Can Lean Principles Assist to Reduce BIM Implementation Costs? A Contemporary Application of Lean Principles to the Sri Lankan Construction Industry

Purpose: Building Information Modelling (BIM) claims to be spearheading the modern technological revolution in the global construction industry. While scholars have emphasised the cruciality of BIM, associated costs have been identified as one of the major barriers to successful BIM implementation, as is the case in Sri Lanka. Besides, Lean Principles (LP) are known for increasing efficiency, quality and eliminating waste, thereby reducing overall costs. Hence, this research aims at addressing the BIM implementation barrier associated with costs by applying suitable LP, enhancing overall value by minimising value-insignificant activities.

Methodology: The study adopted a qualitative research approach. 10 experts with expertise in both BIM and LP were targeted for the primary data collection through semi-structured interviews. The collected data was analysed using manual content analysis.

Findings: Research findings discovered the cost centres that can be applied to the LPs and the effective LPs that can be applied with the cost centres of BIM implementation. The theoretical implication of the study is to provide insights into a potential application of LP for BIM cost centres. Whereas practical consequences include the identification of LP's potential to minimise BIM cost centres, ergo, achieving a successful BIM implementation.

Originality: This study will be the first of its kind in the Sri Lankan construction industry, intending to apply LP with BIM implementation cost centres to achieve a successful implementation. This research also has paved the way forward for further research on the application of both the BIM and LP concepts for similar construction industries in developing countries across the world and in addressing other BIM implementation barriers.

Keywords: Building Information Modelling (BIM), BIM implementation, Construction industry, Cost centre, Lean Principles (LP)

Introduction

The construction industry is widely known to be facing challenges concerning technology, management and coordination, research and development, and skill challenges, leading towards an underperformance (Oraee *et al.,* 2019). BIM has been sought as an silver bullet solution to overcome most of such challenges arising in the construction industry. Nevertheless, Epasinghe *et al.* (2018) found that most construction industries are not yet practically ready to implement BIM for construction activities, as is the case in Sri Lanka. Though a considerable effort has been made to identify the barriers affecting BIM implementation in the construction sector (Chan *et al.,* 2019; Oraee *et al.,* 2019; Olawumi *et al.,* 2019), only a limited number of researchers have specified the strategies to overcome those identified barriers in the Sri Lankan context (Rathnayake, 2017; Siriwardhana *et al.,* 2018). Whilst the high cost has been identified as a major barrier to BIM implementation, the industry stakeholders have expressed their willingness to implement BIM at low or without associated costs (Rogers *et al.,* 2015; Siriwardhana *et al.,* 2018).

Even though successful attempts have been made to implement BIM in the global construction context (Abanda *et al.,* 2018; Rathnasinghe *et al.,* 2020), in the Sri Lankan construction industry, BIM is still in its infancy stage (Epasinghe *et al.,* 2018). Given this, one of the main barriers for effective BIM implementation is the costs associated with the process, discovered to be high (Olawumi *et al.,* 2018). Being relatively new and less familiar with technology, the Sri Lankan construction industry may not be able to implement BIM optimally. On the other hand, the professionals familiar with the concept of BIM and its implementation are limited in number within Sri Lanka and adding further difficulties in cost effective BIM implementation. Eventually, this gives a trigger to numerous waste activities depending on the real objectives of BIM implementation, subject to the context and adopter.

Meanwhile, lean is another novel concept governing the effectiveness of the construction industry. Research has proved that LPs have been implemented in the construction industry to reduce wastage and improve efficiency (Sharma, 2017). Since lean has found to be effective in minimising costs by avoiding unnecessary costs, lean could also help in minimising waste. The adopted rationale in this study is two-fold. First, BIM is primarily about virtual construction, and it has some resemblance to the construction process. Second, LPs are widely developed and adopted in the industry to minimise waste and reduce associated costs. Consequently, a research gap is identified in the potential of LP to support overcoming BIM implementation cost barriers and, thereby, successfully implement BIM in the construction sector. Structured knowledge to identify whether there are any lean principles that can be used to minimise different cost centres of BIM implementation would be of high significance in receiving the expected outcomes of effective BIM implementation. Hence, further research is crucial to explore the possible solutions to address this.

Several research studies have attempted to investigate the applicability of LPs in different contexts, such as civil construction, challenges for waste reduction, and challenges for sustainable construction (Nikakhtar *et al.*, 2015; Carvajal-Arango *et al.*, 2019). On the other hand, studies have also recommended BIM in making the implementation of LPs more efficient (Elmaraghy *et al.*, 2018; Michalski *et al.*, 2022). However, to the best of the author's knowledge, no research has been conducted to investigate the potential of LPs to reduce the associated implementation costs and, thereby, to make BIM implementation an effective one. Hence, this research intends to identify the suitable LPs for addressing the cost centres of BIM implementation.

Accordingly, this paper is structured as follows. First, it provides a comprehensive literature review on the cost centres of BIM implementation and available LPs. Next, the research method, comprising data collection, and analysis techniques, is elaborated upon, followed by the findings and discussion. Finally, a conclusion is derived by achieving the aim of the research paper.

Literature Review

This section presents the concept of BIM and BIM implementation with its challenges and implementation costs. In addition, LPs are thoroughly discussed as a method of reducing BIM implementation costs.

Building information modelling (BIM) and BIM benefits

BIM is a modern construction industry revolution for managing and designing construction projects throughout their building lifecycle (Cao et al., 2018). Moreover, Cao *et al.* (2018) asserted that BIM offers the potential to tackle problems among project stakeholders, such as low productivity, rising costs, poor quality, construction waste, delays, and lack of knowledge management. Further, BIM can be identified as a tool for enhancing the efficiency of the construction industry (Oraee *et al.*, 2019). Over the last two decades, the capacity of BIM has improved and transformed the performance of the construction industry by increasing efficiency, improving productivity, and increasing trust between stakeholders. (Abanda *et al.*, 2018).

BIM is recognised as a change in process as well as a change in technology (Chan *et al.*, 2019). BIM has been acknowledged for its potential to digitally represent the physical and functional characteristics of an asset throughout its life cycle (Abanda *et al*., 2018; Cao et *al.*, 2018). Consequently, BIM improves decision-making transparency and allows construction project stakeholders to make reliable decisions from project conception to demolition (Abanda et al., 2018; Cao *et al.*, 2018). Meanwhile, the traditional methods of architecture, engineering, construction, and operations have been replaced by BIM which is a new approach in the construction industry (Epasinghe *et al.*, 2018). Rathnasinghe and Kulatunga (2019) went on to state that the fundamental result of BIM implementation is to increase collaboration among project partners across all construction stages without causing any interoperability problems. As a result, a continuous information flow throughout the construction lifecycle will be created between the BIM project stakeholders and BIM acts as a mechanism to rectify the issues that occurred due to the exchange of information (Rathnasinghe *et al.*, 2020).

Accordingly, the benefits of BIM implementation have been widely spread throughout the construction industry so as to make reductions in construction costs, integrate the project systems, improve the quality of design information, assess the life cycle of construction projects, improve the accuracy and make collaboration between the participants (Ghaffarianhoseini, et al., 2017). However, Figure 1 can be used to demonstrate the benefits of BIM implementation.

