

DEVELOPING A DEFINITION FOR LEAN CONSTRUCTION MATURITY MODELS THROUGH A PRISMA SYSTEMATIC LITERATURE REVIEW

JAYANETTI J.K.D.D.T.^{1*}, PERERA B.A.K.S.² & WAIDYASEKARA K.G.A.S.³

^{1,2,3}University of Moratuwa, Colombo, Sri Lanka

¹qsthamasha@gmail.com, ²pererabaks@gmail.com, ³anuradha@uom.lk

Abstract: The construction industry faces challenges in achieving efficiency, which has led to the adoption of Lean Construction principles. Defining a Lean Maturity Model specific to the construction context is essential for effectively implementing Lean principles. Prevailing evidence presents a significant gap in the existing literature regarding a consolidated and practically oriented definition of a Lean Construction Maturity Model (LCMM). While various frameworks have been proposed, there is a lack of consensus and a need for a unified understanding of Lean construction maturity. Thus, the paper is aimed at developing a definition for LCMMs through a systematic literature review using the PRISMA technique. The findings were analysed using the thematic analysis method. As per findings, a new definition was developed identifying nine key themes and corresponding sub-themes.

As a theoretical contribution, this paper fills the existing literature gap by providing a precise and comprehensive definition. From an industry perspective, this makes a significant practical contribution to construction practitioners and policymakers by enabling organizations to assess their lean maturity level, identify areas for improvement, and strategically plan their lean transformation journey. The paper contributes to societal advancements by promoting efficiency, productivity, and sustainability in the construction industry through improving lean construction practices.

Keywords: *Definition, Lean construction, Lean Maturity models, Lean construction maturity, PRISMA systematic literature review*

1. Introduction

The significance of a maturity model in the construction industry lies in its capacity to enable organizations to achieve their desired strategic position by consistently enhancing their desired outputs in a predictable, controllable, and reliable manner (Machado et al., 2021). Maturity models (MMs) provide a roadmap for organizations to achieve best practices and reach the desirable state (Lacerda & von Wangenheim, 2018). MMs also clarify the possibilities of reaching higher levels of maturity, thus facilitating the identification of deficiencies and the implementation of corrective or preventive measures (Schlichter, 1999). MMs have their origins in Total Quality Management systems, where the focus is on continuous improvement by assessing the current state and capabilities of an organization in relation to future objectives (Brookes & Clark, 2009). Over time, MMs have been adapted to various domains, including education, health, energy, finance, construction, the industrial sector, government, and general use (Tocto-cano et al., 2020). Essentially, a MM provides a pathway or framework for benchmarking and enhancing performance on a continuous scale (Demir & Kocabaş, 2010). The underlying principle of a MM is that individuals, organizations, functional areas, and processes have the potential to evolve and develop through a growth process toward a higher level of maturity (Vásquez et al., 2021).

A LCMM is of paramount importance in the construction industry as it offers organisations the capability to attain their desired strategic position by continuously improving their outputs in a predictable, controllable, and reliable manner (Rodegheri & Baptista Serra, 2020). The model provides a structured framework that allows organizations to assess and gauge their level of Lean maturity (Nesensohn et al., 2015). Having a clear and well-defined definition for LCMMs holds significant importance for several reasons. Firstly, a precise definition ensures that researchers, practitioners, and stakeholders in the construction industry share a common understanding of what constitutes a LCMM. It establishes clear and unambiguous language, preventing confusion or misinterpretation when discussing or implementing LCMMs (Brooks & Clark, 2009). This common understanding lays the foundation for effective communication and collaboration among industry professionals, leading to more streamlined and efficient adoption of lean practices. While MMs in domains such as Information Technology (IT), Continuous Improvement, and Software Development have presented thorough definitions (Software Engineering Institute, 2006; Liu & Zhang,

*Corresponding author: Tel: +94 775858059 Email Address: qsthamasha@gmail.com
FARU Journal: Volume 10 Issue 2 DOI: <https://doi.org/10.4038/faruj.v10i2.253>

2019), the majority of MMs developed for the sector are mere extensions of conventional models, lacking comprehensive definitions. In the context of existing LCMMs, the situation is even more challenging, as only a limited number of models have been developed and there is a notable absence of a comprehensive and specific definition. The current landscape of LCMMs reveals a significant in terms of a standardized and comprehensive definition. While some LCMMs offer partial indications or hints of definitions, there is a clear absence of a universally accepted and specifically tailored standard definition. This lack of a definitive framework poses a challenge in establishing a consistent understanding and benchmarking of maturity levels in the context of lean construction (LC) practices. Consequently, further research and development are necessary to bridge this gap and provide a comprehensive definition for LCMMs. Therefore, identifying the need, this research was initiated with the aim of proposing a standard definition for LCMMs. To attain this aim, the study set key objectives as, i) Investigate key themes defining existing LCMMs, ii) Investigate key principles that are incorporated in LCMMs, iii) Analyse key components relevant to a definition. To achieve these objectives, this study adopted the PRISMA technique to conduct a comprehensive SLR. The findings of the SLR were analysed using thematic analysis method to derive the final definition.

Establishing a clear definition, this paper contributes to the academic discourse on LC and fills the existing gap in literature regarding a precise and industry-tailored definition of a Lean Maturity Model for construction. From an industry perspective, a well-defined and universally accepted definition provides clarity and a common understanding among practitioners and industry stakeholders regarding the fundamental principles and objectives of LCMMs.

The paper commences with an introductory section that sets the context and purpose of the study. Subsequently, a comprehensive systematic literature review is conducted using the PRISMA systematic review method to examine existing LCMMs, their definitions, and LC principles. The research methodology, including the data collection techniques, is subsequently explained. The collected data from the literature review undergoes a thematic analysis to identify recurring themes for developing a definition for the LCMM. The resulting findings are subsequently discussed, and the final definition of the LCMM is presented.

