Lean Maturity Model for the Sri Lankan Construction Industry: Investigation of Key Model Assessing Components

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Abstract

Implementing lean practices in the construction industry remains challenging, particularly due to the lack of effective mechanisms to assess lean construction maturity. Despite the presence of limited literature on lean maturity models, no model has been developed specifically for the Sri Lankan construction sector. Addressing this gap, the present study takes an initial step toward developing a Lean Construction Maturity Model tailored to the Sri Lankan context by identifying the essential components required for its assessment. Adopting a pragmatic stance, the research employed the qualitative Delphi technique, involving 73 expert interviews conducted over three iterative rounds, followed by five validation interviews. Directed Content analysis was used to extract key elements for the model. The study identified three core components necessary for assessing lean construction maturity: attributes, process areas, and indicators. Specifically, eight attributes were revealed including Production Efficiency, Waste Elimination, Quality Management, People, Customer Focus, Lean Leadership, Transparency, and Lean Philosophy. These attributes are supported by 28 process areas and 140 indicators. Together, these elements form a structured, layered framework for assessing lean maturity. The study contributes original insights by considering the cultural, economic, and institutional dynamics influencing lean implementation in Sri Lanka. While the findings establish foundational components, further research is needed to develop and validate a complete maturity model. Practically, the study enables a more systematic and locally relevant approach to lean adoption, supporting improved industry performance. Socially, it promotes resource efficiency and project success, contributing to more responsible and sustainable construction practices in the Sri Lankan context.

Keywords: lean construction, lean construction maturity model, assessing components, maturity models

Introduction

The construction industry faces significant challenges that traditional management methods struggle to address (Judi and Mustaffa, 2023; Junjia et al., 2025). Lean construction principles have emerged as a transformative solution to address these issues, offering a systematic approach to minimising waste and optimising processes (Aslam et al., 2024). While lean principles have demonstrated success across various industries, their adoption in construction remains inconsistent due to various challenges (Badhotiya et al., 2024). Key challenges in the construction sector include the absence of mechanisms to measure lean construction maturity (Ranadewa et al., 2019; Singh et al., 2023). This indicates that a maturity model can address this issue by providing a framework for assessing lean construction maturity within organisations.

Maturity models for lean construction provide the mechanism to assess lean construction maturity within an entity through lean principles (Nesensohn et al., 2015). The unique characteristics of the construction sector, including project-based nature, fragmented supply chains, and a high degree of variability, necessitate the development of a tailored lean maturity model (Viknaruban et al., 2024). Maturity models come in several forms and provide a mechanism to assess organisations through various assessing components (Ruiz-Lopez et al., 2025). In the context of lean construction, maturity models designed to assess lean maturity are essential for systematically evaluating and driving the advancement of lean practices (Ballard et al., 2002.; Koskela et al., 2000; Nesensohn et al., 2015). However, many countries, particularly in developing regions, face challenges due to the absence of customised lean construction maturity models, leading to fragmented lean adoption in the construction sectors (Jayanetti et al., 2023; Ranadewa et al., 2021). Without a lean construction maturity model, construction firms are unable to systematically assess lean maturity, benchmark progress, or identify gaps that hinder continuous improvement (Arditi et al., 2021). The initial critical step in developing a tailored lean construction maturity model is to investigate the key assessing components of the model. These components include model attributes, process areas, and model indicators, each playing a critical role in shaping the model structure and applicability (Hein-Pensel et al., 2023). Model attributes define the overarching dimensions of lean construction maturity (Kucińska-Landwójtowicz et al., 2024), while process areas provide actionable categories within each attribute that reflect key operational domains (Kusma et al., 2024). Model indicators, in turn, offer measurable criteria that organisations can use to benchmark their performance within each process area (Rashidian et al., 2022). Together, these components form a comprehensive framework for assessing and advancing lean maturity (Bigwanto et al., 2024).

Despite the importance, there is limited research systematically identifying assessing components of lean construction maturity within the construction industry, highlighting a significant gap in the current body of knowledge. Globally, the lack of comprehensive lean construction maturity models and limited research on assessing components, such as attributes, process areas, and indicators, highlights a significant gap. In Sri Lanka, the absence of a tailored model emphasises the need to investigate these components as a crucial first step in addressing local construction challenges. The construction industry in Sri Lanka continues to face significant challenges due to high levels of waste in various forms, which critically hinder project performance (Hewavitharana et al., 2020). In this context, developing practical components to assess lean construction maturity is both timely and essential. Moreover, the lack of a localised model assessing components comprising attributes, process areas, and model indicators specific to lean construction has limited the ability of Sri Lankan construction organisations to fully comprehend lean practices. This gap highlights the need to investigate key assessing components necessary for a comprehensive lean construction maturity model.

To fill the gap, this study aims to investigate the model assessing components applicable to lean construction maturity. By identifying the critical attributes that define lean construction maturity, exploring the process areas under each attribute, and investigating the indicators that measure performance within these areas, the research seeks to bridge the gap in lean construction maturity assessments. Although the focus is on the Sri Lankan construction industry, the findings have broader implications for other contexts due to the universally applicable elements presented. The identified components provide basic guidelines for other countries apart from Sri Lanka, which can be more customised to assess lean construction with minor adaptations. The paper begins with an introduction that outlines the context of lean construction and presents the gap in the existing body of knowledge. The methodology section follows, detailing the approach used to investigate the key assessing components of a lean construction maturity model. Findings and discussions are presented to analyse the results and their implications. The paper concludes by summarising the contributions of the study and proposing areas for future research to advance the field of lean construction maturity further.

Literature review

Lean construction

Lean construction, first articulated by Koskela in 1992, reframed construction as a production system rather than a sequence of isolated conversions (Koskela 1992, Koskela 200; Koskela et al., 2002). His theory of production highlighted the integration of value generation, waste minimisation, and flow reliability as the foundation for performance improvement in construction. Subsequent work expanded this perspective, emphasising the practical application of lean principles through process mapping, planning reliability, and waste reduction strategies (Ballard & Tommelein, 2012; Koskela, 2000).

While early studies focused on operational efficiency, recent scholarship positions lean construction as an organisational and digital transformation philosophy rather than a collection of techniques (Bajjou & Chafi, 2026). Tezel et al. (2020) trace the evolution of lean construction over twenty-five years, identifying the shift from tool-based implementation to system-based capability development. The principle of respect for people, established by Womack and Jones (1997) and reinforced by Arditi et al. (2021), highlights human empowerment as essential for sustainable lean adoption. Hamza Khan et al. (2024) further emphasise that without participatory engagement and workforce alignment, lean practices fail to achieve their intended outcomes.

Contemporary research also integrates lean with digitalisation and sustainability. Rashidian et al. (2022) argue that the digital construction era transforms lean thinking by embedding automation, real-time data, and feedback mechanisms into production management. Görsch et al. (2025) advance this argument through their concept of Lean Construction 4.0, demonstrating how digital visual management systems enable situational awareness and autonomous decision-making. Likewise, Noh et al. (2025) explore the synergy between Building Information Modelling (BIM) and lean methodologies, noting that while digital tools enhance coordination and visualisation, cultural and process misalignments continue to constrain full maturity. Together, these studies show that lean construction is evolving into a digitally enabled socio-technical philosophy, where technology, process design, and human engagement converge to create adaptive and value-driven production systems (Amos et al., 2026).

Lean construction maturity

The concept of lean construction maturity measures the extent to which lean principles are institutionalised within an organisation's culture, systems, and operations (Hamza Khan et al., 2024). Early frameworks, such as those by Nesensohn et al. (2015), defined maturity as a sequential process of adopting and standardising lean tools. However, this linear interpretation has been challenged for its limited sensitivity to contextual dynamics and organisational learning.

Recent frameworks treat maturity as a dynamic, multi-dimensional construct that integrates people, processes, and technology. Tezel et al. (2021) present an assessment framework linking continuous improvement metrics with feedback loops to evaluate lean performance. Jayanetti et al. (2024) extend this model for developing countries, proposing maturity assessment dimensions that include cultural readiness, leadership engagement, and process alignment. Olanrewaju and Ogunbayo (2024) add a stakeholder-oriented lens, highlighting the role of readiness and cross-functional collaboration in achieving sustainable lean transformation.

Empirical evidence demonstrates that lean maturity correlates with both productivity and organisational agility. Alarcón et al. (2019) show that the systematic implementation of lean practices enhances cost, time, and quality performance across projects. Similarly, Babalola et al. (2023) confirm that lean maturity is positively linked to project success metrics in UK construction firms. These studies collectively indicate that maturity is not a static end-state but an evolving capability shaped by learning, technology adoption, and stakeholder collaboration.

Emerging research reinforces the convergence of maturity assessment with digital integration. Yadav et al. (2022) argue that combining lean principles with BIM-driven data analytics enhances decision-making precision. The findings of Görsch et al. (2025) and Noh et al. (2025) further demonstrate that digital maturity and lean capability co-evolve, redefining what organisational excellence means in construction. This suggests that the future of lean construction maturity lies in the development of resilient, data-informed, and people-centred systems that continuously adapt to technological and environmental change.

Key assessing components of lean construction maturity models

The assessing components of lean construction maturity models usually follow a layered and hierarchical structure that allows a comprehensive evaluation of organisational capabilities and lean practices. This structure is comparable to the Capability Maturity Model Integration (CMMI), which progresses from broad thematic levels to specific processes and measurable outcomes, offering a systematic approach to maturity assessment (Lazzaris et al., 2024; Software Engineering Institute, 2006). Such a layered configuration captures the interaction between strategy, process, and performance, which is essential for understanding maturity in the construction context.

