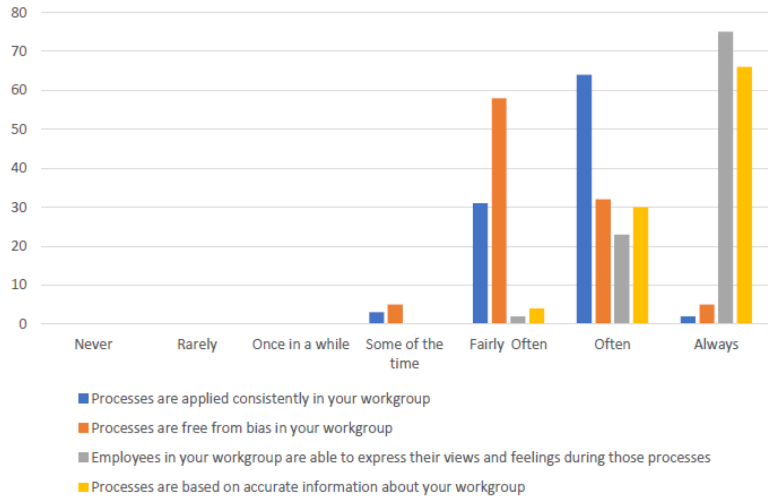

Figure 5: Relationship conflicts in the workgroup

In Figure 6, frequency of different bully behaviours at work were analysed. 'Verbal abuse' and 'Sabotage of your work' peak at 'Rarely' (46, 57, respectively). At the same time, 'Threats of punishment for no reason', 'Ridicule and being put down', 'Offensive messages' and 'Persistent and unjustified criticism' reach their maximum at 'Never' (58, 52, 43, 62, respectively). However, 'Exclusion or isolation from workplace activities' reaches' is most common 'Monthly' (32), while 'Subjects of gossip or false, malicious rumours' happen 'Weekly' (42) and 'Humiliation through gestures, sarcasm, criticism or insults' happen 'Almost daily' (55). This indicates that verbal abuse, threats and being ridiculed very rarely occurred within the workplace. However, criticism, gossip or false rumours was consistently occurring weekly and sometimes daily. All these bully behaviours could increase mental problem of construction workers, which would cause work health and safety problems on construction sites.

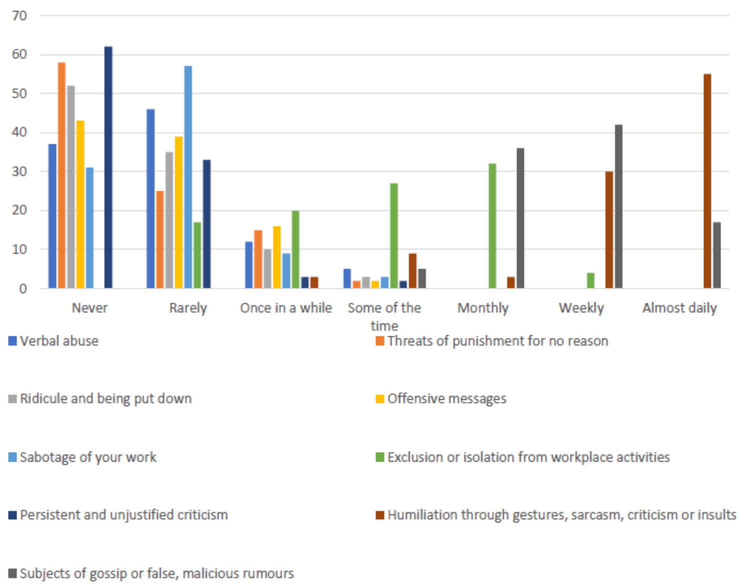

Figure 6: Bully behaviours at work

5. CONCLUSIONS

The research paper aimed to educate readers about some of the factors that influence psychosocial hazards and mental health in the construction industry in NSW. It was critical to survey different companies to examine how psychosocial hazards affect workers' mental health in the NSW construction industry.

The data indicates that most workers are often pressured to stay back and work long hours, which then lead to workers being very frequently tired. Further research must be done to investigate the correlation between being tired and how they can affect the stress levels of a construction worker. The results showed that most of respondents did not have a choice in deciding what they do at work, but they have a say in their own work speed. The results suggested that most workers are 'Often' pressured to work long hours with unachievable deadlines. This can cause high stress levels due to lack of sleep and less free time performing hobbies. If workers are always pressured to work long hours, then the stress levels will continue to rise and thus lead to depression overtime. Although co-workers cannot be helpful all the time, but some of the time workers can help each other at work. Construction workers normally could only hold their feelings to themselves without mental support from co-workers. This increased the chance of mental issues if problems keep building up. Workers may need more praise and credits recognized from their supervisor when completing hard tasks in order to encourage them in continuous work. 'Exclusion or isolation from workplace activities' was found to be a very worrying occurrence for some workers, other negative relational behaviours were also reported as widespread. Verbal abuse, threats and being ridiculed very rarely occurred within the workplace in the past six months. However, criticism, gossip or false rumours was consistently occurring weekly and sometimes daily. All these bully behaviours could increase mental problem of construction workers, which would cause work health and safety problems on construction sites. Hopefully, spreading awareness on these psychosocial hazards can slowly improve the mental health of construction workers in NSW and decrease the overall suicide rates. The limitation of this research was to conduct the research in NSW, Australia, due to geographical focus of primary data collection. The suggestions for future research can be; (1) To extend the research to other regions in Australia, (2) To compare results in different regions and to see whether construction practitioners react differently on psychosocial hazards.

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SIGNIFICANT FINANCIAL AND ECONOMIC RISK FACTORS IN COASTAL LAND RECLAMATION PROJECTS

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ABSTRACT

The demand for land required for construction and development has been rapidly increasing over the past 30 years in the global context because of population growth, especially in coastal cities. Therefore, coastal land reclamation (CLR) has drawn attention both internationally and regionally. However, CLR projects are complex and costly and, therefore, are often associated with numerous risks. Although risk management in CLR projects has been the focus of few past studies, they have not specifically focused on financial and economic risks. This study, therefore, aimed to identify the most significant financial and economic risk factors present in CLR projects to enable the management of those risks. The required empirical data were collected by conducting a two-round Delphi survey, comprising expert interviews and a questionnaire survey. The collected data were analysed using content and descriptive statistics. The results revealed 13 significant financial and economic risk factors of CLR projects. Quality of sand and soil was identified as the most important risk factor of CLR projects. Delayed payment, unpredictable safety and security conditions of the country, dredging volume and defaulting contractors and subcontractors were identified in the next top four ranking in this study.

Keywords: *Coastal land reclamation; Financial and economic risk factors; Risk management, Construction industry*

1. INTRODUCTION

Construction industry is prone to high risks because its complex and dynamic project environments cause uncertainties and risks (Mhetre *et al*., 2016). Most of the risks present in the industry, which can occur at various stages of the project life cycle, are dynamic and linked to stakeholder interests (Wang *et al*., 2016). These distinctive characteristics of the industry have made it risky. Various methods can be used to classify the risks of construction projects (Siraj and Fayek, 2019) into several categories (Siraj and Fayek, 2019; Lee and Schaufelberger, 2014). Almost all past studies have identified financial and economic risks as the two most significant types of risks present in construction projects (Chaudry and Iqbal, 2013). Financial and economic risks are significant because of their negative impact on cash flow, and project viability and profitability (Xenidis and Angelides, 2005). These risks often cause difficulties to construction companies or can even make them become bankrupt (Chen *et al*., 2010). In many developing countries,

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cash flow issues and financial deficiencies have led to underdevelopment and poor performance of the construction industry (Ghoddousi and Hosseini, 2012). Therefore, financial and economic risks that are significant in the construction industry will have a huge impact on the success of construction projects in terms of time, cost, and quality (Perera *et al*., 2020). Perera *et al*. (2020) emphasised that in the construction industry, systematic management of financial and economic risks is important. The importance of identifying the financial and economic risk factors in coastal land reclamation (CLR) projects is discussed below.

In recent years, land has been reclaimed to meet the demand for residential land in coastal and inland areas. Over the past 30 years, land demand in both inland and coastal areas have increased significantly (Sengupta *et al*., 2018). The growth of the population and expansion of cities, especially coastal cities, have brought pressure on land through construction and development activities (Tan *et al*., 2005). Maryati (2012) stated that CLR, which addresses human needs, has to be well managed in terms of material, social and economic development. However, due to their complexity, CLR projects encounter many risks (Li *et al*., 2016). These risks, caused by external and internal factors, can delay the completion of the projects (Prankevich, 2016). A proper assessment of the risks should include the determination of their causes, probability of occurrence, and consequences (Bianchi *et al*., 2010). The purpose of this study was to improve the effectiveness of CLR by synthesising, analysing, and developing the effectiveness of the output of specific CLR projects considering their financial and economic risks (Yurchenko, 2017).

Several past studies have identified the risk factors in the construction sector (Iqbal *et al*., 2015; Perera *et al*., 2020; Siraj and Fayek, 2019). Some of them were on CLR in different countries (Sengupta *et al*., 2018; Yusup *et al*., 2015). However, only few studies have focused on risk management in CLR projects (Yurchenko *et al*., 2019). The literature focussing on the financial and economic risks present in CLR projects is scarce. Therefore, this study aimed to identify the financial and economic risk factors that are significant in CLR projects.

2. LITERATURE REVIEW

2.1 CONSTRUCTION RISKS

Even though the term “risk” has no universal definition (Wang, 2018), different authors have provided definitions to it in different ways (Hansson, 2012; Hansson, 2017). A risk is defined as a probability, which excludes the events whose probability of occurrence cannot be determined correctly (Hansson, 2017). It is "uncertain" because although it indicates a danger, only its probability of occurrence can be specified (Zander, 2010). A risk can be defined using its probability and uncertainty (Aven, 2011). Risks in construction refer to events that can have an impact on project objectives at any stage of the project life cycle (Makombo, 2012). From the start to the completion of a project, and even during its operational phase, risks are present in every construction project, irrespective of the nature, complexity, size, and location of the project (Siraj and Fayek, 2019).

2.2 FINANCIAL AND ECONOMIC RISKS

Financial risks are among the most influential factors influencing construction projects (Budde, 2020). The close connection between the operation of a construction organization and performance of economic and financial institutions is also a risk associated with construction projects (Fernando *et al*., 2017). The financial and economic risks of construction require construction project managers to manage time and the relationship between quality and cost in order to meet customer needs effectively (Kolhatkarl and Dutta, 2013). Therefore, a key factor that contributes to the success of a company is the prevention of financial risks (Chen *et al*., 2010). Thus, in this study, special emphasis was placed on the management of financial and economic risks. In this study, the term financial and economic risks referred to the combination of financial risks and economic risks which found in the literature, complying to the definition of "group of risks affecting the delivery of the project within the determined budget". The prevention of financial and economic risks is important to ensure the success of construction projects (Platon *et al*., 2014). In many developing countries, financial deficits and cash flow problems have exacerbated the underdevelopment and underperformance of their construction industries (Ghoddousi and Hosseini, 2012). Therefore, many researchers have identified financial and economic risks as the most significant risks commonly present in the construction industries of developing economies (Iqbal *et al*., 2015). Table 2 presents the literature review findings on financial and economic risk factors of construction projects.

2.3 RISKS IN CLR PROJECTS

Although the development of new islands through land reclamation has reaped several benefits, particularly in Asia and the Middle East, the development of global coastal areas can place the entire ecosystem of coastlines at risk (Chee *et al*., 2017). CLR causes a large-scale human disturbance to natural ecosystems, and it has already made negative impacts on the environment and ecosystems in coastal areas (Wang *et al*., 2016). Although the pollution caused by CLR can be controlled to a certain extent, its ecological and environmental impact cannot be rectified (Nadzir *et al*., 2014). Similarly, although intertidal reclamation can provide huge economic benefits, it changes local hydrodynamics (Jiao *et al.,* 2006) because of the pollution caused by the reclamation material it releases (Naser, 2011). Land–ocean interactions are directly affected by land reclamation making an impact on the vegetation assessment and habitat distribution of coastal wetlands (Suzuki, 2003). The common risks of CLR include the changes in the domestic and foreign economic environments, which will determine the exchange rate of the stock market, reduce the exchange rates and purchase price of agricultural products, and increase the discount rates (Yurchenko *et al*., 2019). Production, financial, investment, and market risks are the four types of risks present in CLR projects (Yurchenko, 2017).

2.4 NEED FOR IDENTIFYING FINANCIAL AND ECONOMIC RISK FACTORS OF CLR PROJECTS

Rapid urbanisation has increased the population and the number of megacities, and expanded the related cities (Tan *et al*., 2005). Land in coastal cities has developed because of rapid and extensive urbanisation, which has exerted heavy pressure on the land (Li *et al*, 2016; Tan *et al*., 2005). Meanwhile, reclamation of land, commonly referred to as reclamation, is the process of creating new vacant land from the seabed or a riverbed.

Thus, rapid economic development and the resulting urbanisation have led to CLR projects. CLR has played a significant role in the urban development of many developing countries, which have large populations. However, like other constructions, CLR has several risk factors, which hinder their success (Yurchenko, 2017). Financial and economic risks are important in the construction industry because they would have a significant impact on the success of construction projects (Pheng and Hou, 2019). Several past studies have addressed financial and economic risk management in the construction sector (Chen *et al*., 2010; Perera *et al*., 2020). CLR is one of the most significant types of construction. Any country can benefit from CLR. Few past studies have focused on the importance and implementation of land reclamation projects in inland and coastal areas (Sengupta *et al*., 2018; Yusup *et al*., 2015). Although few studies have focused on risk identification in CLR projects, very few of them has focused on financial and economic risk factors present in those projects. Understanding the impacts of reclamation is important to protect national economies (Mostafa, 2012). Thus, this study identified the financial and economic risk factors that are significant in CLR projects.

3. METHODOLOGY

Although a qualitative study is convenient to identify the risks associated with a project, researchers do not recommend that type of study because the collected data would be subjective and dependent on linguistic variables, consequently leading to imprecise outcomes (Islam and Nepal, 2016). This study, therefore, adopted the Delphi technique, a quantitative approach, to determine the financial and economic risk factors that are significant in CLR projects. The Delphi technique is suitable for risk-based construction studies owing to its self-validating mechanism (Perera *et al*., 2014). Literature does not mention the ideal number of rounds required for the Delphi process (Aghimien *et al.*, 2020). However, in most Delphi studies on construction and management, a consensus can be reached after the second or third round (Ameyaw *et al*., 2016). In this study also, a consensus on the subject matter was reached after the second round. Due to the limited time and the possibility of reaching the professionals, data collection was done within the Sri Lankan context only.

3.1 DELPHI ROUND 1

Delphi Round 1 of this study focused on identifying the financial and economic risk factors applying to CLR projects. Table 1 presents the details of the respondents of the two Delphi rounds. In this round, questionnaires were distributed among 75 prospective respondents and 61 completed questionnaires were received.

Respondents were requested to validate for CLR projects, the 48 financial and economic risk factors identified from the literature which are generally considered in the construction industry (refer Table 2). They could also add new risk factors. The factors that received a score above 80% were validated for CLR projects.

Table 1: Details of respondents of Delphi rounds 1 and 2

Designation	Delphi Round 1							Delphi Round 2						
	Y1				Y2			Y1				Y2		
	10-15	**15-20**	**20-25**	**>25**	**1-5**	**5-10**	**10-15**	**10-15**	**15-20**	**20-25**	**>25**	**1-5**	**5-10**	**10-15**
Quantity Surveyor	7	5	4	3	13	2	4	7	5	4	3	13	2	4
Engineer	6	8	2	6	17	3	2	6	6	2	6	17	1	2
Construction Manager	5	2	3	2	8	3	1	5	2	2	2	8	2	-
Town Planner	4	2	1	1	6	2	-	4	2	1		6	1	-
Total	**61**				**61**			**58**				**58**		

Y1: Experience in the Construction Industry and Y2: Experience in CLR Projects

3.2 DELPHI ROUND 2

Delphi Round 2 was conducted to identify the most significant risk factors among the financial and economic risk factors of CLR projects identified from Delphi Round 1. The questionnaires of Round 2 were distributed among the 61 respondents of Delphi Round 1. The number of completed questionnaires received was 58 (Rrefer Table 1). The respondents were asked to indicate the levels of the frequency of occurrence (α) and significance of the impact (β) of each financial and economic risk factor. The severity index of each risk factor was thereafter calculated to rank the risk factors according to their levels of significance. Equation 01 was used to calculate the risk severity level of a risk factor and Equation 02 was used to identify the risk severity index.

$$S_j^i = \alpha_j^i \beta_j^i \quad (01) \qquad RS^i = \frac{\sum_{j=1}^{n} S_j^i}{n} \quad (02)$$

where n = Number of responses, S_j^i= Risk severity level of the ith risk factor indicated by the jth respondent,α_j^i = Frequency of occurrence of the ith risk factor indicated by the jth respondent,β_j^i = Significance of the ith risk factor indicated by the jth respondent, and RS^i = Risk Severity Index of the ith risk factor.

4. FINDINGS AND ANALYSIS

4.1 FINANCIAL AND ECONOMIC RISK FACTORS OF CLR PROJECTS

Through the literature review, 48 financial and economic risk factors present in construction projects were identified. All the factors had scores exceeding 80%. They were validated for CLR projects during Delphi Round 1. 23 of them were combined to form six factors. 10 new risk factors were also identified making the total number of identified risk factors 41. Table 2 shows the financial and economic risk factors that were validated for CLR projects during Delphi Round 1; the newly identified risk factors are highlighted.

Table 2: Financial and economic risk factors

Risk Factors Identified from The Literature	**Risk Factors Validated for CLR Projects During Delphi Round 1**
Financial status of the owner	Financial status of the owner
Financial status of the contractor	Financial status of the contractor
Regulatory issues	Regulatory issues
Restrictions on repatriation of profits	Restrictions on repatriation of profits
Defaulting contractors/ subcontractors	Defaulting contractors/ subcontractors
Increased fuel prices	Increased fuel prices
Delayed payments	Delayed payments
Monopolies	Monopolies
Insurance	Insurance
Treasury policies	Treasury policies
Unexpected long payback periods	Unexpected long payback periods
Poor contract management	Poor contract management
Inflation	Inflation
Exchange rate fluctuations	Exchange rate fluctuations
Uninterested recipients	Uninterested recipients
Errors in feasibility and marketing surveys	Errors in feasibility and marketing surveys
Taxation	Taxation
Political interference	Political interference
Strong competition	Strong competition
Bankruptcy	Bankruptcy
Unfair risk sharing	Unfair risk sharing
Lack of clarity in the allocation of responsibilities	Lack of clarity in the allocation of responsibilities
Reduced profitability	Reduced profitability
Breach of contract	Breach of contract
Lack of provisions for partial payments	Lack of provisions for partial payments
Changes in the market conditions *Lack of financial resources* *Poor financial market* *Uncertainties of economic development* *Market demand* *Financial failures* *Lack of financial solvency* *Credit risks*	Changes in the market conditions
Material shortages *Labour and material price fluctuations* *Extra costs for material & equipment purchases*	Material shortage
Financial problems due to estimating errors *Underestimation of the construction cost* *Financial problems due to document errors*	Financial problems caused by estimating errors
Lack of funds to pay the concessionaire *Unavailability of funds* *Cost overruns* *Budgetary issues* *Unmanaged cash flows*	Unavailability of funds
Loans with variable interest rates *Interest rate fluctuations*	Interest rate fluctuations

Risk Factors Identified from The Literature	Risk Factors Validated for CLR Projects During Delphi Round 1
Restrictions on repatriation of funds *Import/export restrictions*	Import/export restrictions
	Political instability Unpredictable safety & security conditions of the country Deviations from planned works Inappropriate social awareness Environmental conditions Effects of adverse weather Acquisition issues Social responsibilities Quality of sand and soil Dredging volume

4.2 SIGNIFICANT FINANCIAL AND ECONOMIC RISK FACTORS OF CLR PROJECTS

The significance of each of the shortlisted risk factors was identified at the end of Delphi Round 2, based on the severity index. As mentioned by El-Sayegh *et al*. (2018) and Hwang *et al*. (2017), financial and economic risk factors that had a severity index of 10 or higher were considered significant for CLR projects. Table 3 presents these risk factors, and their severity indices and rankings.

Table 3: Significant financial and economic risk factors of CLR projects

Risk Factor	RII - Risk Occurrence	RII - Risk Impact	Severity Index	Rank
Quality of sand and soil	3.90	4.43	17.29	1
Delayed payments	3.96	3.55	14.06	2
Unpredictable safety and security conditions of the country	3.00	4.39	13.16	3
Dredging volume	3.57	3.42	12.19	4
Defaulting contractors/subcontractors	2.81	3.94	11.16	5
Financial problems caused by estimating errors	2.81	3.90	10.87	6
Changes in the market conditions	2.97	3.55	10.77	7
Poor contract management	2.90	3.58	10.74	8
Material shortages	3.03	3.39	10.55	9
Reduced profitability	2.97	3.45	10.23	10
Deviations from planned works	3.48	2.97	10.16	11
Unavailability of funds	2.65	3.80	10.06	12
Inappropriate social awareness	3.09	3.26	10.06	13

According to Table 3, among the 41 financial and economic risk factors of CLR projects, 13 are significant because their severity indices are 10 or higher. Of these 13 financial and economic risk factors, 8 were identified from the literature and the other 5, which are highlighted in the table, were suggested by the experts during Delphi Round 1. *Quality of sand and soil, unpredictable safety and security conditions of the country, dredging volume, deviations from planned works* and *inappropriate social awareness* are the significant risk factors identified by the experts, which were ranked 1st, 3rd, 4th, 11th and 13th, respectively. *Quality of sand and soil*, which has the highest severity index of 17.29, is the most significant risk factor. It is used to determine the construction method to be used in a CLR project. *Payment delays* are ranked 2nd with a severity index of 14.06. However, payment delays are ranked 1st with regard to frequency of risk occurrence. Although some of the risk factors have received high rankings for frequency of occurrence or significance of their impacts, they are not significant according to their severity indices. Because a risk is generally calculated by multiplying its frequency by its impact, severity index will be more reliable than the frequency of occurrence or significance of the impact. The matrix presented in Figure 1 was plotted using the identified 41 risk factors to obtain a basic idea about the level of significance of each risk factor.