2. Literature Synthesis

The construction industry is often perceived as distinct from the manufacturing industry, yet there are notable similarities between them (Andersen et al., 2012). Adapting the principles of lean production management with appropriate modifications has the potential to enhance the effective management of the construction industry (Lean Construction Institute, 2023). In 1992, Lauri Koskela emphasized the importance of integrating lean production philosophy into the construction sector to gain competitive advantage and improve the industry as a whole (Aslam et al., 2020), sparking significant interest among industry specialists, academics, and business managers. As a result of this growing interest, the assessment of lean construction has become crucial (Stevens, 2014). Scholars have highlighted the need to monitor and measure the current state of lean implementation in construction, as well as its progress over time (Jayanetti et al., 2023). MMs have emerged as a prominent approach for assessing organizations, measuring the success of LC processes (Brookes et al., 2014), and tracking the advancement of new implementations (Goksen et al., 2015). However, limited research exists on measuring the maturity of lean construction specifically within the industry (Nesensohn et al., 2015; Rodegheri & Baptista Serra, 2019).

In defining a MM, it is crucial to grasp the underlying concept of "maturity." According to the Oxford English Dictionary (2023), maturity refers to the state of being fully grown or developed, applicable to individuals, organizations, plants, or even principles. Maturity itself embodies the notion of how advanced or refined a person, idea, or subject has become. Within the construction sector, numerous MMs have been utilized in the industry for a considerable period. The Capability Maturity Model (CMM) and Capability Maturity Model Integrated (CMMI) serve as key foundations upon which other MMs have been developed and benchmarked (Nesensohn et al., 2015).

The term "maturity" is employed across various sectors, each providing distinct definitions. In the field of management, maturity refers to the progressive improvement of project management systems and processes, serving as a means to assess an organization's capabilities and establish a pathway for enhancement (Pennypacker, 2001). Conversely, in the realm of IT and software development, MM is viewed as a device for process management, aiming to streamline procedures (Tocto-cano et al., 2020). This highlights that although MMs share fundamental similarities, their definitions vary and offer different contextual meanings.

Through the systematic review of 67 papers, the study has identified a total of 21 key models that are relevant to the discussion. Within these models, a subset can be categorized as LCMMs, explicitly emphasizing the concept of LC maturity and providing a logical framework for measuring it (Carvalho & Scheer, 2015; Nesensohn, 2014). Another group of models and frameworks also clearly acknowledge lean construction as a foundational element, demonstrating its significance within their frameworks (Diekmann et al., 2003; Moyano-Fuentes & Sacristán-Díaz, 2012). Lastly, a set of models were identified that, although not directly related to LC maturity or lean construction, incorporate lean principles and showcase the adaptability of these principles within their respective models and frameworks (Sanchez & Pérez, 2001; Nightingale et al., 2001). The identified models are extensively analysed in the findings chapter, providing how each of the models contributed to the final model definition.

3. Methodology

A thorough examination of the existing literature, through a comprehensive literature review, allows researchers to extract valuable insights from prior studies and gain a deep understanding of the respective subjects (Saunders, Lewis, and Thornhill, 2016). Systematic reviews, such as the well-established PRISMA approach, offer a rigorous and meticulous methodology to gather and analyse all relevant evidence that meets predefined eligibility criteria, thus addressing specific research questions of interest (Sohrabi et al., 2021). These systematic reviews minimize bias and ensure a comprehensive assessment of the available literature, facilitating the identification of patterns, discrepancies, and research gaps. By employing these robust approaches, researchers can contribute to the advancement of knowledge, inform evidence-based decision-making, and guide future research directions in their respective fields. A systematic review is recognized as a comprehensive approach that gathers all relevant studies pertaining to a specific topic and design, subsequently, reviewing and analysing their findings (Ahn and Kang, 2018). The utilization of a methodology such as PRISMA is considered ideal for conducting literature reviews, as it ensures the inclusion of all pertinent evidence through its comprehensive checklist that covers relevant aspects related to the research area (Page et al., 2021). Thus, in this study, the PRISMA systematic review method was employed to identify and examine the relevant literature. A critical aspect of a systematic review is the literature search, which not only shapes the outcomes of the review but also serves as the fundamental process for establishing the available data for analysis (Rethlefsen et al., 2021). Consequently, the literature search process plays a crucial role in informing the results of the systematic review, providing the foundation for data analysis. In this study data were gathered through key databases i.e.; Scopus, Web of Sciences and ScienceDirect. The keywords were identified as 'Definitions for Lean construction maturity models, Lean construction definitions, Definitions of LC, and Lean construction maturity models.' During the selection process of articles from the literature search, two main criteria were employed for screening. Each criterion had specific considerations, as detailed below.

Criteria 1- Relevance of models to the scope of the study:

Articles were assessed based on their suitability, compliance, and relevance to the research objectives. The aim was to identify models that align with the study's focus. To that end following factors were considered:

- Inclusion of any type of LCMM.
- Relevance to lean construction maturity.
- Relevance to lean maturity/assessment.

It was observed that there is a scarcity of literature directly labelled as LCMMs. Hence, the search scope was expanded to encompass models that have a relationship to lean maturity, which closely aligns with the concept of lean construction maturity. This expansion allowed the authors to identify impactful studies that were in line with the study objectives.

Criteria 2- Quality and effectiveness of the papers:

The evaluation of article quality was an important aspect of the screening process. The following criteria were used to assess the quality and effectiveness of documents:

- Explanation of the use of model attributes.
- Reliability of the publisher.
- Originality and reliability of the model.
- Existence of basic concepts of a definition of a maturity model.

These criteria ensured that the selected articles maintained overall excellence, rigor, and contributed significantly to the field of study. The application of these criteria guided the authors in identifying the most impactful articles for inclusion in the study. Figure 1 explains the PRISMA process.

At the outset, a total of 4,886 results were obtained from prominent databases. The systematic elimination of articles that did not meet the aforementioned criteria was carried out, as depicted in Figure 1, since they did not align with the study's objectives. Irrelevant articles were excluded based on the search results. The remaining articles underwent screening based on their titles and abstracts. Subsequently, a comprehensive review of the identified articles was conducted to ensure a thorough understanding. Following this rigorous screening process, 56 articles were selected for the discussion, adhering to the specified selection criteria. Additionally, seven articles were identified through the reference lists of the previously selected articles, and those deemed suitable were also included in the study. Eventually, a total of 63 articles were chosen for the final review and analysis of the study. The findings of these articles are analysed in following section.