Wernicke et al. (2023) highlight that this multi layered design enables a detailed analysis of lean capabilities, providing both diagnostic and developmental insights. It not only measures progress but also identifies gaps between current and desired lean performance. The most widely accepted maturity frameworks converge around three major components: attributes, process areas, and indicators (Arditi et al., 2021; Nesensohn et al., 2015).

Model attributes represent the core principles of lean construction, including waste reduction, process optimisation, respect for people, and continuous improvement. These elements define the guiding values that shape organisational practices and cultural alignment (Hofacker et al., 2008). Process areas translate these broad principles into practical actions. For instance, the process area for waste reduction may include workflow integration, improved collaboration, and visual management practices that enhance communication and material flow (Sun et al., 2009; Jayanetti et al., 2024).

The third layer, measurable indicators, brings objectivity to maturity evaluation by translating conceptual ideas into quantifiable results. Indicators include metrics such as process efficiency, rework rates, cost reduction, safety records, and quality improvement (Goksen et al., 2015). These metrics provide tangible evidence for decision making and ensure that the evaluation of lean maturity is supported by verifiable data rather than abstract interpretation.

Several maturity frameworks have advanced understanding in this field, including the Lean Construction Readiness (LCR) model (Hofacker et al., 2008), CIM3 (Willis & Rankin, 2012), CM3 (Sun et al., 2009), and the Lean Construction Maturity (LCM) model (Goksen et al., 2015; Khoshgoftar & Osman, 2009; Nesensohn et al., 2015). Although these models provide valuable conceptual foundations, many lack explicit definitions of their assessment components, which limits their adaptability to different organisational settings (Wernicke et al., 2023).

Recent studies expand these models by embedding digital transformation and data based evaluation methods. Görsch et al. (2025) propose that digital visual management enhances feedback accuracy and transparency within maturity assessment frameworks. Similarly, Noh et al. (2025) find that linking lean attributes with Building

Information Modelling based performance indicators strengthens the relationship between qualitative maturity evaluation and quantitative outcomes. Collectively, current research suggests that having clearly defined and technology aligned assessment components is vital for establishing consistent, evidence informed, and strategically focused evaluations of lean construction maturity..

The reviewed literature collectively establishes the foundation for this study by tracing how lean construction has evolved into structured maturity frameworks and highlighting the importance of measurable assessing components. Prior research also reveals contextual limitations, particularly within Sri Lanka, where lean implementation lacks systematic evaluation. These insights directly inform the identification of research gaps discussed next.

Gap in lean construction maturity assessments

Global context

The global literature on lean construction maturity assessments continues to reveal the absence of a comprehensive, universally applicable model. Existing research is largely fragmented and limited to regional contexts. Studies in Brazil (Rodegheri & Serra, 2020), Saudi Arabia (Sarhan et al., 2020), and Germany (Johansen, 2015) examine contextual adoption of lean practices but lack holistic maturity frameworks. The model proposed by Nesensohn et al. (2015) remains the only fully developed framework, focused on the United Kingdom. However, its regional specificity constrains wider applicability. Thus the limited mechanisms on assessing lean construction maturity has contributed to organisational hesitancy in implementing lean construction practices.

Recent work by Jagannathan et al. (2025) stresses that despite increased adoption of lean principles for dispute avoidance and process improvement, there is still no globally standardised maturity evaluation system. Similarly, studies by Maasouman and Demirli (2016), Setianto et al. (2016), Cano et al. (2021), and Sajjad et al. (2023) have provided insight into readiness and implementation but fail to establish structured indicators for consistent assessment. The lack of clarity around assessing components such as attributes, process areas, and indicators prevents the creation of robust benchmarking mechanisms. This limitation continues to hinder global comparability and maturity progression in lean construction.

Local context

In Sri Lanka, there is no evidence of a formal lean construction maturity model (Ranadewa et al., 2019, Jayanetti et al., 2024). This gap presents both an industry challenge and a research opportunity. Local studies (Ranadewa et al., 2019, 2021; Parameswaran et al., 2024; Manoharan et al., 2023) have identified persistent inefficiencies such as material waste, cost escalation, and schedule delays. These are aggravated by lack of lean implementation and a lack of standardised evaluation methods.

Lawanga et al., (2025) recently conducted a systematic review identifying the fragmented nature of lean integration in Sri Lankan construction and called for a national framework grounded in measurable maturity indicators. Similarly, Parameswaran and Ranadewa (2024) highlight the importance of context-specific lean learning mechanisms for sustainable performance improvement. Developing a Sri Lanka-specific maturity model that defines clear assessing components and aligns them with local industry characteristics will address these deficiencies and advance both theoretical and practical understanding of lean maturity in developing economies.

Considering both the global and local gap, it is essential to investigate key assessing components, such as model attributes, process areas, and indicators, as the first step in developing an appropriate lean construction maturity model.

Methodology

This study is grounded in pragmatic philosophical stance, emphasising the development of practical and adaptable assessment components designed to effectively evaluate lean construction maturity within organisations (Saunders et al., 2019). Epistemologically, pragmatism focuses on knowledge as action-oriented and problem-solving, combining subjective experiences with objective evidence to generate practical insights. Ontologically, it views reality as dynamic and shaped by human actions and decisions, emphasising the interaction between theory and practice. Axiologically, the research is value-free, with efforts made to minimise researcher biases as much as possible to ensure objective and credible outcomes (Creswell, 2003; Saunders et al., 2019). An abductive approach is used in the study as it integrates inductive and deductive methods, enabling the modification of existing lean construction theories to generate context-specific knowledge (Saunders et al., 2019).

Qualitative research choice was deemed appropriate as it is well-suited for gaining in-depth insights into the phenomenon of lean construction maturity (Yin RK., 2016). Given the limited prior knowledge in this area and the scarcity of local experts in Sri Lanka, qualitative methods allow for a comprehensive understanding by capturing in-depth data through participant perspectives, observations, and contextual analysis, offering valuable insights into how lean construction maturity is perceived within organisational settings (Petchamé et al., 2022). A qualitative survey was adopted as the research strategy through expert interviews within a cross-sectional time horizon

(Fellows and Liu, 2022). The qualitative Delphi technique is a survey-based method designed to achieve expert consensus through structured rounds of questions and qualitative Delphi method is compatible with the pragmatic philosophy (Fathullah et al., 2023). This study utilised the Delphi technique, which is commonly employed to establish expert agreement on subjects requiring detailed analysis (Meijering et al., 2013). Delphi technique relies on non-probability or purposive sampling, with predefined criteria to ensure the inclusion of participants possessing substantial expertise (Skulmoski et al., 2007). Accordingly, experts were selected purposively based on their knowledge and experience as detailed in Table 1.

Table 1: Delphi rounds, expert selection criteria and expert profile

Delphi Rounds and Objectives		
Delphi Round	**Phase (P)**	**Key Objectives**
Delphi round 1	Round 1 Phase 1 (R1P1)	Identify the model attributes of lean maturity model for the Sri Lankan Construction Industry
Delphi round 2	Round 2 Phase 1 (R2P1)	Identify the key model attributes of lean maturity model for the Sri Lankan Construction Industry
	Round 2 Phase 2 (R2P2)	Identify the process areas applicable to model attributes of lean maturity model for the Sri Lankan Construction Industry
	Round 2 Phase 3 (R2P3)	Identify the model indicators applicable to lean maturity model for the Sri Lankan Construction Industry
Delphi round 3	Round 3 Phase 1 (R3P1)	Investigate the applicable process areas under each model attributes of lean maturity model for the Sri Lankan Construction Industry
	Round 3 Phase 1 (R3P2)	Assess the important model indicators under each process area of lean maturity model for the Sri Lankan Construction Industry

Expert Profile												
Expert Code	Compulsory (Must satisfy at least one from each)				Additional Qualifications (Must satisfy at least 3)					Participation		
	A		B									
	5+ experience in LC job role	3+ academic experience in LC	10+ experience Built environment	10+ academic experience in built-environment	Graduated in built environment discipline	Professional affiliation to Lean related institution	Member of professional institution in built environment	Master's qualification in built-environment or lean	2+ indexed publications	Delphi R1 25	Delphi R2 24	Delphi R3 24
E1	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓
E2	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓
E3	✓		✓		✓	✓	✓	✓		✓	✓	✓
E4	✓		✓		✓		✓	✓		✓	✓	✓
E5	✓		✓		✓		✓	✓		✓	✓	✓
E6	✓		✓		✓		✓	✓		✓	✓	✓
E7	✓		✓		✓		✓	✓		✓	✓	✓
E8	✓		✓		✓	✓	✓	✓		✓	✓	✓
E9	✓		✓		✓		✓	✓		✓	✓	✓
E10	✓		✓		✓		✓	✓		✓	✓	✓
E11	✓		✓		✓		✓	✓		✓	✓	✓
E12	✓		✓		✓		✓	✓		✓	✓	✓
E13	✓		✓		✓		✓	✓		✓	✓	✓
E14	✓		✓		✓		✓	✓		✓	✓	✓
E15	✓		✓		✓		✓	✓		✓	✓	✓
E16	✓		✓		✓		✓	✓		✓	✓	✓
E17	✓		✓		✓			✓		✓	✓	✓
E18	✓		✓		✓			✓		✓	✓	✓
E19		✓		✓	✓			✓	✓	✓	✓	✓
E20		✓		✓	✓			✓	✓	✓	✓	✓
E21		✓		✓	✓			✓	✓	✓	✓	✓
E22		✓		✓	✓			✓	✓	✓	✓	✓