As Figure 1 demonstrates, only 13 factors can be identified as significant. The other factors are of average or high significance (Based on the cut-off adopted in this study which explained in the beginning of the sub-section 4.2). Therefore, all 41 factors have to be considered when managing financial and economic risks of CLR projects, with priority given to the most significant factors.

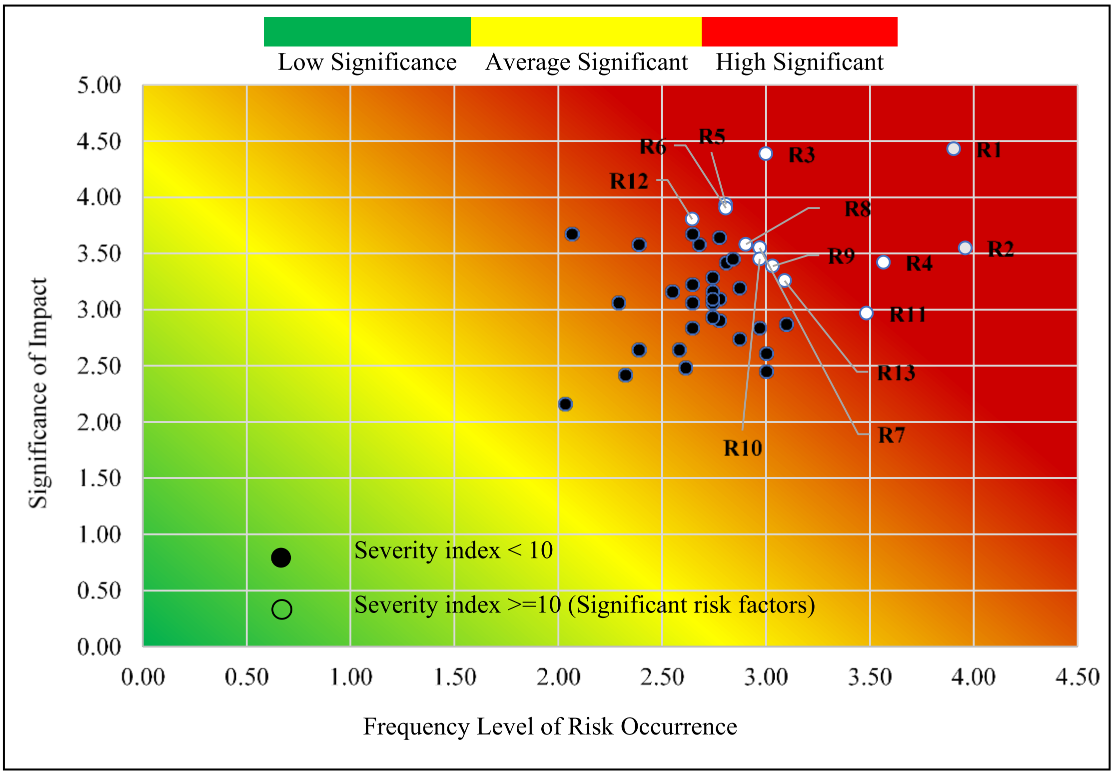

Figure 1: Risk matrix to identify the significant financial and economic risk factors of CLR projects

4.3 DETAILED ANALYSIS OF RISK FACTORS CONSIDERING THEIR FREQUENCY OF OCCURRENCE AND SIGNIFICANCE OF IMPACT

Table 4 shows the factors that were ranked based on the RII of the frequency of risk occurrence and significance of impact. The factors that ranked high in their frequency of occurrence and significance of impact are highlighted in the table. Odeyinka *et al*. (2006) and El-Sayegh *et al*. (2018) used 2.70 and 3.10 as cut-off points to identify the most frequently occurring factors. Therefore, the factors that had a RII higher than 2.90 were selected as high frequency factors. El-Sayegh *et al*. (2018) and Hwang *et al*. (2017) used 3.8 and 3.37 as cut-off points to identify the level of significance of the factors based on the significance of their impact. Thus, the impacts of the factors with a RII higher than 3.40 were considered to be of high significance.

Although only 13 risk factors can be identified as significant based on their severity indices, according to the RII of frequency of risk occurrence, 14 factors are found to be significant. *Environmental conditions, acquisition issues, effects of adverse weather* and *political instability* are the factors that are not found significant according to their severity indices. Similarly, 15 factors can be identified as significant based on the RII of significance of their risk impact.

Table 4: Significance of the risk factors based on frequency of occurrence and significance of impact

Rank	RII	Risk Factors Ranked Based on Frequency of Occurrence	Rank	RII	Risk Factors Ranked Based on Significance of Impact
1	3.96	Delayed payments	1	4.43	Quality of sand and soil
2	3.90	Quality of sand and soil	2	4.39	Unpredictable safety and security conditions of the country
3	3.48	Deviations from pre-determined planned works	3	3.94	Defaulting contractors/ subcontractors
4	3.57	Dredging volume	4	3.90	Financial problems arising from estimating errors
5	3.10	Environmental conditions	5	3.80	Unavailability of funds
6	3.09	Inappropriate social awareness	6	3.68	Contractor's financial status
7	3.03	Material shortages	7	3.68	Breach of contract
8	3.00	Unpredictable safety and security conditions of the country	8	3.65	Client's financial status
9	3.00	Acquisition issues	9	3.58	Poor contract management
10	3.00	Effects of adverse weather	10	3.58	Taxation
11	2.97	Political instability	11	3.58	Bankruptcy
12	2.97	Reduced profitability	12	3.55	Delayed payments
13	2.97	Changes in the market conditions	13	3.55	Changes in the market conditions
14	2.90	Poor contract management	14	3.45	Errors in feasibility surveys
			15	3.45	Reduced profitability

Contractor's financial status, breach of contract, client's financial status, taxation, bankruptcy, and *errors in the feasibility survey* are the factors identified based on the significance of their impact. Q*uality of sand and soil*, which is the most significant risk factor according to its severity index, is ranked 2nd according to its frequency of occurrence. However, *quality of sand and soil* is the most significant risk factor according to the significance of its impact and its severity index. Some of the other risk factors also has similar differences in their levels of significance determined based on the frequency of occurrence and significance of the impact.

5. DISCUSSION

Quality of sand and soil is the most significant risk factor in CLR projects. Because, quality of the sand and soil will affect the entire method of construction which will ultimately affect the financial and economic aspect of the project. Generally, delays in payments will cause serious cash flow problems, especially for contractors, which will have a destructive chain reaction on the procurement chain (Ansah, 2011). The impact of delayed payments was discussed by Perera *et al*. (2020), Siraj and Fayek (2019), Iqbal *et al*. (2015), and Platon *et al*. (2014). Iqbal *et al*. (2015) identified defaulting subcontractors as a significant risk factor of construction. In this study too, *defaulting contractors/subcontractors* were identified as a significant risk factor. Perera *et al*. (2020) stated financial problems caused by estimating errors and changes in the market conditions are the most significant risk factors faced in high-rise apartment construction. The results of the data analysis prove that these two risk factors may seriously affect land reclamation projects. According to the literature, reduced profitability is a significant risk factor of public construction projects (Platon *et al*., 2014). CLR projects are generally implemented by governments. Therefore, in CLR projects, the possibility of profit reduction is high. Through the literature review, many financial and economic factors were identified. Some of these factors are present almost in every construction project. Exchange rate fluctuations, interest rate fluctuations, and uncontrolled cash flows are the most common risk factors, confirmed by many past studies. (Iqbal *et al.*, 2015; Siraj and Fayek, 2019). However, these factors had to be excluded from coastal projects because their impacts were small, or the possibility of their occurrence was low.

6. CONCLUSIONS

This study focused on identifying the financial and economic risk factors of CLR projects, which have received little attention in the past. At the end of Delphi Round 2, based on the cut-off level, 13 significant risk factors were identified, of which *quality of soil and sand* is the most significant risk factor. However, its frequency of occurrence is less than that of the 2nd most significant risk factor, *payment delays*. Thus, the consideration of all 41 risk factors is important to ensure the success of CLR projects. It is recommended that awareness on the importance of contract management be promoted, being the most significant risk factor of CLR projects. *Quality of sand and soil, unpredictable safety and security conditions of the country, dredging volume, deviations from planned works,* and *inappropriate social awareness* are the new factors identified in this study. These risk factors of CLR projects can be taught in the relevant study programmes. The quantity surveyors should consider in their work, the financial and economic risk factors that this study focused on. The contribution made by the study is that the study will draw the attention of the construction industry to the importance of risk identification in CLR projects and to the financial and economic factors that are most significant in those projects. In addition, the study findings will help quantity surveyors to reduce the cost overruns of their projects by considering the financial and economic risk factors highlighted by the study. Moreover, since the demand for CLR is on the increase, the study findings will help CLR project stakeholders to ensure the viability of their future CLR projects. Several past studies have identified the financial and economic risk factors of construction projects in general without specifically focusing on CLR projects. Thus, the findings of this study make a theoretical contribution by providing a benchmark for the significance levels of the financial and economic risk factors of CLR projects. The study findings will also be a useful basis for further research to explore the strategies for financial and economic risk management in CLR projects. The assignment of those strategies to different stakeholders can also be investigated in future studies. One limitation of the study was that the required data were collected only from within Sri Lanka. This limitation will hinder the generalisation of the study findings. However, list of financial and economic factors summarised from this study can be generalised to the other developing countries. But significance order may vary from country to country. Further, this study can be referred by the developed countries as a basic to their investigation. The level of significance of each risk factor can differ from country to country depending on the geographical and weather conditions of the countries.

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SUITABILITY OF ICTAD FORMULA AND CIDA PRICE INDICES TO CALCULATE THE AMOUNT OF PRICE ESCALATED IN CONSTRUCTION PROJECTS

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ABSTRACT

Price fluctuation is a significant risk factor, in every construction project market. It is unavoidable and difficult to forecast. However, it is often argued that there is a difference between the amount calculated with the CIDA price fluctuation formula method and the actual price fluctuation. Therefore, the aim of this research is to investigate the industry opinion on whether there is a difference between price escalations calculated using the CIDA price fluctuation formula and actual price fluctuation.

A qualitative research approach was selected to achieve the aim of this research. Through a broad study of literature, it was identified the most critical factors which affected actual price fluctuation deviation. Meanwhile, semi-structured interviews were carried out to identify the reasons affecting fluctuation difference by analysing the data, which was used, and comparing the opinions given by the interviewees.

The data was analysed using context analysis. The results of the research confirm that. there is a difference between the amount of price escalation using the ICTAD price fluctuation formula and the actual being used. The main reason behind this difference is the less accuracy of cost indices. To improve the accuracy of the results of this formula, appropriate data collection using an appreciate sample of contractors in producing price indices is recommended as the main.

Keywords: *CIDA; Indices; Price fluctuation.*

1. INTRODUCTION

Due to major characteristics; large, heavy and expensive products of the construction industry differ in many ways from other industries. As a result, the higher involvement of many types of inputs is essential for the substantial completion of projects. The gradual increase in the price indices expos a rising cost of construction inputs in the domestic industry mainly, due to inflation (Weddikkara and Devapriya, 2001).

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Price fluctuation is a "percentage increase between the initial base estimate and the final achieved cost" (Dawood and Bates, 2000).

The principle causes of escalation are inflation, market conditions, taxes, other government actions, schedule extension, allocation of risk, and national and international events such as an outbreak of war (Hanna and Blair, 1993). In addition, the construction industry is largely affected by price fluctuation due to its inheritable characteristics such as costliness, long duration of the production process, heterogeneous nature, unique output, and the differences of the other industries. However, Hanna and Blair (1993) stated the main effect of escalation to the construction industry is the risk and uncertainty regarding the project cost. It will also affect financial difficulties for both contractors and the client and ultimately may delay the delivery of the project.

In the past, particularly, most of the contracts were arranged on a fixed/firm price basis. Cook (1991) states that fixed-price contracts where the prices contained in the contract bills are not adjusted to take account of fluctuations in the cost of labour and materials. In those situations, contractor has to bear up the risk of all price fluctuations. More work has been carried out on this basis, with the steady inflationary periods contractors were reluctant to offer firm price contracts since they cannot predict future price fluctuation. Therefore, the variation clause was introduced to the contract in the condition of contract to overcome this difficulty. This embodies after the contract was signed the net amount of such fluctuation would be added to or deducted from the contract sum, when the event of a fluctuation in prices of materials, labour to name a few. Therefore, depending on the contractual agreement the "fluctuation may be recoverable or non-recoverable in whole or in part" (Dawood and Bates, 2000 cited Liyanage, 2005). It creates two different arrangements of contract, which are fixed price/firm price contract and the fluctuating price contract.

There are two broad ways of calculating price fluctuation that compensate the parties to the contract in fluctuation; namely the traditional method and formula method. The traditional method is a full reimbursement method and on the other formula method is a partial reimbursement method (Jayasinghe et *al*., 2015). However, it is often argued that Sri Lankan contractors are not satisfied with the way price fluctuation is paid with the formula method and the way of calculating methods of input percentages used by Sri Lankan professionals due to the difference of actual price fluctuation and the amount reimbursed from formula method.

Therefore, this research was conducted to prove the fact whether there is a difference between CIDA price fluctuation formula and the actual price fluctuation and the reasons for this difference and to improve the accuracy of the CIDA price fluctuation formula.

2. LITERATURE REVIEW

As cited by Ashworth (2005) price fluctuations are considered as an allowance allocated for cost inflation for a particular project that can or cannot be reimbursed by the contractor according to the contract. This amount depends according to the amount of inflation that exists on and during the contractual period.

This further can be stated as the increasing percentage of the initial estimate and the final cost achieved (Dawood and Bates, 2000). As defined by the study by fellows et al. (Suraweera, 2001) fluctuations can be recoverable or non-recoverable. Escalations can be explained as the increase of the cost of the construction elements during the construction which are necessary for the original contract (Hanna and Blair, 1993).

As investigated by the previous studies it is proved that price fluctuations are a risky factor whereas it is difficult to avoid and predict. It is not considered to be the fault of the parties involved with the contract or the client. Due to the inflation in the economy in Sri Lanka Price fluctuations can be commonly observed as this is a developed country.

2.1 REASONS FOR PRICE FLUCTUATION

Most of the prices in the current industry are changing and increasing due to reasons which are globally affected such as inflation, technological changes, and oil price increase (Sendooran, 2005). Price escalations vary from a project to another as per the requirement of the construction elements and method of construction. One of the previous research done by Hanna and Blair (1993) concluded that the major reasons which cause escalations are market conditions, government actions such as taxes, inflation, extension of schedules, and risk allocation. Characteristics of the construction industry such as long duration, costliness and unique output unlike the other industries cause price fluctuations. Hanna and Blair (1993) further stated that the major effect caused by escalations is the uncertainty to the project costs and risks to the construction project. This will eventually cause financial problems for the client and the contractor both and may cause delays in the delivery.

2.2 DEALING WITH PRICE FLUCTUATION CONTRACTS AND PRICE FLUCTUATIONS

As stated by Franks (1984), it is unrealistic that the contractors can submit a fixed price for major contracts in which the works need to be carried out for over of years ahead. Hence it is necessary to submit price fluctuations or variations in the tender stage. As an effect of deciding the markup allocated for the price fluctuations, it is understandable that the risk will be taken by the client.

Fluctuating contracts contain provisions for changes and reimbursement of additional costs for labour, plant and materials (Ramus, 1981). Cook (1991) concluded that the prices in firm price contracts are adjustable in the account of fluctuations after the tender date.

In fluctuating tenders, the agreed contract sum can be changed as the cost of resources is changed before the beginning of the job (Brook, 1998). Hence different methods are used in the construction industry in Sri Lanka, mainly it is categorized into two parts:

1. Price fluctuation and reimbursement method - contractor can recover the price fluctuation of materials, plant and labour
2. Price fluctuation compensation model - this may not be the actual price fluctuation. It only includes a cost or compensation for the additional costs incurred due to price increase in materials, labour and plant by the main contractor.

When comparing the above two methods the most adaptable method to be used can be considered as the reimbursement method than the other method which is the compensation method. But in the practical context, it is difficult to use as it is a time-consuming and costly method. In the current construction industry, the compensation method is used in Sri Lanka.

2.3 CONTRIBUTION OF PRICE FLUCTUATION CLAUSE IN STANDARD BIDDING DOCUMENT

In the standard bidding document second edition in 2007 under the procurement of work in major contracts, clause 13.7 states about dealing with price fluctuations as in adjustment of change in cost. Further, it states that the prices computed according to the given formula in the sub-clause with respect to rise and fall in the cost of labour, material, plant and other works and shall be deducted or added for the payment of the contractor.

The adjustments of payment certificates concerning the changes in legislation and cost can be determined according to the ICTAD formula. Under a special circumstance, the contractor will have to pay an additional amount and no adjustments on the contract price relevant to the fluctuations can be made. In any circumstances, if the contractor fails to complete the construction work within the given time as specified in clause 17 or 28 and the price adjustments can be made for the performed work using the current indices.

2.4 PRICE FLUCTUATION RECOVERY METHODS PRACTICED IN THE CONSTRUCTION INDUSTRY

There are methods, which can be used to recover or reimburse the price fluctuations for the client or the contractor in any case of price increase or decrease. Mainly there are two methods i.e., through the Traditional/Reimbursement method or the Formula/ Compensation method.

The traditional and reimbursement method can be used based on the cost incurred and the formulae method can be used to value the works executed (Ahenkorah, 1994). The main objective of the formulae method is to calculate the prices which will compensate for the loss incurred. None of the attempts are made to formulate or price the actual amount of the fluctuation or loss that occurred. The amounts recovered by the formulae method are different from the sums recovered by the traditional methods. Therefore, it is believed that the traditional method is superior to the formula method (Ramus, 1981).

2.5 PROCUREMENT GUIDELINES

As per the procurement guidelines (2006), the price adjustments for the works exceeding a period of three months and the price variation formula in the Sri Lankan rupee component is included in the contract agreement and bidding document. The price variation formulae formulated by the CIDA shall be used.

For foreign funding projects, it is necessary to understand the requirement and the price adjustments shall be made by foreign currency.

2.6 CIDA FORMULA METHOD FOR PRICE FLUCTUATION

2.6.1 Simplified Formula - CIDA

The following formula has been formulated for the projects with the contract sum of less than Rs. 10 million.

$$F = 0.869\ (V - V_{na})\ x\ \frac{(I_{tc} - I_{tb})}{I_{tb}} \qquad (01)$$

Where; V = value of the work completed during the specified period, V_{na} = non-adjustable element value, I_{tc} = Current composite index for the type of work published by CIDA, I_{tb} = Base composite index for the type of work published by CIDA.

In ICTAD simplified formula standard benefits can be gained as this a standard method and also introduces a number of composite index for inputs instead of indices, therefore, usage of this formula has been simple. Also, in practice consultants may approve the full claim as there are fewer uncertainty factors. Also, complex calculations can be avoided by using this formula. These are the major advantages of this ICTAD simplified formula method.

On the other hand, the composite index is to be considered as an average value of each input and therefore it will not be the actual index. This is a major disadvantage. In addition, as per the definition, some projects may not fall into any category as this can be used for contracts with a contract sum of less than 10 million.

2.6.2 CIDA formula

CIDA formula is the most prominent and adequate method in the Sri Lankan development industrial practice.

This formula has been developed for contracts exceeding Rs 10 million of the contract value.

$$F = \frac{0.966\ (V - V_{na})}{100} \sum_{\text{All Inputs}} \frac{P_x(I_{xc} - I_{xb})}{I_{xb}} \qquad (02)$$

Where; F = Price adjustment for the period, I_x= Price Index for Input X, publishby CIDA, I_{xb} = Base forinput, publishby CIDA, I_{xc} = Current for input X, M_c = 80% of the Invoiced Value of materials used for permanent works on current valuation, M_p = 80% of the invoices Value of. material used for permanent works on previous valuation, P_x = Percentage cost contribution of input X, V= Valuation of work done during the period concerned, V_c = Cumulative Value of work done up to current claim, V_p = Cumulative Value of work done up to previous valuation, V_{na} = Value of Non-adjustable Element.

This CIDA formula price fluctuation recovery method is a standard procedure. Therefore, the claims calculated from this formula can be checked easily with less disputes. Also due to few uncertainty elements are involved the claims can be approved by the consultant.

This method also has disadvantages and can be listed down as follows:

1. Fluctuations are restricted to inputs such as plants and equipment, materials and labour as published in the bulletin.
2. It is problematic and complex to calculate input percentages.
3. Fluctuation is restricted to several inputs like material plant & equipment and labour published from the bulletin.

4. Inaccurate presumption like the equivalent circulation of data sources however out the agreement span is utilized to compute the variance effectively.
5. Indices are produced by considering the whole country not the location of projects (Suraweera, 2001).

2.7 FACTORS THAT AFFECT THE EFFECTIVENESS OF THE CIDA FORMULA

This formula is developed by the CIDA for the calculation of price fluctuation in development contracts has been endorsed by the cabinet of the government for national appropriation. Along these lines, it is a standard technique prescribed by the administration because of its innate attributes. As stated by Chandrasena (2005), one of the salient features of the formula method is that contract price adjustments are determined by the network done value executed or performed during that specific period and the average fluctuation rate. Further, he also has stated that there are two vital fundamentals for an effective application of the ICTAD formula: i.e.;

1. Reliable price indices
2. Accurate input percentages

The price indices are published by the CIDA monthly bulletin. Input percentages are ascertained by the expert at the offering stage and it is made reference to in the delicate report. Therefore, there are no other exceptional necessities to process the change cost looking at the other technique. In addition, it is a speedier and simple strategy for occupied amount surveyors. Therefore, the regulatory expense would be diminished drastically. Facilitate installment for increment would be made much rapidly at the season of every valuation for the temporary worker. Due to these inherent characteristics of the CIDA formula, it turned out to be the most predominant and generally used technique in the Sri Lankan construction industry.