The identified models underwent a rigorous analysis using the thematic analysis method, which is a recognised approach for identifying, analysing, and reporting patterns or themes within data (Braun and Clarke, 2008). Thematic analysis is highly suitable for qualitative studies involving the review of data in the construction sector, as it enables the classification, comparison, interpretation, and definition of qualitative data (Vaismoradi et al., 2016). Given the systematic nature of reviewing model data and the need to identify and analyse themes in the data, the study

employed thematic analysis as the chosen method to analyse the data effectively and derive meaningful insights. Thematic analysis was chosen for this study due to the wide variety of data available, as it allows for the examination of various themes and the identification of overarching themes and wording patterns in the development of the lean construction maturity definition. This methodological approach ensures a comprehensive and in-depth exploration of the data.

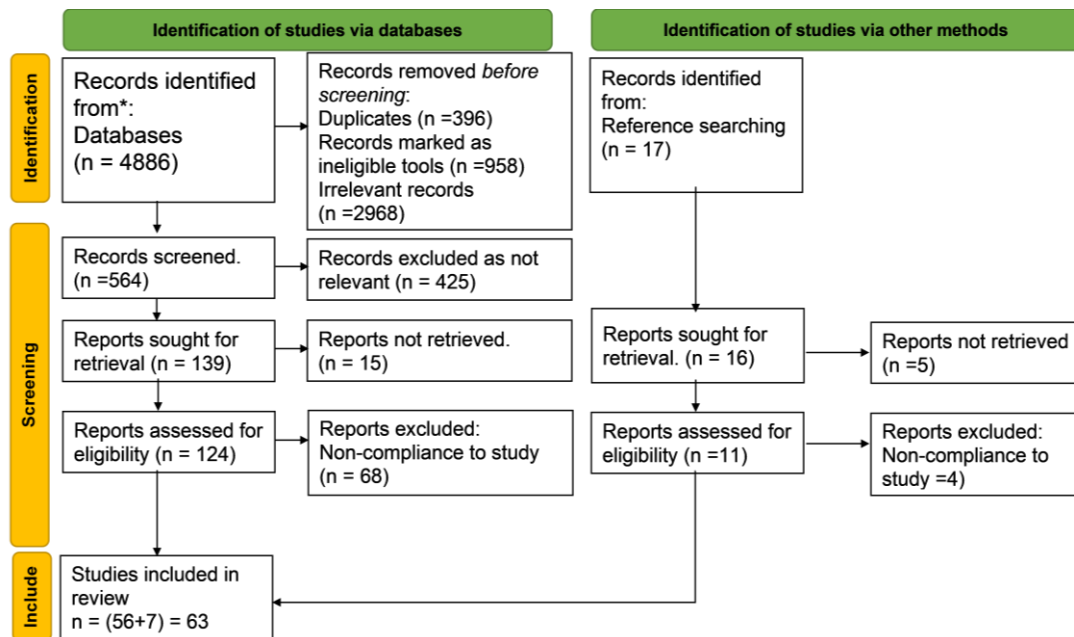


Figure 1, PRISMA process

4. Findings and Analysis

A systematic review of the literature identified 21 models that met the study's criteria and were directly relevant to its scope from analysing 67 documents. These models were subjected to further analysis using thematic analysis, and the findings derived from this analysis are elaborated upon in the subsequent section, highlighting their significance in the research. The following sections methodically explain how a definition for LCMMs were developed using these selected models.

4.1. SELECTED MODELS FOR THE STUDY

A thorough analysis of 21 models was conducted, as indicated in Table 1, to identify the essential components of their definitions and gather data for the development of a comprehensive definition.

Table 1: Derived definition from identified models

Model	Derived Definition	Source of Reference
M1	A model that gives a holistic assessment on LC with respect to Leadership, Philosophy, People, Processes & system, Outcomes & outputs and Learning . The framework utilizes a Likert scale assessment completed by an external evaluator, incorporating 75 statements organized into 11 attributes across 6 layers, to evaluate the performance of a construction project through site visits and conversations with employees.	Nesensohn, (2014)
M2	LCR offers a simple and effective way to assess the quality and level of lean implementation in construction projects. It combines qualitative observation and quantitative analysis , providing a categorized evaluation scheme .	Hofacker et al., (2008)
M3	DOLC diagnoses the current state of the construction company in relation to the level of implementation of concepts of lean construction that the construction company has established	Carvalho and Scheer (2017)
M4	The model incorporates Lean Construction (LC), Last Planner System (LPS), Lean Thinking (LT), and Integrated Project Delivery (IPD) . It assesses four key elements that are further divided into 36 characteristics, each having 191 attributes.	Lean Construction Institute (2016)
M5	MDCE is a framework used to assess and diagnose the level of lean construction implementation within a construction organization or project. It provides a structured approach to evaluate various aspects of lean construction practices and identify areas for improvement.	Arantes (2010)
M6	MMDLCP is designed to gauge the progression and implementation of Lean Construction principles within an organization. It provides a structured pathway for	Soto Becerra (2016) Chile