E23		✓		✓	✓			✓	✓	✓	✓	✓
E24		✓		✓	✓			✓	✓	✓	✓	✓
E25		✓		✓	✓			✓	✓	✓		

Expert Profile for Validation Rounds								
Compulsory (Must satisfy at least one from A and B)				Additional Qualifications (Must satisfy at least 3)				
A		B						
5+ experience in lean job role	5+ academic experience in lean construction	15+ experience Built environment	15+ academic experience in built-environment	Graduated in built environment discipline	Professional affiliation to Lean related institution	Member of professional institution in built environment	Master's qualification in built-environment or lean	2+ indexed publications
✓	✓	✓	✓	✓	✓	✓	✓	✓
✓	✓	✓	✓	✓	✓	✓	✓	✓
✓	✓	✓	✓	✓	✓	✓	✓	✓
✓		✓		✓		✓	✓	
✓		✓		✓		✓		
✓		✓		✓		✓		

This research was conducted in three Delphi rounds, as results are often found to stabilise and achieve accuracy after two iterations, with many construction-related studies reaching consensus within two or three rounds (Mansour et al., 2022). The appropriate size of a Delphi panel depends on the topic, diversity of perspectives, and available resources (Keeney et al., 2011). Notably, Delphi studies necessarily do not require large participant numbers for validity, with panel sizes typically recommended to range from 10 to 18 participants (Mahajan et al., 1976). Similarly, Skulmoski et al. (Skulmoski et al., 2007) suggest that a group of 10 to 15 experts is sufficient to generate reliable and meaningful results. However, the number of participants may vary across rounds due to dropouts or non-participation (Avella, 2016). The experts were selected using a non-random purposive sampling approach, complemented by snowball sampling, as it was essential to identify professionals with demonstrable expertise in lean construction management, an area in which suitably qualified experts are limited within the Sri Lankan context. A rigorous selection criterion was followed as mentioned in Table 1. Experts were purposively selected based on predefined eligibility criteria to ensure substantive knowledge of lean construction and the built environment. Participants were required to satisfy at least one compulsory criterion related to professional or academic experience in lean construction or the built environment, and a minimum of three additional criteria covering academic qualifications, professional affiliations, and research or industry experience. This ensured that the Delphi panel comprised individuals with both practical exposure and scholarly competence relevant to lean construction maturity assessment. The selection process was conducted in two stages including an initial screening survey followed by semi-structured expert interviews. An industry-wide screening survey was administered to approximately 50 potential participants identified through professional networks, industry associations, and academic contacts. From the initial pool of 50 respondents, experts with the highest levels of relevant experience were prioritised for interviews using the selection criteria mentioned in Table 1. A total of 23 interviews were conducted initially, after which data saturation was observed, as no new codes or themes emerged from the qualitative analysis. To confirm saturation and ensure robustness of findings, two additional interviews were conducted, resulting in a final sample of 25 expert interviews. Thus, 25 experts contributed to the first round, while 24 participated in the second and third rounds, reflecting time constraints and the attainment of data saturation. A total of 73 expert interviews were conducted, and each interview lasted from 70 minutes to 90 minutes. Findings with 75% consensus were accepted, aligning with previous studies and the commonly used threshold for expert agreement (Goodarzi et al., 2017). At the end of each round, a summary of the findings from the preceding round was presented to participants to gather any necessary feedback or comments.

A qualitative code based analysis was employed using directed content analysis. This approach is suitable where existing theory informs the initial coding framework while still allowing for the emergence of context specific insights (Williams and Moser, 2019). An initial coding structure was developed deductively from established lean construction maturity constructs. Interview transcripts were then systematically coded, with new codes added inductively where expert responses extended or nuanced existing concepts. Methodological rigour was enhanced through several strategies. Iterative Delphi rounds supported stability and convergence of expert judgement. Moreover, the iterative nature of the Delphi technique provides inbuilt validation, as findings from each round are consolidated and confirmed across the expert panel before newly emerging insights are incorporated into subsequent rounds (Mwita, 2022). The use of an explicit coding framework improved analytical transparency and consistency. Reflexive memoing was used throughout the analysis to document interpretive decisions and reduce researcher bias. Anonymisation of transcripts and secure data handling further supported ethical integrity and credibility. Ethical approval was obtained prior to data collection. Data were anonymised, and the confidentiality of the respondents was secured.

To enhance the rigour and practical validity of the findings, an additional validation step was undertaken to ensure that the developed maturity attributes were meaningful, credible, and applicable within real organisational settings. The findings of the validation are presented in the Findings and Analysis section.

This study employed a qualitative Delphi technique to develop lean construction maturity attributes within a specific context. Some findings are context-specific and based on expert judgement rather than quantitative measurement, which would limit generalisability to those contexts. A limitation of the Delphi technique is its reliance on expert judgement, which may limit the generalisability of the findings. The results represent validated perceptions of maturity attributes rather than their empirical performance, and should therefore be interpreted as contextually grounded and exploratory in nature.

Results and analysis

Key model attributes of lean construction maturity model (Delphi Round 1 Phase1, Delphi Round 2 Phase 1)

During Delphi Round 1 Phase 1, 8, key attributes identified through literature were given to experts to validate for Sri Lanka. Experts validated all eight attributes and added one additional attribute. In Delphi Round 2 Phase 1, all nine attributes were presented to the experts to identify the key model attributes. In that round, experts identified eight attributes as the key model attributes, which cover the fundamentals of lean construction maturity, as shown in Table 2. One attribute, 'Policy', did not receive the 75% consensus. As per experts, Policy at a broader political or regulatory level may influence lean construction implementation, but it does not directly represent an organisation's maturity.

Table 2: Key Model Attributes

	Model Attribute	Identified from literature	Validated by experts	Consensus of 75% or more
1	Production Efficiency	✓	✓	✓
2	Waste Elimination	✓	✓	✓
3	Quality Management	✓	✓	✓
4	People	✓	✓	✓
5	Customer Focus	✓	✓	✓
6	Lean Leadership	✓	✓	✓
7	Transparency	✓	✓	✓
8	Lean Philosophy	✓	✓	✓
9	Policy		✓	x

All experts unanimously emphasised that all 08 model attributes are broad, overarching principles of lean construction and do not require context-specific modifications. In contrast, the model indicators, which function at a more practical level, were significantly modified to align with local practices and conditions. E5 explained, "*Model Attributes is the outermost/principal layer of the model assessing components. This includes fundamentals of lean construction at a very overarching level so that the list is not too much and provides guidance to go into more descriptive layers.*"

Production efficiency emerged as a prominent attribute, supported by literature and confirmed by all experts (100% consensus), with expert opinions suggesting a potential reduction in workflow instability and idle time of around 8% in Sri Lankan construction projects. As E1 noted, "*Production efficiency represents the point where lean principles translate into the actual flow of work on site, determining how smoothly activities* *progress throughout the project,"* underscoring its operational relevance. In practice, the findings confirmed that firms should strengthen resource efficiency, labour output, equipment utilisation, and task readiness by adopting structured Last Planner System practices. A general manager in a major construction firm said, "*When we started doing daily planning and lining up labour, materials, and equipment each morning, a lot of waiting time disappeared, the workflow became much smoother, and we ended up saving about 11 per cent on a USD 3.50 million project*." This observed impact is consistent with expert perspectives in lean construction that emphasise production control and workflow stabilisation through reliable daily commitments. The finding demonstrates that tangible cost savings and a more streamlined production cycle can be achieved by systematically managing the production process from activity readiness through completion through small-scale, process-oriented practices embedded across successive stages of the construction process, rather than through large, capital-intensive, or technology-driven interventions. From a policy perspective, production efficiency becomes equally critical, as policymakers can integrate these requirements into project prerequisites and selection criteria, leading to more reliable project delivery and broader improvements in sector performance.

Waste elimination received unanimous expert consensus, with experts' evidence indicating that systematic waste control can substantially reduce resource waste in Sri Lankan construction projects. As E2 emphasised, "*Removing avoidable waste is the fastest way to improve cost performance on any site, because it immediately affects how money is spent on materials and labour*," highlighting its direct operational value. The findings demonstrate clear practical implications. Firms can improve cost efficiency and site performance by integrating structured waste-control routines. As one expert explained, "*Regular waste inspections, tracking how materials move on site, and using* *simple tagging systems help us see where losses are happening before they escalate."* This is illustrated by a project manager who noted, "*By using waste tags and material logs, we reduced offcuts, lowered disposal costs, and kept the site much cleaner and better organised.*" These findings further indicate that lean waste reduction principles can be applied at the level of routine work activities, including material handling and storage. As the senior construction manager affirmed, "*When these practices are embedded at the site operational level, small, process-oriented improvements start to add up, leading to measurable reductions in material costs,*" providing tangible results that reinforce stakeholder confidence and encourage wider adoption of lean practices.

At a policy level, the results point to the need for formal waste-reporting and monitoring requirements within project guidelines, enabling more transparent resource use and supporting national efforts to reduce construction-sector waste.

Quality management was strongly validated by all experts, with findings confirming that structured inspection routines and total quality management practices reduce rework and late-stage cost overruns. As E3 noted, "*consistent quality control is a cornerstone in lean construction as it prevents the errors that later become expensive cost overruns,*" emphasising its operational value. The results indicate that firms can improve reliability by embedding stage-based checks and supervisor signoffs, while policymakers can strengthen approval processes by requiring evidence of systematic quality practices.

People factor also emerged as a critical maturity attribute, with experts emphasising that lean success depends on how effectively workers are engaged, empowered, and continuously developed. Evidence shows that targeted training initiatives enhance coordination and task readiness, thereby reducing workflow interruptions and rework. As E4 explained, "*Lean only works when all people understand how their actions influence flow. Once that understanding is built through training, teams coordinate better, tasks are ready when needed, and interruptions and rework reduce significantly*," highlighting the central role of competence and shared responsibility. The findings therefore demonstrate that these people-focused practices should be systematically embedded within key organisational functions, particularly construction management units, site supervision teams, and project control offices, where daily coordination and problem-solving directly influence workflow stability. As reflected in the findings, integrating continuous learning mechanisms within operational layers can strengthen collective understanding of flow and waste reduction. As a chief executive officer explained, "Peer learning sessions, short feedback cycles, and role-based lean simulations help our teams see how their daily decisions affect flow and waste." At the firm level, he further noted, "*When performance evaluation and training policies are aligned with lean capability indicators, behavioural change is sustained rather than short lived*." More broadly, the results point to the importance of policy-level support, where industry bodies and regulators facilitate accredited lean training frameworks, incentives for organisational learning, and structured knowledge-transfer platforms across projects. Such institutionalised capacity-building efforts can help mitigate recurring operational bottlenecks and enable scalable lean implementation across the construction sector.

