Lean implementation in the construction industry: A review

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Abstract

The construction industry plays a vital role in the economy but is also a significant contributor to waste generation and resource depletion. Lean construction has emerged as a strategy to address these challenges by focusing on minimising waste, enhancing efficiency, and maximising value throughout the project lifecycle. Moreover, the lean concepts positively impact sustainability in construction projects. Therefore, this study aims to review the evolution, principles, and implementation of lean construction in the construction industry. Through review, the study concludes that the lean construction principles encompass Customer Value, Value Stream, Flow, Pull, and Perfection. Further, the most commonly cited lean tools utilised in the construction industry include Value Stream Mapping (VSM), Last planner system (LPS), visual management, Total Quality Management (TQM), Poka-Yoke, 5S, Takt Time Planning (TTP), first-run studies, JIT, material or component flow, work structuring, kanban, supply chain integration, cell production units, continuous improvement cells, prefabrication and modularisation, Jidoka (in-station quality), line of balance method (LOB), 5 Why's, Gemba walk, PDCA (Plan-Do-Check-Act) cycle, A3 report, Target value design (TVD) and other. Further research is needed to refine lean construction methodologies implementation and overcome implementation barriers, ensuring its widespread adoption and long-term success in the construction industry.

Keywords: Construction industry; Construction industry; Lean; Principles; tools; waste

1. INTRODUCTION

The construction industry contributes to the economy of any country (Butković et al., 2021; Ogunmakinde et al., 2022). Globally, the construction industry and the industries that makeup it are among the major contributors to waste generation and significant amounts of extraction of natural resources (Benachio et al., 2021; Eberhardt et al., 2022; Torgautov et al., 2022). According to Papastamoulis et al. (2021), every year billions of tons of construction and demolition waste are disposed of in landfills around the world, harming the environment, the economy, and society significantly. More than 30% of natural resource extraction and 25% of solid waste generated worldwide are attributed to the construction industry (Benachio et al., 2020). According to the National Waste Report 2020, around 61.5 million tons of "core waste" were generated in Australia in 2018–19, of which 27.0 million tons were from the construction and demolition industry (44% of the total) (Pickin et al., 2020). Norouzi et al. (2021) point out that lean construction focuses on the significance of minimising waste, getting rid of unfruitful and unproductive processes, and streamlining flow. Accordingly, lean construction is a concept that seeks to increase production, decrease waste, and increase value in the construction industry (Benachio et al., 2021). The lean concept aims at maximizing value while reducing waste (Demirkesen et al., 2022). Lean construction is renowned for removing non-value-added activities, providing the product that best satisfies the needs of the client, and working to improve value delivery throughout the

construction process, and it is recognized to have enormous potential to help with the efficient use of resources (Aslam et al., 2022; S. Li et al., 2020; Mohammadi et al., 2022). Besides that, according to Lekan et al. (2022), lean construction promotes the following by removing waste from the construction process, balancing the team, removing any restrictions imposed by material constraints, minimising changeovers and input variance, coordinating the flow of information, shortening the time that workers and equipment are handled, as well as challenging setups, and reducing interpersonal conflicts. Lean practices have several benefits, including decreased waste, higher customer satisfaction, improved safety, and increased production (Demirkesen et al., 2022; S. Li et al., 2020). Furthermore, several lean techniques and tools have been established for lean construction to assist the application of lean construction and to achieve higher value in construction projects (Aslam et al., 2022; Demirkesen et al., 2022). Furthermore, the lean philosophy/principles/practices and lean tools have been increasingly applied to advance and achieve environmental, economic, and social values in construction projects (Solaimani and Sedighi, 2020, Carvajal-Arango et al., 2019). Therefore, there is a need to implement lean practices in the construction industry to benefit from them. Therefore, this study aims to identify the implementation of lean in the construction industry.