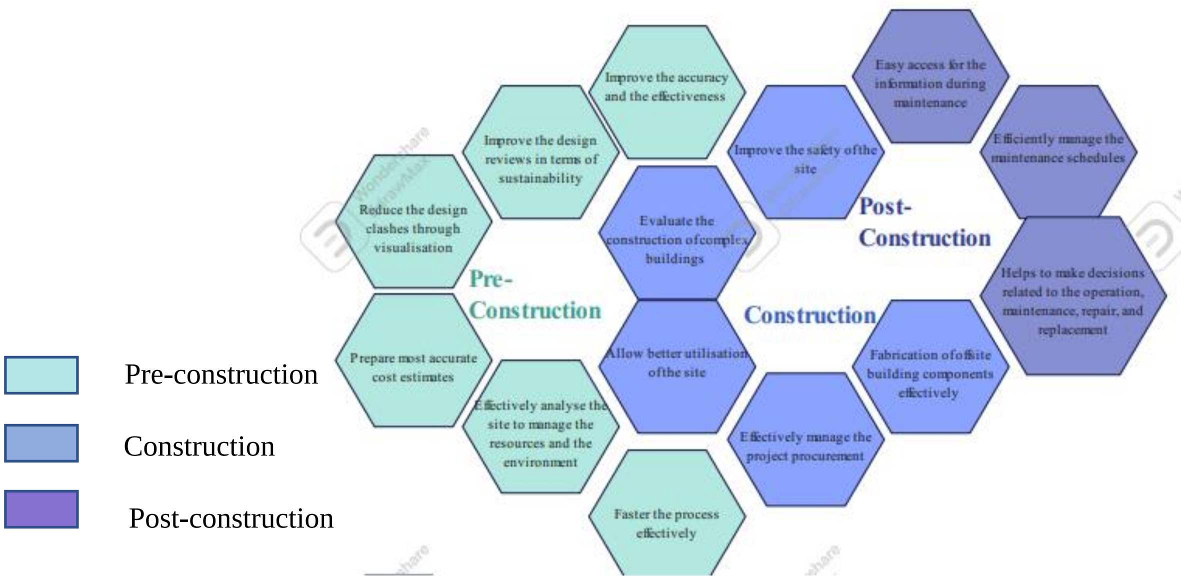


Figure 1: Benefits of BIM implementation

(Adapted from: Azhar et al., 2012; Barlish & Sullivan, 2012; Gardezi et al., 2014; Ghaffarianhoseini, et al., 2017)

BIM implementation in the construction industry

According to Chan *et al.* (2019), BIM can be implemented in three stages: object-based modelling (stage 1), model-based collaboration (stage 2), and network-based integration (stage 3). Moving from 2D documentation to 3D modelling as part of stage 1 in BIM implementation allows for a more realistic representation of the architectural elements (Olawumi *et al.*, 2018). In addition, Olawumi et al. (2018) viewed stage 2 as a collaborative approach among stakeholders that integrates data and information and improves communication, whereas stage 3 is known as the transition from collaboration into integration by realising benefits from the BIM implementation.

When BIM is used for a BIM infant project, it is simple to visualise the project details and create shop drawings for the systems (Saka & Chan, 2020). BIM implementation for building construction projects digitally represents the applications and the maintenance of the building through IT-enabled approaches at various project stages (Rathnasinghe & Kulatunga, 2019; Chan, 2019). Even though BIM implementation requires additional time and money, the investment further creates positive outcomes for all participants in the project without any wastage (Ghaffarianhoseini, et al., 2017). However, BIM implementation in the construction industry largely depends on the willingness of stakeholders (Saka & Chan, 2020).

BIM implementation challenges

Amidst the various challenges, BIM implementation in the construction industry ought to have benefits. Researchers have identified various challenges for BIM implementation in the construction industry. Thus, BIM implementation has been found to be directly affected by both technical and industry challenges (Hijazi et al., 2015). The high initial cost for BIM technology, lack of training facilities, and low-level of awareness can be identified as the technical challenges, while diversity among the stakeholder requirements, not having a fully corporate legal system for the contract agreement or systematic protocol, and governing regulatory body turn out to be the industrial challenges (Gardezi et al., 2014; Hijazi et al., 2015). In view of these, the challenges of BIM implementation can be tabulated as in Table 1.

Table 1: Challenges of BIM implementation

Challenge	**References**
High initial cost (Lack of financial and technical capacity)	Elmualim & Gilder, 2013; Gardezi et al., 2014; Hijazi et al., 2015; Olawumi et al., 2018
Lack of knowledge and understanding of BIM	Gardezi et al., 2014; Ismail et al., 2017
Lack of awareness about the BIM benefits	Hosseini, et al., 2016; Ismail et al., 2017; Olawumi et al., 2018
Not having better training on the use of BIM (Lack of education and training)	Park & Kim, 2014; Ismail et al., 2017; Olawumi et al., 2018
The unwillingness of changing the current industry culture (Reluctance to change)	Olawumi et al., 2018
Not having sufficient support from the government	Olawumi et al., 2018
Not having a fully corporate legal system for the contract agreement	Gardezi et al., 2014; Hijazi et al., 2015; Olawumi et al., 2018
Lack of interest from the stakeholders/ Lack of willingness to adopt BIM	Olawumi et al., 2018
Lack of trust and collaboration (Doubts about the return on investment)	Park & Kim, 2014; Ismail et al., 2017; Olawumi et al., 2018
Not having contractual requirements	Hatem et al., 2018; Olawumi et al., 2018
Lack of protocols and standards	Gardezi et al., 2014; Hijazi et al., 2015; Olawumi et al., 2018

BIM implementation costs

The lack of capital in the industry is a significant challenge to BIM implementation (Elmualim & Gilder, 2013). However, in order to garner the BIM benefits for the construction industry, it is critical to identify and comprehend the cost centres associated with BIM implementation (Ismail *et al.*, 2017). Figure 2 depicts the basic cost centres of BIM implementation during the pre-construction and construction phases based on global construction.

Figure 2: Cost centres associated with BIM implementation

(Adapted from: Elmualim & Gilder, 2013; Liu et al., 2015; Manzoor et al., 2021; Zheng et al., 2017)

BIM in Sri Lanka

BIM found to be yet fully adopted in the Sri Lankan construction industry, while considering as a BIM infant industry (Epasinghe *et al.*, 2018). According to Jayasena and Wedikkara (2012), the absence of knowledge and experience in BIM has highly affected the Sri Lankan construction industry. Moreover, the initial cost of the BIM technology is higher than the conventional construction processes used in Sri Lanka (Epasinghe *et al.*, 2018). Aside from those, lack of training resources, the feasibility of cost implementation, and resistance to change from the existing construction culture has been frequently identified as barriers to BIM adoption in Sri Lanka (John, 2016; Epasinghe *et al*., 2018; Jayasena & Wedikkara, 2012).

Therefore, in order to reap the benefits of BIM, the cost centres incorporated with BIM implementation must be settled (Zheng et al., 2017). By doing so, the benefits depicted in Figure 2 can be brought to the local construction industry by addressing the cost centres of BIM implementation.

LPs contribute to the development of sustainable projects by reducing various waste types identified in the construction industry (Xing *et al.*, 2021). Hence, LPs were considered while addressing the cost centres of BIM implementation.