The findings show that customer focus plays a decisive role in reducing client-driven changes, with evidence demonstrating that early engagement and clear requirement mapping minimise revisions and improve predictability. As E5 noted, "*By taking the time to understand the client's needs early on, we can avoid late-stage surprises, reduce unnecessary changes, and make project outcomes much more* *predictable*," reflecting its operational value. These insights indicate that implementing structured client engagement mechanisms across key project stages, particularly during project initiation, design development, and approval milestones, can significantly enhance workflow stability and resource planning. Within construction organisations, project management offices, design teams, and site planning units are critical areas for incorporating systematic requirement validation, iterative brief clarifications, and milestone-based client reviews. As a senior project manager explained, "*When we clarify client expectations and align our teams at every stage, our design and execution decisions are based on validated requirements, which reduces rework and makes project outcomes far more predictable*," clearly demonstrating the operational value of this approach. The findings indicate that establishing formal organisational guidelines or regulatory requirements for structured client engagement, such as milestone-based briefings and systematic requirement validations, can reduce approval delays and improve workflow predictability. This demonstrates that policy-level interventions, whether through internal governance frameworks or standardised project procedures, play a critical role in supporting lean practices and enhancing overall project efficiency. Collectively, these findings demonstrate that integrating customer focus into operational practices produces measurable benefits in efficiency and lean performance throughout the construction process.

The findings confirm that lean leadership is a central driver of maturity, with visible managerial commitment accelerating adoption and reinforcing behavioural consistency across teams. As E6 mentioned, "*Lean only works when all people understand how their actions influence flow,*" adding that "*it starts at the top — people take their cues from how leaders act*.," highlighting the operational influence of leaders in shaping team practices and creating a culture conducive to lean adoption. The evidence indicates that leadership is particularly critical at the project and site management levels, where decisions regarding workflow coordination, resource allocation, and team engagement directly impact performance. Firms can operationalise these findings by embedding leadership walk-arounds, structured coaching sessions, and routine problem-solving routines, ensuring that managerial commitment is visible and sustained throughout the project lifecycle. Project managers, site engineers, and team supervisors are key nodes for implementing these practices, as they translate strategic leadership into consistent daily behaviours across operational teams. At the policy level, the findings suggest that establishing accountability mechanisms for leadership in project governance including as reporting requirements, performance audits, or mandatory oversight routines, can reinforce managerial commitment and ensure alignment with lean objectives.

Transparency was similarly validated as a critical enabler of lean performance. Evidence from the study demonstrates that clear, timely, and visible information flow reduces delays, prevents task clashes, and improves coordination between interdependent teams. As E7 stated, "*When information is clearly visible to everyone on the team, people stop guessing what others are doing, start coordinating their tasks effectively, and workflow becomes much smoother,*" illustrating the direct operational benefits of transparency. As experts added, within construction organisations, these practices can be implemented through visual boards, progress tracking displays, regular coordination meetings, and digital dashboards that highlight task dependencies and performance metrics in real time. Departments such as site operations, project control, and planning units are particularly important for embedding transparency practices, as they oversee the sequencing of work, resource utilisation, and team communication. Furthermore, policymakers can support these efforts by promoting standards for digital reporting and real-time information sharing in public projects, thereby institutionalising transparency as a mechanism to reinforce lean practices.

Finally, the findings demonstrate that lean philosophy provides the cultural foundation necessary for sustained improvement, with a shared mindset of continuous enhancement reinforcing long-term adoption of lean practices. As E8 explained, "*lean becomes effective when it shifts from a toolset to a way of thinking*, *and it is always necessary to think about the ground you are playing" highlighting that lean's transformative potential relies on embedding improvement as a way of working rather than simply applying techniques considering the environment*. The evidence indicates that fostering this mindset is particularly critical at all organisational levels, where cultural norms, team behaviours, and decision-making processes influence the consistency and effectiveness of lean implementation. As per expert views, firms can operationalise these insights by conducting regular continuous improvement reviews, facilitating cross-functional reflection sessions, and promoting knowledge sharing forums that encourage employees at all levels to identify inefficiencies and implement incremental enhancements. At the sector level, policymakers and professional bodies can reinforce a culture of improvement by supporting awareness campaigns, structured training programs, and professional development initiatives that promote lean thinking across organizations. Collectively, the findings demonstrate that embedding lean philosophy as an organizational culture creates the conditions for sustained performance improvement, aligning behaviours, decision-making, and operational practices with long-term lean objectives.

As indicated in Table 2, one attribute was not carried further as it did not receive 75% consensus from the experts. Experts rejected the inclusion of the attribute, 'Policy', noting that it does not qualify as a key attribute even though it is relevant. Expert E4 elaborated, stating, *"I don't believe 'Policy' qualifies as a key model attribute. While it's relevant, it doesn't stand out as one of the primary attributes. Instead, it could be addressed within process areas or at the indicator level."*

Process areas under each key model attribute (Delphi Round 2 Phase 1, Delphi Round 2 Phase 2, Delphi Round 3 Phase 2)

During the Delphi Round 2 Phase 2, experts were presented with 28 process areas identified from literature for validation to suit the Sri Lankan construction sector. The experts accepted 25 of the identified process areas without alterations and three process areas were modified (indicated in italics). In Delphi Round 3 Phase 2, the finalised 28 model process areas were given to the experts to categorise them under key attributes identified from Delphi Round 2 Phase as detailed in Table 3.

Key Model Attributes	Model process areas	Identified from literature	Validated by experts	Consensus of 75% or more
Production Efficiency	Reduce variability	✓	✓	✓
	Minimise cycle time	✓	✓	✓
	Output flexibility	✓	✓	✓
	Flow & conversion	✓	✓	✓
	Processes and tools	✓	✓	✓
	Supply chain integration	✓	✓	✓
Waste Elimination	Lean waste identification	✓	✓	✓
	Reduce non-value-adding activities	✓	✓	✓
	Waste minimisation	✓	✓	✓
Quality Management	Continuous improvement	✓	✓	✓
	Benchmarking	✓	✓	✓
	Standardisation	✓	✓	✓
	Error detection and prevention	✓	✓	✓
Lean Leadership	*Leadership and strategic drive*	✓	✓	✓
	Alignment to business goals	✓	✓	✓
	Top management commitment	✓	✓	✓
People	Training and development	✓	✓	✓
	Conducive work environment	✓	✓	✓
	Collaborative working	✓	✓	✓
	Competency development	✓	✓	✓
	Knowledge sharing	✓	✓	✓
Customer Focus	Requirement analysis	✓	✓	✓
	Customer-centric approach	✓	✓	✓
	Flexibility	✓	✓	✓

Key Model Attributes	Model process areas	Identified from literature	Validated by experts	Consensus of 75% or more
Transparency	*Information transparency*	✓	✓	✓
	Workplace organisation	✓	✓	✓
Lean Philosophy	Lean culture	✓	✓	✓
	Transformational change	✓	✓	✓

The findings indicate that the 28 process areas provide sufficient coverage for assessing lean construction maturity, with experts confirming that they appropriately operationalise the model attributes. As E3 explained, "*these process areas are the sub-attributes of the model… you cannot put all the items related to lean construction under the first layer, so the attributes previously talked about can now be detailed in the second level*." E4 further noted that "*since these process areas are now grouped… under each key model attributes, it provides a clear understanding to the user… this is methodical and understandable.*" For industry, this structure offers a practical guide for recognising how lean construction principles become visible at the operational level, enabling firms to diagnose performance gaps and prioritise improvement actions with greater clarity. For policymakers, the validated process-area framework provides a robust and standardised basis for integrating lean expectations into procurement, performance monitoring, and capability-development programmes, ensuring greater consistency in how lean maturity is evaluated across projects. For instance, within the process areas, the analysis revealed that reducing variability had a measurable effect on workflow stability, leading to smoother production flow across the Sri Lankan projects examined. . Experts consistently linked this improvement to better control of day-to-day disruptions, with E1 noting that "*once the daily disturbances reduce, crews finally get a stable rhythm of work,*" capturing a common challenge in local sites where interruptions are frequent. The findings indicate that when variability reduces and production flow stabilises, constraint identification naturally becomes embedded within planning routines, enabling teams to address issues before they escalate into delays. As per the findings this becomes particularly important in the Sri Lankan context, where the findings revealed frequent disruptions arising from high variability and weak information flow, making stable production conditions essential for improving project performance. At the institutional level, the same improvement in flow creates a basis for policy makers to integrate variability management into appraisal and progress review frameworks, which in turn contributes to more reliable delivery across public projects. The results also showed that minimising cycle time enhanced labour readiness and equipment utilisation, reflecting how shorter and more predictable work durations support smoother operations under local resource constraints. This implies that firms should adopt regular cycle time reviews within their planning cycles, and that policy makers introduce cycle time reporting in monitoring formats to promote faster decision making. Strengthening flow and conversion processes was likewise associated with reduced bottlenecks and clearer sequencing, a point reinforced by E3 who remarked that *"better flow simply means fewer clashes on site,"* reflecting a persistent coordination issue in the Sri Lankan sector. This suggests that firms apply flow analysis at major handover points, while policy makers require evidence of flow management practices in procurement submissions. Improvements in processes, tools, and supply chain integration were found to enhance coordination among subcontractors and suppliers, an area often weakened by fragmented project structures. These findings imply that firms establish supplier alignment routines and process mapping sessions, while policy makers set clearer expectations for supply chain coordination in contract guidelines.