Model	Derived Definition	Source of Reference
	organizations to assess their level of maturity in adopting Lean Construction practices and guides them towards continuous improvement .	
M7	A tool for assessing the existing level of Lean maturity within an organization. It enables the measurement of the degree of Leanness , identifies areas that need improvement , and offers insights into the overall organizational maturity . This model recognizes the importance of qualitative aspects such as people development, culture building, and strategic leadership in driving Lean principles within the organization.	Sainath et al., (2018)
M8	The toolkit provides a structured approach to evaluate the organization's level of Lean maturity and identify areas for improvement . The toolkit consists of various assessment tools, guidelines, and resources to support the assessment process. It typically includes a set of criteria such as leadership commitment, process optimization, continuous improvement, employee engagement, and customer focus .	HALMAT, (2012)
M9	LCF is a comprehensive approach that incorporates qualitative and quantitative surveys to assess the alignment between implemented techniques and Lean Construction (LC) concepts within the German construction sector.	Johansen, (2015)
M10	A model aims to identify best practices and the most commonly used LC principles . Assess organisations under Standardization, Culture/People, Continuous Improvement/Built-In Quality, Eliminate Waste, Customer Focus ; containing sixteen sub-principles.	Diekmann et al., (2003)
M11	The LCCM Model summarizes the essential concepts of Lean Construction . The purpose of the model is to create a simplified and understandable model that captures the key principles of lean construction . The model aimed to assess the level of awareness and understanding of lean construction principles among industry practitioners	Jeni, M.L., & Akasah, Z.A. (2013)
M12	A model based on the main principles which determined by analysing the most reliable models covering the areas of Customer focus, Supply, Continuous improvement, Waste elimination, People involvement, Planning and scheduling, Quality, Standardization and transparency .	Cookson & Stirk, (2019)
M13	The model outlines a set of lean management principles and practices that can be implemented to improve the efficiency and effectiveness of high-rise apartment construction projects. These principles are derived from the broader concept of lean construction , which aims to eliminate waste, improve collaboration, and optimize project delivery	Sacks & Goldin, (2007)
M14	A specific framework developed for the implementation of lean construction strategies in the Saudi construction industry. This framework utilizes the Interpretive Structural Modeling (ISM) technique to analyse and prioritize the relationships among various lean construction strategies	Sarhan et al., (2020)
M15	A model integrating BIM and LC. This integration serves as a foundation for assessing the effectiveness and success of projects that adopt both BIM and lean principles , enabling a comprehensive evaluation of their performance.	Mollasalehi et al., (2018)
M16	The objective of this model is to examine the alignment between Building Information Modeling (BIM), Integrated Project Delivery (IPD), and Lean Construction (LC) within the framework of Maturity Models . The aim is to identify strategies for synchronizing these three concepts effectively .	Rashidian et al., (2022)
M17	A framework that draws upon the principles of the Toyota Production System (TPS) and integrated project delivery (IPD). It offers an Excel-based tool for analysing construction projects based on four main elements . These elements encompass a total of 152 attributes , distributed across 40 characteristics .	Ireland Lean Construction Institute (2015)
M18	Model incorporates the principles of Lean Construction (LC) by Koskela and Lean Thinking (LT) by Womack and Jones. It consists of 103 statements distributed across 15 categories , which describe LC practices and are linked to scientific references based on the corresponding LC principle. The model assigns different weights to the categories, reflecting their relative importance within the framework	Etges & Saurin, (2013)
M19	Model encompasses the key areas of Customer focus, Culture/people, Workplace organization and standardization, Eliminate waste, and Continuous improvement/built-in quality . The model utilizes a questionnaire consisting of 33 questions , which is administered by an external interviewer . The evaluation is conducted using a Likert scale ranging from 0 to 5 ,	Sweis et al., (2016)
M20	EISLC is a framework that assesses the implementation and effectiveness of lean construction practices . It utilizes indicators and criteria to evaluate process improvement, waste reduction, customer satisfaction, employee engagement, and continuous improvement . The EISLC helps organizations identify areas for improvement and enhance operational efficiency .	Li et al., (2017)
M21	Model assesses the current condition and future direction of Lean Construction implementation. It incorporates principles from Koskela and Womack & Jones, evaluating five categories using a Likert scale (1-5) .	Tezel et al., (2018)

As highlighted, each of the identified model provides an insightful idea for the development of a comprehensive definition. Even though these models did not provide a direct definition, authors were able to derive at a definition upon the descriptions given and with the information provided with each model. The highlighted wordings in the

table show the key insight provided by each model. The highlighted text evidence the distinctive, essential ideas that are expressed by each models giving a foundation to derive at a holistic definition for LCMMs. These data of the models were subsequently analysed using thematic analysis and following key themes were identified.

4.2. IDENTIFYING THE KEY THEMES AND KEY WORDS

Through a rigorous thematic analysis, the authors identified nine distinct themes that encompass all relevant aspects necessary for a comprehensive definition. These themes were carefully derived from an examination of the existing literature and data sources, ensuring that the coverage of key elements related to LCMMs.

Figure 2 presents an illustration of the key themes and their corresponding sub-themes that have been identified in this study. These sub-themes are integral components of the respective key themes, contributing to a comprehensive understanding of the point of interest. The visual representation of these themes and sub-themes enhances the clarity and accessibility of the findings, providing a valuable reference for researchers and practitioners in the field.

