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

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ABSTRACT

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

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

1. INTRODUCTION

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

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

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

2. LITERATURE REVIEW

2.1 LEAN IMPLEMENTATION IN PLUMBING WASTE REDUCTION

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

Waste is unavoidable (Ali et al., 2019), and zero waste may not be entirely achievable in the construction industry (Moreno, 2021). However, waste can be minimised by using

different design concepts, altering the materials (Da-Cunha & De-Aguiar, 2020), and altering construction processes (Porwal et al., 2020). Moreover, researchers such as Ranadewa et al. (2021) and Shaqour (2022) highlighted the possibility of implementing lean to eliminate non-value-adding activities in construction. Initially, lean concepts were practised in the automobile manufacturing industry, and gradually expanded to other sectors, such as construction, healthcare, banking, food industry, etc., to enhance efficiency and quality (Bajjou & Chafi, 2018; Wahab et al., 2013). The International Group for Lean Construction (IGLC) has made a significant contribution to the understanding of theoretical foundations of lean construction by extracting the core concept of lean production and applying the lean concept to the management of the construction process (Salem et al., 2005) in different countries such as United State America (Evans et al., 2022), the United Kingdom (Bashir et al., 2010), Denmark (Hansen, 2005), New Zealand (Likita & Jelodar, 2019), Saudi Arab (Sarhan et al., 2017), Jordan (Al Balkhy et al., 2021) and China (Xing et al., 2021). Even though various countries benefit from lean implementation, it is still at a developing stage in Sri Lanka (Madanayake, 2015). The main issue with the application of lean in developing countries is that the construction industry faces numerous challenges and barriers while implementing the lean concept (Kanafani, 2015).

2.2 CHALLENGES AND BARRIERS TO LEAN IMPLEMENTATION

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

2.3 STRATEGIES TO OVERCOME BARRIERS

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

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

3. RESEARCH METHODOLOGY

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

Table 1: Profile of the experts

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

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

Table 2: Summary of questions used in the delphi rounds

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

4. DATA ANALYSIS AND FINDINGS

4.1 BARRIERS TO LEAN IMPLEMENTATION TO REDUCE PLUMBING WASTE

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

Table 3: Barriers to lean implementation to reduce plumbing waste

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

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

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

Management involvement in lean implementation is very important. Proving that, E11 expressed that "*top management involvement is mostly lacking when it comes to applying new strategies in construction"*. Most of the time top management tends to adhere to traditional management concepts due to time and cost pressure. As a result, sometimes employees may select the wrong or missing lean tools and practices. Existing governmental and organisational rules and regulations may cause deficiencies in information flow, which would slow down the lean adaptation process. Moreover, the lack of resources and inefficiency of resource planning may cause plumbing waste generation and impact lean adaptation. Most of the time plumbing works in high-rise buildings are carried out by specialised subcontractors. They avoid implementing lean due to time, cost and new technology constraints. Installation of plumbing in high-rise buildings is a complex process because it involves intricate pipe systems, fixtures, valves and other accessories with incomplete and complicated drawings. Hence, implementing lean with these difficulties in plumbing installation create many barriers. The current market conditions of Sri Lanka have adversely affected the lean adaptation to plumbing

waste reduction in construction. Market fluctuations can have an effect on the dependability and accessibility of plumbing supplies, leading to supply chain disruptions like delayed deliveries or component shortages, which impede effective lean procedures, causing project timeline delays and lower customer satisfaction. Moreover, sometimes specialised subcontractors such as plumbing subcontractors face difficulties while balancing the workload may cause lean implementation. Since lack of lean practitioners in the Sri Lankan construction industry, consulting cost of lean might be high. Lean adaptation requires effective communication mechanisms among different stakeholders, as it is difficult to have in plumbing installation works since many stakeholders such as architects, engineers, plumbers, contractors, etc are involved in plumbing installation works.

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

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

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

Table 4: Barriers and strategies to overcome the barriers

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

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

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

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

4.3 DISCUSSION

According to the findings of the study, resistance to change is one of the most critical barriers in adapting to the lean concept in the construction industry. Proving this, many authors consider this as an important barrier (Huaman-Orosco & Erazo-Rondinel, 2021; Prasad et al., 2022). The respondents highlighted that unwillingness to learn lean is a significant barrier as it requires effective communication, education and focus on the benefits of the lean methodologies. Researchers disclosed that lack of awareness, fear of

job security and complacency and comfort zone are the major reasons for the unwillingness to learn about lean (Abu et al., 2021; Gomez et al., 2020). The majority of plumbing works are carried out by specialised subcontractors. Hence, the fragmentation and subcontracting nature of the construction industry is another significant barrier to lean adaptation. Maraqa et al (2021) discussed that the fragmentation and subcontracting of plumbing work may lead to lack coordination and control and a barrier to information and communication. In order to adapt the organisation culture towards lean, a systematic and comprehensive approach is required. Hence, leadership commitment, education and training, and fostering a continuous improvement mindset are required (O'Connor & Cormican, 2022). The plumbers should be encouraged to experiment new concepts such as lean and technologies and should provide room for trying out innovation. Promoting a culture of innovation helps plumbers actively seek out and implement lean concepts (Garcia & Murguia, 2021).

5. CONCLUSIONS

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

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