As per the experience of a senior construction manager at a Sri Lankan building project, stabilising flow and embedding routine constraint identification produced noticeable improvements in day to day performance. He explained that once the team introduced a simple constraint log together with a short morning review to clear operational blockers, the number of stoppages caused by late information and missing materials declined substantially. This small practice change reduced task waiting time by nearly ten percent and shortened the cycle durations of several repetitive work packages by two to three days. The manager emphasised that these gains were achieved without major procedural overhauls but through clearer visibility of constraints and consistent follow through. This example illustrates how the improvements identified in the analysis translate into practical benefits on Sri Lankan construction sites, reinforcing the relevance of reduced variability, stronger flow, and structured constraint identification within the maturity model. Similarly, experts validated the inclusion of all 28 process areas, noting that they are essential for broadening the model's key attributes and aligning them with operationally measurable aspects of construction practice.

Model indicators under each process area (Delphi Round 2 Phase 3, Delphi Round 3 Phase 1 and Delphi Round 3 Phase 2)

During Delphi Round 2, Phase 3, experts were presented 80 model indicators identified from the literature to select the applicable model indicators for Sri Lanka. Experts identified 69 indicators without any changes and 11 indicators were modified (Shown in Italicised text). Importantly, experts suggested 60 new indicators under the model process areas (Shown in Bolded text) as relevant for the new lean construction maturity model. Altogether, 140 model indicators are derived to assess organisational lean construction maturity. In Delphi Round 3 Phase 2, experts were asked to group the identified indicators under each process area previously identified in Delphi Round 2 Phase 2, as detailed in Table 4.

Table 4: Key Model Indicators

Model process areas	Model Indicators	Consensus of 75% or more	Model process areas	Model Indicators	Consensus of 75% or more
	Artificial cycles (RV1)	✓		Leadership driven Lean implementation (LS1)	✓
	Batch production (RV2)	✓		Strategic use of lean (LS2)	✓
	Standard methods (RV3)	✓	Leadership and strategic drive	Lead by example(LS3)	✓
Reduce variability	*Less unique content* (RV4)	✓		**Leaders being transparent, realistic, and self-critical** (LS4)	✓
	Collaboration with the design team (RV5)	✓		**Exemplifying by doing** (LS5)	✓
	Design iteration and prototyping (RV6)	✓		*Stretch targets for performance criteria* (AB1)	✓
	Reduced steps (MC1)	✓	Alignment to Business goals	Linking lean goals to organisational goals (AB2)	✓
	Efficient material flows (MC2)	✓		**Review of organisational goals** (AB3)	✓
Minimise cycle time	Pull planning (MC3)	✓		**Demonstrating ROI** (AB4)	✓
	JIT (MC4)	✓		Leaders trust lean (TM1)	✓
	Application of BIM (MC5)	✓		Management control over lean goals (TM2)	✓
	Rapid Prototyping and Feedback Loops (MC6)	✓	Top management commitment	Clear communication and engagement (TM3)	✓
	Requirements analysis (RA1)	✓		**Monitoring and guiding employee engagement** (TM4)	✓
	Risk analysis (RA2)	✓		**Consideration for employee feedback** (TM5)	✓
Output flexibility	Multi-skilled workforce (RA3)	✓		LC training (TD1)	✓
	Pre cost building analysis (RA4)	✓	Training and development	Multi-skilled, self-directed teams (TD2)	✓
	Inhouse labour camps (RA5)	✓		Coaching, mentoring (TD3)	✓
Flow & conversion	Value stream mapping (FC1)	✓		**Internal best practices used in organisational teachings** (TD4)	✓

	Activities restructured to flows (FC2)	✓
	Differentiating Flows and Conversions (FC3)	✓
	Focus control on entire process (FC4)	✓
	Yamasumi charts (FC5)	✓
	Reduced idle times (FC6)	✓
Processes and tools	Right tools and techniques (PT1)	✓
	LPS (PT2)	✓
	Progress review on process and tools (PT3)	✓
	ERP systems (PT4)	✓
Supply chain integration	Inhouse supply chains (SC1)	✓
	Stakeholder engagement (SC2)	✓
	Supplier quality assurance (SC3)	✓
	E-procurement system (SC4)	✓
Lean Waste identification	Proactive waste identification (LW1)	✓
	Waste defined as any cost without value (LW2)	✓
	Waste analysis (LW3)	✓
	Waste categorisation (LW4)	✓
	Gemba Walks (LW5)	✓
	Root Cause Analysis (LW6)	✓
Reduce non-value-adding activities	*Defined value adding and non-value adding activities* (RN1)	✓
	Proactive methods to decrease non-value adding activities (RN2)	✓
	Flowcharting (RN3)	✓

	Systematic identification of training needs (TD5)	✓
	LC workshops (TD6)	✓
Conducive work environment	Assured work safety (CE1)	✓
	Innovation and cooperation (CE2)	✓
	Conducive work environment (CE3)	✓
	Constructive feedback (CE4)	✓
	Open Communication (CE5)	✓
	Employee welfare (CE6)	✓
Collaborative working	Strategic teams (CW1)	✓
	Less power distance (CW2)	✓
	Group targets (CW3)	✓
	Respecting all stakeholders (CW4)	✓
Competency development	CPD (CD1)	✓
	Systematic analysis on HR gaps in terms of LC (CD2)	✓
	In-house trainers and mentors (CD3)	✓
	Task oriented Realtime scenario training (CD4)	✓
Knowledge sharing	Knowledge sharing is considered a core value (KS1)	✓
	Team building during project work (KS2)	✓
Requirement analysis	Continuous link with customer (RA1)	✓
	Understanding customer value proposition (RA2)	✓
	Systematic investigating of customer requirement (RA3)	✓
	Customer feed-back analysis (RA4)	✓

	Work-in-Progress (WIP) Limits (RN4)	✓
	Ergonomic design (RN5)	✓
Waste minimisation	Monitoring and making waste visible (WM1)	✓
	Recycling and reusing (WM2)	✓
	Measuring efficiency of workstations (WM3)	✓
	Waste walks and audits (WM4)	✓
Continuous improvement	*Progress monitoring and reporting* (CI1)	✓
	Stretch targets (CI2)	✓
	Employee empowerment (CI3)	✓
	Encouraging innovative ideas (CI4)	✓
	Continuous improvement cycles (CI5)	✓
	Learning by doing (CI6)	✓
Benchmarking	Benchmark to high industry standards (B1)	✓
	Industry analysis (B2)	✓
	Best practices incorporated to sub-processes (B3)	✓
	Up to date benchmark criteria (B4)	✓
	Performance Metrics (B5)	✓
	Shared internal best practices (B6)	✓
Standardisation	Defined work processes (S1)	✓
	Maintenance of quality standards (S2)	✓
	Process controlling and quality assurance (S3)	✓
	Proper documentation (S4)	✓
	Standard Operating procedures for site operations (S5)	✓

	KPIs targeted on customer satisfaction (RA5)	✓
Customer centric approach	Long-term customer relationships (CC1)	✓
	Customer centric culture (CC2)	✓
	Workforce benefits aligned to maximise customer value (CC3)	✓
	Monitoring the effectiveness of delivering value (CC4)	✓
	Proactive customer reach (CC5)	✓
	Value engineering (CC6)	✓
Flexibility	Trained workforce for evolving needs (F1)	✓
	Responsiveness to customer feedback (F2)	✓
	Multi optional solutions (F3)	✓
	Multi-functional teams (F4)	✓
Information transparency	Visual management (IT1)	✓
	Improved connection across borders (IT2)	✓
	Transparent information sharing (IT3)	✓
	Real-time information sharing (IT4)	✓
Workplace organisation	Defined organisational structure (WO1)	✓
	Defined lean roles (WO2)	✓
	Complying to 5S (WO3)	✓
	Workplace layout analysis (WO4)	✓
	Clean and clutter-free workspace (WO5)	✓
Lean culture	Lean embedded as a philosophy (LC1)	✓
	Lean organisation culture (LC2)	✓
	Management lead lean maturation (LC3)	✓

	Matching building standards to performance metrics (S6)	✓
Error detection and prevention	Prompt defect response & Error prevention (ED1)	✓
	Establishing teams for bottlenecks (ED2)	✓
	First-Time Right (FTR) Rate (ED3)	✓
	Independent quality assurance entity (ED4)	✓
	Lean pilot projects (LC4)	✓
	Systematic evaluation of strategic lean goals (LC5)	✓
	No blame culture (LC6)	✓
Transformational change	Barrier detection to strategic lean vision (TC1)	✓
	Benefit analysis and sharing (TC2)	✓
	Low resistance to progressive change (TC3)	✓
	Change agents identified (TC4)	✓
	Empowering employees (TC5)	✓
	Lean Learning (TC6)	✓

The analysis confirmed that the third layer of the model, the indicators, strengthens the precision of maturity assessment by extending the evaluative depth of the existing components. Evidence showed that the indicators help capture practical dynamics, with E23 noting that "*they serve as critical tools for linking global lean principles with local realities,*" highlighting their value for identifying performance gaps. This implies that Sri Lankan firms will be able to diagnose specific maturity shortcomings more accurately, while policy makers can use these indicators to structure context sensitive evaluation criteria for public projects. The findings also revealed that developing context-specific indicators is essential in a setting where lean adoption remains at an early stage. As E22 explained, "*it is essential for firms to run lean pilot projects to gain practical experience,*" indicating that indicators aligned with early stage practices can guide organisations through incremental capability building. This suggests that firms can apply the indicators to frame pilot project learning goals, while policy makers support staged maturity development through phased assessment requirements. The importance of design collaboration was similarly validated, as E12 emphasised that "*continuous design collaboration is vital for the Sri Lankan construction sector to avoid unnecessary errors, idle time, and rework.*" This finding implies that firms should integrate design coordination indicators into their project planning routines, while policy makers embed design collaboration expectations into procurement and design review procedures. Collectively, the results demonstrate that the model indicators offer a practical and contextually grounded mechanism for evaluating lean maturity in Sri Lanka and for guiding both organisational and sector level improvement actions.

