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REVIEW ARTICLE

Identification and evaluation of lean tools, techniques and methods: Pre-construction, construction and post-construction processes

Emine Demircioğlu [1], Gizem Can [2]

[1] Istanbul Medipol University, Graduate School of Engineering and Natural Sciences, İstanbul, Türkiye
[2] Istanbul Medipol University, School of Fine Arts Design and Architecture, Department of Architecture, İstanbul, Türkiye

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Abstract

The lean management approach, which is based on the principles of lean thinking, focuses on the elimination of waste and the maximization of value. It has become a fundamental strategy in the management of construction projects. Lean construction applies various Lean Tools, Techniques, and Methods (LTTMs) within this framework. The main objective of this study is to identify the most appropriate LTTMs that can be applied during the pre-construction, construction, and post-construction processes of a building project. The aim of this study is to identify and categorize LTTMs that are most suitable for each process of the building life cycle. To achieve this, a Systematic Literature Review (SLR) was conducted, analyzing relevant scientific publications based on their titles, abstracts, and full texts. The identified LTTMs were then classified according to the corresponding processes of the building life cycle, and the findings were compared with those of similar studies. The results of the analysis revealed that a total of 42 LTTMs have been employed across various processes of the building life cycle. It was determined that 34 LTTMs are applicable during the pre-construction process, 26 during the construction process, and 8 during the post-construction process. The Last Planner System (LPS), recognized for its effectiveness in the planning process, has been determined as the only LTTM applicable across all three processes of the building life cycle: pre-construction, construction, and post-construction. Furthermore, it was observed that LPS can be implemented jointly during the pre-construction and construction processes, while both 5S and LPS can be used together during the construction and post-construction processes. This study is expected to be beneficial in identifying the most appropriate LTTMs for each process of the building life cycle and in enhancing these processes through their effective application.

1. Introduction

Given the rapid and increasingly complex developments in the construction industry, there is a growing need for innovative management approaches to enhance the efficiency and controllability of building life cycle processes [1]. The construction industry, which holds a significant position in the global economy, is not only one of the industry most prone to waste generation but also a dynamic and complex industry due to the many different stakeholders it involves [2, 3].

Correspondence Emine Demircioğlu edemircioglu97@gmail.com

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Considering the sensitive and complex nature of the construction industry, it is crucial that current management approaches adopted in the industry emphasize aspects related to process efficiency, waste minimization, and productivity.

Lean thinking emphasizes the elimination/minimization of non-value-adding activities, promoting direct focus on the value-adding activities and its efficient completion within the shortest possible timeframe [4]. The primary objective of lean thinking is to distinguish between waste and value, eliminate/minimize waste, and maximize value [5]. Value is defined as the benefit delivered to the customer, embodied in a product or service that possesses the features required to meet customer needs, is available at the defined time and location, and for which the customer is willing to pay. Conversely, waste is defined as anything that increases cost without adding value, representing all activities or elements that do not contribute to value creation from the customer's perspective [6]. In addition, a deeper understanding of lean thinking necessitates a thorough examination of its fundamental principles. Womack and Jones [7] asserted five fundamental principles of lean thinking to enable its application in production processes. They emphasized the necessity of clearly defining value for a product/service, identifying the value stream for each product/service, ensuring a continuous flow of value, allowing the customer to pull value from the producer, and pursuing perfection.

The lean production is defined as an ideal production system that aims to manage waste, reduce the need to manage stocks, make quality control a part of production processes and produce better quality production at minimum cost [8, 9]. In the context of lean production, the primary objective is to eliminate/minimize waste and maximize value throughout the entire production process, in accordance with lean principles capabilities [10]. According to Ohno [11] and Liker [12], these wastes include: overproduction, defects, waiting, unnecessary motion, overuse of resources, unnecessary or incorrect processing, excessive transportation, and underutilization of employee skills and capabilities. To achieve the objectives of lean production, there are various Lean Tools, Techniques and Methods (LTTMs). By eliminating/minimizing waste and managing it effectively, these LTTMs contribute to increased productivity, improved collaboration, greater transparency regarding the outcomes of lean practices, enhanced stakeholder engagement in production processes, and reduced costs [13]. The lean production system, developed through the adoption of LTTMs as well as the main principles of lean thinking, particularly the emphasis on flow and the pursuit of perfection, offers significant benefits throughout the production process. By focusing on the minimization of waste and the maximization of value, the implementation of lean thinking in production has been shown to lead to increased product quality, reduced lead times, minimized costs, improved workforce efficiency, decreased inventory levels, enhanced machine utilization, increased production output, and the development of employee skills [14].