Lean principles

Lean is a concept used to boost the efficiency of the construction industry by reducing waste that does not add value to clients (Albalkhy & Sweis, 2020). Lean construction is a growing and popular construction theme that aims to improve quality and productivity by adding more value to the construction process (Xing *et al.*, 2021). Lean, on the other hand, can be used to manage production in order to achieve significant improvements in terms of time and resources that do not add value to the product or service delivered to the customer, thereby eliminating all waste (Albalkhy & Sweis, 2020). "Lean principles have been applied to processes such as project delivery systems, production control, work structuring, design, supply chain, and project control, including overall construction project management by the project managers" (Hosseini *et al.*, 2012, p.1). Moreover, Hosseini *et al*. (2012) contended that "LPs have been based on time-based management and value-based management to reduce the cycle time and increase the output value, respectively" (p. 5). According to Koskela (1992), eleven construction principles are centred on one main principle called flow, with some being fundamentally oriented and others being application-oriented. The author further explained that these eleven principles can be applied to the entire flow process as well as its sub-processes to solve flow process problems like complexity and transparency.

Koskela (1992) has identified the eleven principles as "reducing the share of non-value-adding activities; increasing output value through systematic consideration of customer requirements; reducing variability; reducing the cycle time; simplifying by minimising the number of steps, parts, and linkages; increasing output flexibility; increasing process transparency; focusing control on the complete process; building continuous improvement into the process; balancing flow improvement with conversion improvement; and benchmarking" (p.16).

Use of lean principles in the construction

The misconception in the construction industry was theoretically believing that lean concepts can be applied successfully only in the manufacturing industry (Ruan et al., 2016). However, the authors claimed that the application of the lean concept in the design and construction industry was slow due to the conflation of reasons such as the disinclination of making capital investments. Even though Vilasini et al. (2011) stated that the lean construction philosophy modernised and value the construction industry as a key driver, it reorganised the construction industry. Implementing innovative, effective, and efficient concepts such as lean construction into the construction industry causes changes by driving it to focus on value for money (Jørgensen & Emmitt, 2009).

LPs can help to reduce waste and speed up the construction process by reducing rework and non-value-added activities (Yahya & Mohamad, 2011). Furthermore, the use of LPs in construction projects has been identified as an innovative solution to problems such as rehabilitation and replacement in terms of reducing environmental impacts, construction time, and design processes (Carvajal-Arango, 2019). The reduction of rework due to less integration between parties is a significant benefit that can be gained through LP implementation (Common et al., 2000). Aside from that, the major benefits of implementing LPs in construction projects have been identified as cost savings, fewer management costs, reduced project duration, increased completion of the current plan, and fewer inventories (Mohan & Iyer, 2005; Yahya & Mohamad, 2011; Ruan et al., 2016).

The next section discusses the potential of applying LPs and BIM to make BIM implementation more effective in the construction industry.

Application of lean principles to minimise the cost centres of BIM implementation in the construction industry

According to Sacks et al. (2010), lean and BIM are two major developments affecting the architecture, engineering, and construction industries. They further highlighted that lean is a conceptual approach for construction and project management where BIM is a standard and transformative information technology. Even though lean and BIM are two separate and independent philosophies that have an impact on the construction industry, there can be a coaction between them to make the construction industry more effective by applying both approaches (Kekana *et al.,* 2014). However, both approaches are in their infancy stages, and both are still urging their effective adoption in the construction industry (Hettiaarachchige *et al.*, 2022). Higher costs have acted as a barrier to the BIM implementation, and thereby the benefits of the implementation can outweigh the costs (Tan *et al.*, 2019). Further, Chan (2019) describes key problems for BIM adoption as underutilisation and interoperability, while a lack of conceptual understanding is a barrier to applying LPs. In addition to that, poor coordination of stakeholders (human attitudinal barriers), unwillingness to change the organisational culture (management barriers), lack of experts (educational barriers), time-consuming adaptation due to staff training (technical barriers), and less support from the government (government barriers) are some other common barriers that affect the implementation of both the BIM standard and the LPs (Kekana *et al.*, 2014; Enshassi *et al.*, 2019).

Sacks *et al.* (2010) proposed a framework based on the interaction between BIM and LPs and concluded that combining both approaches will reduce issues in the construction industry by providing benefits in terms of time and quality. Further, Bhat *et al.* (2018) developed a matrix by addressing the BIM functionalities and LPs to increase the construction industry efficiency by adding value to the final outputs. Eventually, the collaboration of two concepts in complex building projects has created more benefits as the owner can visualise the greater returns from the investments by implementing them from the initial stage (Tuan, 2019). Accordingly, a great deal of research has been conducted based on the application of BIM and lean concepts for construction projects to gain more benefits throughout the construction life cycle by adding value in terms of time and quality (Tuan, 2019; Sacks *et al.*, 2010).

Even though research has been conducted on the application of BIM for LP implementation (Elmaraghy *et al.*, 2018; Gómez-Sánchez *et al.*, 2019; McHugh *et al.*, 2019), minimal attention has been given to the application of LPs for the BIM implementation in Sri Lankan construction projects, while marking a gap of knowledge for more research. This research was conducted to apply LPs with the aim of minimising the BIM implementation costs in the Sri Lankan construction industry. As identified in previous studies, such application of BIM and LPs may mitigate the non-value-adding activities and the misconceptions between the stakeholders and allow the projects to be completed more effectively with high quality and shorter duration, which is a worthy context to be investigated in the Sri Lankan construction industry.

Methodology

Research approach

The research approach is the way that is used to collect data and analyse the collected data to achieve the defined aim of a study (Naoum, 2007). Generally, researchers have used qualitative, quantitative, and mixed approaches to incorporate the collected data (Kothari, 2004). A qualitative approach is a type of data collection and analysis approach used to provide descriptions, build theories, and test theories (Shah & Corley, 2006). Furthermore, Sha and Corley (2006) have asserted that the qualitative method can be used to create new relationships with the variables to understand the complex processes and to illustrate the influence of society. In addition, the qualitative research approach is most appropriate for instances evaluating social, attitudinal, and exploratory behaviours and beliefs (Naoum, 2007). Yin (2014) also highlighted that the qualitative approach is noteworthy in terms of considering a specific group of people and representing their opinions and aspects.

This research aims to apply LPs to the cost centres of BIM implementation to efficiently implement BIM for the Sri Lankan construction industry. Due to a lack of expertise in construction practices that can explicitly apply LPs with BIM cost centres, the primary data required to achieve this goal cannot be collected directly. Therefore, expert interviews were identified as the most appropriate method to identify the suitable LPs that could possibly be applied with cost centres associated with BIM implementation. Furthermore, the nature of the data collected was qualitative and subjective with the aim of this research. Accordingly, the qualitative approach was adopted as the most suitable approach for this research.

Research strategy

The type of the research problem, the degree of influence of the investigator over the actual behavioural actions, and the degree to which current situations are centred have to be considered while selecting the most suitable strategy for a study (Saunders *et al.*, 2019). The survey strategy has been identified as a flexible research strategy that can be used for social and psychological research (Singleton & Straits, 2017). Moreover, the primary purpose of a survey is to collect more information from a large sample of the population who are interested in the research area (Ponto, 2015). Hence, with the aim of this research, a survey strategy could be more appropriate. According to Ponto (2015), the survey strategy can be used to collect both quantitative and qualitative data. Quantitative surveys can be conducted when more data is available, whereas qualitative surveys are conducted when the sources to collect data are limited. This study seeks experts who can demonstrate adequate knowledge of both LPs and the cost centres of BIM implementation in the construction industry. However, BIM is a relatively new concept in Sri Lanka, and therefore to collect rich data, the number of experts who can be identified in the construction industry of Sri Lanka under the above criteria is comparatively low (Epasinghe *et al.*, 2018; Pandithawatta *et al.*, 2018). Due to this, a qualitative survey was selected as the most suitable strategy for this research.