For instance, The analysis showed that the indicators associated with reducing variability capture the underlying mechanisms through which workflow stability improves in Sri Lankan projects. Evidence pointed to artificial cycles, batch-based work practices, and inconsistent methods as recurrent sources of disruption, while more standardised work methods and reduced unnecessary uniqueness helped teams maintain a smoother production rhythm. One expert explained that these indicators "show us exactly where the instability begins, because when we identify patterns such as batching or uneven methods, we can then see how these issues ripple through the entire workflow. In the Sri Lankan setting, where day to day uncertainty is high, these indicators give us a practical way to control what was previously unmanageable." This suggests that firms can rely on these indicators to diagnose the origins of instability more accurately, while policy makers can embed variability related assessment criteria into project monitoring formats to support more reliable delivery across public projects. The findings also confirmed that collaboration with design teams and structured design iteration are crucial in reducing variability, especially in Sri Lanka where late design adjustments frequently create disruptions. As highlighted by another expert, "when the design team works continuously with the site team, we prevent many of the avoidable mistakes that lead to rework, idle time, and frustrated crews. These indicators push us to make design collaboration routine rather than something we only do when problems appear." This implies that firms integrate design collaboration indicators into planning reviews, while policy makers strengthen design coordination obligations during procurement and design approvals.

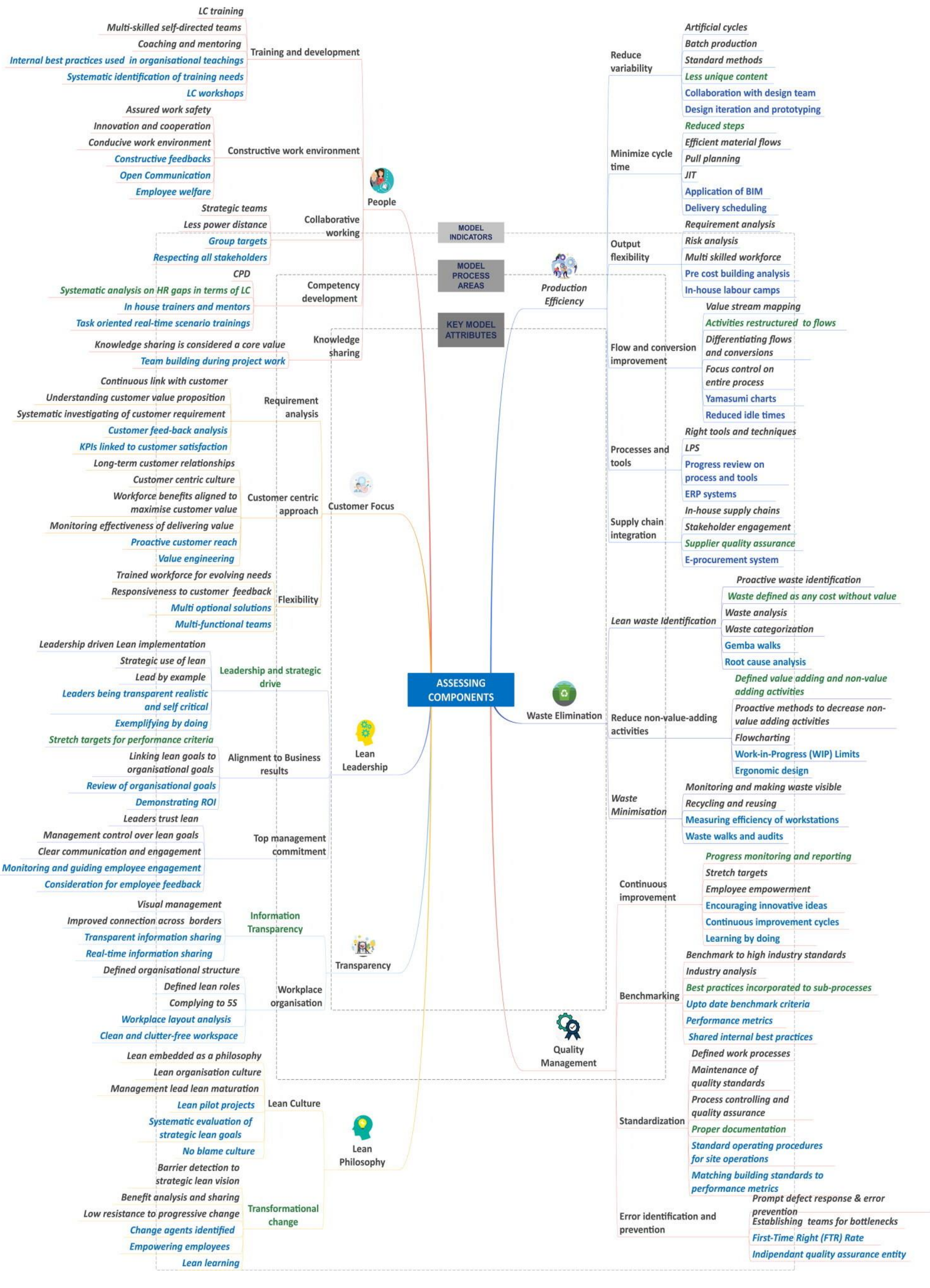
The indicators linked to waste identification further clarified how waste reduction contributes to lean maturity. The evidence showed that proactive waste identification, defining waste clearly as any cost without value, analysing waste sources, and categorising waste types provided teams with a structured method for improving time and material efficiency. Practical tools such as walking the site to observe actual conditions and applying root cause analysis were particularly effective in exposing persistent issues. One expert described this impact, noting that "once we start looking for waste in a structured way, we see how much of our time is lost not because of big failures but because of small, repeated problems. These indicators force us to ask why it happens and how we stop it, which is essential for improving performance in Sri Lankan projects where resources are always stretched." This implies that firms embed proactive waste identification and root cause practices into their daily and weekly routines, while policy makers introduce formal waste reporting and waste analysis criteria into project evaluation guidelines to promote transparent and efficient use of resources. Overall, the validated indicators align closely with the operational challenges of the Sri Lankan construction sector and offer a practical basis for assessing and improving maturity in variability control and waste reduction.

Detailed explanation of model assessing components.

The assessing components of eight key model attributes, 28 key process areas, and 140 model indicators present a comprehensive approach to evaluating lean construction maturity, as described in Figure 1 below.

Figure 1

Model Assessing Components



ASSESSING COMPONENTS
MODEL INDICATORS
MODEL PROCESS AREAS
KEY MODEL ATTRIBUTES
People
Training and development
LC training
Multi-skilled self-directed teams
Coaching and mentoring
Internal best practices used in organisational teachings
Systematic identification of training needs
LC workshops
Constructive work environment
Assured work safety
Innovation and cooperation
Conducive work environment
Constructive feedbacks
Open Communication
Employee welfare
Collaborative working
Strategic teams
Less power distance
Group targets
Respecting all stakeholders
Competency development
CPD
Systematic analysis on HR gaps in terms of LC
In house trainers and mentors
Task oriented real-time scenario trainings
Knowledge sharing
Knowledge sharing is considered a core value
Team building during project work
Customer Focus
Requirement analysis
Continuous link with customer
Understanding customer value proposition
Systematic investigating of customer requirement
Customer feed-back analysis
KPIs linked to customer satisfaction
Customer centric approach
Long-term customer relationships
Customer centric culture
Workforce benefits aligned to maximise customer value
Monitoring effectiveness of delivering value
Proactive customer reach
Value engineering
Flexibility
Trained workforce for evolving needs
Responsiveness to customer feedback
Multi optional solutions
Multi-functional teams
Lean Leadership
Leadership and strategic drive
Leadership driven Lean implementation
Strategic use of lean
Lead by example
Leaders being transparent realistic and self critical
Exemplifying by doing
Alignment to Business results
Stretch targets for performance criteria
Linking lean goals to organisational goals
Review of organisational goals
Demonstrating ROI
Top management commitment
Leaders trust lean
Management control over lean goals
Clear communication and engagement
Monitoring and guiding employee engagement
Consideration for employee feedback
Transparency
Information Transparency
Visual management
Improved connection across borders
Transparent information sharing
Real-time information sharing
Workplace organisation
Defined organisational structure
Defined lean roles
Complying to 5S
Workplace layout analysis
Clean and clutter-free workspace
Lean Philosophy
Lean Culture
Lean embedded as a philosophy
Lean organisation culture
Management lead lean maturation
Lean pilot projects
Systematic evaluation of strategic lean goals
No blame culture
Transformational change
Barrier detection to strategic lean vision
Benefit analysis and sharing
Low resistance to progressive change
Change agents identified
Empowering employees
Lean learning
Production Efficiency
Reduce variability
Artificial cycles
Batch production
Standard methods
Less unique content
Collaboration with design team
Design iteration and prototyping
Minimize cycle time
Reduced steps
Efficient material flows
Pull planning
JIT
Application of BIM
Delivery scheduling
Output flexibility
Requirement analysis
Risk analysis
Multi skilled workforce
Pre cost building analysis
In-house labour camps
Flow and conversion improvement
Value stream mapping
Activities restructured to flows
Differentiating flows and conversions
Focus control on entire process
Yamasumi charts
Reduced idle times
Processes and tools
Right tools and techniques
LPS
Progress review on process and tools
ERP systems
Supply chain integration
In-house supply chains
Stakeholder engagement
Supplier quality assurance
E-procurement system
Waste Elimination
Lean waste Identification
Proactive waste identification
Waste defined as any cost without value
Waste analysis
Waste categorization
Gemba walks
Root cause analysis
Reduce non-value-adding activities
Defined value adding and non-value adding activities
Proactive methods to decrease non-value adding activities
Flowcharting
Work-in-Progress (WIP) Limits
Ergonomic design
Waste Minimisation
Monitoring and making waste visible
Recycling and reusing
Measuring efficiency of workstations
Waste walks and audits
Quality Management
Continuous improvement
Progress monitoring and reporting
Stretch targets
Employee empowerment
Encouraging innovative ideas
Continuous improvement cycles
Learning by doing
Benchmarking
Benchmark to high industry standards
Industry analysis
Best practices incorporated to sub-processes
Upto date benchmark criteria
Performance metrics
Shared internal best practices
Standardization
Defined work processes
Maintenance of quality standards
Process controlling and quality assurance
Proper documentation
Standard operating procedures for site operations
Matching building standards to performance metrics
Error identification and prevention
Prompt defect response & error prevention
Establishing teams for bottlenecks
First-Time Right (FTR) Rate
Indipendant quality assurance entity