The adoption of the lean production approach offers various advantages to companies in the manufacturing industry. These include gaining a competitive advantage in the global market, fostering a culture of continuous improvement, reducing waste, increasing productivity, shortening lead times, minimizing costs, and maximizing customer satisfaction [8, 15]. The successful outcomes achieved through lean production have led to the emergence of the idea that this approach could also be applied in the construction industry to improve building life cycle processes [16,17]. Koskela [18] argued that the construction industry should be evaluated in terms of flow and value, like the manufacturing industry. Accordingly, the idea of applying the lean production approach to the construction industry was first introduced by Lauri Koskela in 1992 [18]. Koskela [18] highlighted the lengthy time between error detection and correction, as well as the insufficiently accurate assessment of customer requirements, emphasizing that these issues represent significant challenges in the construction industry. Consequently, the concept of lean construction emerged to eliminate/minimize waste related to materials, time, and labor while maximizing value in the construction industry [2]. Lean construction is considered an effective approach that aims to minimize/eliminate waste in construction projects, enhance project efficiency, and meet customer expectations by applying the principles and practices of the lean production system to the construction industry [19, 20].

The adoption of lean production in the construction industry provides many economic, social and environmental benefits such as waste management, increasing customer satisfaction, strengthening communication between stakeholders, successful task management, improving planning and control processes, shortening delivery times, improving safety conditions and reducing rework activities [21, 22]. For lean construction to be successfully implemented, lean principles must be adopted throughout all processes of the project, from the design process to the completion of the construction process [23].

In the construction industry, the integration of lean principles entails the utilization of LTTMs to facilitate a streamlined workflow process as in the manufacturing industry [24]. LTTMs are tangible tools, methodological frameworks, and comprehensive systematic approaches that facilitate the reduction of non-value-adding activities in the production process, enhancement of product and process quality, improvement of occupational safety, reduction of lead times, minimization of operational costs, prevention of unnecessary resource utilization, elimination of various forms of waste, and mitigation of errors [16, 17, 22, 25, 26]. For example, the Last Planner System (LPS), 5S, Just in Time (JIT), Kanban, Kaizen, Concurrent Engineering (CE), Visual Management (VM), and Value Stream Mapping (VSM) are considered LTTMs [16]. It has been identified in the literature that LTTMs used to implement lean principles are not clearly distinguished through a specific classification as tools, techniques, or methods. For instance, while Kumar and Ramasamy [25] consider the Daily Huddle Meeting (DHM) as a lean technique, Enshassi et al. [27] argue that DHM can be regarded both as a lean tool and a lean technique. While Kumar and Ramasamy [25] and Indira and Jyothsna [28] identify the LPS as a technique, Garces and Pena [29] refer to LPS as a lean tool. Similarly, while Kumar and Ramasamy [25] and Singh and Kumar [30] describe 5S as a lean technique, Cabrera et al. [31] classify 5S as a lean method.

In construction projects, achieving project objectives within the predefined constraints of time, cost, and quality is critically important. This creates a need for the use of appropriate LTTMs, either individually or in combination, in alignment with the expertise and competencies of the relevant stakeholders [5]. The integration of LTTMs into the construction industry entails the elimination of waste, the removal of non-value-adding activities, the improvement of time, cost, and quality performance, the increase in profit and market share, the achievement of competitive advantage, the enhancement of project team motivation, the assurance of safety, the improvement of performance metrics, the strengthening of supplier relationships, and the elevation of customer satisfaction [26].

In the literature, the LTTMs used in the construction project life cycle processes have been predominantly evaluated within the scope of the pre-construction, [32-34], construction, [2, 27, 35-39], and post-construction [40] processes. Many researchers have conducted studies on LTTMs used during the pre-construction process within the scope of design and planning sub-processes. To illustrate; Gomez-Cabrera et al. [41] stated that Building Information Modeling (BIM) and Set Based Design (SBD) can be used to avoid delays and cost overruns in design processes. Moreover, several studies have demonstrated that BIM, as a tool utilized in the construction industry, contributes to enhancing collaboration, identifying potential issues before the construction process begins, reducing costs, increasing productivity, minimizing design-related errors, and achieving favorable project outcomes [29, 33, 39]. On the other hand, Tauriainen et al. [33], Orihuela et al.