2. LITERATURE REVIEW

2.1. Evolution of lean construction

The word "lean" was adopted through the Japanese and adapted for usage in the construction industry (Ogunbiyi et al., 2014). Accordingly, Lean construction emerged from the application of lean thinking principles in the construction sector, which were originally developed in the Toyota Production System (TPS) (Albalkhy and Sweis, 2021). Moreover, this concept involves implementing and adapting the core principles and concepts of the TPS, established in the 1950s, to develop a new method for managing construction projects (Gao and Low, 2014). Furthermore, Oey and Lim (2021) and Sacks et al. (2010) emphasized that since lean introduction in the early 1990s, lean construction has attracted many firms to integrate the lean concept into their construction processes. Koskela (1992) observes construction as a manufacturing process, depicting it as a transformation, flow of information and materials, and value creation. Moreover, Koskela, the creator of the Transformation Flow View philosophy (TFV) of production (Koskela, 2000), was a key pioneer of lean construction (Ogunbiyi et al., 2014).

Subsequently, Gao and Low (2014) and Mostafa et al. (2016) findings indicate that new production philosophies can be adapted and applied to manage the process of construction project processes. Sacks et al. (2010) and Shang and Sui Pheng (2012) indicated that, while many principles and tools from the TPS are applicable in construction, there are also specific principles and techniques unique to lean construction that are not transferable. In addition, Bertelsen and Koskela (2004) described two major streams in lean construction: the theoretical stream which began in 1992 with Koskela's introduction of the theory of TFV, and the practical stream, which began in 1994 with Gregory Howell and Glenn Ballard's introduction of the LPS. Nevertheless, the core of lean construction has been coined by LPS and TFV, and tools, concepts, and numerous principles have been brought or created to lean construction although they were presented.

Moreover, Gao and Low (2014), Green and May (2005) and Tezel and Nielsen (2013) identified various government institutes, policymakers, studies, construction management practitioners, professionals and researchers, and specific occupational organizations who have advocated for and researched the concept of lean construction since the early 1990s. Accordingly, the Lean Construction Institute (LCI) and the International Group for Lean Construction (IGLC) are the two most prominent organizations focused on promoting lean principles within the construction industry (Sarhan & Fox, 2013; Tezel & Nielsen, 2013). The formation of the LCI, along with promotional firms and various consultancy focused on lean construction, has significantly increased awareness of lean principles. Additionally, several organizations and universities now provide lean education, which has been instrumental in integrating

lean thinking into mainstream construction education (Sarhan and Fox, 2013). Lean construction has been adopted with significant benefits in construction industries worldwide (Shaqour, 2022).

2.2. Lean construction

Sacks et al. (2010) mentioned lean construction, like the TPS, focuses on continuous improvement, waste reduction, and increase customer value. Similarly, the objective is to complete the project while increasing value, reducing waste, and striving for perfection (Al-Aomar, 2013). Thereafter, during the construction process, lean construction involves two major goals: increase value generation for the customer and reduce process and physical waste (Dave et al., 2013). Due to that, Al-aomar (2012) confirmed, as a result, many project management methods, such as lean construction, value engineering, and lean project management, have evolved to enhance construction performance. The definitions for lean construction are illustrated in Table 1.

Table 1: The Definitions for Lean Construction

Reference	Definitions
(Koskela, 1992)	A method of designing production systems to reduce waste of time, effort, and material in order to create the maximum value possible
(Marhani et al., 2012)	Lean Construction is a method of continuously improving a construction project by minimizing waste of resources while also increasing productivity, and ensuring a better health and safety environment in order to meet the needs of the customer while also contributing to a more greener environment and sustainable.
(Aziz & Hafez, 2013)	Lean construction is the outcome of a new type of production management being applied to the construction industry. Further, a defined set of delivery process objectives aimed at optimising performance for the client at the construction project level, the use of production control all across the product's life cycle from design to delivery, and, concurrent product and process design are all essential elements of lean construction.
(Bajjou et al., 2017)	Lean construction is a new technique of organising construction project management in such a manner that waste is reduced and the maximum value is generated for the client with the least amount of resources.
(Albalkhy & Sweis, 2021)	Lean construction is a philosophy that focuses on improving collaboration among all project-relevant stakeholders to increase value for the whole of them for the client in particular and in general, as well as achieve continuous improvement, eliminate all types of waste, improve material flow, improve quality and safety and reduce costs.