As shown in Figure 1, the black-coloured text represents components identified from the literature and verified by experts. The green-coloured text indicates model components that were accepted by experts with modifications. The blue-coloured text indicates the components that were newly suggested by experts. A total of eight Key attributes, 28 process areas, and 140 model indicators were identified. The following section explains how model-assessing components are utilised to assess lean construction maturity, taking the model attribute production efficiency as an example.

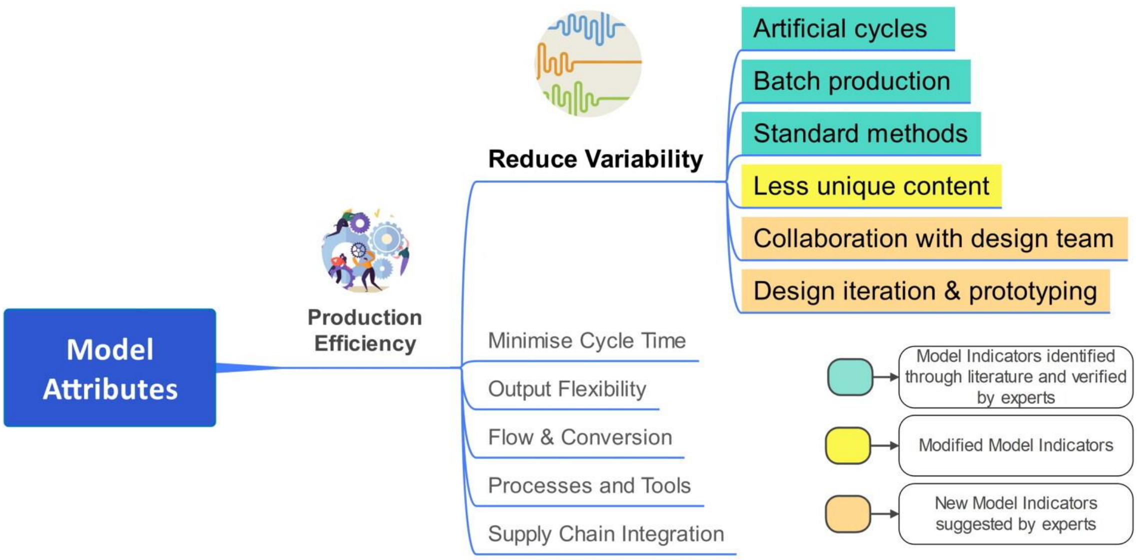
The following section provides a worked explanation of how the identified model assessing components provides a mechanism to assess lean construction maturity in an organisation.

Sample explanation of model assessing components.

Figure 2 presents a detailed explanation of the model attribute Production efficiency.

Figure 2

Detailed explanation of model assessing components



Production efficiency is one of the eight key model attributes. Production efficiency revolves around optimising productivity and effectiveness within construction processes to achieve maximum output while minimising wastage. Under the key model attribute production efficiency, six key process areas were identified, including Reducing variability, Minimising cycle time, Output flexibility, Flow and conversion, Processes and tools and Supply chain integration, as shown in Figure 2. All the lean construction experts agreed on this key attribute and its six model process areas. Reduce Variability is one process area identified under Production Efficiency. To evaluate this process area, several model indicators were identified, as depicted in Figure 2.

Artificial Cycles were a prominent indicator that lean construction experts seem to have a common consensus. E8 explained that several projects under the supervision of E8 have implemented this and gained positive results. "*Pro-active planning and checking on tasks gave us the opportunity to identify the bottlenecks and plan. One good example is formworks in high riser. We identified all the necessary labour requirements and resource requirements. The planning team was able to foresee the entire process and we saved a lot of time."* Another indicator of reduced variability in Lean construction is batch production. All the experts unanimously agreed that batch production is a key success factor for higher lean maturity. E6 expressed that "*Batch production is not new to any construction project, there are items that are produced in batches like structural elements, road parts, below-ground items, etc. This also brings you benefits like cost, time and quality. So, this is an obvious and practically visible indicator*.

Less unique content was identified as an indicator for assessing lean maturity. Over 75% of experts agreed that reducing these unique elements benefits reaching higher lean construction maturity. Confirming that E4 stated "*Lean is built on less variability, and unnecessary uniqueness is a killer of it. You need to have some uniqueness of a* *design, but here what we talk about is in the practices and in general construction, there has to be some consistency*." However, one expert expressed concern due to the perceived lack of control over this aspect. All the other experts agreed with this model indicator. The overwhelming majority of the experts said most of their sites follow standard operating procedures. E9 stated, "*The core pillar of any operation is its standard. Sometimes, things like a basic construction activity have 100 small activities; I am not saying you need to look at a book all the time, but if we need to be mature, it is important to follow a systematic order."*

A new model indicator suggested by experts is Collaboration with the design team. It emphasises close collaboration and integration of all project stakeholders, including the design team, throughout the entire construction process. As E11 stated, "*Our projects have many variations. You can't stop that. But good relationship and proper communication with the design team helps us to avoid large changes in the projects".* E22 pointed out that "*early and continuous involvement allows for the integration of design and construction knowledge, enabling potential issues to be identified and resolved before they become costly or time-consuming problems. When a construction organisation collaborates effectively with the design team from the beginning, it shows a higher level of maturity in implementing lean principles*." Moreover, in suggesting another specific model indicator for the new LCMM, the overwhelming majority agreed that Design iteration and prototyping are imperative in reducing variability. Design iteration allows the process of repeating and refining the design of a product or system through multiple cycles of evaluation, feedback, and modification. As elaborated by E15 "*We reduce variability and improve quality and efficiency by continuously refining our designs together. This back-and-forth process is* *crucial for successful project outcomes by constantly refining designs. We can spot and fix loopholes, cut down on variability, and speed up the process*."

As explained, these investigated model assessing components provide a systematic path to assess the lean construction maturity of an organisation through a segmented mechanism where it will provide a more granular assessment of the construction maturity. Please see Annexure 1 for other model component details.

Validation of findings

To enhance the reliability, practical relevance, and applicability of the developed lean construction maturity model, a focused validation exercise was conducted. This involved five expert validation interviews, comprising two participants from the original Delphi panel and three additional experts with substantial professional and academic experience in lean construction. The inclusion of both prior and new experts ensured that feedback was informed by earlier consensus while also capturing fresh perspectives to strengthen the applicability of the model components.

The validation focused on assessing the hierarchical structure of the model, the relevance of process areas, and the suitability of individual indicators for capturing organisational lean maturity. All Validation Experts (VEs) confirmed the presence of three distinct layers of assessment components. VE1 observed, "The hierarchical layers reflect a logical flow, connecting fundamental lean construction principles to practical process areas," highlighting the alignment between theoretical constructs and operational considerations. VE3 emphasized the importance of contextualisation, stating, "It's essential that the indicators capture unique local conditions to ensure accurate evaluation," underscoring that the model balances universal lean principles with locally embedded practices. VE5 noted, “These components provide holistic coverage across an organisation,” indicating that the model’s breadth supports comprehensive assessment of lean construction practices at multiple organisational levels.

In addition to confirming the structure and coverage, the Validation Experts evaluated the recent additions and refinements made to model components. They provided actionable recommendations to enhance usability and context sensitivity, such as tailoring certain indicators to organisational scale, industry norms, and project-specific workflows. The experts also highlighted the need for clear guidance on applying the indicators in practice, reinforcing the importance of linking assessment outcomes to actionable improvement initiatives.

While the Delphi technique provides a structured approach for reaching expert consensus, it relies primarily on subjective qualitative data, and the robustness of findings depends on the credibility and convergence of expert opinions. This dedicated validation exercise further strengthened methodological rigour by triangulating the Delphi-derived findings with expert-led evaluation. Through systematic review and discussion, the experts verified that the model captures locally embedded practices without compromising alignment with universal lean principles, ensuring that the framework is both theoretically robust and practically applicable. Overall, the validation exercise provided a several benefits. It reinforced the credibility of the model through convergence of expert opinion while simultaneously ensuring that the framework is sensitive to contextual realities and practically actionable. The integration of Delphi consensus with focused expert validation enhances confidence in the reliability, context specificity, and operational relevance of the proposed lean construction maturity model, establishing a solid foundation for its use in organisational assessment and future empirical testing.