3. RESEARCH METHODOLOGY

Initially, literature survey was conducted by referring Books, journal articles, e-journals, e-articles, conference papers, publications and previous unpublished dissertations to identify the concept of inflation risk, price fluctuation, price fluctuation recovery method in construction projects and its applications. It was identified all the breadth and depth factors that affect price fluctuation, CIDA price fluctuation and advantages and disadvantages of it.

Considering the in-depth investigation required in this study, a qualitative research approach was selected for this study. Data were collected using semi-structured interviews. Interviewees were selected using the non-probability sampling technique. Semi-structured interviews were conducted among quantity surveyors among contractor quantity surveyors and professionals at CIDA that have immense knowledge in ICTAD price fluctuation formula. Ten quantity surveyors from various contractor organizations, who are using the CIDA price fluctuation formula and five professionals, who are working at Construction Industry Development Authority (CIDA) were selected for the qualitative survey of this research. The selected professionals from CIDA were between 15-25 years of experience in the industry and the contractor quantity surveyors ar between 07-31 years of experience and five were charted quantity surveyors, on Director/Principal Quantity Surveyor and the rest were Graduate Quantity Surveyors. Th interviewees were questioned about their opinion on the suitability of using the CID formula for calculating price escalation and according to their experience, the accuracy of the outcome of using this formula. Next, they were questioned about the reasons for the difference of actual price fluctuation and the fluctuation amount calculated through the ICTAD formula and recommendations to improve the outcome of using such formula. The data collected were analysed using code-based content analysis.

4. ANALYSIS AND RESEARCH FINDINGS

4.1 INTERVIEWS WITH CIDA PROFESSIONALS

Interviews with CIDA professionals were analysed under three themes.

4.1.1 Difference between Actual Price Escalated Amount and Compensated Price Escalated Amount

With the literature found contractors are dissatisfied with compensated price escalated amount paid. They argue that in the real situation, the actual price escalated amount differs than that in the compensated price escalated amount. This fact was proved by the CIDA expertise. The reason behind this is that the formula has been developed assuming that the work done on the project is equal whereas in the actual situation it is not. Therefore, it will lead to a difference of 5-10%. However, as it is compensation the accumulated value will be the same 5-10% tolerance.

4.1.2 Methods which CIDA can help the Accuracy of Compensating the Contractor when using the ICTAD Price Fluctuation Formula

As the possible methods, the experts suggested that if CIDA could publish more accurate indices and this will lead to increase the accuracy of compensating the contractor when using the ICTAD formula.

CIDA collects data from contractors to make indices. Even though it is the best solution this has not been practical as the data collected from the contractor's side is less accurate.

Further, the accuracy of Indices is low due to the location changes.

4.1.3 Accuracy of Cost Indices

As identified from the literature survey, cost indices are important when using the ICTAD fluctuation formula. If these cost indices are not accurate there will be a difference in the outcome from the ICTAD price fluctuation formula. According to the expertise, the data collection method has to improve. This is due to the inaccuracy of data as the price of inputs used to prepare are average prices out of many number suppliers. The data is collected from many different suppliers, but the suppliers do not give accurate data or sometimes they do not give this data.

Prices of materials are fluctuating rapidly. Most of the material prices are collected directly from the supplier on the other hand for materials such as Bitumen the data is collected from Ceylon Petroleum Corporation. There is some decanted bitumen which is also used they are collecting prices from the private suppliers which have become the most difficult part because in some months they are not producing these. Even though it is a very small amount, it is also affected when preparing indices.

The other item is labour. Normally, labour wages are collected from the contractors. There is a list of contractors but only a few people are providing information. Furthermore, labour wages are not changed every month, unlike materials. Most of the contractors provide incorrect information and CIDA individuals have to analyse this and have to stop getting information from these contractors. This has become a major issue as a contractor to contractor, the range of wages are different. For example, for unskilled labours, one contractor may pay LKR 2,000 and another contractor may pay LKR 1,000. CIDA individuals will have to stop one contractor and then they have to get another contractor in the same range. The same theory applies to suppliers. It was recommended that the industry should provide accurate information to publish correct indices. Therefore, it is important to develop a procedure to get real data.

4.2 INTERVIEWS WITH CONTRACTORS' QUANTITY SURVEYORS

Interviews with contractor's quantity surveyors were analysed under twelve themes.

4.2.1 Widely used Price Fluctuation Formula

It was revealed the CIDA formula and FIDIC formula are widely used methods for price fluctuation. Generally, the FIDIC formula is used for foreign-funded projects and the CIDA formula is used for location projects. The main advantage of using the CIDA formula in Sri Lanka is that it is the standard method to recover price fluctuations, it is in industry practice, and all the data relevant to this can be easily obtained. Therefore, the claims calculated from this formula can be checked easily with fewer disputes. However, due to few uncertainty elements are involved the claims can be approved by the consultant.

4.2.2 Satisfaction of ICTAD Price Fluctuation Formula

It was revealed the majority of contractors' Quantity Surveyors were not completely satisfied. This is due to the inaccuracy of the basis which takes to create indices monthly bulletin. There are lapses in collecting these data to develop indices. It was further revealed that sometimes there is inclusive of taxes to the price of materials, which directly affects the output of the ICTAD formula.

At the same time, it was revealed that there are only one price indices for all heavy machinery. However, the rates between machinery have a huge difference. Therefore, the price fluctuation can be varied.

4.2.3 Advantages in using the CIDA Formula instead of other Formulae (JCT, FIDIC)

It is difficult to apply JCT and FIDIC in the Sri Lankan context. FIDIC formula is not currently practicing in Sri Lanka but it has been used a few periods back. Even if the FIDIC formula is used as a form of contract, the ICTAD price fluctuation formula is amended. As CIDA is in the Sri Lankan context it is an advantage because required indices can directly use in the formula.

4.2.4 Advantages Faced as a Contractor by using ICTAD Formula

The main advantage when using this formula is time-saving and no advanced knowledge is needed; simple calculation. There is a positive impact on the financial side for contractors, which enables them to claim price variance monthly because they have all the required data.

4.2.5 Proposals to Improve the Process of Calculating the Inflation Amount

It is required to increase the accuracy of the bulletin by considering location, therefore; it was suggested to prepare indices separately for different districts as location indices. The main drawback with the indices is that they are prepared on a national basis disregarding the regional variations of prices of inputs, thus gives inaccurate fluctuation calculations. It is also required to develop this ICTAD formula and increase the accuracy of collecting data. Further, separate indices for every heavy machinery should be provided.

4.2.6 Issues faced in using the Formula

There is an issue in the timely issuing of the CIDA bulletin. This is because in Sri Lanka most of the contractors are submitting the Interim Payment Application on the 10th of every month. Sometimes bulletin is not issued at this time and contractors will have to use the previous month's bulletin.

4.2.7 Difference between Actual Price Escalated Amount and Compensated Price Escalated Amount

There is a price difference between the actual price escalated amount and compensated price escalated amount. According to experts, CIDA is taking an index as a composite price. They take prices from 3, 4 sources. A contractor must have used a different source and given details about another source.

4.2.8 Strategies to Improve the Process of Price Escalation Amount Paid

Overall strategies gathered from the interviews are presented below.

- **Appropriate data collection with proper contractors** - if this method is followed then the accuracy of cost indices will be high. As cost indices are directly affecting to result from the ICTAD fluctuation formula then the reimbursement will also be accurate. And this will result in a positive way for the contractor.
- **Issue the monthly bulletin at least 5 days earlier** - If this method is carried out then the contractor can use the same month bulletin for the same month of Interim Payment Application. Even if it is a small amount change in indices in different months, it will result in relatively large amounts.
- **Proper calculation method or regional indices should be introduced** - since locational price differences are unavoidable - Since the indices are prepared on national basis disregarding the regional variations of prices of inputs, thus gives inaccurate fluctuation calculations. Prices of materials, such as sand and rubble and aggregate, is highly varying in every regional area. If regional price indices are prepared, then the reimbursement from the ICTAD price fluctuation formula will be highly accurate.
- **A recognized institute or regulatory body should maintain long term price records** - to calculate base indices and current indices to analyse – If a recognized body such as International Quantity Surveyors of Sri Lanka can interfere and gather data to build up a database to keep records to calculate base indices and current indices then it will be highly accurate. And those data can be analysed.
- A proper calculation method should be proposed to calculate the work done quantity relevant to each valuation period.

4.2.9 Satisfaction on the ICTAD Formula

The majority of CIDA professionals were satisfied. The main reason behind this is that the no need to keep many records/documents. Less paperwork because the simple calculation is there in this formula and it is time-saving therefore, price fluctuation claim can be calculated within a lesser time duration with the information provided in the interim statement. As this is a standard method over the country to calculate price fluctuation formula it leads to dispute-free environment.

4.2.10 Proposals to Improve the Accuracy of Indices

Contractors are the main stakeholders in this process. Therefore, it is important to get data that are more accurate from the stakeholders of the industry. Further, it is required to review the system by discussing with the suppliers, contractors, clients and consultants every year. As the price indices are calculated based on Colombo and Gampaha district price only. Therefore, the sample size must be spread island wide for more accurate price indices.

4.2.11 Proposals to Improve the Accuracy of the Price Fluctuation Formula

There are no proposals to improve the accuracy of the price fluctuation formula. If an attempt is given to improve this formula means, this will lead to complications.

4.2.12 Problems faced when using the ICTAD Formula

It is supposed to submit interim statements monthly if that does not happen the contractor cannot use the actual indices (indices in the same month cannot be used) which means real fluctuation cannot be matched.

A summary of the key findings is presented in Figure 1.

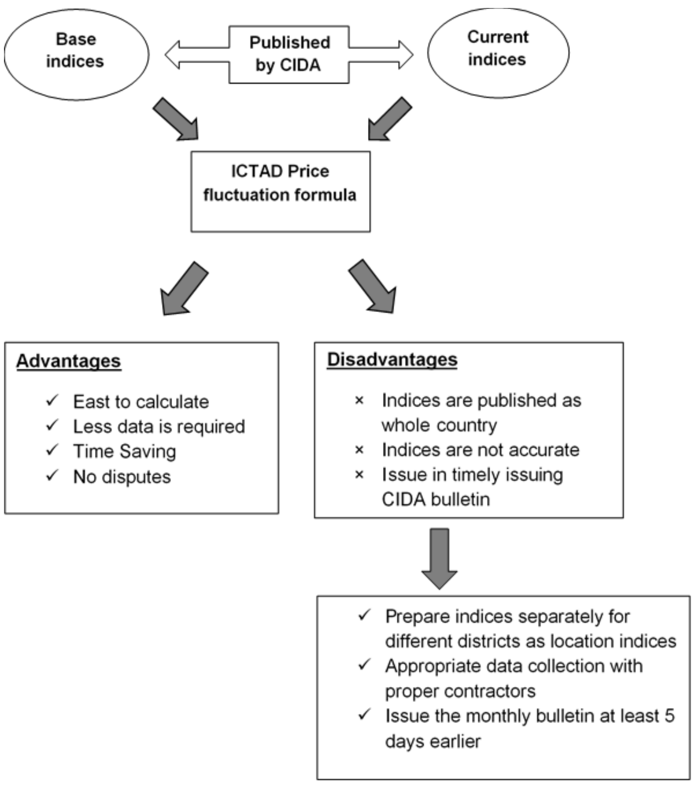

Figure 1: Summary of the knowledge gained

5. CONCLUSIONS, RECOMMENDATIONS AND LIMITATIONS

With reference to the above findings now it can be concluded that there is a difference between the amount calculated with the ICTAD method and actual price fluctuation. The cause of this difference was primarily attributed to issues in price indices. Strong evidence could not be found to conclude the inadequacy of the ICTAD price fluctuation formula.

In light of findings and conclusions, strategies proposed to improve the process of price escalation amount paid to Sri Lankan road construction projects perspective are appropriate data collection using an appreciate sample of contractors in producing price indices, issue the monthly bulletin at least 5th date of the month so that the contractors can use the same month indices, proper location adjustment method or regional indices should be introduced since locational price differences are unavoidable, a competent institute (E.g. IQSSL) should maintain long term price records to calculate base indices and current indices to analyse and adequacy of ICTAD price fluctuation formula should be revisited after attending to above recommendations.

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THE CHOICE OF PROJECT GOVERNANCE MODES TO MINIMISE CONTRACTORS' OPPORTUNISTIC BEHAVIOUR

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ABSTRACT

In this era of globalisation and fierce competition among businesses, contractors in the construction industry often tend to engage in opportunistic behaviour to gain more benefits at the expense of owners. The past researchers have defined contractors' opportunistic behaviour (COB) as the behaviour of the contractor that is motivated to pursue self-interests at the expense of the client. The researchers in this field have identified project governance (PG), which considered as management of project management can be used to minimise the COB. Trust and formal control are the major PG modes that are used in the global construction industry. However, there is a dearth of research that identified the suitable PG modes to minimise the effects of COB in the Sri Lankan construction industry. Hence, this study aims to investigate the PG modes that can be used to minimise the effects of COB. Accordingly, qualitative research approach was adopted to achieve the research aim. A comprehensive literature review followed by case studies was conducted to investigate the synergy between the concepts. Information gathered were subjected to content analysis. This study revealed that formal control and combination of trust and formal control as the most suitable PG modes for Sri Lankan construction industry. The research further identified the factors that affect the COB namely, contractors focus on revenue maximisation, external uncertainties, contractual complexity, and dynamic complexity. The study further highlighted the importance of minimising COB to help minimise conflicts and reduce the financial losses incur for project stakeholders.

Keywords: *Construction industry; Contractors' Opportunistic Behaviour (COB); Formal control; Project Governance (PG); Trust.*

1. INTRODUCTION

Poor performance and low efficiency of construction projects have set the practitioners and researchers to think more about performance and efficiency (Bankvall *et al*., 2010). Lu *et al*., (2015) identified that the over the course of the last few years, profit rates in the construction industry have been decreased to become lower than other industries. Love, Irani, and Edwards (2004) identified lack of coordination among participants to construction projects as the root cause of the problems. Zhang and Qian (2017) explained that relationships between the owner and contractor have a major impact on project performance in the construction industry. In construction projects, contractors often engage in opportunistic behaviour to gain more benefits at the expense of clients or other

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stakeholders (Cheung *et al*., 2014). As stated by Shi *et al.* (2018), it can be divided into strong and weak forms. It is found that trust and formal control are two regular modes of project governance (PG) that can be utilised to execute governance in projects, which are widely viewed as reasonable techniques that can decrease opportunistic behaviour to a certain level (Meng, 2015).

The two governance methods would lead to different project outcomes, and it may provide different outcomes to different projects due to the unique nature of each and every construction project. Thus, there are numbers of gaps that still not filled related to the project governance and there is a necessity to identify the use of project governance to reduce the effect of contractors' opportunistic behaviour (COB) to maximise the project performance and identify the factors that directly affect to the contractors' opportunistic behaviour. Hence, this paper aims to investigate the project governance modes that can be used to minimise the effects of contractors' opportunistic behaviour. In order to achieve the aim, the paper is organised as follows. First, a literature review, which discuss about opportunistic behaviour and project governance. This is followed by a justification of data collection methods used and the results of the study.

2. LITERATURE SYNTHESIS

2.1 THE OPPORTUNISM AND THE OPPORTUNISTIC BEHAVIOUR

Opportunism is characterised as a behaviour by a party that seeks after personal interests with deceiving the other party with their expense (Das and Rahman, 2010). Opportunism was frequently connected with negative feelings and incorporates activities such as stealing, cheating, breach of contract, deceitfulness, twisting information, jumbling issues, confusing transactions, bogus threats and promises, cutting corners, cover-ups, disguising attributes and preferences, retaining data, misdirection, and deception, as some examples (Crosno and Dahlstrom, 2008). Opportunism without much of a stretch is envisioned and dispensed with through governance (Verbeke *et al*., 2019). The interaction between formalisation and unity and also participation's link with role integrity and commonality appears to improve opportunism. In contrast, the interaction between formalisation and role integrity decreases opportunism (Paswan *et al.,* 2017). Opportunistic behaviour (OB) considered as an act or behaviour of partnership motivated by the maximisation of economic self-interest and occasioned the loss of the other partner which is very much similar to the opportunism definitions (Luo, 2006). The vital fact about OB was such behaviour not always exists, but the possibility of OB was always present (Sulong *et al*., 2018). Furthermore, the authors mentioned that most people act honourably and do the right things, and some do more than what required from them, however, there are always a few who are without conscience and would not perform in the best interest of all parties but rather acting for their interest.

The relationships between client and contractor have a major effect on project performance in the construction industry (Drexler Jr and Larson, 2000). Despite the fact that temporary nature of relationships and low profits to contractors emerge from furious rivalry in this industry, made contractors become opportunist to recover at least the cost (Meng *et al*., 2011). Contractors' opportunistic behaviour is defined as the contractor's acts of exercising private control, conceal or alter information, disengage from commitments or promises, avoid obligations, and breaches explicit or implicit agreements, trying to earn for themselves at the expense of the owner (Luo, 2006).

2.2 Minimising the Contractors' Opportunistic Behaviour

Strong form OB is progressively recognisable by owners, which diminishes the inclination of contractors to violate contracts (Luo, 2006). Furthermore, Luo (2006) mentioned that strong form OB is culpable dependent on terms and statements or clauses of contracts, while there were no principles to follow to remedy losses caused by weak form OB. At the point when clients take measures to punish contractors for weak form OB without enough evidence, it might prompt clashes and in any event, bring an end to transactions, causing more prominent misfortunes (Shi *et al.*, 2018). Moreover, if clients to manage the behaviour appropriately, they should recognise behaviour, collect evidence, estimate losses, negotiate, and bargain with contractors and implement solutions, which will bring about significant transaction costs (Luo, 2006). Contrasting transaction costs with actual losses, clients would, in general, persevere through their accomplices' weak form OB and learn a lesson, except there are incredibly extreme results (Luo *et al*., 2015).

In the construction sector, one of the essential explanations for project failures is the unequal division of risks between client and contractor (Rahman and Kumaraswamy, 2002). Laan *et al.* (2011) identified that different parties, including public bodies, were using new contract forms that focused on improving project performance by balancing and preventing the risks between client and contractor through new types of formal and informal control. Academics and practitioners attempt to discover powerful techniques to forestall COB in the last decades (Lu *et al*., 2015). Most common methods were project management (ul Musawir *et al.*, 2020), project alliance (Laan *et al.,* 2011), and project governance (Too and Weaver, 2014). Project management is used to meet the project requirements by utilising knowledge, skills, tools, and techniques to carry out project activities (PMI, 2013). Project alliances were introduced to evade the unsupportive patterns of conduct looked by client and contractor organisations in traditional and design-build types of contract (Laan *et al.*, 2011).

2.3 Benefits and Drawbacks of Minimising Contractors' Opportunistic Behaviour

Opportunism has negative impacts on the relationship between the client and contractors and the general procedure of a construction project (Lu *et al*., 2016). Furthermore, authors mentioned that due to the major impacts of opportunism, researchers have concentrated on the most proficient method to limit it. Mitropoulos and Howell (2001) said that the contract used as the main measure to govern COB.

A complete contract can decrease the vulnerability of decision making and it prompts to limit the intentions of OB (Williamson, 1985). An outside party can make a judgment in relation to the contract agreement thus it limits the extent of OB (Anderson and Dekker, 2005). Besides, more obligations increase contractors' knowledge to their obligations and duties, accordingly it grows the obligation to the relationship. Because of a paranoid fear for harsh punishment, the contractors would pay attention to the terms of the agreement seriously and would not embrace an opportunistic method to staying away from their duties (Lu *et al.*, 2016). Contracts can determine unsatisfactory behaviour thus, the code of behaviour seems transparent and it is completely clear what behaviour ought to be monitored in order to see whether the other party disregards the agreement, in this manner diminishing monitoring expenses (Reuer and Ariño, 2002). Parties might become flexible and alludes to the eagerness to adjust and change the original terms of the contract encountering specific requests of the other party (Yilmaz *et al*., 2005). Detailed terms in the contract also show that client has doubts about the contractors (Cavusgil *et al.*, 2004).

2.4 WHAT IS PROJECT GOVERNANCE?

Project governance system possesses a focal situation for guaranteeing that projects understand their business case and the target benefits expressed in that, which thusly bolsters the usage of the organisational strategy (Hjelmbrekke *et al.*, 2014). PG operates at the top level and includes the creation and usage of an arrangement of checks intended to settle project decision-making aligns with the targets of providing funds to the entity (Biesenthal and Wilden, 2014). Locatelli *et al.* (2014) identified PG as a budding field, that has as of late become an area of interest in the executive community related to the field of project management (Samset and Volden, 2016).

Müller *et al*. (2015) investigated how the PG structure is impacted by corporate governance (CG). Furthermore, the authors identified institutional enablers impact the determination and execution of PG and found that the presence of PG mechanisms. On the other hand, Müller *et al*. (2016) investigated the relationship between PG and CG and its impact on moral issues in temporary organisations such as project-based organisations by utilising institutional theory and agency theory. Authors considered that CG instruments substitute PG instruments, formal control, and social control to decrease moral issues. Table 1 shows definitions provided by authors on project governance.

Table 1: Definitions of project governance

Author	Definition
Turner (2009, p. 311)	The governance of a project involves a set of relationships between the project's management, its sponsor (or executive board), its owner and other stakeholders. It provides the structure through which the objectives of the project are set, and the means of attaining those objectives and monitoring performance are determined.
PMI (2013, p. 579)	The alignment of project objectives with the strategy of the larger organisation by the project sponsor and project team. A project's governance is defined by and is required to fit within the larger context of the program or organisation sponsoring it but is separate from organisational governance.
Müller (2009, p. 4)	Governance, as it applies to portfolios, programs, projects, and project management, coexists within the corporate governance framework. It comprises the value system, responsibilities, processes, and policies that allow projects to achieve organisational objectives and foster implementation that is in the best interests of all the stakeholders, internal and external, and the corporation itself.