[42], Ghosh et al. [43], Lujan and Murguia [44] and Ramalingam [45] have also emphasized in their studies the LTTMs that can be used in the pre-construction process within the scope of design or planning processes.

Like the pre-construction process, it has been observed that many researchers focus on the application of LTTMs in construction processes in the context of site activities and Occupational Health and Safety (OHS) sub-processes. For example, Enshassi et al. [27], Wu et al. [35] and Enshassi and Zaiter [36], who examined the impact of lean construction practices on improving site safety and preventing workplace accidents during the construction process, emphasized that the use of LPS, 5S, Five Why Analysis (5Whys), JIT, and VM would contribute to enhancing site safety while helping to prevent workplace accidents. On the other hand; Yücenur and Şenol [2], Shaqour [22], Kumar and Ramasamy [25], Singh and Kumar [30], Eldeep et al. [37], Tabrizikahou and Nowotarski [38], Patel et al. [39], Jain et al. [40] and Fitchett and Rambuwani [46] have also highlighted LTTMs applicable to the construction process, particularly in the context of construction site process or OHS process.

In addition to the discussion of LTTMs application in pre-construction and construction processes, literature has also addressed its potential use in post-construction processes. However, studies on post-construction processes are considerably fewer than those on pre-construction and construction processes. It has been observed that researchers focusing on LTTMs that can be used in post-construction processes mostly evaluate them through operation or demolition sub-processes [40, 47].

It has been determined that most studies in literature examine LTTMs by focusing on different processes of the building life cycle, such as design, construction, and demolition. In addition, there are studies aiming to identify the LTTMs commonly used in the construction industry. For instance, Singh and Kumar [48] conducted a Systematic Literature Review (SLR) to identify the LTTMs used in construction processes by examining studies published between 2008 and 2018. In their study, a holistic perspective was adopted toward all processes without making any specific distinction related to sub-processes within the building life cycle. In the literature, some studies have also been identified that examine LTTMs in relation to different processes of the project life cycle. For example, Babalola et al. [49] conducted an SLR of studies published between 1996 and 2018 to classify lean construction practices in building and infrastructure projects. In their study, the identified LTTMs were evaluated based on their level of impact on the processes of "design and engineering", "planning and control", "construction and site management", and "health and safety management". Similarly, Le and Nguyen [50] examined the LTTMs applicable to supply chain management processes in construction projects and assessed them according to their impact on the same processes: "design and engineering", "planning and control", "construction and site management", and "health and safety management".

Studies have shown that LTTMs are often addressed separately for different processes of the construction industry, or that the impact of one or more LTTMs on a specific process is evaluated. When examining the project life cycle, it has been observed that some researchers classify LTTMs according to the sub-processes of the life cycle. However, these studies generally overlook the post-construction process. On the other hand, in studies employing the SLR method to analyze LTTMs, it has been found that the research covers the periods between 1996–2018 and 2008–2018 [48, 49].

Pavnaskar et al. [14] highlight that improper selection, use, and implementation of LTTMs throughout the building life cycle can lead to time and cost inefficiencies, as well as a decrease in employee confidence regarding the advantages of lean manufacturing. Furthermore, Pavnaskar et al. [14] stated that the classification, organization and description of LTTMs will facilitate the usability of LTTMs and will contribute to reducing the uncertainties that may arise in their application processes. Therefore, this study aims to contribute to the lean transformation of the construction industry and to approach the building life cycle from a holistic perspective. Additionally, it seeks to support industry stakeholders in identifying which LTTMs should be prioritized for specific processes of the building life cycle to address the challenges they face within the framework of lean construction. To achieve this, the SLR method is conducted to examine which processes of the building life cycle are most frequently addressed in the current literature in relation to LTTMs. This study will address the following research questions:

- Which LTTMs are predominantly emphasized in the current literature across the different processes of the building life cycle?
- Which processes of the building life cycle present research gaps in terms of LTTMs implementation in the current literature?

This study aims to identify the most frequently addressed, investigated, and preferred LTTMs within the main and sub-processes of the building life cycle, to eliminate/minimize waste, maximize value, and enhance the efficiency of the building life cycle.