Meanwhile, Al-aomar (2012) affirmed several construction managers accept that the construction sector is prone to project inefficiency, excessive expenditure, errors, and delays, however, projects are seldom within the schedule, on acceptable quality, and on the budget the client accepts.

2.3. Lean principles and tools

Lean-related tools have been developed, and effectively implemented to both complex and simple construction projects (Abdelhamid et al., 2008). Besides, Tezel et al. (2018), Solaimani and Sedighi (2020) and Carvajal-Arango et al. (2019), listed the most commonly mentioned lean approaches used in the construction sector to maximise the value and achieve sustainable construction: VSM, LPS, visual management, TQM, Poka-Yoke (Mistake-proofing systems), 5S, set-up preparation and improvement, TTP, first-run studies, JIT, material or component flow, work structuring, kanbans (Pull production system), supply chain integration, cell production units (Multi-functional construction work units), continuous improvement cells, prefabrication and modularisation, Jidoka (in-station quality), line of

balance method (LOB), 5 Why's, Gemba walk, PDCA cycle, A3 report, Target value design, and information technologies to support lean construction deployments.

Lean construction is based on production management principles drawn from the TPS. Further, its primary goal is to eliminate waste in processes, which helps shorten cycle times, improve efficiency and enhance quality (Akanbi et al., 2019). Moreover, lean construction principles resulted to a process efficiency increase of 14%, a cycle time decrease of 17%, and a process productivity increase of 41% increase (Bajjou & Chafi, 2019). Applying lean principles to construction is grounded in the theory of TFV in production management. Further, the theory highlights three distinct aspects of production: (1) transformation driven by equipment, and workers, resources, (2) materials flow, and (3) a focus on customer needs (Akanbi et al., 2019). However, several authors have identified lean principles in different ways. Accordingly, Koskela (1992) and Khodeir and Othman (2018) outlined eleven lean construction principles, while Womack and Jones (1996) listed them into five categories. Consequently, Liker (2004) discovered 14 principles that form the foundation of the Toyota Way, organizing them into four interrelated groups: philosophy, process, people, and problem-solving. These differing classifications of lean principles by researchers as indicated in Table 2.

Table 2: Lean principles

References	Lean principles
Koskela (1992); Khodeir and Othman (2018)	1. Reduce the share of non-value-adding activities (waste) 2. Increase output value through systematic consideration of customer requirements 3. Reduce variability 4. Reduce cycle times 5. Simplify by minimizing the number of steps, parts and linkages 6. Increase output flexibility 7. Increase process transparency 8. Focus control on the complete process 9. Build continuous improvement into the process 10. Balance flow improvement with conversion improvement 11. Benchmarking
(Womack and Jones, 1997)	1. Specify value 2. Identify the value stream 3. Flow 4. Pull 5. Perfection
(Liker, 2004)	1. Base your management decisions on long-term systems thinking, even at the expense of short-term financial goals. 2. Connect people and processes through continuous process flow to bring problems to the surface. 3. Use “pull” systems to avoid overproduction. 4. Level out the workload, like the tortoise, not the hare (heijunka). 5. Work to establish standardized processes as the foundation for continuous improvement. 6. Build a culture of stopping to identify out-of-standard conditions and build in quality. 7. Use visual control to support people in decision-making and problem-solving. 8. Adopt and adapt technology that supports your people and processes. 9. Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others. 10. Develop exceptional people and teams who follow your company’s philosophy. 11. Respect your value chain partners by challenging them and helping them improve. 12. Observe deeply and learn iteratively (PDCA) to meet each challenge. 13. Focus the improvement energy of your people through aligned goals at all levels.

	14. Learn your way to the future through bold strategy, some large leaps, and many small steps.

Most definitions of the principles utilise similar concepts, therefore, a critical analysis of all the definitions allows us to categories lean construction principles primarily in terms of Customer Value, Value Stream, Flow, Pull and Perfection. Further, Koskela (1992) defined: value-adding activity as "Activity that transforms information and/or materials into what the client needs"; non-value-adding activity (waste) as "An activity that consumes resources, or space, time, however, adds no value".