It was identified that COB has a negative impact on project performance. Minimising COB would provide benefits such as parties become more transparent as well as flexible. Hence, PG can be used to minimise the effects of COB on project performance. The literature review reveals that there were few or no sources accessible about the utilisation of PG to limit COB in Sri Lankan construction industry. Therefore, essential to look at the effect on using PG to minimise COB in Sri Lankan construction industry.

3. RESEARCH METHODOLOGY

Research approach is the procedure for research, which traverses the choices from more extensive assumptions to more informative methods of data collection and analysis (Creswell, 2014). Yin (2017) presented two types of research approaches as Qualitative and Quantitative. The qualitative approach is subjective in nature. Creswell (2014) mentioned that qualitative approach incorporate gathering data and information through raising questions and strategies comprehensive of researcher making interpretations of the data. Considering the merits and demerits of the research approaches, qualitative approach was selected over the quantitative and mixed approaches. Yin (2011) clarified the points of interest as could concentrate on explicit arrangement of individuals, in depth study on wider areas, offer more prominent scope in choosing topics and representing the perspectives and viewpoints of the individuals. In depth opinion of the industry practitioners under case studies were needed to propose suitable PG modes to the local context. On the other hand, PG was a new development thus the projects that use this concept was extremely limited in the Sri Lankan construction industry. Hence, the obtainable sample size was limited. Furthermore, the data and information gathered were mostly based on the opinion of the practitioners and needed to be analysed in detail. Therefore, the study needed to be done based on the qualitative approach.

The background study was carried out by referring to books, journal articles, electronic sources, and other relevant sources and then the research gap was identified to carry forward the research. A comprehensive literature survey was conducted to review opportunistic behaviour, COB, PG and client's choice on PG modes to minimise contractors' opportunistic behaviour. Journal articles, books, conference proceedings and unpublished dissertations helped with building up the literature review. Considering the fact that the literature relating to project governance was hard to find and ultimate objective of the research is to evaluate the suitability of the project governance modes to minimise the contractors' opportunistic behaviour in Sri Lankan construction industry, case study analysis was selected. Four building construction projects were selected as cases. Out of four, two projects had a public client, and the other two projects had a private client. The study is based on a qualitative approach and therefore qualitative data was collected through the semi structured interviews. Analysis procedure of those qualitative data was incorporated recognising, coding, and categorising patterns. Further, a content analysis was utilised as the data analysis technique.

4. RESEARCH FINDINGS AND ANALYSIS

Four building construction projects were selected as cases. Cases A and B were governed by formal control mode, case C was governed mostly based on trust and case D was governed by a combination of two modes. The public institute held ownership for two projects and the other two project had private owners. Out of four cases, only case C did not have a consultant for their selected project. Cases related to both modes were selected in order to get an idea about the applicability of each mode to the Sri Lankan context and to investigate whether using different project governance modes are feasible and beneficial to use in Sri Lankan construction industry. Other than that, choosing public and private projects lead to provide different perspective regarding the project governance mode used in the respective cases. The interviews were carried out among sixteen professionals who are currently involved in the Sri Lankan construction industry in four different cases. A brief description of the four cases has been shown in Table 2 and Table 3 provides a brief description about respondents.

Table 2: Details of selected cases

	Case A	**Case B**	**Case C**	**Case D**
Nature of the project	Building construction	Building construction and renovation	Building construction	Building construction including hotels and apartments
Project duration	9 months	6 months	2 Years	2 Years
Tendering method	Open tendering		Direct negotiation	
Standard form of contract	Standard Bidding Document (SBD 2)			FIDIC
Governance mode used	Formal Control		Both but mostly Trust	Combination of both Trust and Formal Control equally

Table 3: Details of respondents

Case	**Respondent Code**	**Type of the organisation**	**Ownership of the organisation**	**Designation**	**Experience in the industry**
Case A	RA1	Client	Public	Chief Manager Technical Services	30 years
	RA2	Consultant	Private	Chief Architect	12 Years
	RA3	Contractor	Private	Project Manager	10 Years
	RA4	Contractor	Private	Project Quantity Surveyor	8 Years
Case B	RB1	Client	Public	Assistant Director Construction	5 Years
	RB2	Consultant	Public	Chief Engineer	24 Years
	RB3	Contractor	Private	Chief Quantity Surveyor	9 Years
	RB4	Contractor	Private	Chief Quantity Surveyor	35 Years
Case C	RC1	Client	Private	Director Project Management	20 Years
	RC2	Client	Private	Senior Quantity Surveyor	8 Years
	RC3	Contractor	Private	Project Quantity Surveyor	3 Years
	RC4	Contractor	Private	Project Manager	11 Years
Case D	RD1	Client	Private	Director (CFO)	3 Years
	RD2	Consultant	Private	Director Operation	25 Years
	RD3	Contractor	Private	Project Manager	10 years
	RD4	Contractor	Private	Director Projects	14 Years

The researcher asked about the respondents opinion on the; (a) meaning of PG, (b) importance of project governance to construction projects, (c) impact of contractors' opportunistic behaviour to the construction industry, (d) benefits of minimising opportunistic behaviour, (e) factors affect to the contractors' opportunistic behaviour, (f) relationship between contractors' opportunistic behaviour and the client's choice on project governance modes, and (g) suitable project governance mode to construction projects in Sri Lanka. The answers given by 16 respondents in the 4 cases are given below.

4.1 MEANING OF PROJECT GOVERNANCE

Professionals identified what the project governance was meant for the construction industry of Sri Lanka. They provided different views regarding it. These are the few definitions provided by them. One respondent identified it as a method that helps in timely procurement. Six respondents identified PG as a method that can be used to manage and control a construction project in order to get the expected outcome. One respondent had a view that it was a process of decision making in a construction project in order to make the project effective, efficient, and transparent. From the views of respondents, it can be said that project governance is a process that can be used to manage and control a construction project in order to get an expected outcome from it within expected time and cost.

4.2 IMPORTANCE OF PROJECT GOVERNANCE TO CONSTRUCTION PROJECTS

Different respondents added different ideas on why they thought PG is an important attribute to practice. A respondent had a view "*Good project governance shall streamline the project decision making process so the confusions and lack of trust in decision making are minimised as much as possible*". Following are the reasons to consider PG as an important attribute as identified by the professionals.

- Guide to go in one direction
- Can get the expected outcome
- Minimise conflicts
- Improve project decision making
- Leads to timely completion and time saving
- Better management of resources
- Provide quality output
- Can complete within budget

Through the literature review it was identified that PG must be, built up to empower productive and viable project decision-making and it was identified by RA4 and RC3.

4.3 IMPACT OF CONTRACTORS' OPPORTUNISTIC BEHAVIOUR TO THE CONSTRUCTION INDUSTRY

Professionals were questioned about the impact of COB to the construction industry and professionals provided valuable insight into the impact with their experience. Their ideas are summarised as follows:

- Could lead to time and cost overruns
- Quality may be affected

- Project objectives would not be achieved
- Dissatisfaction could occur between parties
- Contractors will be blacklisted.
- Claims will be increased in the industry.
- Demotivate the clients in investing
- Affect to all other stakeholders
- Leads to mistrust between all parties

4.4 BENEFITS OF MINIMISING OPPORTUNISTIC BEHAVIOUR

The benefits of minimising opportunistic behaviour identified through the literature synthesis and responses collected from interviews were also summarised in Table 3.

Table 3: Benefits of minimising opportunistic behaviour

No	Benefits of opportunistic behaviour	Respondents															
		RA 1	RA 2	RA 3	RA 4	RB 1	RB 2	RB 3	RB 4	RC 1	RC 2	RC 3	RC 4	RD 1	RD 2	RD 3	RD 4
1	Narrow the scope of opportunistic behaviour	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
2	Legal and economic consequences take into consideration by contractors	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
3	Increase contractors' sensitivity to their duties and responsibilities	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓
4	Increasing the commitment to the relationship	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
5	Take the contract terms seriously	✓		✓	✓	✓	✓		✓	✓		✓	✓		✓	✓	✓
6	The code of behaviour becomes transparent	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
7	Parties might become		✓	✓	✓	✓		✓	✓	✓	✓		✓		✓		✓
8	Reduce the cost related to opportunistic behaviour	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

RB4 said that "*Contractors are always sensitive to their duties if there is a proper management within the contractor's organisation and when they are ethical. Thus, the minimising it will not have a huge impact*". RA2 highlighted that contractors would always take contract terms seriously when they get into a contract thus it led them to identify the areas that they can get benefits from.

4.5 FACTORS AFFECTING TO CONTRACTORS' OPPORTUNISTIC BEHAVIOUR

The factors affecting contractors' opportunistic behaviour identified through the literature synthesis, which was validated through the interviews are listed below:

- Client's prevention focus and promotion focus
- Contractor's focus on revenue maximisation, short time to completion, taking projects as security and relationship marketing
- Internal and external uncertainty
- Control, coordination and adaptation related to contractual complexity

- Structural complexity, uncertainty, dynamic complexity, pace and socio-political under project complexity

All respondents agreed to all factors related to the contractual complexity and all respondents agreed to the factors namely contractor's focus on revenue maximisation, external uncertainty, structural complexity, uncertainty under project complexity, dynamic complexity, and pace under project complexity. According to that, it was clear when contract become complex contractors tend to be opportunistic because of the freedom they did not get from it. Other than that, when contractor is focusing on revenue maximisation, they will be opportunistic, because it was the only way they can generate more profit from a project. Furthermore, when the project is technically difficult, uncertainties are highly related to the project, frequent changes instructed by the Employer and milestones needed to achieve in the project will also affect to the COB.

4.6 RELATIONSHIP BETWEEN CONTRACTORS' OPPORTUNISTIC BEHAVIOUR AND THE CLIENT'S CHOICE ON PROJECT GOVERNANCE MODES

It was identified that there is a relationship between contractors' opportunistic behaviour and the client's choice on project governance modes because all the respondents mentioned that COB would have an impact when the client selects a project governance mode. Too and Weaver (2014) mentioned that PG can be used as a method to minimise the opportunistic behaviour of the parties in a construction project. RB1, RB2, RC3 and RD1 mentioned that based on the client's experience on previous projects related to the COB, clients would choose a project governance mode. If the methods used previously not helped to control the COB and it led to losses for client most probably client would select a different governance mode. Furthermore, all respondents mentioned that there are some factors affect client's choice on PG other than COB. Few of them are time, cost, quality, nature of the project, complexity of the project and focus of the client.

4.7 SUITABLE PROJECT GOVERNANCE MODE TO CONSTRUCTION PROJECTS IN SRI LANKA

It was identified that at the beginning, construction industry must go for either formal control mode or a hybrid mode of formal control and the trust. Apart from a one respondent, no one mentioned trust could be used as a PG mode in Sri Lankan construction industry and respondent one respondent mentioned that the selection of the mode would depend on the factors that needed to analyse when selecting a PG mode. RA1 mentioned "If a combination of trust and formal control can be used in Sri Lanka it will be better but as per the current scenario, formal control is the best because contractors are not ethical." RB1 mentioned that contract must be there to make sure all parties contribute to a project but when there is trust it can lead to make decisions suit for all parties.

The study revealed that it is hard to totally eliminate COB in the construction industry and it meant that project governance cannot eliminate contractor's opportunistic behaviour by 100% but it would help to achieve minimisation of it to the greater extent. Both formal control mode and the combination of trust and formal control mode have identified by the professional as suitable modes for the construction industry.

5. CONCLUSIONS

The changing nature of the construction industry, its competitiveness and work environment that affected by internal and external factors have forced the firms to find out relevant management strategies to achieve objectives of the projects for the client. Project governance is a framework, which was adopted for construction projects in the global context over the past few years. In order to cope up with the change in the industry, it needed to be adopted in the Sri Lankan context.

According to the background literature review, there are lack of studies related to the use of PG to minimise COB in the Sri Lankan construction industry. It was further revealed that construction industry practitioners paid less attention to the clients' choice regarding PG modes and their ability to control the COB. Hence, there was a need to investigate the use of PG to reduce the effect of COB to maximise the project performance and identify the factors that directly affect to the COB. This study revealed that formal control and combination of trust and formal control as the most suitable PG modes for Sri Lankan construction industry. Therefore, this research offers factors to consider when selecting a PG mode such as complexity, duration, and cost of the project. Furthermore, the research identified the factors that affect the COB namely, contractors focus on revenue maximisation, external uncertainties, contractual complexity, and dynamic complexity. The study further revealed the importance of minimising COB such as helps to minimise conflicts and reduces the financial losses incurred for project stakeholders.

Research findings confirmed that PG is existing in the construction industry as a management method, and it can be used to overcome the COB. This study exposed that, even though PG is used worldwide, it was a new field to Sri Lanka, yet it was used in construction projects without knowing with project management. Hence, this research offers insights about PG in order to enhance project performance by minimising the COB.

Findings of this research will be beneficial for the construction industry practitioners, for increase the project performance in Sri Lankan construction organisations by minimising COB in order to enlighten the corporate image of the industry and increase the satisfaction of all stakeholders in a project as recommended below.

1. Employing the findings of this research as guidance to select a suitable PG mode out of formal control and combination of trust and formal control.
2. Use the findings of this research to promote the use of PG in Sri Lankan construction industry

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THE OBSTACLES TO ENERGY SAVING IN RESIDENTIAL BUILDINGS IN NIGERIA: STAKEHOLDERS' PERSPECTIVES

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ABSTRACT

Over the past three decades research on energy use in buildings has become significant due to increasing scientific and political pressure on issues concerning global warming and climate change. As part of the impact by climate change, tropical nations are faced with several challenges in achieving energy savings, particularly the energy consumption behaviour of building occupants, with very little research coming from Africa. Previous research has shown that variations due to occupant behaviour is substantial. To address these challenges in line with the objectives of some of the UN Sustainable Development Goals (SDGs) (namely, clean and sustainable energy, as well as climate action) in residential buildings, this paper explores the perceptions of stakeholders by identifying the barriers which affect energy use from different cultural perspectives. Qualitative data were collected using semi-structured telephone interviews with experts in the energy and construction fields in Nigeria. The purpose of the interviews was to provide an insight into residential energy consumption behaviour and the barriers faced in the adoption of sustainable energy sources. The results were analysed using an energy cultural framework. An analysis of the results shows that continuous awareness of energy saving behavioural change, government subsidies for renewable energy, government checks, and the standardization of energy-efficient appliances imported into the country can improve people's trust regarding sustainable choices and can promote efficient energy use. The outcome from this work is expected to give a better understanding of energy use behaviour and inform future energy policies and interventions related to household energy saving.

Keywords: *Barriers; Energy saving; Energy culture framework; Stakeholders.*

1. INTRODUCTION

Energy is essential for sustained human development, social improvement and economic growth. Moreover, sufficient energy at an affordable price is a necessity for economic stability and is also regarded as vital for the sustainable development of a nation (Sepúlveda, 2016a). The literature has shown that the building industry is viewed as a major contributor to energy consumption and greenhouse gas emissions (Allouhi *et al.*, 2015) and the International Energy Agency has advised on the relevance of effective measures to be put in place to mitigate the effect of climate change in the energy sector (International Energy Agency, 2015). In Europe, about a third of total energy use and

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carbon emissions is as a result of household energy use (Dietz *et al*., 2009; Bertoldi, 2012) and this has the possibility of being reduced by up to 20% in a decade with the implementation of non-regulatory interventions (Dietz *et al*., 2009). As a result, there are suggestions that accomplishing the reduction of these carbon emissions through interventions that consider social, cultural, psychological and organizational factors can influence our choice of energy which could be beneficial (Stern *et al*., 2016). While technical advances and tougher environmental regulations are important requisites for improving energy efficiency (Geels *et al.*, 2018), several researchers argue that behavioural factors demand more attention (Sovacool, 2014). Therefore, solving energy challenges also requires improvements in human behaviour and in successfully shifting consumer behaviour in the desired direction. As previously emphasized in literature, energy is used by people/occupants and not buildings (Janda, 2011). To adopt a more sustainable practice to complement innovative solutions for energy efficiency, the behaviour, as well as attitude, of occupants are crucial. Therefore, the main research question of this study is "What are the challenges to the adoption of energy saving practices in Nigerian residential buildings?". Accordingly, this study attempts to identify the challenges to making energy savings in residential buildings by contacting experts in the energy and building sectors. The purpose of the main research (upon which this paper is based) is to develop a model for the reduction of energy consumption within residential buildings in Nigeria from an end use perspective to inform understanding. The paper is structured to discuss the present state of energy (electrical energy) consumption in Nigeria and then presents the methodology adopted for the study. This will be followed by a discussion on the challenges faced by stakeholders in the energy and construction sector with analysis and discussions in this regard.

2. LITERATURE SYNTHESIS

2.1 BACKGROUND TO THE STUDY

Residential buildings' net energy demands can be reduced through technical and behavioural interventions (Ornaghi *et al*., 2018). Technical interventions can be implemented at the design or operational stages of a building. However, behavioural changes aim to improve the environmental consciousness of occupants. There is a vital need for the efficient management of energy and for investigations into the inherent challenges or barriers to energy saving within residential buildings. In analysing efficient energy management in buildings, Pelenur and colleagues attributed demographics as key barriers to energy efficiency measure adoption in the UK residential sector (Pelenur and Cruickshank, 2012). Stieß and colleagues also analysed homeowners who used low and zero carbon technologies as compared to those who carried out standard refurbishment measures (Stieß *et al.*, 2013). The work also allows homeowners to assess achieving their objectives in residential refurbishments and the associated barriers. The study observed that a major barrier to achieving energy-efficient refurbishment measures is poor dissemination of information and transfer of knowledge.

Further studies examined data from a 2009 survey of more than 400 owner-occupiers of single-family detached and semi-detached houses to identify key drivers for, and barriers to, the adoption of building energy retrofits in Germany (Achtnicht *et al*., 2014). It was noted that private owners with financial capacity are likely to carry out building retrofit to achieve efficient energy savings. Furthermore, a survey of technology adopters has been carried out by Caird *et al*. (2008) to investigate the drivers for, and barriers to, the adoption of energy efficiency measures and renewable energy systems. Price barriers were identified as one of the reasons for rejecting technologies (Caird *et al*., 2008). It was noted that when considering the input of stakeholders, Caird *et al.* (2008) looked at the perceptions of the stakeholders involved in the building life cycle and industrial value change were sorted to identify barriers of significance to the industry. The greatest challenge identified in this was the inefficiency in terms of how energy savings, translated into benefits and profits. This resulted in the identification of three major barriers which were dissatisfaction with policy design and implementation, stakeholder lack of implementation capacity for developing and constructing high-performance new residential buildings, as well as an inadequate legalization of the relevant market (Li *et al*., 2019). Furthermore, studies by Camarasa *et al*. (2021) by interviewing a range of stakeholders in European Union countries, identified technical and economic barriers as the main barriers to the adoption of energy efficient technologies (Camarasa *et al*., 2021). This, amongst other research, underscores the crucial need to consider studies on energy savings' behaviour with a focus on barriers and on stakeholders' perspective. It is also noted that most of the literature that was analysed for this study with focus on barriers are studies conducted in Europe and Asia. Hence, similar studies in African countries, particularly Nigeria, will be a valuable addition to the research database in this area.

2.2 CURRENT STATUS OF THE POWER INDUSTRY IN NIGERIA

Nigeria is one of the largest oil producing nations in the world with a population of over 190 million people (Olaniyan *et al*., 2018). It is a lower medium-income economy with a per capita income of about $2,250 (World Bank, 2019). Undeveloped electricity production systems exist in the country making the generation and distribution of electricity unreliable (Urban *et al.,* 2007; Emodi and Yusuf, 2015). Currently, Nigeria is the largest nation in Africa. It accounts for almost half of West Africa's total population and more than 15 per cent of the entire African continent's total population (World Bank, 2019). Nigeria is the largest oil producer in Africa, with around 37 billion barrels of proven oil reserves and 203.16 trillion cubic feet of established natural gas reserves (EIA), 2020). This has enabled fuel energy to be available at a lower cost (through government subsidies) in comparison to international prices. The generated electricity in the country consists of a combination of three hydro and nine thermal power generation plants, with thermal generation based on gas (Remy *et al*., 2021). The generation plants have a total installed capacity of 6910MW generated mainly from hydro power and fossil fuel (oil and natural gas) with a ratio of 27.9% and 67.2% respectively (AFDB, 2011; National Energy Policy (NEP), 2003). Nigeria's grid supplies underperform as compared to other developing countries (Adeniyi, 2019). This is because more than half of the electricity generated is estimated to be off the grid, mostly by diesel and gasoline generators. In 2018 the Nigerian government estimated that Nigeria needed to install at least 40 GW (Gigawatts) by 2020 to meet its then projected goal to become one of the 20 largest economies in the world by 2020 (Ikpe and Torriti, 2018). Unfortunately, that target was not achieved and currently it is not a realistic target as a result of numerous challenges associated with the power sector. These challenges, amongst other factors, are the main focus of this paper, that is, to determine the obstacles to energy savings within Nigeria residential building is the main focus area by considering the aggregate views of key stakeholders in this regard.

3. METHODOLOGY

The chosen data collection method for the study was the interview. This is because it encourages researchers to explore the beliefs, motivations, views and experiences of the subjects concerning the investigated phenomenon (King *et al*., 2018). Additionally, the semi-structured interview format was chosen as it offers the opportunity for the interviewer to ask additional questions or follow-up questions and to change the questions based on the interviewees' answers (thus seeking more detailed answers). This study is part of a larger sequential exploratory mixed-method research where interviews are carried out first, and the data obtained are expected to inform the quantitative aspect of the study (Saunders *et al*., 2019) As a result of the Covid pandemic and subsequent lockdowns, telephone interviews were considered to be most appropriate method to undertake the interviews. Although researchers generally disapprove of telephone interviews, often citing the lack of visual cues, establishing a rapport and interaction (Gillham, 2005; Hargreaves *et al*., 2013; Burton, 2018), they are inexpensive, convenient and easily generate a substantial amount of data (Babin *et al*., 2019).