Based on the identified research questions and the preliminary literature review, the building life cycle processes have been categorized into three main processes as pre-construction, construction, and post-construction to classify the studies to be obtained through the SLR. In the literature, studies that examine LTTMs in terms of sub-processes have also been reviewed. In this study, the sub-processes have been classified as follows according to the literature review: "the planning process", which includes planning and control activities; "the design process", which encompasses design and engineering processes; "the construction site process", which refers to the management of on-site construction activities; "the OHS process", covering occupational health and safety procedures; "the operation process", which includes post-construction maintenance and facility management activities; and "the demolition process", which pertains to end-of-life dismantling operations. These sub-processes, along with the main processes, are illustrated in Fig. 1.

Identifying the most suitable LTTMs for specific processes has the potential to enable more informed and efficient decision-making in managing these processes. So, this study which identifies and categorizes LTTMs applicable to the pre-construction, construction, and post-construction processes of building projects, is expected to support both practitioners and researchers in the field of lean construction. Specifically, it helps to assist construction industry organizations and companies, either initiating or advancing their lean construction practices in selecting appropriate LTTMs for specific main and sub-processes within the building life cycle, and in enhancing the efficiency and effectiveness of these processes.

2. Methodology

To identify and classify LTTMs that can be used throughout the building life cycle in accordance with the aim of this study, the Systematic Literature Review (SLR) method was applied, as it is recognized as a way to identify, evaluate, and interpret existing research related to a specific research question, topic area, or phenomenon of interest [51]. This method has been widely applied in areas such as lean construction [48, 49], project management [52], the use of digital technologies in the construction industry [53], and sustainability [54].

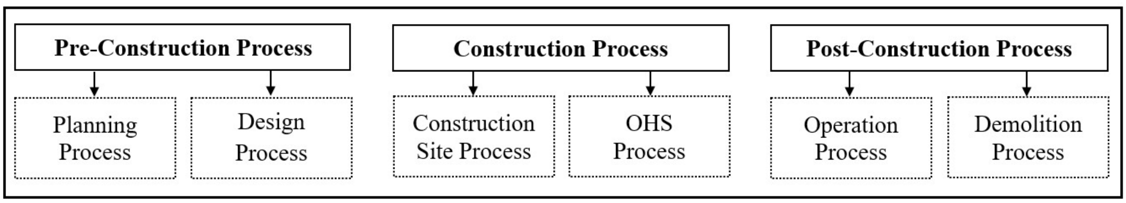

Fig. 1. Building life cycle processes where LTTMs are evaluated

In studies that address and evaluate LTTMs applicable to the construction industry, SLR method is also commonly preferred. For instance, as mentioned in the introduction of this study, Singh and Kumar [48], as well as Babalola et al. [49], preferred the SLR method in their research to identify the use of LTTMs in the construction industry, utilizing different keywords and covering various time periods.

In this study, as illustrated in Fig. 2, a preliminary literature review was first conducted to identify the problem related to the use of LTTMs in the building life cycle, and the background of the study along with the research questions were established. The SLR method, also shown in Fig. 2, was carried out in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, which includes the four main steps of "identification", "screening", "eligibility", and "inclusion" [55]. The results obtained from the SLR were then classified and evaluated based on the main processes of the building life cycle as pre-construction, construction, and post-construction. In accordance with the objectives of this study, the sub-processes of the main processes have been planned as structured in Fig. 1.

For the first step of SLR shown in Fig. 2, the keywords "lean construction" and "lean tools" or "lean construction" and "lean techniques" or "lean construction" and "lean methods" were selected in accordance with the objective of the study. While determining the keywords to be used within the scope of this study, preliminary reviews were conducted in databases using the core keyword of the study, "lean construction." However, many studies were identified that fall outside the scope of this research, addressing topics such as lean construction management, the relationship between lean and sustainability, barriers to the adoption of lean construction, and the benefits of the lean construction approach [56-60].