Research Techniques - Data collection and analysis

Semi-structured interviews were adopted as the main data collection technique. As mentioned earlier, due to the lack of experts available in Sri Lanka, the authors have also identified experts who are established abroad but engaged with the Sri Lankan construction industry as potential interviewees for the research. As per Ponto (2015), a sample with a small population can be used to conduct qualitative surveys. Accordingly, only ten (10) interviews were conducted due to data saturation.

Due to the difficulty of finding respondents, the snowball sampling method was used to identify the respondents. This was useful because BIM was not a common practice, and few construction professionals were aware of it. However, the respondents knew of others in their networks who had the required capacity to provide significant input to this study. Accordingly, the initial respondent was asked to propose suitable experts for the study, and the process was followed with subsequent respondents.

Furthermore, difficulties were faced in conducting face-to-face interviews with the respondents due to the COVID-19 pandemic restrictions, but such difficulties were well managed by alternatively arranging online interviews with the selected respondents. Table 2 illustrates the profile of the respondents.

Table 2: Profile of the respondents

Interviewee	**Designation**	**Experience**	**Awareness about**	
			Lean	**BIM**
R1	Lecturer (BIM & Lean Researcher)	10 years	Yes	Yes

R2	Senior Quantity Surveyor	20 years	Yes	Yes
R3	Engineer (Researcher on Built Environment)	12 years	Yes	Yes
R4	Quantity Surveyor (BIM & Lean Researcher)	3 years	Yes	Yes
R5	Chief Engineer (BIM Engineer)	15 years	Yes	Yes
R6	Project Manager (BIM & Lean Researcher)	25 years	Yes	Yes
R7	Chief Quantity Surveyor (BIM Researcher)	20 years	Yes	Yes
R8	Senior Lecturer (BIM & Lean Researcher)	12 years	Yes	Yes
R9	Project Manager (BIM & Lean Researcher)	22 years	Yes	Yes
R10	Senior Engineer (BIM Engineer)	18 years	Yes	Yes

As per Table 2, interviews were conducted with experts who were selected by the snowball sampling method. After 10 interviews, there was neither significant nor new information gathered, hence the number of interviews was limited to 10 due to the data saturation.

The primary data collected through semi-structured interviews in this research were analysed using the content analysis method. Content analysis is a widely used data analysis method in a qualitative approach (Drisko, 2016). Drisko (2016) further asserted content analysis is a technique that is used to identify the presence of specific words, themes, or concepts in qualitative data. This method can be done either manually or with the use of computer-aided software, where a manual content analysis was performed with the collected data in this research.

This study adopted the three-phase coding content analysis process introduced by Williams and Moser (2019), where the research findings were explored as themes (selective codes) following the formation of open and axial codes. Firstly, the data collected through expert interviews were transcribed. Then, by examining the transcripts, open coding was created to identify different concepts and themes. The deductive coding principle was applied to the pre-defined codes, and the inductive coding principle was applied to newly generated codes identified through the interviews. This was repeated several times until selective codes were met when there were no new codes. As a result, qualitative data was thoroughly analysed under the respective codes in order to draw conclusions and add value to the final outcome of the research.

Internal validity refers to seeking to establish a causal relationship (Yin, 2014). The literature review has been established to confirm the relationship between BIM and LPs. Hence, the internal validity of the research was partly achieved through the literature review. Further, the logic of pattern matching has been used to test the internal validity of the research. Within the data analysis discussion, the empirical evidence was analysed by comparing and contrasting it with the existing literature to further test the research for its internal validity. The study's external validity is concerned with establishing a domain to which the study's findings can be generalised. Accordingly, the study findings can be generalisable to the context of the Sri Lankan construction industry.

Research Findings

Challenges to implementing BIM in the Sri Lankan construction industry

Lack of trust and collaboration; lack of knowledge and understanding of BIM; lack of financial and technical capacity; lack of willingness to adopt BIM; reluctance to change; and lack of education and training related to BIM are the main challenges identified in the literature for implementing BIM in the Sri Lankan construction industry.

All ten respondents expressed their opinions on the BIM implementation process. Before implementing BIM in a country like Sri Lanka, R5 expressed that "*the industry should consider the scale of the construction projects, the requirements of the employers, and the willingness of the other professionals*". According to R5, it is preferable to use BIM only for large-scale projects because BIM benefits are much more applicable in their context. In agreement, R7 stated that the employer requirements and the work scopes must be well defined prior to BIM implementation, while also ensuring that most construction professionals are willing to implement BIM on their construction projects. In addition, R2 also expressed that "*the employer and the consultant team have to express their willingness before sharing the model with the contractors*". Following the opinion of R2, the employer and the consultant team should have the capability to implement BIM and develop the initial model. In addition, they should be willing to share the developed model with the contractor team to continue with the construction process. As such, R2 has highlighted that, if all three parties are capable and willing to use BIM, it can be implemented in the construction projects to achieve better performance.

Furthermore, as expressed by R4, R5, and R9, the attitude of the professionals should also be considered before implementing BIM as most of their manual practices would be substituted by BIM. Therefore, a sufficient understanding of the concept of BIM is an essential requirement for the industry, as per R1, R3, R4, and R6.

Confirming this, R3 expressed that "*the industry needs to understand the concept of BIM*". The respondent stated that when senior stakeholders have a better understanding of the BIM concept, it would strengthen the implementation process as they believe their prior knowledge and experience would create a positive attitude among the other staff when adapting to the BIM culture. But in reality, *"most industry professionals in Sri Lanka are uninformed about the concept of BIM*" [R3]. This is one of the main barriers that should be addressed in the process of BIM implementation. As per the respondents, when the key professionals have the knowledge and the understanding, then the rest of the staff can easily be trained with BIM-related software and, in return, a smooth BIM implementation can be achieved.

All respondents agreed that investing in BIM-related training is a critical initiative that the industry should undertake in order to implement BIM. R10 has asserted that "*firms need to invest in BIM and BIM-related software training.*" Construction firms should have the financial and technical capability to hire experts and software to implement BIM. However, R8 and R9 expressed that before recruiting experts and software for BIM, "*the employer needs to be aware of the benefits of BIM and make it a requirement for their projects.*" Adding to that, R1 and R4 emphasised that the feasibility and suitability of the BIM software have to be considered with the requirements of the project and the nature of the construction industry. As a solution, R4, R5, and R6 made it a point to "*start BIM implementation with a basic BIM tool such as Revit."* Upon the selection of suitable software, followed by training of the staff members, the standards for the objects and templates that have to be used in the construction projects can then be set up. Further, respondents explained that BIM can be implemented in a BIM-infant industry by creating convenience for the professionals and then with the proper training about BIM usage and its benefits. Finally, R3 expressed that *"universities should educate undergraduates about BIM technologies"* and R6 also expressed the same opinion by mentioning that it would be easier to implement BIM when graduates have basic knowledge of BIM technologies, but unfortunately, most existing professionals lack knowledge about BIM technologies, and hence, the industry usually adhere with the manual processes.