To get an in-depth insight into the barriers to energy efficiency, an interview schedule was created. The interviewees consisted of ten professionals from the Nigerian electricity and construction industry. The reason for the interviews was to obtain independent viewpoints from a cross-section of stakeholders to generate qualitative data as an initial pilot study. A similar approach has been employed for exploring an area when there is a scarcity of empirical data in the specific area of research (Trotta, 2018). Purposive sampling was used to identify the energy and construction experts (energy providers, energy regulators, energy consultants and construction contractors) who were consulted for the qualitative interviews. Additionally, the stakeholders were selected on accessibility and from the contacts that the researcher had with the Nigerian electricity and construction industry? However, before the interviews were conducted, preliminary contacts were undertaken through an introductory phone call, an email to explain the research and why their participation would be appreciated, and to set up an interview. The participants had 5-15 years' experience in the energy and construction industry. All participants were recruited voluntarily and signed a consent form which pre-informed them of their voluntary participation and the nature of the study. All the participants except for participant G had experience of working in the electricity industry. The consultant (participant G) had various experiences of dealing with key electricity providers around Nigeria, which positioned him as an appropriate participant for this research. The telephone interviews were recorded, transcribed and analysed. The analysis processes involved coding and constructing themes by classifying similarities in the interview data, with thematic analysis used to analyse the results.

4. RESULTS AND DISCUSSION

4.1 ANALYSIS OF DATA

The analysis started with the transcription of the interviews. This involved listening to the recorded audio, transcribing, and clarifying in-depth with the participants, which was followed by the generation of coding and themes. The data analysis used here depended on the research question and the research design. This technique is effective in understanding patterns across the data about the respondents' experiences, practices and behaviour (Braun *et al.,* 2016). This method was performed using Microsoft Excel and thematic analysis was used (Braun and Clarke, 2006). Since the transcriptions of the interview were based on semi-structured questions, some of the responses were difficult to categorise as they were lengthy and subject to the experience, opinions and perceptions of the interviewees. For this purpose, the researcher concentrated mainly on the research questions (and in this case is, "what are the barriers to energy saving in Nigeria from a stakeholder perspective?") while not ignoring the valuable additional knowledge that emerged from the interview sessions. To safeguard the confidentiality of the results, the participants involved were labelled alphabetically.

4.1.1 The Factors that Could Influence Energy Efficiency Implementation

There were several factors, identified by the participants, that are important in enhancing or militating against energy efficiency behaviour. These include a lack of leadership commitment to energy efficiency; poor incentives; mixed messages sent out by providers on the value of efficiency offers and a lack of clarity in policy direction on energy-efficient savings. Other factors are a lack of cross-government buy-in to efficient energy use; a lack of enforcement of mandatory standards, a lack of helpful information, training and accountability, as well as ignorance of the term sustainability, thus it is having little impact. Some of these factors will be discussed in more detail subsequently.

4.1.2 Lack of Leadership Commitment Towards Energy Efficiency

The lack of leadership commitment has been identified as one of the major barriers towards achieving energy efficiency in Nigerian residential buildings. According to participant A as shown in Table 1, most Chief Executives of both government and private organisations responsible for the coordination or implementation of energy policies either lack the understanding of energy efficiency or are complacent on the approach required to effectively drive the implementation of policies, programmes and directives in this regard. This assertion is also supported by the literature, namely that leadership commitment is lacking in attaining the efficient utilisation of energy (Hart *et al*., 2009). It was noted that a lack of active participation by the leadership of organisations in the energy sector has a negative impact on energy efficiency in households. Table 1 also shows that over 70% of the responses are in agreement that a lack of leadership is a shortcoming with the statistical trend showing similar views.

This lack of leadership from the executives reflects on performance within the industry and exhibits a lack of accountability for energy efficiency. Without a leader's commitment to energy efficiency, those making sourcing decisions will be unclear on what priority to give to efficiency, and also will be left in doubt about how to deliver efficiency in energy savings. It is pertinent to note the attitude of the leadership within an organization generally reflects in the behaviour of their subordinates (such as in services' delivery and in efficient energy savings for residential buildings in Nigeria). Participants noted that: The result of this lack of leadership is that commitment in principle to sustainable development and energy efficiency did not translate into sustainability in practice.

4.1.3 Lack of Reliable Information and Training

Participants D and F concurred that it is important to look at the role information and training play in achieving energy efficiency. Regarding this barrier, over 60 per cent of the participants substantiated that a lack of reliable information affects sustainable energy saving behaviour. Such a lack of sufficient information can be manifested in households not using energy saving equipment. Generally, there is poor understanding of the benefits of energy saving. A comprehensive initiative by the Government to address the barriers expatiated by Participants F and G will deliver a clear and consistent signal to the market for sustainable technologies. It will ensure that the sector values sustainability in enhancing the chances of achieving UN SDG. It will also help the sector to ratchet up supplier and product performance over time and to identify potential savings. It will put Nigeria among the leaders in sustainable development. Existing training courses are often traditional or generic in nature and do not focus on how to deliver sustainable energy. This is because the training providers are not sustainability specialists. There is a lack of experienced practitioners to deliver sustainability training to staff.

Table 1: Obstacles to energy efficiency and sustainable development implementation

Barriers/ motivative factors	Participant A	Participant B	Participant C	Participant D	Participant E	Participant F	Participant G
Lack of leadership commitment	√	√	√		√		√
Lack of helpful information and training		√		√		√	√
Inadequate use of new technologies	√				√	√	
Poor financial support		√				√	
Social and organisational challenges			√	√			√

4.1.4 Inadequate Use of Technologies

Lack of integration of new technology is considered as a barrier to efficient energy saving practice in Nigerian residential Sector. Because Nigeria is not a technology advanced country, most of the new technologies for sustainable energy are imported from different countries. As a result, proliferations of such technologies are experienced with limited capacity for standardization. It was further noted the use of these technologies amongst residences, with some of the available technologies with compatibilities issues and difficult to integrate. All these are serious barriers to achieving sustainable efficient energy savings amongst residential sector in Nigeria as highlighted by Participants A, E and F in Table 1.

"*You know Nigeria is a developing market, and this comes with non-availability of technology, inadequate technologies, poor quality of designs, poor codes and standards associated with technology, poor performance of green buildings, lack of proven alternate energy-efficient technologies, lack of labelling and measurement standards; these are some of the barriers identified which are associated with incompatible technology*." [Participant A].

"For progress in energy efficiency, new and innovative and renewable materials need to be developed which may replace new and conventional materials. Lack of success of new

and greener materials, non-availability of green and energy-efficient materials are some of the barriers which are an important part of technological barriers." [Participant F].

4.1.4 Poor Financial Support

The challenge to achieving energy efficiency and, broadly, sustainability is accelerated among the smaller service providers because of financial constraints. A willingness to provide financial support to providers could help to boost their energy efficiency. This was noted when analysing the contributions of some participants.

According to Participant B, "*a lack of financial means is an important factor impeding the energy efficiency programmes of service providers in Nigeria*."

"...well some of the problems we are facing are lack of efficient funds, lack of capital for energy efficiency projects, lack of access to capital for carrying out energy efficiency projects, limited availability of resources and inappropriate infrastructural support; these are some of the factors contributing to the scarcity of financial means" [Part F].

5. DISCUSSIONS

One of the major barriers to the implementation of sustainable and efficient energy practice in residential buildings in Nigeria is the lack of leadership commitment from both government and private sector organisations. It is shown in Table 1 that more than 70% of respondents are of the view that leadership commitment to driving policies and programmes on sustainable energy efficiency is extremely low. This is contrary to the current commitment of the Nigerian Government in achieving sustainable development goals. UN Sustainable Development Goals. Judging from responses from Participants A and G, an unclear direction and coordination strategy on energy saving from the leadership of most organisations indicates that efforts of individual staff override any organisational drive to facilitate an energy efficiency process. This sentiment is also shared by Participants B and C, as analysed above, where they reiterated that the implementation of energy efficiency in most organisations in Nigeria is left for individuals rather than being driven from the Chief Executives, without a clear direction for the organisations on implementation of energy policies. Additionally, this factor also showcases the slow pace of implementing the UN SDGs by Nigeria. In the same vein, Participant E stated that there is a lack of incentives to promote and encourage energy efficiency amongst communities or dwellings and this is a barrier to achieving energy efficiency in residential buildings. This has a connection to the poor commitment by the leadership of organisations to consider the use of incentives as an option to facilitate the implantation of energy efficiency. This low leadership commitment can partly be attributed to the weak implementation framework of most government policies as well as poor accountability. This low leadership commitment is contrary to the situation in the UK where the government has criteria for investment appraisal to ensure regulating agencies have benchmarks to meet to obtain effective implementation of government policies on energy efficiency (Rosenow *et al.,* 2018). Similarly, the collective regional efforts by EU on implementing the UN SDGs, which also aligns with achieving sustainable energy saving practice, also have some impact in influencing leadership commitment as outlined in the current EU efforts in implementing energy policies (Tromop *et al.,* 2015). Hence, the behaviour of the leadership of organisations towards sustainable energy efficiency in residential buildings could be improved by a realistic implementation framework, attitudinal change and accountability.

Another major challenge identified in energy-saving behaviour is a lack of sufficient information available to households and poor training of staff within both government and private organisations. While over 60% of the participants are of the view that consumers and householder owners lack the knowledge and information on the appropriate products or measures to take for efficient use of energy in households, less than 40% are neutral or have divergent views. For instance, Participants F and G corroborate views on issues of poor knowledge, lack of information, false or misinformation as barriers to achieving energy efficiency in residential buildings. From discussion with the stakeholders, it was noted that poor information on new energy efficient technology, products and methods is a major barrier. Due to a lack of sufficient information on more sustainable energy approaches, most households rely on the use of a power generating set as an alternative to mainstream energy supply with a monthly minimum approximate cost of US$250 (Osae-Brown and Olurounbi, 2019). This cost has a significant impact and is unrealistic to sustain for households that rely on salaries of less than US$200 per month. The literature has also shown that relevant information and guidance on available products would ease the implementation of sustainable energy policies and activities (Palm and Reindl, 2018). It was highlighted by Participants B and D that a lack of critical skills or education on energy efficiency and insufficient awareness are also constraints, restricting households from achieving sustainable energy savings. These lack of critical skills and education also have direct implications on the cost of energy consumption in residential buildings as compared to when there is awareness of alternative and more cost-effective approaches. Additionally, poor training of staff in energy companies or government regulators to facilitate the implementation of energy efficient policies would prevent the attainment of the desired goals of achieving an energy efficiency and saving culture in residential buildings. It was also noted that the slow adoption of new innovative technology is a barrier to achieving sustainable energy efficient households. In the UK, for instance, the use of more innovative energy-efficient building materials for recent buildings is mandatory in line with government policies to achieve the UN SDGs (Department for Energy and Climate Change, 2012). However, this is not the case in Nigeria as the introduction of new products to facilitate energy-efficient practice is uncoordinated and is on an individual or personal basis rather than by deliberate government efforts; this is a huge barrier to attaining energy efficiency in residential homes in Nigeria (as well as in achieving the UN SDGs).

During the data collection and interview sessions with the participants within the research, it was also identified that poor financial support has a significant impact on achieving sustainable energy-savings in residential buildings. In Nigeria, poor funding for energy-efficient projects and the non-availability of requisite resources to develop the required infrastructure are also key setbacks in this regard (amongst other financial challenges). This is made worse in the current financial situation, with Nigeria going into recession in 2020, the negative financial impact of COVID-19 and huge funds being channelled to address the present security challenges. It was also noted within the literature that the extreme fluctuation in the fuel price, which is the main source of revenue for Nigeria, also reduces the resources allocated to the energy sector (Geissler *et al.,* 2018). all these reasons, amongst other reasons, were reiterated by the stakeholders, particularly by the government regulators in the energy sector, during the interview sessions. To assist in dealing with the situation, participants suggested that government subsidies for energy in Nigeria would reduce the cost paid by households. However, this approach is currently not sustainable because of the huge financial burden faced by the economy and a lack of funds to provide the requisite infrastructure for a more sustainable energy saving culture. Another major area of concern is the inadequate use of technology or energy efficient equipment, and poor standards of equipment and standardization processes. It was noted by the participants that the high cost of more reliable energy efficient equipment is also an impediment to achieving sustainable energy savings. Furthermore, some participants reflected on certain other barriers including a poor regulatory framework to ensure high quality equipment is imported into the country, the risk associated with new technology, and the absence of innovative technology within the country. Thus, the high cost could prevent low-income earners from purchasing more reliable energy efficient equipment, while poor standards and design could erode trust in such technology thereby instigating a barrier to attaining a more sustainable energy saving culture amongst residential households.

The discussions above highlight the obstacles to energy savings in residential buildings from the stakeholders' perspectives. The study elicited some major findings. One of the major findings of the research is the existential gap in top management commitment to ensure full implementation of existing policies or national strategies on the sustainable efficiency of households. This issue could have a direct effect on Nigeria's ability to meet some of its commitments to the UN SDGs. Additionally, poor knowledge of new sustainable energy saving products, misinformation, poor training and education, and a lack awareness are also huge impediments in this regard. Hence, a holistic framework on continuous awareness and on an extensive capacity building programme in sustainable energy savings' culture and equipment could make a significant impact in mitigating or reducing the future impact of such obstacles. Lastly, the research also revealed that government subsidies on renewable energy, government checks and the standardization of energy-efficient appliances imported into the country can improve the trust towards sustainable choices and promote efficient energy use. While this study highlights initial results obtained from research on energy efficiency in Nigeria, more data generation and analysis are required to make realistic conclusions on the subject matter.

6. CONCLUSIONS

The purpose of the current study was to determine different obstacles to, and pathways for, adopting energy efficiency and saving behaviour in Nigerian residential buildings. This study has identified several barriers to energy saving. The most significant findings to emerge from this study was that continuous awareness of energy-saving behavioural change, supportive leadership commitment and government subsidies on renewable energy crucial to achieving sustainable energy saving practice in Nigerian residential buildings. Furthermore, government checks and the standardization of energy-efficient appliances imported into the country can improve trust regarding sustainability and promote efficient energy use. Other results identified include information sharing and training, the use of technologies, financial support, and other organisational factors; these factors can facilitate energy efficiency policies' implementation and could also reduce the barriers affecting implementation. These findings complement those of earlier works in the field. Additionally, the outcome from this work is expected to further give a better understanding of energy use behaviour and to inform future energy policies and interventions relating to household energy saving.

The key contribution of this study has been to confirm the obstacles to energy saving in residential buildings. This will contribute to the existing knowledge on efficient energy consumption and on sustainable growth ambitions by providing a deeper insight from energy professionals. While the outcome of this exploratory research may offer the true state of a specific situation, but it may not be suitable for statistical generalisability. The broader impacts of energy efficiency and saving behaviour have not been assessed. As a result, the extent to which energy efficiency or energy-saving behaviour could enhance economic, environmental, and social sustainable goals is not well understood. As such, there will be a further survey examination to enable theory testing. The survey research will be undertaken to corroborate the findings of the interview analysis.

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TOWARDS LONG-TERM SUSTAINABLE PERFORMANCE OF POST-DISASTER HOUSING RECONSTRUCTION: SECOND LIFE FOR TEMPORARY HOUSING

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ABSTRACT

The pressing human needs caused due to post-disaster effects may force donors to provide a roof above the heads of the displaced communities than focusing on fulfilling the references of a 'home,' which is a step toward restoring a certain sense of stability embedded with social, cultural, economic, and other interactions. And several displaced communities around the world continue to live in their temporary housing on a long-term basis. Therefore, this study aimed at investigating methods to consider a second life for the post-disaster temporary housing which may ensure long-term sustainable performance. A comprehensive literature survey has been carried out in attaining the aim. Many studies have found that the rapid post-disaster housing re-construction strategies through universal working standards have become unsustainable and culturally unacceptable in the long term. Furthermore, in various instances, the real-life post-disaster temporary housing has been simply dismantled or abandoned due to the end of usage and cultural incompatibility, without giving any concern for future disasters. This could be minimised by transforming the donor initiated temporary housing into a permanent basis. To achieve this, scholars have identified the need of considering the socio-cultural and related physical needs through active involvement of affected communities. Therefore, to achieve prolonged use of temporary housing, the findings suggest that the social and cultural needs of communities and associated physical transformations need to be considered by the donors. The findings serve as a way forward to explore a transformational space that can accommodate social and physical transformations in post-disaster housing reconstruction.

Keywords: *Post-disaster housing; Sheltering; Sustainability; Temporary housing; Transformation.*

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1. INTRODUCTION

A disaster is often described as a potential disruption to an individual's or society's quality of life that results in prevalent human, material, environmental and economic disruptions, and effects (United Nations Office for Disaster Risk Reduction [UNISDR], 2010). There will be substantial casualties in the event of a disaster, such as partial loss of physical infrastructure, interruption of essential facilities, and harm to means of livelihoods in the affected areas. Of the many called tragic results, household damage is one of the most noticeable outcomes of a disaster, resulting in many homeless individuals (Biswas, 2019).

As a result, reconstruction is a highly valued task following any catastrophe, and it occurs in unstable environments, often in remote areas, and under severe time constraints (Wu and Lindell, 2004). The reconstruction mechanism is mostly concerned with two aspects: the construction of housing units and the restoration or construction of facilities. In most post-disaster reconstructions, housing schemes take precedence over other projects (Karunasena and Rameezdeen, 2010). As it is agreed that to restore the livelihoods of the displaced peoples, the reconstruction of the fundamental unit of the community (i.e., family) should begin as soon as possible by providing a home (United Nations Disaster Relief Organization [UNDRO], 1982). A house is a communal space that provides necessities for domestic life, convenience, security, and safety. During a tragedy, the need for housing must be addressed quickly because homelessness is anything more than a structural hardship; it is also a loss of reputation, personality, and safety (Barakat, 2003). Therefore, temporary housing is essential in recovering stage after a disaster, allowing the survivors to take back to their regular activities such as employing, schooling, housekeeping, socialising, and many more with a common standard of living (Arslan and Cosgun, 2008; Johnson, 2007). Temporary housing refers to physical structures that the people inhabit after a disaster or as a part of the post-disaster reconstruction programme, which provides shelter for the people, who affected by a disaster until they are relocated to a permanent house (Johnson, 2007). However, previous studies have scrutinised the long-term feasibility of temporary housing scenarios considering their sustainability and the cultural insensitivity of the occupants (Yau *et al*., 2014; Felix *et al*., 2013). Hence, Biswas (2019), Arslan (2007) and Johnson (2007) have presented the second life scenario under five possibilities (refer section 4.2) for temporary housing structures to gain better value for the money invested by the donors. Felix *et al*. (2013) identified two main categories in temporary housing namely, ready-made units and kit suppliers. The ready-made units are constructed in factories and carried to the site or parts of the units are transported and assembled at the site. Due to the transportation difficulties, small elements are produced and assembled at the site following the 'kit concept'.

In most cases, the temporary housing is provided through a top-down approach by the government and other donor agencies, where the housing units are mostly being mass-produced upon a common standard without being tailored to any specific needs of a family upon their socio-cultural, economic, and psychological upbringing before any such disaster. Consequently, Shelter Center (2012) described the essential quality of temporary housing structures to withstand physical and social transformations, which influenced by the operational and physical aspects as well as social and psychological aspects of the people implemented by occupants for a smooth landing to their normal daily routine. Therefore, this paper aims to identify the strategies to be followed by the donors (i.e., government or disaster-related organisations) with regards to the long-term use of post-disaster temporary housing through a physical and social transformation in achieving the sincere desire for post-disaster reconstruction.

This paper is structured in six sections, the introduction followed by the methodology adopted in this study are presented first. Then, an overview of post-disaster housing reconstruction and the problems of sheltering are discussed. Thereafter, attention is drawn to temporary housing second life and strategies for transition of temporary housing in terms of social and physical transformations. Finally, the conclusions have been drawn with the way forward in this study.

2. METHODOLOGY

This paper expects to answer the research problem of "why the donors must consider the long-term use of temporary housing structures to withstand against the long-lasted claims on unsustainability and cultural inadequacy of traditional post-disaster housing reconstruction" through a qualitative research approach. The qualitative research approach has been appraised for its ability to achieve an in-depth analysis of new concepts. Hence, the literature review for this study was developed on the themes of post-disaster housing, sheltering, temporary housing, problems of temporary housing and sheltering, and transformation. Accordingly, this research critically analyses the secondary data obtained through existing case studies and literature sources on post-disaster temporary housing construction. The focus of the study was further narrowed down to investigate the affected communities from natural hazards in a global context to identify any barriers in existing post-disaster housing reconstruction and explore mechanisms suggested by scholars to withstand those in future disaster incidents. Thereby, this study would bring up the mechanisms to be followed by the donors to achieve a second-life instance for temporary housing structures in terms of social and physical transformations.

3. POST-DISASTER HOUSING RECONSTRUCTION

Natural hazards have frequently caused extreme impacts on the built environment, which can change the morphology of the surrounding and individual spaces of people that are hit by such disasters (Wijegunarathna *et al*., 2018). The short-term effects of disaster rehabilitation and reconstruction are getting more attention, which includes providing temporary housing, assisting in rebuilding the original house and permanent relocation to special schemes designed for reconstruction (Rahmayati, 2016). Previous studies signify the failures of many reconstruction projects done by the government and other donor funding agencies without the consideration of the requirements of the relocatees (Danquah *et al.*, 2015; Rahmayati, 2016). Post-disaster relocation may have negative impacts on the livelihood of the survivors including, disruptions to daily habits, interruptions to socio-cultural networks, and conflicts with host communities in the relocated area (Wijegunarathna *et al*., 2018). Hence, the relocation schemes ought to ensure that the survivors are satisfied with the long-term performance of post-disaster housing. Thus, the recovery actors along with the government and non-government organisations, policymakers, built environment professionals, builders and financial and technical donors shall recognise and understand the long-time outcomes of post-disaster reconstruction.