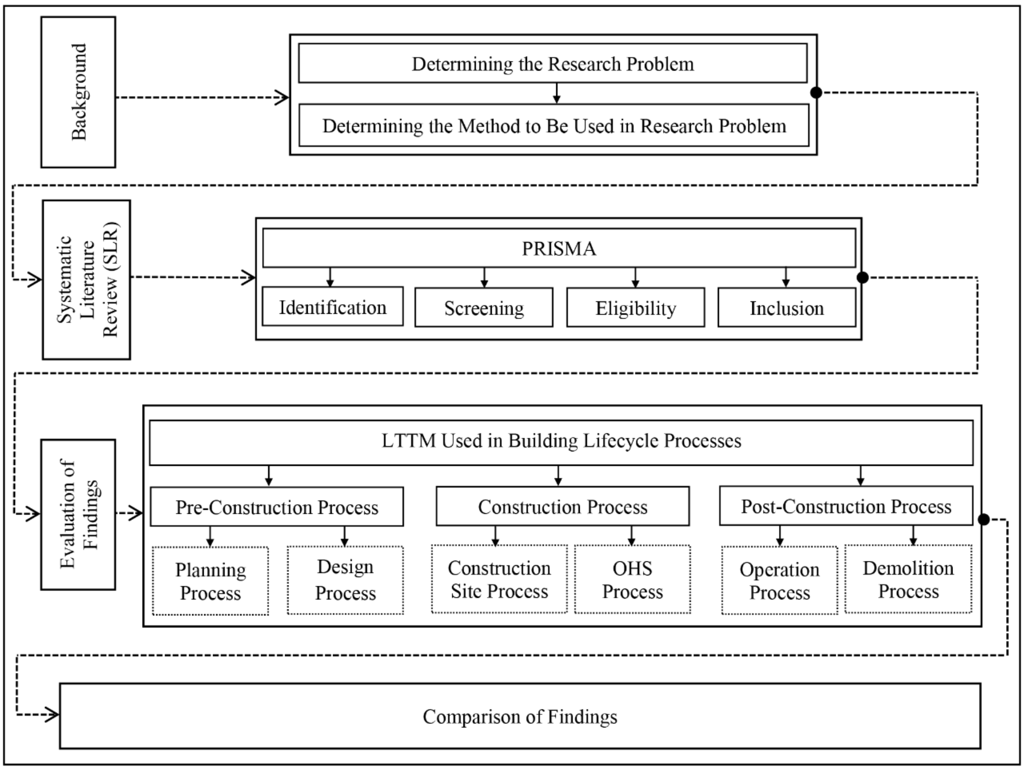

Fig. 2. Methodology

Therefore, in addition to the keyword "lean construction," studies that included the keywords "lean tools," "lean techniques," or "lean methods" were also reviewed to identify research that is closely aligned with the aim of this study. The main reason for not including additional keywords related to building life cycle processes was to ensure that all existing studies within the scope of LTTMs could be captured, allowing for the necessary classifications to be made according to these processes after the review.

In the screening step of the SLR, the selected research databases were identified as Scopus, Web of Science, Science Direct, and Taylor & Francis. It has been observed that studies on lean construction using the SLR method in these databases have covered publication periods of 10 years [48], 22 years [49], 23 years [61], and 19 years [62], respectively. Although the foundations of the lean construction approach date back to 1992 [18], the reviewed studies indicate that there were only a limited number of publications addressing this topic in the early years, while research interest in lean construction has significantly increased in recent years. Therefore, in this study, to access the most up-to-date sources available at the time of the research, English-language “research articles” and “conference papers” published between 2014 and November 2024 were examined within the databases. Through this process, LTTMs used across the building life cycle processes were evaluated.

In the third step of the SLR, duplicate studies identified through title screening across databases were excluded, retaining only the most relevant versions. Subsequently, the titles, abstracts, and full texts of the remaining studies were reviewed, and those that did not align with the scope of this study were also eliminated. In the last step of the SLR, the full texts of the studies included in the research were examined in a detailed way, and the identification and classification of LTTMs were carried out in accordance with the processes presented in Fig. 1. The findings and classification results were then compared and evaluated against similar studies in the existing literature.

3. Findings and Discussion

In the SLR, conducted based on the keywords outlined in the methodology section and illustrated in Fig. 3, relevant studies were retrieved from four academic databases. A total of 290 studies were identified: 159 from the Scopus database, 58 from the Web of Science, 14 from ScienceDirect, and 59 from Taylor & Francis (Fig. 3).

Among the 290 initially identified studies, 70 were retrieved from multiple databases and were therefore counted only once. Following a thorough screening of titles, abstracts, and full texts, 178 studies were excluded. These studies primarily focused on topics such as the benefits of lean construction, lean construction management, barriers to implementation, the relationship between lean and sustainability, efficiency improvement in construction projects, and waste reduction in the construction industry. However, they did not specifically address LTTMs. Consequently, 42 studies were deemed relevant and included in the final scope of this research. When the 42 studies included in the research scope were examined as part of the SLR, it was found that 34 LTTMs were identified by researchers as applicable during the pre-construction process. These LTTMs, categorized according to planning and design processes, are presented in Table 1.