Contextualising the cost centres associated with BIM implementation in Sri Lanka to integrate LP

A total of 16 cost centres were identified through a literature review, as shown in Figure 1. These 16 cost centres were further examined in the Sri Lankan context using expert interviews. While validating the cost centres, which mainly occurred during the pre-construction and construction stages, the experts also identified the cost centres for the post-construction stage. Accordingly, Table 3 shows the cost centres that are contextualised for the Sri Lankan construction industry.

Table 3: Contextualising BIM implementation cost centres for Sri Lanka

	Cost centres	**Pre-construction**		**Construction**		**Post-construction**		**Possibility of Integrating LP**
		Literature	**Expert**	**Literature**	**Expert**	**Literature**	**Expert**	
1	Cost of hardware and software	√	√	√	√	X	√	√
2	Staff training	√	√	√	√	X	√	√
3	Coordination of stakeholders	√	√	√	√	X	X	√
4	Data collection	√	√	X	X	X	X	√
5	BIM-based decision review	√	X	√	X	X	X	X
6	Additional design details	√	√	X	X	X	X	√
7	Early decision making	√	X	X	X	X	X	X
8	Cost of BIM experts	√	√	√	√	X	X	√
9	Organisation costs	√	X	√	X	X	X	X
10	Repurposing BIM design	X	X	√	X	X	X	X
11	Developing as-built BIM	X	X	√	X	X	X	X
12	BIM ownership determination	X	X	√	X	X	X	X
13	Space requirement	√	√	X	X	X	X	X
14	CAD rework costs	√	X	X	X	X	X	X
15	Contractual cost	√	√	√	√	X	√	√
16	Risk of using new technology	X	√	√	√	X	X	√

The cost centres that are associated with the BIM implementation are found to be the cost of hardware and software; staff training; coordination of stakeholders; data collection; additional design details; cost of experts; space requirement; contractual cost; and risk of using new technology.

All respondents expressed that "*purchasing of the hardware and software is not enough for the BIM implementation and they have to be maintained by updating licencing throughout the construction process.*" According to the statements given by the respondents, the highest costs have to be disbursed within the pre-construction stage to implement BIM. Respondents R1, R2, R4, R5, and R7 highlighted that there should be suitable IT infrastructure and space to accommodate the hardware and its users. Accordingly, R5 expressed that "*BIM is based on technology, and there should be a suitable environment to place hardware used for the process of BIM.*" As a result, the cost of hardware and software can be identified as the major cost centres associated with BIM implementation.

Other than that, as expressed in the cost centres of the BIM implementation, experts have to be hired and staff should be trained to implement BIM for building construction. Table 3 also revealed staff training and the cost of experts as specific cost centres for both the pre-construction and the construction stages. As such, the costs associated with BIM-related training and development have to be considered as one of the cost centres.

The costs for the data collection, the cost for additional design details, and the time consumed for the model creation are identified as the costs specified only for the pre-construction stage. According to the opinion of R1, "all design details have to be complied with at the design stage itself to develop the BIM model, which incurs an additional cost," and this was the opinion of several other respondents, such as R2, R7, R8, R9, and R10. For instance, R8 expressed that "*due to the inadequacy of data during the design stage, model creation will take a long time, which highly affects the employer as a cost heading*," and R10 also had a similar opinion.

R2, R3, R4, and R6 have expressed that the coordination of the stakeholders incurs a cost during the pre-construction and construction stages with the implementation of BIM. According to R7, "*the basic concept of BIM is to create better collaboration between the stakeholders, and the infrastructure to facilitate all stakeholders working together from the design stage costs more compared with the conventional methods.*" Other than that, the contractual cost also affects both the pre-construction and construction stages with the implementation of BIM. According to R5, "*as BIM is a new concept for building construction in Sri Lanka, it costs much more than the conventional methods for the contracts*." A similar opinion has been expressed by both R3 and R6.

According to the opinions given by the respondents, the risk of the usage of new technology is affected during all three construction stages. As the developed BIM model is practically used at all construction stages, R4, R5, and R6 are identified risk of new technology as an additional cost for all construction stages. Other than that, the developed model has to be shared with the contractors during the whole life cycle of the construction. As a result, R4 and R5 identified data transfer costs as an additional cost as it incurs high data for the transferring of the models, which is not affected while using the conventional method. Therefore, besides the findings of Table 3, interviewees have explored the following: the time-consuming of model creation as an additional cost during the pre-construction stage; the cost of transferring data for the construction stage; the cost of experts, hardware, and software; the cost of staff training; and the cost of data transfer as the additional costs associated with the post-construction stage.

Application of lean principles with BIM implementation cost centres

This section analyses the integration of LPs with BIM implementation cost centres. Accordingly, the following LPs were explored as the principles that can be applied with the cost centres for BIM implementation:

- **LP 1: Reduce the share of non-value-adding activities**

According to the experts, the cost of high time consumption, the cost of experts, and the cost of staff training can be reduced with the "reduction of the share of non-value-adding activities".

R1 detailed that the reduction of non-value activities is a basic concept of lean and saves time and money with the removal of activities that take time, space, and resources and do not add value to the final product. R2, R4, and R5 also emphasised a similar opinion. Further, R1 expressed, "*while implementing BIM, all the requirements have to be documented step by step to evaluate where we need the service of experts,*" and then it eases the hiring of experts in cases where they are needed. All other respondents expressed a similar opinion, and they elaborated that hiring experts during the whole process would affect the high cost of experts. Further, the statements of R4, R5, R7, and R9 highlight that the reduction of non-value-adding activities automatically saves time. R1, R3, and R4 mentioned that giving staff training only for the selected staff within a suitable period can save the cost of staff by implementing the principle of "reducing the share of non-value-adding activities."

- **LP 2: Increase output value through systematic consideration of customer requirements**

Respondents expressed that, increasing output value through systematic consideration of customer requirements can be implemented to reduce the cost centres of BIM implementation. R1 detailed that "*before implementing BIM, it is better to identify the needs of the employer and identify relevant software and experts. This principle can also be used to plan all of the project's other requirements*". R2 and R4 expressed a similar opinion and highlighted that this principle can be used to select the appropriate software based on the requirements of the employer, which will reduce the licencing cost. Accordingly, R6 specifies that "*identify the real requirements of the construction sector and use customised software with low costs.*" Apart from that, all the respondents emphasised that the consideration of employer requirements can select suitable experts and, automatically, that will affect the time of the project. Accordingly, this principle can be implemented to reduce the cost of BIM implementation.

- **LP 3: Simplify by minimising the number of steps, parts, and linkages**

In the opinion of the R4, "*this principle is also similar to the reduction of non-value-adding activities, and similar cost centres can be reduced with the implementation of this principle.*" All respondents expressed a similar idea that the cost of experts can be reduced with this principle. According to the respondents, the help of experts can be acquired when it is necessary by simplifying the full hiring period of the experts in order to reduce the cost of experts. Apart from that, R2, R5, R7, and R8 expressed costs of staff training can be reduced with the minimisation of unnecessary documentation during the construction process. Additionally, training can be given to the staff only by identifying their current level of capacity to use the software. In addition to that, R10 expressed, "*construction projects have multiple trades of work coming together to form the final output, and simplification of this process will lead to saving time and the contractual costs due to fewer disputes.*" R7 and R8 mentioned a similar idea and ensured that contractual cost and time consumption could be reduced with the implementation of this principle.