Post-disaster housing reconstruction programmes have focused on addressing urgent needs by adopting immediate actions, thereby, delay in aiding for housing puts the survivors under mental stress and leads to community displacement (Varas and Boano, 2013). In this manner, permanent housing is considered the final stage and is typically performed by organisations, which includes planners and builders. However, the post-disaster housing reconstruction has a critical influence on the affected community in terms of social and cultural aspects, thereby, the socio-cultural processes of recovery at large cannot be ignored from the provisions of sheltering and housing in the post-disaster stage (Rahmayati, 2016).

3.1 SHELTERING VS HOUSING

For the people, who suffered from natural hazards, and must mobilise from their homes, remobilise in a long-term shelter is an essential part of the recovery process (Bolin and Stanford, 1991). Further, Quarantelli (1995) made a distinction between sheltering and housing. Sheltering refers to the asylum for people immediately afterwards any disaster suspending their normal living process while housing denotes the return to household responsibilities and daily routine. Based on this distinction, four stages of different forms of disaster-related sheltering and housing are briefly described below.

- **Emergency shelter:** Emergency sheltering is a place, where the survivors will stay for a brief period before a hazard, during the height of the emergency, or immediately after the impact. This can be in the house of a friend or relative, or a public shelter (Peacock *et al.*, 2017). The period is expected to be short, depending on the severity of the hazard and the community affected by the disaster. However, it is around two weeks or subjected for extensions up to eight weeks depending on the case. This emergency sheltering has s spontaneous nature and focused on locational or regional convenience and promptness of the need (Alexander, 2002).
- **Temporary shelter:** Temporary sheltering is also thought to be short-term, nonetheless, there is no pre-defined period for what short-term entails as express by Peacock *et al*. (2017). Further to the authors, the survivors can stay in temporary shelters while waiting for a safe return to their permanent residences. Thus, the government and other donors shall provide them with daily necessities including food, water, sanitation, security, and other requirements, thereby, requires more preparedness than emergency shelters.
- **Temporary housing:** Temporary housing is a place, where the survivors can be settled temporarily for a planned period range from six months to three years. The survivors can return to their normal routine while occupying temporary housing, or they can wait until they relocate for permanent housing, either to their homes, which they lived in pre-disaster or an alternative permanent house (Tierney *et al*., 2001).
- **Permanent housing:** In this stage, the affected people will return to their rebuilt house, or they will resettle in a new build house permanently when they are unable to return or refused to return to their pre-disaster home (Bolin, 1994). According to Peacock *et al.* (2017), certain other problems such as crime, violence and other social influences coming from the clusters or congested quarters they are living in may impact moving to permanent housing.

3.2 PROBLEMS WITH SHELTERING

Provisions of sheltering and housing for the community affected by a disaster is a complex process subject to many challenges (Quarantelli, 1995). Bolin and Stanford (1991) present cultural, environmental, political, and economic constraints relating to the behaviour of survivors on the choice of temporary provisions. These include the availability of non-hazardous locations to build temporary shelters, modifications for the uses in post-disaster lands, disaster risk reduction programmes, housing and other related aid programmes, socio-cultural patterns on housing, and political conflicts on fostering specific class interests in the reconstruction process.

After a disaster or soon after the immediate disaster threat has gone, the affected community will leave the emergency shelters to resume their daily routine, unless the disaster caused severe damage to their houses. When their houses are inhabitable and impossible to return, the emergency sheltering may need a transition to temporary sheltering. Yet, the intention of temporary sheltering is not to replace their original pre-disaster houses (Bolin, 1994). Providing emergency shelters or temporary shelters is not a consistent social approach, which can be subjected to the varying needs of survivors over time. For instance, those with higher incomes will stay at hotels or motels, while the others will stay in tents or other temporary shelters with their families (Morrow, 1997). Hence, the financial capacity, ability of travelling and the absence of relatives outside the hazardous area will critically affect the choice of temporary shelters. In most cases, the survivors are reluctant to stay in temporary shelters such as tents, however, ended up there, since no other options available (Peacock *et al*., 2017). The reason for this reluctance is the temporary shelters are not planned well in advance to fulfil the needs of the community who were displaced. Those were adaptive responses with little or no planning with the focus on having many people, who need temporary sheltering after a disaster. Hence, the process of transition from sheltering to housing will vary depending on the time and resources available irrespective of the needs of the people.

4. TEMPORARY HOUSING

Following the definition of Quarantelli (1995), it is inevitable to ignore the importance of temporary housing to recuperate from disasters and let the people resume their routine (Arslan and Cosgun, 2008; Johnson, 2007). The people are indeed fortified in shelters from the consequences of disasters, but it is almost impossible to continue their daily life within a shelter, and so they are unlikely to stay longer in shelters. Considering the external factors that may deteriorate the temporary shelters, it is particularly important to think about more durable and resistant solutions to minimise the jeopardy of people, while it brings much value to the concept of providing temporary housing (Steinberg, 2007). Further, reconstruction of houses takes ample time and to bridge this gap, temporary housing can be an essential alternative option (Johnson *et al*., 2010). Moreover, Felix et *al.* (2013) identified the criticality of temporary housing to provide a comfort level for the survivors comprising the common standard of living soon after a disaster. Temporary house's need is expected to end when permanent housing is provided. In contrast, Bris and Bendito (2019) elaborated on many instances in the global context where temporary houses have been used as permanent solutions by communities by improving the high-quality standard of living. Nevertheless, Hooper (2020) found out that the desire of affected communities to continue their life in temporary houses (in this study, communities in Montserrat island of UK have spent two decades in temporary housing following hurricanes) was majorly affected by the low cost to upgrade the existing structure, compatibility of the location with their daily needs and the community spirit as faced to the same disaster.

4.1 PROBLEMS WITH TEMPORARY HOUSING

Notwithstanding the success of temporary housing in letting the survivors resume their normal life aftermath disasters, criticism based on sustainability and cultural adequacies hits the temporary housing immensely and pervert the dignity of its success in a controversial manner (Barakat, 2003; Hadafi and Fallahi, 2010; Johnson, 2007, 2008; UNDRO, 1982).

4.1.1 Sustainability Problems

Post-disaster temporary housing solutions have sustainability problems in two ways: i.e.

- Unsustainable in terms of costs and;
- Unsustainable in terms of environmental issues.

Based on the findings of UNDRO (1982), the permanent housing unit is comparably cheaper than a temporary housing unit, Hadafi and Fallahi (2010) significantly portrayed that temporary housing units are as three times expensive than a permeant housing unit. In addition to the unit cost of temporary housing, infrastructural components such as roads, water, sewerage, electricity, etc. also need to be accounted for in the expenses to function a temporary housing. Thus, the temporary housing seems to be expensive substantiate the above fact, and it is not a potential solution because of its life span considering the amount of investment for each unit (Johnson, 2008). Even though most of the times considering the durability, comfortability and ephemeral conditions, units are made up for resisting longer-time rather than the amount they required. Therefore, even after the intended period of usage, units are still usable, but the immense sizes of structures hinder the usage. Often the units are simply dismantled due to the lack of a plan for their usage in future (Felix *et al.*, 2013).

In addition to these facts, the places occupied by the units become more contaminated with dirt and wastages. It is especially important to remove all the infrastructure, foundations, debris, garbage, etc., due to occupancy of such temporary units and ensure the place be as it was earlier (Biswas, 2019; Yau *et al*., 2014). Yet sometimes it is not what happens, causing great environmental consequences. Consequently, temporary housing becomes environmentally unsustainable because of its requirements of resources and scarcity of plans after its intended usage which creates huge problems in terms of economy and environment.

4.1.2 Cultural Inadequacy Problems

The temporary housing units are intended to be utilised all over the world (Barakat, 2003). Although, this concept is not feasible as it often ignores the diversities and requirements of various users from different areas consisting of different variations in climate, house forms and family size, etc. (Gulahane and Gokhale, 2012), including environments that may be culturally alien (Gulahane and Gokhale, 2012). Studies by Caia *et al*. (2010) portray the importance of shape and material to match the prototype of a home. Further, Caia *et al*. (2010) revealed the psychological stress that may create in temporary housing unit users due to the incompatibility of a unit with their pre-disaster status. Thus, the type of housing unit determines the psychological well-being of the users.

Many studies have suggested alternative strategies and recommendations to overcome the issues in temporary housings (Biswas, 2019; Yau *et al*., 2014; Felix *et al*., 2013; Arslan, 2007; Johnson, 2007). Among those Arslan (2007), Johnson (2007) and Biswas (2019) have insisted that principles such as community participation, usage of local resources and the development of solutions to reuse units, to find more sustainable and culturally adequate solutions concerning temporary housing.

Though Quarantelli's (1995) distinction brought four stages in post-disaster housing reconstruction, this study has continued its focus only on the temporary or permanent housing due to the identified problems (refer section 4.1) associated with the first two stages; emergency and temporary sheltering. Accordingly, it has been established that the longer period of occupancy in the first two stages takes, it would be impossible to achieve the desired outcome of successful rehabilitation where the focus of the donors would be vested upon the final two stages. On the other hand, either governments or donors worldwide cannot provide permanent housing for affected communities within a shorter period where the top authorities should think of an alternative solution for the provided temporary housing to be evolved itself to permanent housing (Johnson, 2007). Further, to achieve a better value of money from temporary housing, researchers like Biswas (2019), Yau *et al*. (2014) and Felix *et al*. (2013) have identified recycling and reusing instances for temporary housing to overcome identified problems in section 4.1.

4.2 TEMPORARY HOUSING 'SECOND LIFE'

Due to the concerns raised, it is vital to explore the most sustainable solutions for temporary housing units. Accordingly, this study reflects a 'second life' phase for temporary housing units which can be interpreted as becoming beneficial even after completing their expected lifetime or fulfilling intended purpose. Even though temporary housing is an important stage in achieving the true aspects of post-disaster reconstruction, the overall impact of these structures is proven to be more negative on their occupants and surrounding ecosystem. Accordingly, based on the studies of Biswas (2019), Yau *et al*. (2014) and Johnson (2007), five possibilities for temporary housing can be identified as such 'second life' contexts.

- The occupants can use the same temporary housing units in the long term. As the temporary housing schemes are not mostly provided up to the quality standard of living, occupants may face social and financial stigma in the long-term to fulfil their day-to-day activities as before facing the disaster. This might result in social dysfunctions, illegal occupancy, and high crime rates (theft, burglary, etc.) in the housing scheme and neighbourhood.
- The donors can dismantle the housing units after permanent housings are being provided and keep the units securely stored in use of future disasters. However, as such, the government need to bear the costs of dismantling, transporting, storing and reassembling.
- The donors can sell the used units, or in parts to recover the initial investment on temporary houses. However, considering the depreciation rate of the used housing elements, it is difficult to recover the initial investment.
- The used structures can be demolished and donate their parts for occupants in building their own permanent houses through active community involvement (bottom-up approach in post-disaster housing reconstruction). However, due to the

final conditions of housing units after long-term use, the building components often have little value in return.

- The existing structures can be reused by the occupants for the same purpose or a different purpose after a certain modification. Arslan (2007) states that units should be able to be re-used after the end of usage while gaining the recognition of a permanent structure.

However, the heart of above identified possibilities is the need to address transitional strategies that take into the account the cultural and social needs of the affected communities.

5. TRANSITION OF TEMPORARY HOUSES: STRATEGIES

For families socially and mentally wounded by disasters, finding a long-term solution or a permanent home might take years owing to a variety of factors such as the financial burden, complexity of wreckage clearance, land distribution, and a shortage of available land or resources, amongst many others. As a result, modest temporary housing would be the only accessible location to dwell for some vulnerable groups during the rehabilitation process (IFRC, 2011, p.4). As a result, they change their temporary housing. These changes might enhance the performance of the transitional home, but they can also re-create concerns caused by a lack of oversight and technical understanding (Wagemann, 2015).

However, to facilitate this process, the top-level of the decision-makers (donor organisations or disaster-related government organisations) are required to foresee such occasions during the feasibility stage of temporary housing designs. Therefore, studies have identified two main strategies such as "planning ahead" and "design beyond the unit" for the designers or decision-makers to consider in developing the designs or the establishment of temporary housing sites (Biswas, 2019). In the process of designing temporary housing units, designers are required to anticipate any prospects of the structure to be used for various purposes, which is called '**planning ahead**'. This mechanism would inevitably provide many opportunities for the temporary housing unit structure in future after fulfilling their intended usage. It can be designed with great flexibility as much as possible for reuse after the intended purposes. In addition to that, it must give space for users to customise and personalise the units following their whims and fancies (Biswas, 2019). During the disaster periods, these temporary housings are often used for working purposes (Kellett and Tipple, 2000; Lizarralde and Davidson, 2006) thus, the flexibility of such housing is particularly important to acquire different functional requirements at once. As substantiated by the number of authors (UNDRO, 1982; Kellett and Tipple, 2000; Barakat, 2003; Bedoya, 2004; Lizarralde and Davidson, 2006; Arslan and Cosgun, 2008; Sener and Altum, 2009).

'Design beyond the unit' simply refers that the success of a unit is not only determined by its user's needs, cultural issues, and integration of economic and environmental values (Felix *et al.*, 2013). In addition to all these, it is important to establish the location of the unit that can be situated close to people's workplaces, services, and amenities. Further than location, it should provide the opportunity for socialising and the design of public spaces can create community spirit, maintain social ties and it can be an opportunity to develop new relationships. In the meantime, considering the services, it is important to be close to schools, medical centres, community centres, shops, and worshipping places to grant all the conditions for normal life in the temporary settlement (Felix *et al.,* 2013).

However, the government and other donor funders usually failed to fulfil the real housing needs of stricken communities through temporary housing. Hence, the socio-cultural aspects such as cultural living needs, lifestyles, and habits of the people as well as the physical aspects of location, typology, size, and layout design of housing must be considered to re-establish their normal lifestyle in a post-disaster situation (Rahmayati, 2016). The deficiency of accommodating the socio-cultural needs of the affected communities may lead to transformations in the socio-cultural life of the people as well as transformations in physical aspects of temporary housing structures which are identified in subsequent sections.

5.1 SOCIAL TRANSFORMATION

Periods after disasters present the affected communities with considerable short and long-term challenges. In addition to meeting the needs of emergency measures, reconstruction measures have direct and indirect effects on the long-term development path of an affected society (Monteil *et al.,* 2019). Meantime, since disasters are closely related to daily life and development processes, social transformation plays a vital role in sustainable recovery from disasters (Mayer, 2018; Aldrich and Meyer, 2014; Hsueh, 2019). The term social transformation incorporates "the change of existing parameters of a societal system, including technological, economic, political and cultural restructuring." (Bruggen *et al.,* 2020, p.6). However, after a natural hazard, in the process of rehabilitation and reconstruction interventions, it is extremely hard to integrate some of these parameters, significantly due to its ill-suited nature to the norms, values and exact requirements of the victims (Makachia, 2010). Therefore, post-disaster reconstruction actions need to consider the long-term impact of temporary housing, especially their impact on the establishment of social cohesion, which is a key factor for a sustainable recovery in a dynamically changing society. The above-mentioned gap could be bridged with the integration of socio-spatial studies in the housing process (Makachia, 2010). Consequent to these statements, the need to integrate social parameters within the design has evolved. Therefore, the people who are going to be accommodated should be assessed in their own needs and ensure the temporary solutions will be suitable for them without any drawbacks (Gulahane and Gokhale, 2012). It can be said, the design process of such buildings needs to consider the point-of-view of the users rather than from functional and technical approaches along with routine activities and additional symbols (Bedoya, 2004). Therefore, designing post-disaster housing is all about designing the physical structure for social cohesion. In the long term, the second life of temporary housings need to aim at the social transformation which will promote social cohesion and hence encouraging sustainable recovery.

5.2 PHYSICAL TRANSFORMATION

The physical transformation refers to a change in the physical appearance of a house from its original appearance after occupation. This phenomenon is a typical manifestation of the privatisation of public housing (Danquah *et al*., 2015). The human agent is at the heart of the system, with varying functional demands that are the subject of various design strategies. Nevertheless, the formal provider of temporary housing is just as alien to the inhabitants and did not realise their desires, where the inhabitants would not be a part of the system, giving rise to transformations to fulfil their needs (Makachia, 2010).

The study of Wijegunarathna *et al.* (2018) on assessing the physical performance of post-disaster housing projects revealed that the affected communities got minimal satisfaction with the long-term physical performance of their relocation. Out of the physical parameters of housing that was considered in the study, minor satisfactions were received for many aspects including plot area, size of the house and number of rooms available, and provision for alterations. Among these, the provision for alterations found to be the most significant parameter to expand the houses according to various requirements of the occupants. This would make it possible for the survivors to improve their houses that initially offered as per their changing needs. The empirical evidence of previous research (Wijegunarathna *et al.,* 2018; Rahmayati, 2016; Boano and Garcia, 2011) signified that many of the post-disaster housing reconstruction projects have not got the affected communities involved during the planning and design stages, hence, the actual requirements of the people were not appropriately captured. Thereby, those have failed to achieve the long-term sustainable performance of post-disaster housing reconstruction projects. Therefore, the decision-makers at the top level must 'plan ahead' by considering the real needs of the affected communities during the design phase itself through a systematic approach to provide successful temporary housing solutions considering its second life. Hence, the active community involvement in the process of providing long-term sustainable post-disaster housing is found to be a key requirement for future post-disaster housing projects.

6. CONCLUSIONS

Household damage is one of the most significant consequences of disasters. Thus, reconstruction is vital in the recovery process of post-disaster reconstruction. Emergency sheltering and temporary sheltering are the two most immediate and common post-disaster reconstructions given to the affected communities. Nevertheless, these provisions are mostly not up to the standards of the victims' pre-disaster housings. The emergency shelters and temporary shelters are often provided in an alien environment as disaster aftermath. However, the victims need a place to stay safe along with their physical, social, cultural, and other similar requirements, until they shift to their permanent residences. This is where the transition from temporary housing to permanent housing occurs. Even though the temporary housing allows the victims to continue their normal day to day life, studies have found out their unfeasibility in several aspects. The sustainability and cultural inadequacies are the two major criticisms placed on the temporary housing solutions. Post-disaster temporary housings are found to be unsustainable in the long term due to the cost implications and environmental issues. Further, these temporary housings lead to the loss of the victim's symbolic inclusions of a 'house' such as social, cultural, religious, political, economic, environmental, technical, and other interactions. Therefore, these temporary housings become culturally inadequate in prolong nature. Thereby, the victims tend to modify the given temporary houses to fulfil their needs and wants for long term occupation by considering a 'second life' of temporary housing. 'Planning ahead' and 'design beyond the unit' were found as the strategies to facilitate an effective transition for temporary housing second life. In addition, the failure of addressing the socio-cultural needs of the affected communities has led to social and physical transformations in many post-disaster housing reconstruction projects. Hence, the requirement of the people must be appropriately captured during the design feasibility stages to accommodate their needs and create access for transformations for long-term sustainable performance in temporary housing. Therefore, the study findings serve as a way forward to investigate a transformational space in temporary housing units as a third space to accommodate social and physical transformations to achieve long-term sustainable performance.

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USE OF AUGMENTED REALITY FOR EFFICIENT BUILDING MAINTENANCE IN SRI LANKA

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ABSTRACT

With the advent of technological advancements in the field of building maintenance, attempts have been taken to address the issues confronted by building maintenance technicians in the global context. Augmented Reality (AR) is one such concept which combines real environment with virtual content in 3D space that is experimented and proven to be effective in making the building maintenance activities more efficient by eliminating the causes for such difficulties faced by the technicians. In Sri Lanka, there is very limited use of such technologies in building maintenance practices and it is reasonable to mention that use of AR is minimum in this field. A gap is identified as there is no considerable literature exploring applications of Augmented Reality to ease building maintenance activities in Sri Lanka. Therefore, an effort is made to investigate into this area through a qualitative approach by taking a case into study and conducting interviews among technicians followed by an expert interview. The research highlights the use of AR in making the building maintenance practices in terms of data and instruction visualization leading to more efficient and effective outcomes while discussing on the benefits such as making maintenance tasks efficient, cost and time savings and high customer satisfaction as well as possible barriers for implementation of a similar program such as developing a Building Information Model to an existing building, inconvenience in making technicians adopted into a new system in the context of Sri Lanka

Keywords: *Applications of augmented reality; Augmented reality; Efficient building maintenance; Issues.*

1. INTRODUCTION

Augmented reality technology has been adopted in numerous industries such as marketing, medicine, education, entertainment (Billinghurst *et al.*, 2014), tourism, geometry modelling and scene construction, assembly and maintenance (Chatzopoulos *et al.*, 2017). In Sri Lanka, efforts of finding viability of AR application has been made areas such as education, Medicine, Urban planning and Marketing (Adikari *et al.*, 2020; Chandike, 2016; Chandrasekara, 2015). According to Wang *et al.* (2013), Architecture/ design and construction is one prominent field that has caught considerable attention in research relating Augmented Reality and it is the idea of the researchers that integration of Augmented Reality with Facilities Management is still at an elementary level but it has great potential for evolvment. Especially in the Sri Lankan Context, there are no

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considerable studies conducted to explore application of AR in the field of facilities management and building maintenance except for few that are related to construction field (Rajaratnam *et al.*, 2021), but not specifically addressing the maintenance phase of a building. Therefore, with this research it is intended to explore the applications of AR for efficiency in the maintenance phase of a building in Sri Lanka. Proceeding with this aim, one of the main objectives is to gain a wide perspective on features of AR technology and its application on building maintenance through a literature survey. Followed by this objective, it is also intended to identify the issues that are currently faced by the maintenance technicians in Sri Lanka when conducting their activities how AR can be used as a solution to address and remedy these identified issues with the intention of making the maintenance activities more efficient.

2. LITERATURE REVIEW

2.1 AUGMENTED REALITY

Many authors adopt Azuma's definition of Augmented Reality which provides a more descriptive and deeper explanation given by identifying 3 major requirements of the technology (Adikari, *et al.*, 2020; Chen, *et al.*, 2020; Katiyar, *et al.*, 2015).