It was found through the reviews that, of the 34 LTTMs that can be used in the pre-construction process, 25 were studied for their impact on planning process, and 21 for their impact on design process (Table 1). Among the 34 LTTMs used in the pre-construction process, it was determined that BIM, BR, VSM, IPD, 5S, CBA, VM, collaborative meetings, ICT, Kanban, PDCA, and LPS were addressed by researchers for their impact on both processes (Table 1). The studies reviewed showed that the impact of LPS, BIM, and VSM on planning process, as well as the impact of BIM, IPD, SBD, TVD, LPS, and VSM on design process, were most frequently discussed. When looking at the LTTMs used in the pre-construction process holistically, it was determined that LPS, BIM, and VSM were the most addressed and evaluated LTTMs in the pre-construction process.

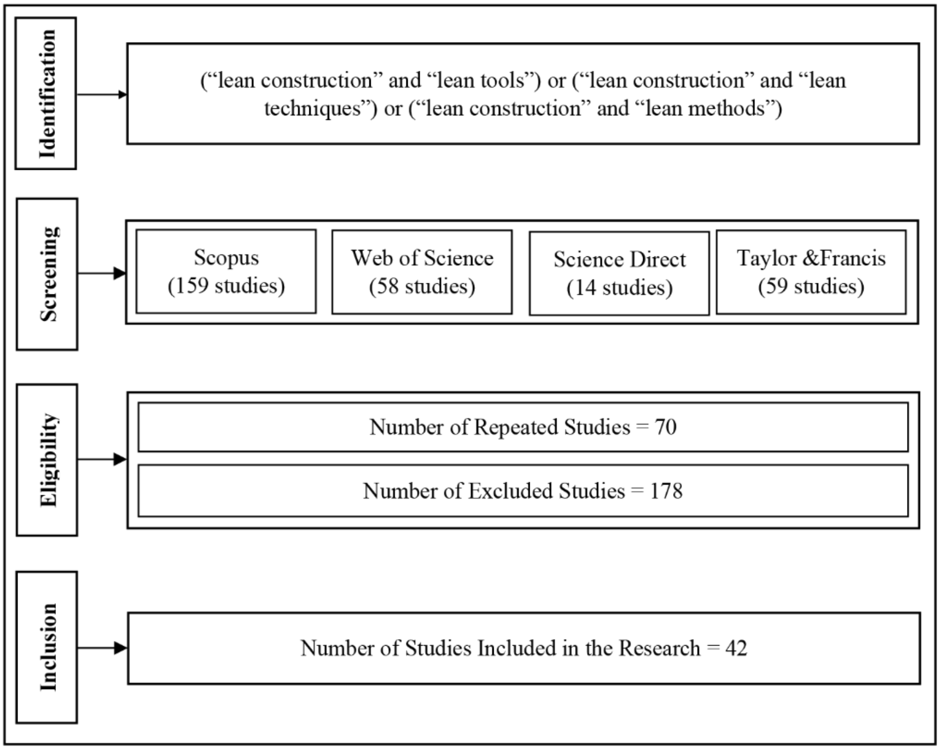

Fig. 3. SLR findings

Table 1. LTTMs used in the pre-construction processes

	Lean Tools, Techniques and Methods (LTTMs)	Planning Process	Design Process
1	5 Why Analysis (5 Whys)	[63]	-
2	5S	[47], [63]	[47]
3	Set Based Design (SBD)	-	[32], [33], [41], [44], [64]
4	Six Sigma (SS)	[50], [64]	-
5	Choosing By Advantages (CBA)	[65]	[44], [66]
6	Information and Communication Technologies (ICT)	[47]	[47]
7	Computer Aided Design	-	[67]
8	Building Information Modelling (BIM)	[29], [30], [39], [64], [68], [69]	[29], [30], [33], [34], [37], [39], [41], [64], [68]
9	Big Room (BR)	[30], [64]	[32], [33], [50]
10	Pull Planning	[43]	-
11	Multidisciplinary Teams	-	[32]
12	Value Stream Mapping (VSM)	[42], [47], [50], [63], [70]	[42], [45], [47], [64]
13	Integrated Project Delivery (IPD)	[29], [43], [68]	[29], [32], [43], [50], [68]
14	Concurrent Engineering (CE)	-	[50]
15	Visual Management (VM)	[47]	[47]
16	Daily Huddle Meeting (DHM)	[25], [50], [64], [70]	-
17	Failure Mode and Effects Analysis (FMEA)	[63], [64]	-