- **LP 4: Increase output flexibility**

According to respondents, the principle of "increase output flexibility" can be implemented to reduce the cost of data collection, contractual costs, and the cost of additional details. R1 described that "*if the final output is clear, the cost of the design details and the collection of data will be saved."* All other respondents also expressed a similar idea and mentioned that the cost of data collection can be reduced due to the flexibility of output. Besides, all respondents emphasised that with the flexibility of the output, professionals will be willing to work with the new technology and contractual costs can be reduced. Also, they highlight that when the output flexibility is increased, the disputes are reduced and contractual costs can be minimised. Apart from that, R4 and R5 added to the statement of R1 that it is easy to collect the additional information related to the construction by reducing the complexities associated with the final output.

- **LP 5: Increase process transparency**

With increasing process transparency, the cost of staff training, expert fees, cost of coordination of the stakeholders, and contractual costs can be reduced. R4 detailed that "*when following Integrated Project Delivery (IPD), there is a clear understanding between the stakeholders, and it will reduce the cost of the project due to transparency."* Likewise, if process transparency is high in the BIM implementation, it can reduce the non-value-adding activities, and that can affect the coordination cost of stakeholders and experts. All other respondents have also emphasised that the stakeholders can be coordinated easily by having transparency in the BIM implementation process. As a result, all respondents agreed that the transparency principle can reduce the cost of experts and coordination. Apart from that, R1, R3, and R8 mentioned that having transparency in the process can reduce the cost of staff training as all the necessary tasks have been defined. Further, R3, R5, R6, and R7 elaborated that disputes can be minimised with the increase in transparency and, in return, the contractual cost can be reduced.

- **LP 6: Focus on the complete process**

R1 expressed that the principle "focus on the complete process" is also similar to the reduction of non-value-adding activities and increasing transparency. The remaining respondents expressed similar sentiments, and they all agreed that incorporating this LP can reduce the time and cost of experts. Apart from that, as in the above cases, R1, R5, and R6 explain that this principle can be integrated with staff training to reduce its cost. Hence, as per the experts, if professionals always focus on the final output, it will reduce the non-value-adding activities that are going to be conducted throughout the process. However, experts highlighted that the principle focus on the complete process greatly contributed to reducing the non-value costs associated with the time-consuming and consultation of experts.

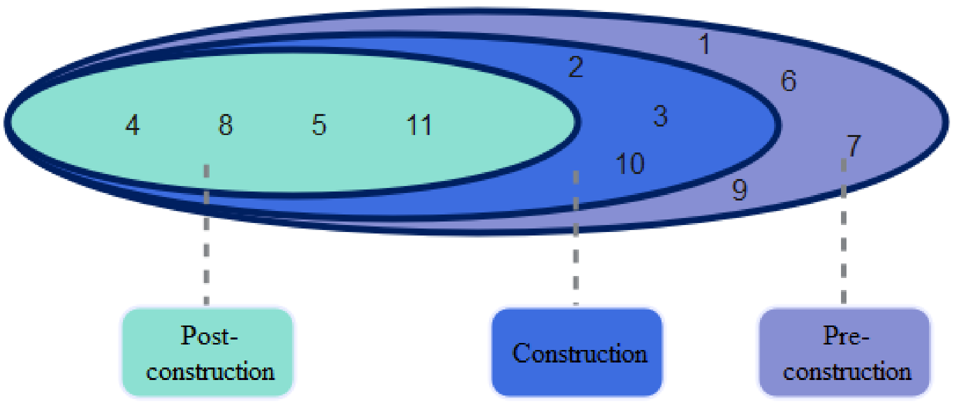
Discussion of the findings

The willingness of the stakeholders to collaborate is a critical factor that needs to be considered while implementing BIM. A detailed design will be created at the initial stage while implementing BIM in construction projects. As a result Sacks *et al.* (2010) explained that when compared with the traditional methods, knowledge related to the construction procedures will be expanded with the BIM implementation. Additionally, Kekana *et al.* (2014) asserted that BIM implementation heavily depends on the willingness of the stakeholders to take part, which is currently lacking in the construction industry. In agreement with this, the empirical findings revealed that there is a lack of willingness among the stakeholders to share their BIM-related knowledge with other stakeholders. Furthermore, Epasinghe *et al.* (2018) and Jayasena and Wedikkara (2012) asserted that the Sri Lankan construction industry is at the infant stage of BIM implementation. According to the respondents, stakeholders can be trained for BIM by hiring BIM experts for construction projects. As a result, BIM can be successfully implemented in the Sri Lankan construction industry.

To increase the value and lower overall costs, we should consider all activities associated with BIM implementation within organisations. Table 3 contextualises the identified cost centres for the Sri Lankan construction industry as per the research findings. As a result, in addition to the cost centres expressed by the experts during the pre-construction stage, BIM-based decision review, early decision making, organisation costs, and CAD rework costs were identified from the literature survey. However, experts have recommended that such costs be included in the cost centres (cost of hardware and software, cost of experts, staff training, and the additional design details) detailed by the experts. In addition to the literature findings, experts have identified the time-consuming nature of model creation as an additional cost during the pre-construction stage.

According to Figure 1, additional cost centres during the construction stage are BIM-based decision review, organisation costs, repurposing BIM design, developing as-built BIM, and BIM ownership. However, BIM ownership costs can be taken under the hardware and software costs as per the respondents. Similarly, they expressed it is not necessary to have an additional cost centre named organisation costs as it will be discovered through the costs of staff training, experts, and stakeholder coordination. Accordingly, experts mentioned that the additional costs revealed in the literature have also been indirectly covered by the cost centres expressed by the experts. In addition, experts have identified data transfer costs as an additional cost for the construction stage.

However, cost centres at the post-construction stage were directly explored through expert interviews. Finally, 11 cost centres for the pre-construction stage, 7 cost centres for the construction stage, and 4 cost centres for the post-construction stage that influence the BIM implementation have been illustrated in Figure 3. Accordingly, there are cost centres overlapped for all three phases and pre-construction and construction phases. In addition, individual cost centres valid for the pre-construction phase were identified. However, there were no individual cost centres for the post-construction and construction phase. The identified cost centres which are experienced by the Sri Lankan construction industry can be illustrated in Figure 3.



1- Additional design details
2 - Contractual cost
3 - Coordination of stakeholders
4 - Cost of experts
5 - Cost of hardware and software
6 - Data collection
7 - IT infrastructure
8 - Staff training
9 - Time-consuming for the creation of model
10- Risk of new technology
11 - Transferring of data

Figure 3: BIM Implementation Cost centres associated with Sri Lankan construction industry

When implementing BIM for Sri Lankan construction projects, LPs are helpful in improving value and at times reducing real costs. However, certain principles are more effective while reducing the costs of each cost centre (refer to figure 3). Even though Koskela (1992) identified eleven (11) LPs, only six principles can apply to the cost centres of BIM implementation. On the other hand, Figure 3 illustrates eleven (11) cost centres for Sri Lankan BIM implementation and only seven (7) cost centres can apply with the LPs. Hence, LPs can be applied to minimise the BIM implementing cost centres by eliminating the non-value-adding activities associated with them. As a result, the application of lean and BIM will create a successful construction industry by increasing its value. The most appropriate cost centres that can be effectively applied with the LPs are illustrated in Table 4 based on both literature findings and expert opinions.