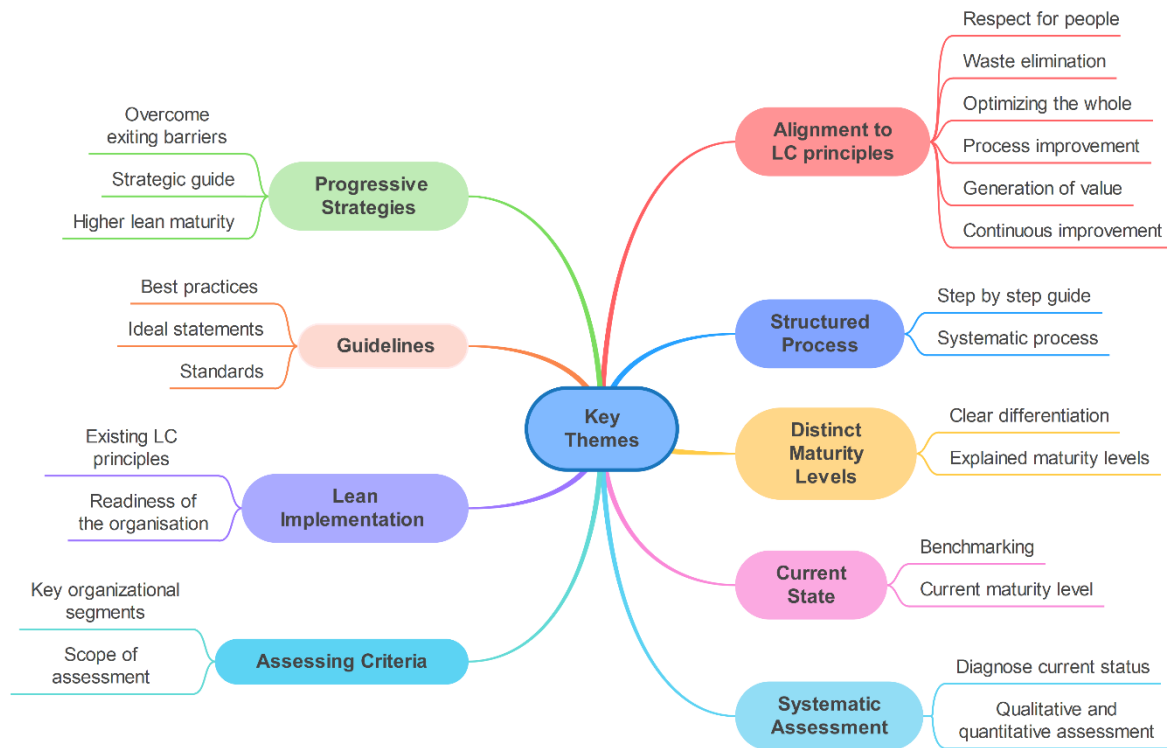


Figure 2, Key themes for the proposed definition

As shown in figure 2, the analysis of the themes and associated keywords strongly indicates that all the models examined in this study have recognized the significance of the nine key overarching themes in defining LC maturity. As a result, each of these themes has been thoroughly considered and incorporated into the development of the proposed LCMM definition. In the following section, a detailed critical analysis is provided, explaining how each of these themes was systematically utilized in the formulation of the new definition. This explains the comprehensive approach taken in integrating these themes, ensuring the robustness and relevance of the proposed model definition.

In defining the models, all of the models identified in the study explicitly mentioned the alignment of model attributes with LC principles. This is apparent on looking at the model information as well as on studying the model attributes. Many scholars also have confirmed this idea stating that LC principles is the bedrock for LCMMs (Jayanetti et al., 2023; Rodegheri & Baptista Serra, 2019). On the same note, most of the models were identified as *structured frameworks/ tools or models*. For instances models such as M1, M4, M5, M10, M11 are only few models from the rest of the models which presented the idea.

“A lean construction maturity model is a defined framework, developed based on fundamental lean construction principles....

A key theme identified through the analysis is that models provide a systematic pathway to assess organisational capabilities and proficiency in terms of LC implementation. This theme was also highly visible amongst the overwhelming majority of the models. Models used several wordings giving similar meaning i.e.; M2- ‘assess the quality and level of lean implementation’, M3- ‘current state of the construction company in relation to the level of implementation of concepts of lean construction’, and M4- ‘diagnoses the current state of the construction.’

*"A lean construction maturity model is a defined framework, developed based on fundamental lean construction principles, **providing systematic assessment criteria for organizations to assess their capabilities in terms of lean construction practices...***

Through the assessment of LC capabilities, the organisations have the ability to comprehend their current level of LC maturity. It allows organisation to systematically identify how each of the organisation capabilities arrived at the respective maturity level. As identified through the systematic analysis, this notion was also visible in many models such as M7 as it elaborates ' *assessing the existing level of Lean maturity within an organization, proving the notion*

*"A lean construction maturity model is a defined framework, developed based on fundamental lean construction principles providing systematic assessment criteria for organizations to assess their capabilities in terms of lean construction practice, **enabling them to systematically evaluate their organizational capacity, indicating the current state of lean construction maturity...***

Models such as evidenced by M6, M7, M8, and M21, provides another important notion reaching higher maturity as it mentions ' *achieving future direction of Lean Construction implementation*'. This provides the evidence to prove that LCMMs are merely not indicators of current maturity level but are means of tools providing strategies to reach higher maturity by minimising the barriers.

*"A lean construction maturity model is a defined framework, developed based on fundamental lean construction principles providing systematic assessment criteria for organizations to assess their capabilities in terms of lean construction practice, enabling them to systematically evaluate their organizational capacity, indicating the current state of lean construction maturity. **A LCMM offers effective strategies to mitigate barriers and challenges for successful lean construction implementation, empowering organizations to enhance their lean construction practices and continually improve their performance to reach higher LC maturity levels....***

Finally, apart from providing strategies LCMMs provide various guidelines to the end users of the models to understand on how to identify successful pathways to higher maturity by presenting various best practices, ideal statements and indicators. M1, M5, M8, M12, M13, M20 have all presented some kind of an impression on guidelines, making it also an essential theme in the proposed LCMM definition. Therefore, considering the themes and ideas supported by the examined models, the final definition of the lean construction maturity model can be summarized as follows:

*"A lean construction maturity model is a defined framework, developed based on fundamental lean construction principles, providing systematic assessment criteria for organizations to assess their capabilities in terms of lean construction practices, enabling them to systematically evaluate their organizational capacity, indicating the current state of lean construction maturity. **A LCMM offer effective strategies to mitigate barriers and challenges for successful lean construction implementation, empowering organizations to enhance their lean construction practices and continually improve their performance to reach higher LC maturity levels, providing practical guidelines encompassing industry best practices and ideal statements."***

The suggested definition encompasses the essential areas that have been identified through various models, presenting a more comprehensive and detailed definition that holds practical relevance for the lean construction sector. This definition takes a holistic approach, considering multiple facets and dimensions of lean construction, thereby providing a pragmatic perspective. It captures the key elements necessary for a thorough understanding of lean construction principles and practices, making it a valuable resource for organizations operating in the construction industry.

5. Discussion

The aim of this study was to develop a comprehensive definition for LCMMs by analysing and synthesizing the key characteristics of existing models. Through a careful examination of the derived definitions from 21 identified models, a clear understanding of the essential elements of LCMMs has emerged. A key highlight of models is the alignment with LC principles (Nesensohn, 2014; Hofacker et al., 2008; Lean Construction Institute, 2016). Most of the models were reliant on Koskela's LC principles (Koskela, 1992; Koskela et al., 2002). Numerous scholars have supported the notion that Lean Construction (LC) principles serve as the foundation for LCMMs (Rodegheri & Baptista Serra, 2019).