In addition, while implementing lean construction to reduce and manage the impact of the majority of the project's risk factors, as a result, due to reducing Time-overrun (PET) values, overall project time was decreased by 15.57 percent, while Percent Plan Completed (PPC) values increased (Issa, 2013). Furthermore, Oey and Lim (2021) highlighted lean construction minimised the seven construction waste such as; waiting, overproduction, transportation, inventory, extra processing, motion, and defects. Even though, wastage can be categorised into eight such as; unnecessary processes, overproduction, underutilised people, defects, transportation, waiting, inventory, and unneeded movement (Abdelhamid et al., 2008; Garrett & Lee, 2011). The comparison between the construction and manufacturing industry wastage of time is shown in Figure 1.

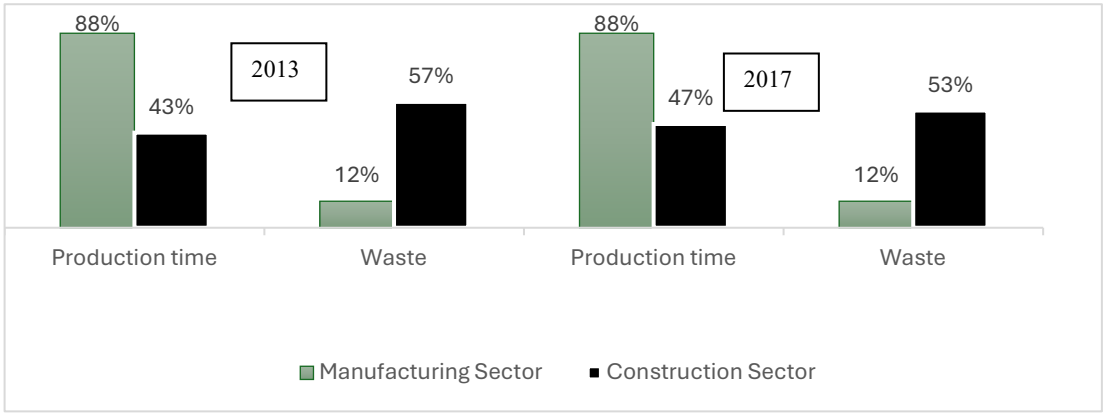

Figure 1: The Comparison between Construction and Manufacturing Industry Wastage of Time
Source: Adapted from Aziz and Hafez (2013) and Bajjou et al. (2017)

As seen in Figure 1, the construction industry has a greater production/waste ratio than the manufacturing sector. According to its enormous potential to meet customer expectations in order to enhance value and decrease all kinds of waste, the lean construction concept is regarded as an alternative strategy that may offer revolutionary transformation to the construction sector (Bajjou et al., 2017). However, Issa (2013) revealed price escalation or changes in material costs, delay in processing the Contractor's interim payments, inadequate local material quality and design flaws, and appropriateness to the environment are four risk aspects that are not changed by utilising lean.

3. CONCLUSIONS

Globally, the construction industry stands as a pivotal economic contributor. However, it also faces significant challenges, mainly concerning waste generation and resource extraction. Accordingly, the study discussed that lean construction emerges as a promising solution, aiming to minimize waste, enhance efficiency, and maximize value throughout the project lifecycle. Through the adoption of lean principles and tools, such as waste reduction strategies and process optimization techniques, the construction industry can achieve substantial benefits including increased productivity, improved customer satisfaction, and enhanced sustainability. Further, study provided the information on lean construction principles which have been identified in various ways by different authors, but they generally encompass five principles such as: Customer Value, Value Stream, Flow, Pull, and Perfection. Furthermore, various lean tools have been identified for use in the construction industry. Despite the

recognized benefits of lean in construction, its implementation has not reached the same level as in manufacturing. Challenges and barriers hinder its widespread adoption, indicating a need for further research to address implementation issues and improve its effectiveness in the construction sector.

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