Table 4: Application of Lean and BIM

Cost centres / **Lean principles**	Cost of BIM experts	Staff training	Cost of hardware and software	Contractual costs	Additional design details	Data collection	Coordination of stakeholders
Reduce the share of non-value adding activities	√	√	X	X	X	X	X
Increase output value through systematic consideration of customer requirement	√	X	√	X	X	X	X
Simplify by minimizing the number of steps, parts, and linkages	√	√	X	√	X	X	X
Increase output flexibility	X	X	X	√	√	√	X
Increase process transparency	√	√	X	√	X	X	√
Focus on the complete process	√	√	X	X	X	X	X

For effective BIM implementation in Sri Lankan construction organisations, the industry must consider the entire implementation process as well as potential future benefits. However, several studies (Elmualim & Gilder, 2013; Hallberg & Tarandi, 2011; Epasinghe *et al.*, 2018) have identified possible challenges to BIM implementation in Sri Lanka. Most of the challenges, according to the respondents, can be overcome by reducing the cost centres associated with BIM implementation. Therefore, as revealed by this study LPs can be applied with the BIM implementation cost centres to successfully implement BIM in the Sri Lankan construction industry. As a result, the client, consultant, and contractors will be able to work collaboratively through BIM by developing the Sri Lankan construction industry.

Conclusions and Way forward

The main findings of the study derived from the literature and the expert interviews have confirmed that BIM and Lean are widely researched and that professionals are willing to implement BIM to gain its widely known benefits. However, no adequate research exists to reduce the cost centres of BIM implementation with the help of LPs. Accordingly, this study has addressed this knowledge gap which is specific to the Sri Lankan context. As a result of survey strategy and qualitative data analysis, the study identified the possible benefits, challenges and available cost centres with the BIM implementation, and the LPs that can be applied for BIM implementation. Accordingly, this study found six LPs that can be effectively applied to minimise the BIM implementation cost centres for Sri Lankan construction projects. This study added to knowledge by identifying the best LPs to apply with BIM to overcome implementation cost centres and an opportunity to prioritise LPs in real-life BIM implementation. As with any empirical study, the data collection in this study was limited to the Sri Lankan context, with the possibility to generalise the findings to similar construction industries in other developing countries. In addition, the findings of this study would pave the foundation for BIM implementation at a lower cost by identifying the possibilities of applying the LPs to reduce the cost centres.

References

Abanda, F. H., Mzyece, D., Oti, A. H. & Manjia, M. B., 2018. A study of the potential of cloud/mobile BIM for the management of construction projects. *Applied System Innovation,* 1(2), pp. 1-9.

Albalkhy, W. & Sweis, R., 2020. Barriers to adopting lean construction in the construction industry: a literature review. *International Journal of Lean Six Sigma,* 12(2), pp. 210-236.

Azhar, S., Khalfan, M. & Masqsood, T., 2012. Building information modeling (BIM): now and beyond. *Construction Economics and Building,* 12(4), pp. 15-28.

Barlish, K. & Sullivan, K., 2012. How to measure the benefits of BIM — A case study approach. *Automation in Construction,* Volume 24, pp. 149-159.

Bhat, V., Trivedi, J. S. & Dave, B., 2018. *Improving Design Coordination with Lean and BIM an Indian Case Study.* s.l., s.n., p. 1206–1216.

Cao, D., Li, H., Wang, G., Luo, X., & Tan, D. 2018. Relationship Network Structure and Organizational Competitiveness: Evidence from BIM Implementation Practices in the Construction Industry. *Journal of Management in Engineering,* 34(3).

Carvajal-Arango, D., Bahamón-Jaramillo, S., Aristizábal-Monsalve, P., Vásquez-Hernández, A., & Botero, L. F. 2019. Relationships between lean and sustainable construction: Positive impacts of lean practices over sustainability during construction phase. *Journal of Cleaner Production,* Volume 234, pp. 1322-1337.

Chan, D. W., Olawumi, T. O., & Ho, A. M., 2019. Perceived benefits of and barriers to Building Information Modelling (BIM) implementation in construction: The case of Hong Kong. *Journal of Building Engineering,* Volume 25.

Common, G., Johansen, E. & Greenwood, D., 2000. *A survey of the take-up of lean concepts among UK construction companies.* s.l., s.n.

Creswell, J. W., 2012. *Educational research: Planning, condusting, and evaluating quantitative and qualitative research.* 4th ed. s.l.:Boston, MA:: Pearson Education.

Drisko, J. W. (2016). *Content Analysis.* New York, Oxford University.

Elmaraghy, A., Voordijk, H. & Marzouk3, M., 2018. *An exploration of BIM and Lean interaction in optimizing demolition projects..* s.l., s.n., pp. 112-122.

Elmualim, A. & Gilder, J., 2013. BIM: innovation in design management, influence and challenges of implementation. *Architectural Engineering and Design Management,* 10(3-4), pp. 183-199.

Enshassi, A., Saleh, N., & Mohamed, S., 2019. Barriers to the application of lean construction techniques concerning safety improvement in construction projects, *International Journal of Construction Management*, s.l., s.n.

Epasinghe, E., Jayasena, H., Kolugala, L. & Wijewickrama, M., 2018. *Open BIM adoption in Sri Lankan construction industry.* s.l., s.n., pp. 1-13.

Gardezi, S., Shafiq, N., Nuruddin, M., Farhan, S., & Umar, A. U. 2014., Challenges for Implementation of Building Information Modeling (BIM) in Malaysian Construction Industry. *Applied Mechanics and Materials,* Volume 567, pp. 559-564.

Ghaffarianhoseini, A., Tookey, J., Ghaffarianhoseini, A., Naismith, N., Azhar, S., Efimova, O., & Raahemifar, K., 2017. Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges. *Renewable and Sustainable Energy Reviews,* Volume 75, pp. 1046-1053.

Gómez-Sánchez, J. M., Ponz-Tienda, J. L. & Romero-Cortés, J. P., 2019. *"Lean and BIM Implementation in Colombia; Interactions and Lessons Learned.* s.l., s.n., pp. 1117-1128.

Guthrie, J., Petty, R., Yongvanich, K. & Ricceri, F., 2004. Using content analysis as a research method to inquire into intellectual capital reporting. *Journal of Intellectual capital,* 5(2), pp. 282-293.

Hettiaarachchige, N., Rathnasinghe, A., Ranadewa, KATO., & Thurairajah, N., 2022. Lean Integrated Project Delivery for Construction Procurement: The Case of Sri Lanka. *Buildings*, 12(5)

Hijazi, M., Kensek, K. & Konis, K., 2015. Data Transparency Tool: Enhancing Building Information Modelling to BEM Interoperability. *Engineering & Technology Reference,* pp. 1-12.

Hosseini, S. A. A., Nikakhtar, A. & Ghoddousi, P., 2012. Flow Production of Construction Processes through Implementing Lean Construction Principles and Simulation. *International Journal of Engineering and Technology,* 4(4), pp. 475-479.

Huovila, P. & Koskela , L., 1998. Contribution of the principles of lean construction to meet the challenges of sustainable development. *Sustainable Development,* pp. 13-15.

Ismail, N. A. A., Chiozzi, M. & Drogemuller, R., 2017. *An overview of BIM uptake in Asian developing countries.* s.l., s.n., pp. 080008-1 - 080008-7.

Jayasena , H. S. & Wedikkara, C., 2012. *Building information modelling for Sri Lankan construction industry.* s.l., s.n., pp. 199-201.