- Combines real and virtual objects in the real environment
- Interactive in real time and
- Registered in 3 Dimensions

Augmented Reality enables simultaneous interactions between virtual objects such as text, images, 3D models, music, and video (Chen *et al.*, 2020) and real objects in the real time, so that any problem or issue can be analysed efficiently with the help of these virtual and real objects (Li *et al.*, 2017). This way, the two types of objects blend potently with each other (Chen *et al.*, 2020) enhancing the sense of reality through integration of virtual and real objects in real time (Alkhamisi and Monowar, 2013). Another interpretation for Augmented Reality can be derived from the concept of mixed Reality through introduction of "virtuality continuum" which demonstrates a mixture of classes of objects in a display situation (Milgram *et al.*, 1994). As illustrated in Figure 1, this model discusses two ends; Real environment which is visible to the naked eye without any electronic display and Virtual Environment which fully comprises of virtual objects while the Augmented Reality is considered one that is in the intermediate state between the two ends. Nevertheless, the Augmented Reality interface does not occupy a particular point as tend to move along the continuum as per the extent of virtual cues added in order to enhance the user experience (Billinghurst *et al.*, 2014).

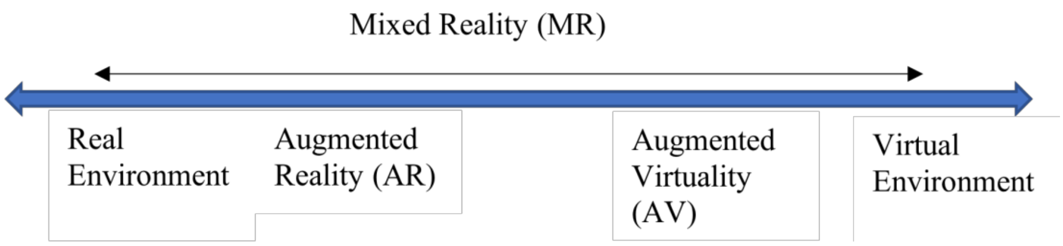

Figure 1: Virtuality continuum (Source: Milgram et al., 1994)

2.2 APPLICATIONS OF AUGMENTED REALITY IN BUILDING MAINTENANCE

2.2.1 Information Visualization

Architecture, engineering, construction and facilities management usually involves a lot of information (Liu and Seipel, 2018), and as facilities managers, it is required to relate the physical objects to this information database (Gheisari *et al.*, 2014). By incorporating Augmented Reality and Information needed for maintenance activities, a framework was introduced after a thorough study of the industrial challenges faced (Amo *et al.*, 2018). It focusses on diagnosis, repair and analysis tasks and defines that information systems and maintenance environments connected to the activities as shown in the figure. Accordingly, it uses the sensor data and creates 3D models helping the technician to correctly diagnose the issue. For repairing, 3D animated Real Environment Augmented Reality (AR) instructions can be given for the repair task identified and furthermore, the captured data in previous processes can be used for further improvement. It is also argued that real time data are essential for making prompt decision and diagnosing problems correctly (Natephra and Motamedi, 2019) and has been remedied using an Internet of Things (IoT) platform with sensors incorporating with Augmented Reality. For instance, an energy data visualization system has been developed which provides the user with energy parameters such as consumption, voltage, current of different appliances (Alonso-Rosa *et al.*, 2020). With the help of IoT sensors, cloud computing and Augmented Reality, this system has shown positive result in terms of maintenance personnel's habits and usability perception. Augmented Reality also enables visualization of installations and facilities such as power lines and plumbing that provides better experience for the user (Liu and Seipel, 2018).

2.2.2 Training and Skill Development

In Augmented Reality Training, one of the major advantages is its ability to allow the worker to interact with real and virtual objects simultaneously with the required information and guidance in virtual form (Di Cecca *et al.*, 2016; Ferrise *et al.*, 2013; Schwald and Laval, 2003; Webel *et al.*, 2013). It displays information such as technical description on task components, task progress, and critical information (Gavish *et al.*, 2011), instructions and location based information directly over real objects (Webel *et al.*, 2013). Overlaying of such virtual information on real environment helps to reduce cascading of errors by eliminating the reliance on erroneous landmarks that can be results of the previous step and has proved to reduce error rate (Tang *et al.*, 2003).In addition the above, technician training by Augmented Reality means has other advantages such as technician's attention on cautions and warnings and improvement of technician's ability to discriminate different operational conditions (Di Cecca *et al.*, 2016). Also, Tang *et al.* (2003) point out that overlaying of information reduces the time taken for searching manuals, thus boosts the efficiency of the training process.

3. RESEARCH METHODOLOGY

A qualitative approach is selected on the premise that the aim of this research is to explore the viability of Augmented Reality for efficient building maintenance in Sri Lanka and it highly involves questions starting with "how" and "why" and it is quite hard to scale it with a numerical value. As the research method, case study stands out as a viable method for this particular research as it is a powerful tool to answer "how" and "why" questions in depth in a holistic manner (Ebneyamini and Moghadam, 2018). According to Yin

(2003), a case study may comprise of a single case or multiple cases and therefore, based on the phenomenon, the writer should select the most appropriate number of cases for the study (Gustafsson, 2017). On this basis, since making a project proposal presenting a solution for the identified issues using AR was an objective of the major research, selecting a single case seemed more practical. Therefore, a case is seleced on the criterion on whether or not the building has in house maintenance program, the unit of analysis chosen is the issues or causes for delays faced by maintenance technicians in the selected building . Online interviews are used to collect data related to the issues currently faced from maintenance technicians as they are te front liners in maintenance activities of a building and expert interviews with 2 professionals in the field of providing IoT based solutions for building management is later conducted in order to find solutions to these issues with the help of Augmented Reality. The method that is used to analyse data is content analysis.

4. ANALYSIS AND DISCUSSION

4.1 ANALYSIS OF DATA COLLECTED FROM THE INTERVIEWS WITH THE TECHNICIANS

The collected data is analyzed under 5 main categories in which data was collected and the issues faced by maintenance technicians were identified.

4.1.1 Issues Related to Comprehension of the Instructions Received

According to the answers received, it was mentioned that the mean of receiving instructions to perform tasks was in verbal content. Usually, a brief meeting is taken every morning explaining the technicians regarding the activities that are scheduled and instructions are given during this time. Other than that, any other activity that requires immediate attention are communicated to the technicians through a mobile phone call which is also carried out in a verbal manner. Regarding the clarity of the instructions received, half of the respondents had no issues heeding the instructions while the rest faced issues understanding the instructions given by the executives and managers.

Especially, those technicians with less experience and knowledge would often get confused when a task is assigned only with words. It would require extra inputs and effort to convince them the intention of the task and the required steps to be followed in the process. It seems that the instructions in verbal form has a tendency to create difficulties in heeding the gist of what is being said to certain technicians making the tasks inefficient in the long run.

The first issue identified is in regard to technicians comprehending the instructions received by them when tasks are assigned to them. This showed some deviation from the issues highlighted in literature findings. “Less experienced” technicians with experience levels “1-5 years” as well as comparatively experienced technicians with “5-10 years” experience answered that they faced confusions with verbal instructions. The response they gave regarding using animation-based instructions seems to pave the way for integration of augmented reality.

4.1.2 Issues Related to Accessing Standard Operating Procedures, Instruction Manuals and Similar Media

The responses revealed that the technicians are using these documents considerably but, there are no SOP/instruction manuals and other similar media in adequate level. When inquired about the location and accessibility of these documents, a questionable scenario was arisen as 50% of them responded saying that these documents are not accessible while they were accessible to the rest. It was asked on their preference to use animation-based instructions instead of text-oriented media and all of them extended their preference over this.

It is evident that half of the population of technicians are unaware on the availability of SOP and other similar media that are useful in executing tasks that are considerably alien to them that are out of the routine tasks. The accessibility to such media seems to be an issue prevailing in the facility. Instead of these text-based instructions, the technicians were highly willing to use some type of animated instructions overlaying the work carrying out.

4.1.3 Issues Related to Building Inspection

The answers given to the questionnaire showed that all the technicians are involved with the inspection activities of the building and they face issues in accessing the building elements from time to time. It was even mentioned that the building service they face accessibility issues the most is Heating Ventilation and Air Conditioning system while electrical system and elevators and escalators rank the second. In addition to accessibility issues, they also face safety concerns when performing these inspection activities.

The results showed availability of inconveniences when performing building inspections accessing the building elements subjected to inspection. The reason for that could be due to heights, hindrances from other elements or safety concerns. Due to this reason, the technicians are more likely not to perform the tasks up to required standards or quality that can cause greater loses in the long run.

The third issue focusses on the accessibility and safety concerns during inspection activities, which was responded by technicians stating they "sometimes" face issues when inspecting building elements in terms of accessing, safety and various other aspects. According to the responses received, the main building services related to which these issues arise are Heating Ventilation and Air Conditioning system, Electrical system and elevators and escalators.

4.1.4 Issues Related to Data Retrieval

The data collected showed that they are making use of history of maintenance tasks related to each asset and the most common way of retrieving these documents was asking from the supervisor while they also refer to the maintenance records by themselves if possible. It was even revealed that sometimes the tasks get delayed because of the unavailability of maintenance records and uncertainties of the previous maintenance activities done to certain assets.

The common method of getting history data which is coordinating with supervisor that seems to take considerable amount of time retrieving the required data that in turn makes the activities inefficient. The technicians were prone to idling that leads to low productivity during this data retrieval process. It also appears to rely on human activity and therefore possibility of occurrence of errors is also high. The other method of getting required data is the accessing them by themselves that incur considerable time as they often need to make several trips to find the desired log sheets and other documents that in result causes some delays performing tasks.

The final issue that was prevalent among the technicians of the facility is in relation to retrieval of the maintenance history data. It was the response of all the technicians that they "ask from the supervisor" for any information that they require. It was highlighted by them that "sometimes" their tasks get delayed due to lack of information that are essential for the activity. It is straightforward that their mode of data retrieval involves two parties – the technician and the supervisor and therefore, it is more time consuming and it even raises questions in terms of reliability.

4.2 ANALYSIS OF DATA COLLECTED FROM THE EXPERT INTERVIEWS

It was idea of the experts that the mentioned that the facility requires a virtual server comprising of data related to each of the assets, their current conditions and the concept of Building Information Modelling (BIM) that acts as a database of all the asset related as well as maintenance related information that can be easily retrieved comes into play in this regard. In addition to data retrieval, it is also in integration with the IBMS of the building that allows users to control the assets from the 3D view. However, this system is built on a complete virtual platform which could only be accessible for maintenance executives and managers who are privileged with personal computers. Therefore, in order to fit the use case especially to technicians, a separate system involving Augmented Reality should be built by considering the mentioned program as a basis. This would provide solutions to the issue arisen when retrieving maintenance history records and other asset data.

It was further stated that their company currently possess systems that provides instructions to perform certain maintenance tasks but this system only covers preventive maintenance routine tasks that are programmed beforehand. This would satisfy the requirement of the facility in providing instructions to technicians who would not comprehend when communicated verbally, but it would be only applicable to routine tasks. It was suggested to incorporate this system with another system that they are currently developing aiming at corrective workorder generation that involves automatic detection of issues with assets and providing technician with what task is to be carried out. It makes use of an algorithm similar to a root cause analysis and finds the real reason for the failure of the asset. It can be programmed to provide the end user with what action to be taken to fix the problem with animated instructions projected in real time.

4.3 DISCUSSION OF APPLICABILITY OF AUGMENTED REALITY TO ADDRESS THE IDENTIFIED ISSUES

Solutions to identified issues have been explored with the help of the literature review as well as with the inputs given by the experts who are engaged in providing IoT based solutions for building management.

A number of cases can be quoted from literature where Augmented Reality based systems have been adopted in order to remedy similar problems mentioned above. For instance, the framework in Figure 2 introduced by Amo *et al.* (2018) diagnoses breakdowns with the help of sensor data and provides the necessary instructions in 3D animated fform andaddressed more effectively with Augmented Reality. It not only helps technicians in receiving instructions even with the lack of SOP, but also minimizes the time taken to diagnose the issue causing the failure.

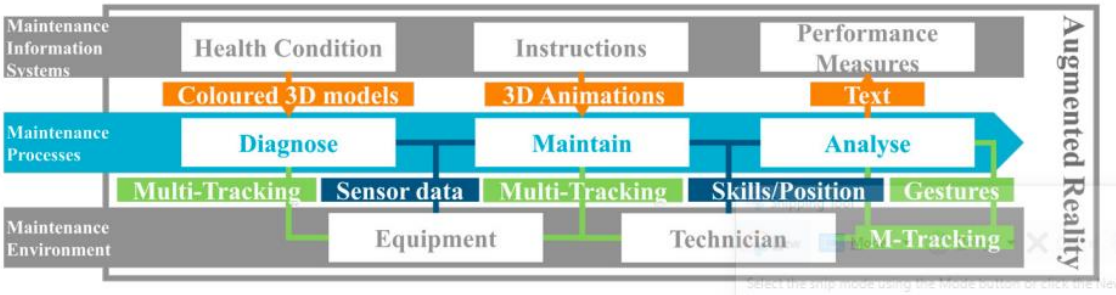

Figure 2: Framework for use of AR technology for maintenance activities (Source: Amo et al., 2018)

A system for "image based indoor localization" incorporating Augmented Reality was developed by Baeka *et al.* (2019) targeting sanitary pipes, but it is reasonable to assume that a similar model would provide solutions to the problem in this particular case. It makes use of "real time data" collected from sensors which are controlled with a "Building Information Model (BIM)" as the base.

From the expert interview, it is revealed that a "virtual server" is needed to act as the database and the concept of "Building Information Modelling (BIM)" is important in that regard. Accordingly, it would act as the base for the whole system while integrated with Augmented Reality to facilitate visualization of required "information and instructions" for end users. Data is made abundant and access to them is made instant with such a reliable database.

In addition, it is the opinion of the experts that integration of "automatic workorder generation" program with this system in order to include corrective maintenance instructions in addition to the prior arranged preventive maintenance routine tasks. This system would run an algorithm similar to a "root cause analysis" and conclude on what element is causing the failure and propose corrective actions and Augmented Reality is used to visualize the steps included in the actions in real time.

The proposed system would mainly comprise of two major features.

1. **Visualization of information - Addressing the issues discussed in sections 4.1.2, 4.1.3 and 4.1.4**
    - Maintenance records, asset data and other related data
    - Real time data
2. **Visualization of instructions - Addressing the issues discussed in sections 4.1.1 and 4.1.2**
    - Visualization of instructions for routine preventive maintenance tasks
    - Visualization of instructions for corrective maintenance tasks

4.3.1 Architecture of the Working Principle of the Proposed System

As depicted in Figure 3, Building Information Model acts as the server or the repository encompassing the required information while processing the incoming inputs. Inputs are fed to the BIM through the IoT sensors providing real time information while other asset data and maintenance records can be inserted to the server manually. It also receives signals coming from the system that automatically detects corrective actions required for breakdowns which functions separated from this program.

When the camera of the device is directed towards a certain asset, it tracks the markers that are attached to the asset and request is sent to the BIM. This request could be either or a combination of request for maintenance history, active cases, PM tasks steps or real time information. This request is processed in the BIM server and then relevant information is fed to the virtual layer with the positions of the markers so that the virtual elements such as texts, symbols, charts, graphs, animations could be overlaid in the real time at correct geographical location. When the task is completed, a report is automatically given to the BIM that stores the information for future use. The below Figure 3 summarizes the basic Architecture of the proposed Augmented Reality based system that aims at solving the identified issues of the selected building.

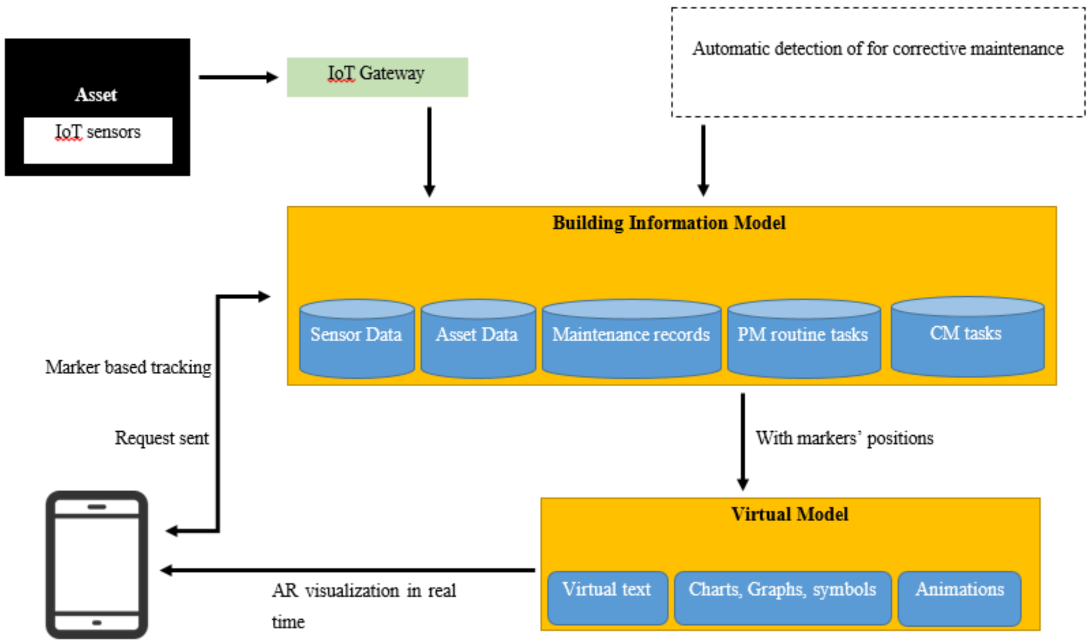

Figure 3: Architecture of the proposed Augmented Reality based maintenance system

4.3.2 Other Advantages of using an Augmented Reality based System for the Facility

It is straightforward that this system basically remedies the identified issues of the facility, but it is also evident from the literature survey that it carries other advantages as well.

1. Reduction of time spent on head and neck movement during task

A study conducted by Henrysson *et al.* (2005) emphasizes on the fact that "there is no need for distracting domain switching", as the user can concentrate solely on the task being carried out without distracting between paper-based manual and the equipment. In this model, augmented reality enables this benefit to the user providing an exclusive experience integrated with real time interaction.

2. Facilitates informed decision

From the interview with the technicians, the respondents revealed that their activities "get delayed due to lack of information or time taken to receive the information". It is clear that the decisions they make often do not take information into consideration due to this situation. But with this system, the maintenance related decisions they take would be more reliable, information based and with least amount of error.

3. Allows employment of less skilled technicians

With the instructions in the animated form, even technicians with less experience can conveniently carry out the tasks (Fiorentino *et al.*, 2014) thus leading to cost savings on high skilled technicians, time savings and less human error.

4. Training and skill development

Although training is not a primary purpose of the proposed system, the animation based instruction visualization provides a sound platform for novice technicians to carry out tasks and many augmented reality based systems have shown success in training and skill development of the technicians (Damiani *et al.*, 2018). Similarly, in this model, the visualization of instructions for preventive as well as corrective tasks provides an opportunity for user to learn and develop his skills.

5. Virtual repository of all information

As discussed, the architecture of the system shows that Building Information Model acts as the central server storing information such as maintenance records, real time data, and instructions. It is clear that it eliminates the need for hard bound copies which had to be accessed through "calling supervisors" when technicians needed to refer them. A more reliable repository of information is created as a result of implementation of this system in addition to making maintenance activities efficient.

4.3.3 Possible Barriers for the Proposed AR based System

1. Developing a BIM for an existing building

The expert interview revealed that a Building Information Model is usually built for a "proposed building" with abundant of information to be incorporated with the model, but developing one for an existing building could be "challenging" and "complex" resulting high costs for the client. There could be possibility of required data being unavailable or not adequate to build the model that would result an unsuccessful end product.

2. Adopting to a new system

The facility not implementing any system that is similar to the proposed system, it is reasonable to expect a resistance or a reluctance from technicians. Therefore, it would require a separate workshop or a training program to introduce and train them on the applications and benefits of the proposed system. However, from the response received showing their preference to "animation-based instructions", a positive reaction and embracing of the new technology can also be expected from the technicians. Nevertheless, making the users adopt to a new system could be challenging, therefore suitable strategies will have to be exercised by the management of the facility.

5. CONCLUSIONS AND RECOMMENDATIONS

AR which is a novel concept that is applicable in numerous fields is adopted in the field of Facilities Management especially in relation to building maintenance in order to make the processes efficient. The major aim of this study which was to establish the application of AR in making the maintenance tasks in a building more efficient was first achieved by gaining a thorough knowledge on applications of this concept worldwide in building maintenance as well as other fields by conducting a literature survey. Proceeding to the second objective which was to identify the issues faced by maintenance technicians in Sri Lanka that causes delays and inefficiencies, interviews were held with them that revealed 4 major issues that were related to mode of instructions given, inconvenient access to SOP and similar media, issues when performing inspection activities in terms of safety and accessibility and retrieval of history data and asset data. Following up with these issues, the final objective which was to remedy them using the concepts of AR was achieved with the inputs of the experts in the field of providing IoT based solutions for building management as well as the knowledge gathered from studying the previous work carried out by other researchers globally in the literature review. With the use of a Building Information Model and Augmented Reality, a system is proposed to address these issues and it has the potential of leading to cost and time savings, high customer satisfaction that ultimately results in high profitability. However, there could be challenges in developing a Building Information Modell to a prevailing building and also in making the technicians adopt into a new system. Through this research, it is recommended to conduct more comprehensive research to identify causes and issues faced by frontline maintenance technicians making the maintenance practices inefficient and explore the applications of novel concepts such as Building Information Modelling, Internet of Things and Augmented Reality in building maintenance for Sri Lanka.