The reviewed models encompass a wide range of approaches and methodologies, highlighting the diversity within the field of lean construction. Several models, such as M2- LCR (Hofacker et al., 2008), M7- Multi-Dimensional Matrix (Sainath et al., 2018), M19-ALC (Li et al., 2017) , and M21- EISLC (Tezel et al., 2018), utilize Likert scales as a means of evaluating. On the contrary, models like M5-MDCE and M9-LCF incorporate qualitative surveys and interviews to capture a more in-depth understanding of the implementation of Lean Construction concepts and techniques (Arantes 2010; Johansen, 2015). However, as per expert LC practitioners, it is advised to have both quantitative and qualitative measures in LC in order to grasp the holistic picture (Ballard et al., 2007; Koskela, 1992).

All the models showcased some level of representation of maturity levels. The importance of this was well supported by the experts in the field as well indicating that first an entity needs to be sure of the current status (Albalkhy & Sweis, 2021; Ranadewa et al., 2021). It is evident that certain models such as Model M1, offer a holistic assessment of lean construction by considering multiple dimensions (Nesensohn, 2014). It is explained under the model information by doing that it allows the assessment to be more accurate and practical since it covers all the aspects relates to an organisation. However, some of the models such as DOLC and EISLC have not considered the holistic view where as they have only assessed certain technical capacities (Carvalho & Scheer, 2017; Li et al., 2017). Emerging evidence suggests that assessing the entire organizational landscape is crucial to obtaining an accurate and comprehensive understanding of lean implementation. Merely focusing on isolated aspects or individual components of lean practices may not provide a complete picture of the organization's lean journey. Instead, considering a holistic perspective that incorporates various factors is deemed essential for capturing the intricacies and complexities involved in the successful enactment of lean principles (Lean construction Institute 2023).

A well-established definition of LCMMs contributes to the advancement of knowledge and theory in the field of LC. It provides a foundation for further research and investigation into the effectiveness and applicability of MMs, facilitating the development of more refined models and frameworks that address the unique challenges and requirements of the construction industry (Jayanetti et al., 2022). Similarly, the developed model facilitates benchmarking and performance measurement, enabling organizations to identify their current position, set goals, and track progress over time. The ability to gauge maturity levels consistently and accurately aids in identifying areas for improvement, allocating resources effectively, and implementing targeted strategies to enhance lean construction practices.

6. Conclusions

This study addressed the existing gap of a standard definition for LCMMs by conducting a systematic literature review using the PRISMA technique. The aim was to develop a precise and industry-tailored definition for LCMMs specific to the construction context. Through the analysis of 21 key LCMMs using thematic analysis, nine key themes, i.e.; Alignment to lean principle, Structured process, Distinct maturity levels, Current state, Systematic assessment, Progressive strategies, Guidelines, Lean Implementation, Assessing Criteria, and corresponding sub-themes were identified, which moulded the basis for the development of the new definition.

The new definition provides a comprehensive framework based on fundamental lean construction principles. It offers a systematic assessment criterion for organizations to evaluate their capabilities in terms of lean construction practices, enabling them to assess their current state of lean construction maturity and identify areas for improvement. The developed definition also highlights the role of LCMMs in addressing barriers and challenges faced in successful lean construction implementation. By offering effective strategies and practical guidelines encompassing industry best practices and ideal statements, LCMMs empower organizations to enhance their lean construction practices and continuously improve their performance.

6.2. CONTRIBUTION FROM THE STUDY

The formulated definition for LCMMs holds considerable significance across multiple dimensions. The theoretical contribution of this paper lies in filling the existing literature gap by providing a precise and industry-tailored definition for LCMMs. This definition serves as a foundation for future research and standardization efforts in the field of lean construction. This paper not only serves as an initial reference for future research and investigation but also stimulates a more reflective comprehension of the application and assessment of MM

From an industry perspective, the practical contribution is substantial, as it equips construction organizations with the means to assess their lean maturity level, identify areas for improvement, and make informed decisions to enhance their lean practices and overall performance. Furthermore, an established definition allows for standardized evaluation and comparison of organizations' maturity levels in LC. The outcome of this study has significant implications for construction practitioners and policymakers, as it provides them with a tool to strategically plan their lean transformation journey and drive organizational improvement. Lastly, the development of a comprehensive definition for LCMMs also holds significant societal contributions. By establishing clear guidelines and criteria for assessing and improving lean construction practices, LCMMs promote efficiency, productivity, and sustainability within the construction industry.

6.2. FUTURE AREAS OF STUDY

As future areas of research, the developed definition can be utilised as a guideline to craft model assessing tools for LCMMs. The developed definition can be empirically tested for validation in further studies as well. Further, future research can explore the customization of the LCMM definition to address the specific requirements of different construction types and emerging industries. Moreover, the outcome of the research can be taken as the first step of developing conceptual LCMM.