John, D. D., 2016. Building information modeling (BIM) technology adoption and implementation in the Sri Lankan construction industry; First part – The diagnosis. pp. 1-27.

Jørgensen, B. & Emmitt, S., 2009. Investigating the integration of design and construction from a "lean" perspective. *Construction Innovation,* 9(2), pp. 225-240.

Koskela, L., 1992. *Application of the new production philosophy to construction,* s.l.: Stanford University.

Kothari, C. R., 2004. *Research Methodology.* s.l.:New Delhi: New Age International.

Liu, S., Xie, B., Tivendal, L. & Liu, C., 2015. Critical Barriers to BIM Implementation in the AEC Industry. *International Journal of Marketing Studies,* 7(6), pp. 162-171.

Manzoor, B. et al., 2021. BIM-Based Research Framework for Sustainable Building Projects: A Strategy for Mitigating BIM Implementation Barriers. *Applied Sciences,* 11(12).

McHugh, K., Dave, B. & Craig, R., 2019. *"Integrated Lean and BIM Processes for Modularized Construction – A Case Study.* s.l., s.n., pp. 227-238.

Michalski, A., Głodziński, E. & Böde, K., 2022. *Lean construction management techniques and BIM technology–systematic literature review.* s-10.l., s.n., pp. 103643.

Mohan, S. B. & Iyer, S., 2005. Effectiveness of lean principles in construction. *Strategy and Implementation,* pp. 421-429.

Naoum, S. G., 2007. *Dissertation research and writing for construction students.* 2nd ed. s.l.:UK: Elsevier Ltd.

Nikakhtar, A., Hosseini, A. A., Wong, K. Y. & Zavichi, A., 2015. Application of lean construction principles to reduce construction process waste using computer simulation: a case study. *International Journal of Services and Operations Management,* 20(4), pp. 461-480.

Olawumi, T. O., Chan, D. W., Wong, J. K. & Chan, A. P., 2018. Barriers to the integration of BIM and sustainability practices in construction projects: A Delphi survey of international experts. *Journal of Building Engineering,* Volume 20, pp. 60-71.

Oraee, M., Hosseini, M., Edwards, D., Li, H., Papadonikolaki, E., & Cao, D., 2019. Collaboration barriers in BIM-based construction networks: A conceptual model. *International Journal of Project Management,* 37(6), pp. 839-854.

Pandithawatta, T.P.W.S.I., Zainudeen, N., & Perera, C.S.R., 2018. An integrated approach of Lean- Green construction: Sri Lankan perspective. *Journal of Built Environment Project and Asset Management,* 10(2), pp. 200-214.

Park, K. & Kim, K., 2014. Essential BIM Input Data Study for Housing Refurbishment: Homeowners' Preferences in the UK. *Buildings,* 4(3), pp. 467-487.

Ponto, J., 2015. Understanding and evaluating survey research. *Journal of the Advanced Practitioners in Oncology,* 6(2), pp. 168-171.

Rathnasinghe , A. P., Kulatunga, U., Jayasena, S., Jayasena, S., & Wijewickrama, C., 2020. Information flows in a BIM-enabled construction project: developing an information flow model. *Intelligent Buildings International*, s.l., s.n. pp. 1-15.

Rathnasinghe, A., & Kulatunga, U., 2019. Investigation on Comparative Roles of Major Stakeholders for BIM Implementation in a Traditional Construction Project Environment. In A. J. Marshall-Ponting, Y. Ji, K. P. Keraminiyage, A. Lee, T. Poppelreuter, W. Swan, . . . H. Van Dijk (Ed.), *14th International Postgraduate*

Research Conference 2019: Contemporary and Future Directions in the Built Environment, pp. 175-188.

Rathnayake, A., 2017. *Building information modelling (BIM) educational framework for the quantity surveying students:*. s.l.:s.n.

Rogers, J. et al., 2015. *BIM development and trends in developing countries.* s.l.:Bentham Science Pulisher Ltd.

Ruan, X., Zuofa, T. & Yang, M., 2016. An Appraisal of Lean Construction Project Delivery: Application of Lean Construction. *SSRN Electronic Journal.*

Saka, A. B. & Chan, D. W., 2020. Profound barriers to building information modelling (BIM) adoption in construction small and medium-sized enterprises (SMEs). *Construction Innovation,* 20(2), pp. 261-284.

Saunders, M., Lewes, P., & Thornhil, A. (2019). *Research methods for business* (8th ed.). New Delhi: Dorling Kindersely (PVT) Ltd.

Shah, S. K. & Corley, K. G., 2006. Building Better Theory by Bridging the Quantitative?Qualitative Divide. *Journal of Management Studies,* 43(8), pp. 1821-1835.

Sharma, S., 2017. Banish Waste from Civil Engineering Operations Applying Lean Thinking. *MOJ Civil Engineering*, 3(4).

Singleton, R. A. & Straits, B. C., 2017. *Approaches to Social Research.* 6th ed. s.l.:Oxford University Press.

Siriwardhana, M. S., Jayasena, H. S., Wijewickrama, M. K. & Kolugala, L., 2018. *Suitable government initiative strategy for BIM implementation in Sri Lanka.* Sri Lanka, s.n., pp. 519-526.

Tan, T., Chen, K., Xue, F., & Lu, W., 2019. Barriers to Building Information Modeling (BIM) implementation in China's prefabricated construction: An interpretive structural modelling (ISM) approach. *Journal of Cleaner Production,* Volume 219, pp. 949-959.

Thomas , E. & Magilvy, J. K., 2011. Qualitative Rigor or Research Validity in Qualitative Research. *Journal for Specialists in Pediatric Nursing,* 16(2), pp. 151-155.

Tuan, N. M., 2019. An analysis of the integration of Lean construction principles in the BIM coordination process. *urnal of Science and Technology in Civil Engineering (STCE) - NUCE,* 13(1), pp. 109-116.

Ullah, K., Lill, I. & Witt, E., 2019. *An overview of BIM adoption in the construction industry: Benefits and barriers.* s.l., s.n., pp. 297-303.

Vilasini, N., Neitzert, T. R. & Rotimi, J. O., 2011. Correlation between Construction Procurement Methods and Lean Principles. *International Journal of Construction Management,* 11(4), pp. 65-78.

Williams, M., and T. Moser. 2019. “The art of Coding and Thematic Exploration in Qualitative Research.” *International Management Review* 15 (1). Pp. 45–55.

Xing, W., Hao, J. L., Qian, L., Tam, V. W., & Sikora, K. S., 2021. Implementing lean construction techniques and management methods in Chinese projects: A case study in Suzhou, China. *Journal of Cleaner Production,* Volume 286.

Yahya, M. A., & Mohamad, M. I., 2011. Review on lean principles for rapid construction. *Jurnal Teknologi,* Volume 54, pp. 1-11.

Yang, J.-B., & Chou, H.-Y., 2018. Mixed approach to government BIM implementation policy: An empirical study of Taiwan. *Journal of Building Engineering,* Volume 20, pp. 337-343.

Yin, R. K., 2014. Qualitative research from start to finish. Guliford Press.

Zheng, L., Lu, W., Chen, K., Chau, K., & Niu, Y., 2017. Benefit-sharing for BIM implementation: Tackling the moral hazard dilemma in inter-firm cooperation. *International Journal of Project Management, 35*(3), pp. 393-405.