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WASTE HEAT GENERATION AND POTENTIAL RECOVERY SYSTEMS USED IN SRI LANKAN HOTELS

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ABSTRACT

The waste heat recovery concept can be used as a solution to optimise energy consumption while reducing the waste heat in energy generation systems. However, its application in Sri Lankan hotels is still in the infancy stage even though the hotel sector accounts for high energy consumption. Therefore, this research aimed to assess the amount of waste heat generated from the different sources in hotel buildings and thereby identify the most appropriate waste heat recovery systems to the hotel buildings in Sri Lanka through a comparative case study analysis of three similar natured hotel buildings. The required data to perform waste heat calculation were extracted through document reviews and site visits. This study identified the three main waste heat generating sources in hotel buildings: HVAC condenser out, boiler exhaust, and kitchen exhaust. The analysis shows that the condenser out of the HVAC system is the highest waste heat generating source which accounts for an average of 41,823GJ per year while boiler exhaust and kitchen exhaust generate the waste heat of an average of 11,000GJ and 8GJ per year. It is further found that the quality of waste heat generated from the boiler exhaust is higher than the condenser out of the HVAC system and kitchen exhaust. Hence, this study concludes that the boiler has the highest potential of using the waste heat recovery system than the condenser out of the HVAC.

Keywords: *Hotel building; Waste heat source; Waste heat; Waste heat recovery system.*

1. INTRODUCTION

Currently, the world population is about 7.5 billion, and by the year 2050, it is expected to reach 9.9 billion (Population Reference Bureau [PRB], 2019). With the increment of population, people tend to increase the industrial activities to fulfil human requirements. According to the U.S. Energy Information Administration (2017), industrial sector accounts for 35% of global energy consumption. However, 20-50% of heat is ultimately discharged to the environment as waste heat from the energy consumption in the industrial sector (Papapetrou *et al*., 2018). According to environmentalists, unsustainable Green House Gases (GHG) and tons of toxic gases are released into the atmosphere because of this heat discharging. Most of the recent researchers identified this as the major reason for global warming and climatic changes (Gunggut *et al*., 2014). These burning

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environmental limitations motivate to reduce energy consumption and utilise the waste heat in the industrial sector (Forman *et al*., 2016).

Currently, there are various technologies used to minimise energy waste and thereby improve the efficiency of energy conversion. However, a considerable percentage of energy is still wasted in the forms of solids, gas, or liquid while a large part of the waste energy can be recovered (Irwindale, 2008). Waste heat recovery is a better application that has been used in the industry to optimise energy consumption while reducing the environmental impact that occurred in energy generation systems in the global context (Liu *et al*., 2004). According to Teke *et al*. (2009), a heat recovery system can contribute to the reduction in CO_2 emissions to the environment.

In Sri Lanka, the industrial sector accounts for 39% of annual energy consumption and generates about 48% of CO_2 to the atmosphere (Ministry of Power and Energy, 2016). It is found that the most energy-consuming industries in Sri Lanka are tea, apparel, hotel, commercial, food and beverage, tire, steel and iron, pulp, and paper sectors (Sri Lanka Sustainable Energy Authority, 2017). These industries together contribute about 25% of the annual Gross Domestic Product (GDP) of Sri Lanka (Central Bank of Sri Lanka, 2019).

Among those industries, the hotel sector is consuming around 5% of grid electricity and other liquid and solid fuels including furnace oil, diesel, biomass (Sri Lanka Sustainable Energy Authority, 2017). In most hotel buildings, electricity is the popular energy source that is used to operate HVAC, mechanical transport, lighting, and all other systems in the building. Cooking activities are facilitated by liquid petroleum. Apart from that biomass, diesel, or furnace oil are used in boiler operation as an energy source for boilers (Perera *et al*., 2005). Therefore, hotel sectors could be considered as the major contributors to the increment of energy consumption and negative environmental impacts in the country. However, the hotel sector currently accounts for about 12% of Sri Lankan GDP (Central Bank of Sri Lanka, 2019). Hence, this indicates that improving energy efficiency through waste heat recovery systems could help to improve the economy and to reduce CO_2 emissions. Even though the waste heat recovery system can minimise the primary energy source usage and emission of CO_2 to the environment, the waste heat recovery concept is still at a lower level in the Sri Lankan context. Hence, this study aimed to assess the amount of waste heat generated from the different sources in hotel buildings and thereby identify the most appropriate waste heat recovery systems used in the hotel buildings in Sri Lanka.

2. LITERATURE REVIEW

2.1 DEFINITION OF WASTE HEAT

Waste heat is the heat that is released into the environment by combustion or chemical reactions, that can be reused for useful and economic purposes (Karellas *et al*., 2013). Waste heat is emitted and released in a variety of ways, including radiation, cooling fluid, exhaust gas, and air, wherever products are produced, and machines are run (Bruckner *et al*., 2015). The authors further depicted that approximately 30% of the input energy is lost due to waste heat in the industrial sector. Waste heat can be categorised into three temperature stages; High temperature (heat at temperatures greater than 400 °C), Medium temperature (heat at temperatures 100°C-400°C), Low temperature (heat at temperatures less than 100°C) (Bruckner *et al*., 2015). According to above authors, direct combustion is the source to generate waste heat in the high-temperature range, while the exhaust of combustion units and the process unit components products and the equipment generate medium range and low-temperature range heat respectively.

2.2 WASTE HEAT RECOVERY SYSTEMS

A waste heat recovery system is a kind of technology used for the effective adoption of waste heat generated from different sources (Jouhara *et al*., 2018). Those technologies can be passive or active. In active waste heat recovery systems, waste heat is directly used at the same or low or high temperature or transformed the waste heat into another form of energy. Heat exchangers and thermal energy storages are the main passive waste heat recovery systems (Bruckner *et al*., 2015). Figure 1 further illustrates the different types of passive and active waste heat recovery systems.

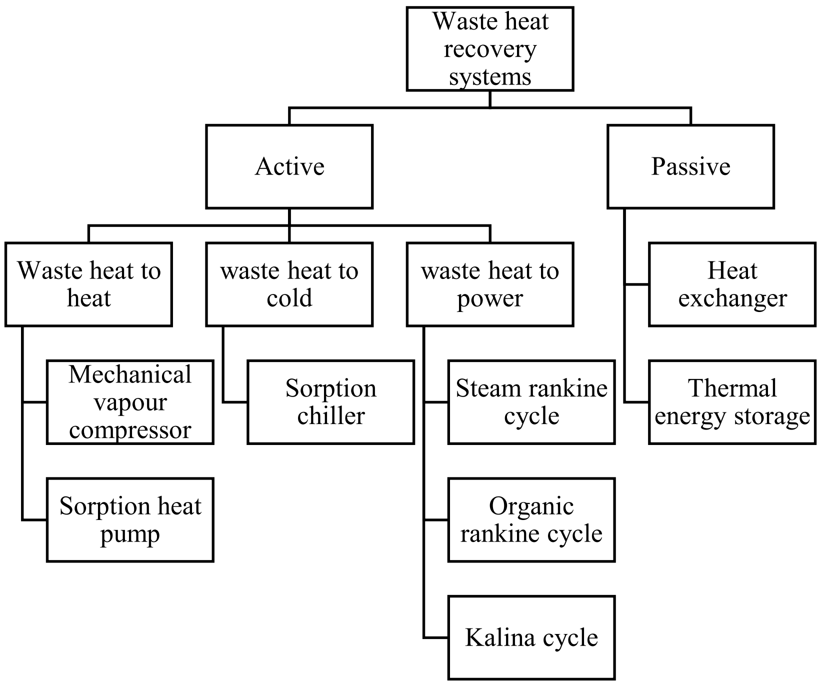

Figure 1: Waste heat recovery systems (Source: Bruckner et al., 2015)

Recently, the energy demand for heating and cooling has been reduced as a result of the usage of the heat recovery system due to its ability to limit heat losses and optimised energy consumption (Pfafferott, 2003). However, the application of a waste heat recovery system depends on the temperature range of generated waste heat (Tafone *et al*., 2017). There are three important factors to consider in selecting a waste heat recovery system; quantity, quality, and temporal availability (Arzbaecher *et al*., 2007). According to the authors, quantity, quality, and temporal availability refers to amount of waste heat generation, temperature of the generated waste heat and the availability of the waste heat when it is required, respectively. The quality of the waste heat depends on the waste heat source (Tafone *et al*., 2017). Table 1 illustrates the quality of waste heat and its uses of different waste heat sources.

Table 1: Waste heat source and quality

Source	Source of Waste Heat	Quality of Waste Heat
1	Heat in flue gases	High Temperature
2	Heat in vapor streams	High Temperature
3	Convective and radiant heat lost from the exterior of equipment	Low Temperature
4	Heat losses in cooling water	Low Temperature
5	Heat losses in providing chilled water or in the disposal of chilled water	High or Low Temperature (Based on usage of refrigeration)
6	Heat stored in products leaving the process	Medium Temperature
7	Heat in gaseous & liquid effluents leaving process	Low Temperature

(Source: Jouhara *et al.*, 2018)

Generally, waste heat in high temperatures accounts for the higher quality waste recovery as well as more cost-effectiveness. Similarly, waste heat in low temperatures accounts for low-quality waste recovery with minimum cost-saving (Tafone *et al.*, 2017).

The total amount of waste generated from the different sources cannot be fully recovered (Arzbaecher *et al.*, 2007). Hence, it is important to identify the most suitable heat recovery system which gives the maximum amount of heat recoverable and maximum efficiency. Furthermore, regenerative and recuperative burners, economizers, waste heat boilers, air preheaters, rotary regenerators, run-around coil, plate heat exchangers, heat pipe systems, and heat pumps are the most commonly available waste heat recovery systems (Tafone *et al.*, 2017). Table 2 illustrates the applicability of waste heat recovery systems.

Table 2: Application of waste heat recovery technologies

Waste Heat Recovery System	Quality of Waste Heat	Relevant Waste Heat Sources (Reference to Table 1)
Regenerative Burners	High	1, 2
Recuperative Burners	High	1, 2
Economisers	Low - Medium	3, 4, 5, 6, 7
Waste Heat Boilers	Medium-High	1, 2, 5, 6
Recuperators	Low - High	1, 2
Regenerators	Medium - High	1, 2, 5, 6
Rotary Regenerators	Low - Medium	3, 4, 5, 6, 7
Run around coil (RAC)	Medium - High	1, 2, 5, 6
Heat Recovery Steam Generator (HRSG)	High	1, 2
Plate Heat Exchanger	Medium-High	1, 2, 5, 6
Heat Pipe Systems	Medium-High	1, 2, 5, 6
Thermoelectric Generation	Medium - High	1, 2, 5, 6
Piezoelectric Power	Low	3, 4, 7

Waste Heat Recovery System	Quality of Waste Heat	Relevant Waste Heat Sources (Reference to Table 1)
Generation		
Thermionic Generator	High	1,2
Thermo Photo Voltaic (TPV) Generator	Low - High	1, 2, 3, 4, 5, 6, 7
Heat Pump	Low -Medium	3, 4, 5, 6, 7
Direct Contact Condensation Recovery	Medium-High	1, 2, 5, 6
Indirect Contact Condensation Recovery	Medium-High	1, 2, 5, 6
Transport Membrane Condenser	Medium-High	1, 2, 5, 6

(Source: Jouhara *et al.*, 2018)

However, the literature findings proved that it is not appropriate suggesting a suitable waste heat recovery system to a source only based on calculating the generated waste heat amount. It is because of a considerable amount of heat is lost while recovering. Hence, before selecting a suitable waste heat recovery system it is important to focus on the waste heat recoverable amount in the sources.

Therefore, this research aimed to assess the amount of waste heat generated from different sources in hotel buildings and thereby identify the most appropriate waste heat recovery systems that can be used in the hotel buildings in Sri Lanka.

3. RESEARCH METHODOLOGY

The research was conducted using a quantitative data collection and comparative data analysis techniques. Initially, a preliminary investigation was carried out through site visits to identify the most suitable research cases for this study. Furthermore, for this comparative study, there needs to be similar natured hotel buildings to calculate the amount of waste heat generated from selected waste heat sources. When finding cases, it was important to focus on minimising errors that could occur due to the deviation of physical properties of those selected cases. Hence, when selecting the cases, due consideration was given to the factors affecting the waste heat generation, such as the rating of the hotel, occupancy, and waste heat generated sources and thereby to ensure the reliability and accuracy of the research findings.

Given the constraints of time and accessibility, three hotel buildings which fulfil the above requirements were identified during the preliminary investigation. Subsequently, interviews conducted with management of selected hotels identified that the HVAC condenser out, boiler exhaust, and kitchen exhaust as the most common waste heat sources in those hotels. Table 3 illustrates the profile of the three hotels studied.

Table 3: Profile of three hotel buildings

Hotel	**No. of rooms**	**No. floors**	**No. of occupied rooms (Avg.)**	**System description**		
				System	**Type**	**Capacity**
01	500	14	281	Chiller	Water cooled centrifugal type	1050TR
				Boiler	Three pass fire tube	6T/H
				Kitchen exhaust	Back shelf type with extraction fans	69l/s
02	501	18	257	Chiller	Water cooled centrifugal type	1050TR
				Boiler	Three pass fire tube	7.3T/H
				Kitchen exhaust	Back shelf type with extraction fans	60l/s
03	450	19	236	Chiller	Water cooled screw type	1000TR
				Boiler	Back flame fire tube	7.2T/H
				Kitchen exhaust	Back shelf type with extraction fans	87s/l

Furthermore, the data required to calculate the waste heat amount was collected through expert interviews and documentary reviews of relevant standards which describe the operation of selected systems. The following equation 01 was used to calculate the generated waste heat quantity from each source in the selected three buildings.

$$Q = V \times \rho \times CP \times \Delta T \qquad (01)$$

Where, Q (J) is the heat content, V is the flow rate (m^3/s), ρ is the density of the flue gas (kg/m^3), Cp is the specific heat (J/kgK) and ΔT is the temperature difference (K).

Subsequently, three expert interviews were conducted with the hotel management of the selected hotels to identify the suitable waste heat recovery systems that can be used for the identified waste heat sources; boiler exhaust, condenser out of the HVAC system, and kitchen exhaust.

4. DATA ANALYSIS AND FINDINGS

Table 4 illustrates the calculated waste heat amounts of different sources in each building as per equation 1. The temperature difference and flow rate of waste heat were collected through the site visits and interviews among the experts in that hotel buildings. Specific heat capacity and density were gathered by referring to standards.

Generated waste heat amounts from the HVAC condenser out in Hotel 01 can be elaborated as follows:

Where, V= 89 kg/s, ρ=997 kg/m³, Cp = 4200 J/kg^{0}C, ΔT = 6^{0}C

Q = 2,242,800 J/s

However, this could vary depending on the working time of the selected source. The working time per day of identified sources was obtained by referring to the daily records available at each hotel. The mean value of operating hours within 30 days was taken as the operating time of each source. Accordingly, it was calculated as 24 hours, 20 hours, and 10 hours per day for the HVAC system, boiler exhaust, and kitchen exhaust, respectively.

Table 4: Generated waste heat amounts of different sources in each building

System	Hotel	Medium	Temperature (^{0}C)		Flow rate (kg/s)	Waste heat amount	
			Range	Quality		(J/s)	(GJ/y)
HVAC condenser out	H1	Water	30-36	Low	89.0	2242800	70729
	H2	Water	30-35	Low	63.15	1326215	41824
	H3	Water	30-36	Low	70.0	2058000	64901
Boiler exhaust	H1	Air	30-180	Medium	1.63	295719	8549
	H2	Air	30-210	Medium	2.34	508248	14692
	H3	Air	30-190	Medium	1.76	339066	9802
Kitchen exhaust	H1	Air	30-35	Low	0.06	364	5
	H2	Air	30-38	Low	0.05	437	6
	H3	Air	30-40	Low	0.09	1092	15

As per Table 4, condenser out of HVAC system and kitchen exhaust belongs to the low-temperature category in each building while boiler exhaust belongs to the medium temperature category. It is seen that the quality of waste heat generated from the boiler exhaust is higher than the quality of waste heat generated from the condenser out of the HVAC system and kitchen exhaust.

When considering the quantity of waste heat generated from the identified sources, the condenser out of the HVAC system is the highest waste heat generating source. It generates an average of 41,823 GJ per year. In the same vein, the boiler exhaust produces 11,000 GJ of waste heat per year on average while the kitchen exhaust produces only an average of 8GJ per year. Hence, kitchen exhaust is the minimum waste heat generating source among the identified sources.

The result of this calculation shows that the quality and the quantity of generated waste heat of kitchen exhaust in hotel buildings are very less compared to the other two sources. However, literature findings evident that the sources which generate less waste heat amount and emit low temperature are not cost-effective in the waste heat recovery concept. Furthermore, even though the condenser out of the HVAC system shows a high quantity of waste heat, the quality of the waste heat is less and no more cost-effective. Hence, boiler exhaust could be considered as the best waste heat source for waste heat recovery among the identified sources.

Based on the assessment of waste heat generation, it is difficult to suggest the appropriate waste heat recovery systems for the identified waste heat sources in the hotel sector due to the technological constraints in Sri Lanka. Hence, following the assessment, experts were approached to recommend the most appropriate waste heat recovery systems that can be used for these waste heat sources. Table 5 illustrates the different waste heat recovery systems that can be used for the boiler exhaust and condenser out of the HVAC systems.

Table 5: Waste heat recovery systems for boiler exhaust and condenser out of the HVAC systems

Boiler Exhaust	Condenser out of the HVAC systems
1. Hot water generation with heat pump method	1. Hot water generation with heat pump method
2. Hot water generation with direct heat exchanger	2. Hot water generation with direct heat exchanger
3. Boiler combustion air-free heat with direct heat exchanger	3. Hot water generation with vapor compression refrigeration
4. Furness oil-free heat with direct heat exchanger	

As shown in Tables 5, there are four types of waste heat recovery systems used for the boiler exhaust; (1) hot water generation with heat pump method, (2) hot water generation with direct heat exchanger, (3) boiler combustion air-free heat with direct heat exchanger, and (4) furnace oil-free heat with direct heat exchanger. Amongst, the hot water generation with direct heat exchanger was recommended as the most suitable waste heat recovery system for the boiler exhaust in the hotel industry, mainly due to two reasons: (1) In the hotel industry, boilers are mainly used for the steam and hot water generation and (2) Heat exchangers are more efficient and effective than heat pumps.

An expert elaborated;

> *"Boiler exhaust is a main waste heat source in a hotel. The boiler exhaust temperature is nearly $250^{o}C$, depending on boiler capacity and the operating time. If there is a close circuit boiler circulation, it can collect waste steam directly to the boiler feeding tank. Similarly, we can generate hot water by using exhaust heat through the heat exchanger (economizer). Because the normal water temperature is $30^{0}C$-$35^{0}C$ and the boiling point is $100^{0}C$. Therefore, we should spend more energy to heat water ($65^{0}C$-$70^{0}C$). Although, when using feed water through the economizer (heat exchanger) organisation can save more energy. Therefore, hot water generation with direct heat exchanger is the most effective waste heat recovery method for boiler exhaust".*

This was further strengthened by an expert stating;

> *"Boiler exhaust directly emits more heat (around 3000C<) to the environment. When recovering the heat for hot water generation and may affect energy saving. When considering waste heat recovery systems, heat exchangers are more effective than heat pumps".*

Another expert pointed;

> *"Relatively boiler exhaust emits more heat than other waste heat sources. In the hotel industry boilers are used for steam generation and hot water generation. As in cold country, we are recovering waste heat to heat swimming pool water. Therefore, a heat exchanger (like economizers) is effective to recover waste heat from exhaust".*

Similarly, experts stated that there are three main types of waste heat recovery systems used for the condenser out of the HVAC systems: (1) hot water generation with heat pump method, (2) hot water generation with direct heat exchanger, and (3) hot water generation with vapor compression refrigeration. Amongst, hot water generation with a direct heat exchanger is the most suitable waste heat recovery system for the condenser out of the HVAC systems in the hotel industry.

An expert stated;

> *"Air-cooled chillers are the best type than water-cooled chillers for heat recovery. The water-cooled type uses cooling towers to decrease chilled water temperature, but air-cooled type chillers use environmental temperature (air) to cool down. Therefore, this method is most suitable for air-cooled chillers. Through the heat exchangers, it can be recovered the waste heat from the HVAC system."*

Another expert opined;

> *"Hot water generation with direct heat exchanger is most suitable than hot water generation with vapor compression refrigeration and using the heat pump to recover heat loss of chillers because replacing a heat exchanger is more effective than the heat pump."*

Hence, experts evident that the hot water generation with a direct heat exchanger is the most suitable waste heat recovery system for both boiler exhaust and condenser out of the HVAC system.

5. CONCLUSIONS

Industrial waste heat refers to the heat lost to the environment through the different industrial processes. Waste heat recovery is the method used to reuse the lost heat through industrial processes. Waste heat recovery systems are introduced to the waste sources based on the waste heat ranges such as high temperature, low temperature, and medium temperature. Furthermore, quantity, quality, and temporal availability are the main factors to be considered in selecting the waste recovery system.

The findings of this study identified that the main three waste heat generated sources in Sri Lankan hotel buildings include HVAC condenser out, boiler exhaust, and kitchen exhaust. According to the calculations, the condenser out of the HVAC system is the highest waste heat generating source is at an average of 41,823GJ per year. Then respectively, boiler exhaust is at an average of 11,000GJ per year and kitchen exhaust is at an average of 8GJ per year. Furthermore, analysis shows the quality of waste heat generated from the boiler exhaust is higher than the quality of waste heat generated from the condenser out of the HVAC system and kitchen exhaust. Subsequently, it concluded that the usage of a waste heat recovery system for the kitchen exhaust waste source in the Sri Lankan hotel sector will be less effective. This study further identified that hot water generation with a direct heat exchanger is the most suitable waste heat recovery system for both boiler exhaust and condenser out of the HVAC system among the available different waste heat recovery systems.

This study is limited to the HVAC condenser out, boiler exhaust, and kitchen exhaust waste sources in the Sri Lankan hotel sector. However, many other industries generate waste heat from their day-to-day operations. Therefore, it is suggested the future studies to assess the waste heat generated from different industrial processes to introduce waste heat recovery systems and thereby reduce the non-renewable energy consumption in the country.

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