7. References

- Ahn, E., & Kang, H. (2018). Introduction to systematic review and meta-analysis. *Korean Journal of Anaesthesiology*, 71(2), 103–112. doi:10.4097/kjae.2018.71.2.103
- Albalkhy, W., & Sweis, R. (2021). Barriers to adopting lean construction in the construction industry: a literature review. *International Journal of Lean Six Sigma*, 12(2), 210–236. <https://doi.org/10.1108/IJLSS-12-2018-0144>
- Andersen, B., Belay, A. M., & Seim, E. A. (2012). Lean construction practices and its effects: A case study at st olav's integrated hospital, Norway. *Lean Construction Journal*, 2012, 122–149.
- Arantes, L. (2011). *Diagnosis of the application of two principles of embedded construction in builders of the building sector that operate in Belem-PA*. [PhD Thesis]. Federal University of Para, Belem-PA, Brazil
- Aslam, M., Gao, Z., & Smith, G. (2020). Exploring factors for implementing lean construction for rapid initial successes in construction. *Journal of Cleaner Production*, 277, 123295. <https://doi.org/10.1016/j.jclepro.2020.123295>
- Ballard, G., Tommelein, I., Koskela, L., & Howell, G. (2007). Lean construction tools and techniques. *Design and Construction*, 227–255. <https://doi.org/10.4324/9780080491080>
- Braun, V. and Clarke, V., 2008. Using thematic analysis in psychology using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), pp.77–101. doi:10.1191/1478088706qp063oa
- Brookes, N. and Clark, R., 2009. Using maturity models to improve project management practice. In: POMS (Production and Operations Management Society), *20th Annual conference*. January 2009, Orlando, Florida U.S.A, 1- 4 May 2009. UK: Aston University
- Brookes, N., Butler, M., Dey, P., & Clark, R. (2014). The use of maturity models in improving project management performance: An empirical investigation. *International Journal of Managing Projects in Business*, 7(2), 231–246. <https://doi.org/10.1108/IJMPB-03-2013-0007>
- Carvalho, B. S., & Scheer, S. (2017). Analysis and assessment for lean construction adoption: the DOLC Tool. 25th Annual Conference of the International Group for Lean Construction (IGLC), 9-12 July 2017, Heraklion, Greece. <https://doi.org/10.24928/2017/0117>
- Cookson, M. D., & Stirk, P. M. R. (2019). The potential effectiveness of lean construction principles in reducing construction process waste: an input-output model. *Wood and Fiber Science*, 12(4), 4141–4160. <https://doi.org/10.15282/jmes.12.4.2018.12.0358>
- Demir, C. and Kocabas, I., 2010. Project management maturity model (PMMM) in educational organizations. *Procedia - Social and Behavioral Sciences*, 9, pp.1641–1645. <https://doi.org/10.1016/j.sbspro.2010.12.379>
- Diekmann, J. E., Balonick, J., Krewedl, M., & Troendle, L. (2003.). Measuring lean conformance. In *Proc. 11th Ann. Conf. Intl. Group for Lean Construction* 102, 2–8
- Etges, B. M. B. S., Saurin, T. A., & Bulhões, I. R. (2013). A protocol for assessing the use of lean construction practices. *Proceedings of the 21th Annual Conference of the International Group of Lean Construction (IGLC)* (pp 93–101). Fortaleza, Brazil
- Goksen, Y., Cevik, E., & Avunduk, H. (2015). A Case Analysis on the Focus on the Maturity Models and Information Technologies. *Procedia Economics and Finance*, 19(15), 208–216. [https://doi.org/10.1016/s2212-5671\(15\)00022-2](https://doi.org/10.1016/s2212-5671(15)00022-2)
- Highways Agency Lean Maturity Assessment Toolkit (HALMAT). (2012).
- Hofacker, A., Oliveira, B. D., Gehbauer, F., Freitas, M. D. C. D., Mendes Júnior, R., Santos, A., & Kirsch, J. (2008, July). Rapid lean construction-quality rating model (LCR). In *16th International Group for Lean Construction Conference*, 1–11
- Jayanetti, J. K. D. D. T., Perera, B. A. K. S., Waidyasekara, K. G. A. S., & Siriwardena, M. (2023). Critical Analysis of Lean Construction Maturity Models: A Systematic Literature Review. *Buildings*, 13(6), 1508.
- Jayanetti, J.K.D.D.T., Perera, B.A.K.S. and Waidyasekara, K.G.A.S., 2022. Defining a 'maturity model' in the construction context: A systematic review. In *Proceedings of the 10th World Construction Symposium*, 24–26 June 2022, Sri Lanka. pp. 298–312. DOI: <https://doi.org/10.31705/WCS.2022.25>. Available from: <https://ciobwcs.com/2022-papers/>
- Jeni, A., Luthfi, M., & Akasah, Z. A. (2013). Implementation of lean construction concept among contractors in Malaysia. In *The International Conference on Engineering and Built Environment*, 112671200(1), 1–6
- Johansen, E., & Walter, L. (2007). Lean construction: Prospects for the German construction industry. *Lean construction journal*, 3(1), 19–32
- Koskela, L. (1992). Application of the New Production Philosophy to Construction. *Centre for Integrated Facility Engineering*, (72). Stanford University.
- Koskela, L., Howell, G., Ballard, G., & Tommelein, I. (2002). The foundations of lean construction. *Design and construction: Building in value*, 291, 211–226.
- Lacerda, T. C., & von Wangenheim, C. G. (2018). Systematic literature review of usability capability/maturity models. *Computer Standards & Interfaces*, 55, 95–105.
- Lean Construction Institute – LCI (2016), *LCI Lean IPD Health and Maturity Assessment Tool 1.0*, LCI, Arlington, TX, USA, available at: <https://www.leanconstruction.org/learning/tools-and-technologies/> (accessed on 10 May 2023)
- Lean Construction Institute. LCI Tenets. 2023. Available online: <https://leanconstruction.org/about/lean-tenets/> (accessed on 25 June 2023)
- Lean Construction Institute—LCI, Ireland Community of Practice. Lean Assessment Tool Baseline for Ireland; CoP 09022116; LCI: Dublin, Ireland, 2015. Available online: <http://leanconstructionireland.ie/gettingstarted/lean-assessment-tool/> (accessed on 2 May 2023).
- Li, S., Wu, X., Zhou, Y., & Liu, X. (2017). A study on the evaluation of implementation level of lean construction in two Chinese firms. *Renewable and Sustainable Energy Reviews*, 71(January), 846–851. <https://doi.org/10.1016/j.rser.2016.12.112>
- Liu, Z. and Zhang, Y. X., 2019. Assessing the maturity of China's seven carbon trading pilots. *Advances in Climate Change Research*, 10(3), pp.150–157. <https://doi.org/10.1016/j.accre.2019.09.001>
- Machado, F., Duarte, N., Amaral, A., & Barros, T. (2021). Project Management Maturity Models for Construction Firms. *Journal of Risk and Financial Management*, 14(12), 571. <https://doi.org/10.3390/jrfm14120571>
- Mollasalehi, S., Aboumoemen, A. A., Rathnayake, A., Fleming, A. J., & Underwood, J. (2018). Development of an integrated BIM and lean maturity model. *Proceedings of IGLC 26* (pp. 1217–1228). Chennai, India. <https://doi.org/10.24928/2018/0507>
- Moyano-Fuentes, J., & Sacristán-Díaz, M. (2012). Learning on lean: A review of thinking and research. *International Journal of Operations and Production Management*, 32(5), 551–582. <https://doi.org/10.1108/01443571211226498>