Discussion

The findings indicate that lean construction maturity can be effectively assessed through a layered structure that connects fundamental lean principles with operational practices and context specific indicators. Rather than reiterating established maturity concepts, the results clarify how maturity assessment operates in practice within the Sri Lankan construction sector, where variability, fragmented workflows, and uneven lean capability remain dominant challenges.

The validation of eight key model attributes, 28 process areas and 140 indicators indicate that, while the foundational logic of lean construction reflects broadly recognised principles, their manifestation within maturity assessments is strongly shaped by context specific organisational, cultural, and operational conditions. Consistent with Koskela's conceptualisation of lean as a universal production philosophy (Koskela 1992), the findings show that maturity does not evolve through abstract principles alone but through locally embedded practices, leadership behaviours, and capability development patterns. This confirms that effective lean maturity assessment requires sensitivity to institutional arrangements, industry norms, and implementation realities within the studied context. Attributes such as production efficiency, waste elimination, quality management, people, leadership, transparency, customer focus, and lean philosophy were unanimously validated by experts without modification. This supports foundational lean theory (Koskela, 2000; Koskela et al., 2002) and subsequent maturity studies (Nesensohn et al., 2015; Tubis, 2023), which position these principles as core dimensions of lean systems. The findings extend this literature by demonstrating that while attributes remain stable across contexts, their explanatory power depends on lower-level operationalisation.

Production efficiency and waste elimination emerged as especially influential attributes, reflecting their direct linkage to daily site operations. The findings show that maturity is closely associated with stabilising workflow, reducing interruptions, and embedding routine planning and constraint identification practices. This empirically supports lean flow theory (Ballard and Tommelein, 2012; Hamzeh et al., 2012) while demonstrating how modest, low complexity practices can generate measurable performance improvements under Sri Lankan conditions. Unlike studies in industrialised contexts that emphasise advanced systems, the results indicate that maturity progression can be achieved through consistent application of basic planning and flow control routines. However, this may limit transferability to highly mechanised or prefabricated construction systems where stability is achieved through different mechanisms.

The second layer of the model, the process areas, plays a critical role in translating these attributes into assessable organisational practices. The validation of twenty eight process areas confirms that maturity assessment requires sufficient breadth to represent organisational behaviour without fragmentation. Consistent with CMMI and lean health assessment models (Ünlü et al., 2024; Harold, 2023), the process areas operationalise abstract principles into domains such as planning, people development, collaboration, supply chain coordination, and continuous improvement. The findings align with Nesensohn et al. (2015) and Ortega et al. (2023) in demonstrating that maturity must be assessed across multiple organisational dimensions rather than isolated practices. Importantly, experts emphasised that these process areas function as interdependent mechanisms, reinforcing the need for holistic rather than linear maturity assessment.

At the indicator level, the findings provide strong evidence for contextualisation. While most indicators from the literature were retained, the addition of sixty new indicators highlights the limitations of applying generic metrics without adaptation. This supports arguments by Babalola et al. (2019) and Ayalew et al. (2016) that construction practices vary significantly across regions. The findings further align with Sarhan and Fox (2021) and Liu et al. (2024), showing that indicators must reflect cultural, operational, and capability related conditions to be meaningful. Indicators related to variability reduction, waste identification, and design collaboration were particularly significant, as they exposed the mechanisms through which instability, rework, and inefficiencies emerge in Sri Lankan projects. This confirms the role of indicators not only as measurement tools but also as learning mechanisms that support incremental capability development. A practical boundary, however, is the volume of indicators, which may require phased application in resource constrained organisations.

Overall, the study demonstrates that lean construction maturity is best understood as the alignment between principles, processes, and practices rather than the presence of isolated tools. The proposed assessing components provide a structured and empirically grounded mechanism for diagnosing maturity gaps and guiding improvement actions. While the conceptual structure aligns with established maturity models, its contribution lies in demonstrating how universal lean principles are operationalised through context sensitive process areas and indicators. Transferability to other construction contexts is therefore conditional on recalibrating indicators to reflect local operational realities.

Contributions and Implications of the Research

1. Theoretical Contribution and Research Implications

This study presents a layered Lean Construction Maturity Framework that explains how lean behaviours and practices develop within Sri Lankan construction organisations. By highlighting the interplay of workflow stability, waste control, design collaboration, leadership engagement, and workforce competence, the framework provides a theoretical foundation for understanding maturity progression as an evolving organisational system shaped by contextual, cultural, and behavioural factors.

The proposed framework offers a foundational canvas for constructing country specific maturity models that reflect regional industry structures, regulatory environments, and labour dynamics. In the near term, researchers can generate comparative maturity profiles across firms and examine how specific components affect operational outcomes. The framework also supports empirical testing of links between maturity progression and performance dimensions including predictability, resource utilisation, and quality improvement. Over the longer term, it can be extended through advanced analytical approaches such as machine learning and data driven monitoring to enhance predictive capability and support adaptive lean maturity assessment across diverse construction contexts.

2. Practical Contribution and Implications

This research provides organisations with a structured basis for diagnosing capability gaps, prioritising improvements, and aligning site practices with higher maturity levels. By integrating components such as workflow stability, waste control, design collaboration, and leadership engagement, the framework highlights where inefficiencies originate and shows how targeted routines including constraint management, waste visibility, staged inspections, or collaborative design reviews can enhance performance.

The framework offers a practical guide for immediate and medium-term action. In the near term, organisations can conduct internal maturity assessments and implement high-impact routines indicated by the framework, such as daily planning, waste categorisation, or structured quality checks, to stabilise workflow and reduce rework. Over a one to three year horizon, firms can adopt the full framework to institutionalise continuous improvement structures, integrate design and site coordination into planning processes, strengthen leadership behaviours across project teams, and establish data driven maturity monitoring at the organisational level.

3. Policy contributions and implications

By translating lean principles into concrete and measurable indicators, the study provides policymakers with a robust tool to evaluate and strengthen lean construction maturity across projects and organisations. The findings demonstrate that maturity linked behaviours such as systematic waste monitoring, transparent information flows, and leadership led routine reviews directly enhance project reliability, cost stability, and accountability. This approach makes lean adoption measurable, actionable, and embedded in everyday project practices, bridging the gap between policy expectations and on-site performance.

The framework offers guidance for both immediate and longer-term policy action. Regulators can integrate key indicators into procurement processes and reporting to improve consistency in evaluating workflow stability, waste performance, and design and site coordination. Over time, the full maturity structure can support the development of a national lean capability framework that enables contractor classification, targeted capability building initiatives, and performance based procurement that prioritises consistent lean behaviours alongside cost considerations.

4. Educational and Capacity-Building Contribution and Implications

The model provides a structured knowledge base that training institutions, universities, and professional bodies can use to develop competency frameworks grounded in construction industry realities. The findings clarify the behavioural, technical, and managerial capabilities required to advance lean construction maturity, including proactive problem solving, error prevention routines, waste identification, and design coordination.

The framework offers guidance for both immediate and longer term educational action. Training providers can design programmes focused on high-impact process areas such as variability control, waste identification, and frontline quality assurance. Over time, the full maturity structure can be integrated into curricula, certification systems, and organisational training plans, supporting the development of a sustained pipeline of practitioners and managers capable of assessing and advancing lean maturity across the construction sector.

Conclusions and recommendations

- The study identified and validated a three-layer Lean Construction Maturity Framework consisting of eight attributes, 28 process areas, and 140 indicators, developed through iterative Delphi consensus and expert validation interviews.
- The framework demonstrated strong reliability, contextual suitability, and diagnostic value for the Sri Lankan construction sector in assessing organisational construction maturity.
- The components captured measurable operational improvements, including increases in workflow stability, cycle time reductions, and reductions in task waiting time when aligned with organisational practices.
- Results remained consistent across multiple validation rounds, with experts affirming the broad relevance of the attributes and the contextual accuracy of the process areas and indicators, strengthening the empirical validity of the framework.
- By addressing the absence of a structured, context-specific mechanism for evaluating lean construction maturity, the framework provides an evidence-based tool for distinguishing organisational performance in areas such as variability management, waste control, design collaboration, leadership commitment, and people capability.
- The validated components demonstrate clear practical and policy relevance, offering organisations a structured means to identify maturity gaps and prioritise improvement

actions, while giving policymakers a reliable basis for embedding lean evaluation criteria into procurement, reporting, and sector-level performance monitoring.

- Based on findings, the study recommends applying the validated framework as a benchmarking tool for lean maturity assessment, utilising diagnostic insights to plan targeted capability development initiatives, integrating lean maturity metrics into procurement and reporting systems, supporting policy-level standardisation of lean evaluation across the sector, and strengthening leadership engagement and workforce development to sustain lean performance.

The way forward

Future research should prioritise the application of the proposed framework in real project environments to strengthen its practical relevance. The framework can serve as a blueprint for investigating quantitatively measurable and achievable improvements and benefits through longitudinal studies. Initial studies may involve testing the framework across diverse organisational and project contexts to refine assessment components and confirm their contextual robustness, supported by standardised assessment tools and trained evaluators. Model indicators can be translated into key performance indicators (KPIs) for organisations to monitor lean maturity and guide performance improvements. Further investigation should track changes in lean maturity over the project lifecycle and examine their influence on outcomes such as cost control, schedule reliability, and sustainability. Concurrent collaboration with industry institutions can enable structured organisational-level applications supported by clearly defined performance measures and targeted capacity-building initiatives. Challenges associated with limited adoption and varying levels of lean capability can be mitigated through early engagement with decision makers, focused training, and clear guidance on assessment procedures.

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Data availability statement

The data that support the findings of this study are available from the corresponding author, [JKDDT], upon reasonable request.

Conflict of interest statement

The authors declare that there are no conflicts of interest related to this work.

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