- Nesensohn, C. (2014). *An innovative framework for assessing lean construction maturity*. Liverpool John Moores University (United Kingdom).
- Nesensohn, C., Bryde, D., Ochieng, D. E. G. and Fearon, D., 2015. Maturity and maturity models in lean construction. *SSRN Electronic Journal*, January 2018. <https://doi.org/10.2139/ssrn.2622152>
- Nightingale, D., Broughton, T., Brown, K., Cool, C., Crute, V., James-Moore, M., & Womersley, M. (2001). Lean enterprise self assessment tool. *Lean Aerospace Initiative, Cambridge, Mass, 68*
- Oxford Dictionary, 2023. *Oxford Advanced Learner's Dictionary*. [online] UK; Oxford University Press. Available at: <<https://www.oxfordlearnersdictionaries.com/definition/english/maturity#:~:text=%2Fm%C9%99%CB%88t%CA%8Ar%C9%99ti%2F,in%20a%20sensible%2C%20adult%20manner>> [Accessed 01 June 2023]
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., & Moher, D. (2021). Updating guidance for reporting systematic reviews: development of the PRISMA 2020 statement. *Journal of Clinical Epidemiology*, 134, 103–112. <https://doi.org/10.1016/j.jclinepi.2021.02.003>
- Pennypacker, J. S., 2005. *Project portfolio management maturity model*. PA, USA: Center for Business Practices.
- Ranadewa, K. A. T. O., Sandanayake, Y. G., & Siriwardena, M. (2021). Enabling lean through human capacity building: an investigation of small and medium contractors. *Built Environment Project and Asset Management*, 11(4), 594–610.
- Rashidian, S., Drogemuller, R., & Omrani, S. (2022). *The compatibility of existing bim maturity models with lean construction and integrated project delivery*. 27(December 2021). <https://doi.org/10.36680/j.itcon.2022.024>
- Rethlefsen, M. L., Kirtley, S., Waffenschmidt, S., Ayala, A. P., Moher, D., Page, M. J. and Koffel, J. B., 2021. PRISMA-S: an extension to the PRISMA statement for reporting literature searches in systematic reviews. *Systematic Reviews*, 10(1), pp.39. <https://doi.org/10.1186/s13643-020-01542-z>
- Rodegheri, P. M., & Baptista Serra, S. M. (2019). Lean construction and maturity models: Applying five methods. *27th Annual Conference of the International Group for Lean Construction, IGLC 2019, September*, 1081–1092. <https://doi.org/10.24928/2019/0195>
- Rodegheri, P. M., Mara, S., & Serra, B. (2020). Maturity models to evaluate lean construction in Brazilian projects. *Brazilian Journal of Operations & Production Management*, 17(2), 1–20
- Sacks, R., & Goldin, M. (2007). Lean Management Model for Construction of High-Rise Apartment Buildings. *Journal of Construction Engineering and Management*, 133(5), 374–384. [https://doi.org/10.1061/\(ASCE\)0733-9364\(2007\)133:5\(374\)](https://doi.org/10.1061/(ASCE)0733-9364(2007)133:5(374))
- Sainath, Y., Varghese, K., & Raghavan, N. (2018). Framework for progressive evaluation of lean construction maturity using multi-dimensional matrix. *Proceedings of the 26th Annual Conference of the International Group for Lean Construction: Evolving Lean Construction Towards Mature Production Management Across Cultures and Frontiers* (pp.370–380). Chennai, India. <https://doi.org/10.24928/2018/0416>
- Sanchez, A. M., & Pérez, M. P. (2001). Lean indicators and manufacturing strategies. *International Journal of Operations & Production Management*.
- Sarhan, J. G., Xia, B., Fawzia, S., Karim, A., Olanipekun, A. O., & Coffey, V. (2020). Framework for the implementation of lean construction strategies using the interpretive structural modelling (ISM) technique: A case of the Saudi construction industry. *Engineering, Construction and Architectural Management*, 27(1), 1–23. <https://doi.org/10.1108/ECAM-03-2018-0136>
- Saunders, M., P. Lewis, and A. Thornhill., (2016). *Research Methods for Business Students*. 7th ed. England. Pearson Education Limited.
- Schlichter, J., 1999. Surveying project management capabilities. *PM Network*, 13(1), pp.39-40
- Software Engineering Institute, 2006. *CMMI for Development Version 1.2*. Pittsburgh: Software Engineering Institute
- Sohrabi, C., Franchi, T., Mathew, G., Kerwan, A., Nicola, M., Griffin, M., Agha, M., & Agha, R. (2021). PRISMA 2020 statement: What's new and the importance of reporting guidelines. *International Journal of Surgery*, 88(March), 39–42. <https://doi.org/10.1016/j.ijsu.2021.105918>
- Soto Becerra, U.B. (2016). Assessment of the Maturity of Lean Principles in Construction Projects, Master's Thesis in Engineering Sciences, Pontificia Universidad Católica de Chile, Santiago, Chile
- Stevens, M. (2014). Increasing adoption of lean construction by contractors. *22nd Annual Conference of the International Group for Lean Construction: Understanding and Improving Project Based Production, September*, 377–388
- Sweis, G. J., Hiyassat, M., & Al-Hroub, F. F. (2016). Assessing lean conformance by first-grade contractors in the Jordanian construction industry. *Construction Innovation*, 16(4), 446–459. <https://doi.org/10.1108/CI-04-2015-0024>
- Tezel, A., Koskela, L., & Aziz, Z. (2018). Current condition and future directions for lean construction in highways projects: A small and medium-sized enterprises (SMEs) perspective. *International Journal of Project Management*, 36(2), 267–286. <https://doi.org/10.1016/j.ijproman.2017.10.004>
- Tocto-Cano, E., Paz Collado, S., López-Gonzales, J. and Turpo-Chaparro, J., 2020. A systematic review of the application of maturity models in universities. *Information*, 11(10), pp.466. <https://doi.org/10.3390/info11100466>
- Vaismoradi, M., Jones, J., Turunen, H., & Snelgrove, S. (2016). Theme development in qualitative content analysis and thematic analysis.
- Vásquez, J., Aguirre, S., Puertas, E., Bruno, G., Priarone, P. C. and Settineri, L., 2021. A sustainability maturity model for micro, small and medium-sized enterprises (MSMEs) based on a data analytics evaluation approach. *Journal of Cleaner Production*, 311 <https://doi.org/10.1016/j.jclepro.2021.1276>