Table 1. Cont'd

18	Target Value Design (TVD)	-	[33], [42], [44], [64], [66]
19	First-Run Studies (FRS)	[64]	-
20	Standardization	-	[50]
21	Collaborative Meetings	[47]	[47]
22	Work Structuring and Scheduling	[50]	-
23	Kanban	[2], [39], [63], [64]	[2]
24	Theory of Constraints (TOC)	[64]	-
25	Benchmarking	[50]	-
26	Root Cause Analysis	[63]	-
27	Plan-Do-Check-Action (PDCA)	[47], [63]	[47]
28	Poka-Yoke	[70]	-
29	Prefabrication and Modularization	-	[50]
30	Virtual Design and Construction (VDC)	-	[39], [50]
31	Last Planner System (LPS)	[25], [28], [29], [30], [39], [47], [50], [63], [64], [69], [70], [71], [72], [73], [74]	[32], [33], [47], [64], [71]
32	Just In Time (JIT)	[2], [63], [64]	-
33	Frequent Communication Between the Parties (Freq Comm)	-	[32]
34	Total Productive Maintenance (TPM)	[63]	-

Some new LTTMs that were not identified during the preliminary literature review but emerged from the results of the SLR are also presented in Table 1. For instance, it was found that LTTMs such as Virtual Design and Construction (VDC), and Frequent Communication Between the Parties (Freq Comm) have been featured in studies conducted over the past five years. For instance, in their study, Patel et al. [39] considered VDC as an LTTM and suggested that it can be used to identify potential issues and optimize the design. By doing so, the need for rework and corrections during the construction process can be reduced, resulting in time and cost savings. Therefore, in this study, VDC has been classified as an LTTM relevant to the design process.

When examining the studies that addressed the 25 LTTMs affecting planning processes, it was found that these LTTMs could be used to manage waste, increase collaboration, strengthen communication among stakeholders, and ensure coordination between teams in the planning processes. When reviewing the studies on the 21 LTTMs affecting design processes, it was determined that these LTTMs could be used in the design processes of projects to manage waste, enhance collaboration, manage time, cost, and quality parameters, evaluate design alternatives to reach the most advantageous design alternative, and improve information sharing. Additionally, it was found that all LTTMs used in the pre-construction process can either be applied independently during the planning and design processes or integrated with one another. This integration has a significant impact on both the design and construction processes. Because LTTMs that can be used in pre-construction processes have the potential to enhance communication among stakeholders, ensure coordination between teams, prevent conflicts between design and construction processes, and reduce problems arising from planning and design processes. As a result, they contribute to more effective management of construction processes. Therefore, it is understood that LTTMs implemented during the pre-construction process can also have a significant impact on the success of construction activities.

When examining Table 2, which includes LTTMs related to the management of construction sites and OHS processes during the construction processes, it is determined that the researchers highlighted 26 LTTMs that can be used in construction processes. The effects of 5S, VM, LPS, conference management, JIT, and TPM on both processes are discussed. When LTTMs that can be used in construction processes are considered together for both sub-processes, it is understood that the impact of 5S, LPS, and JIT on construction processes has been most frequently evaluated in the studies. Among the studies reviewed, researchers have evaluated the impact of 5S, BIM, VSM, LPS, and JIT on construction site process, while for OHS process, the effects of 5S, VM, and LPS were most frequently emphasized in the studies.

Table 2. LTTMs used in the construction processes

	Lean Tools, Techniques and Methods (LTTMs)	Construction Site Process	OHS Process
1	5 Why Analysis (5 Whys)	[22]	[27]
2	5S	[22], [25], [30], [31], [39], [40], [47], [50], [64], [75]	[35], [27], [36], [64], [75]
3	Information and Communication Technologies (ICT)	[47]	-
4	Building Information Modelling (BIM)	[29], [30], [37], [39], [69]	-
5	Big Room (BR)	[30]	-
6	Value Stream Mapping (VSM)	[38], [47], [76], [77], [78]	-
7	Gemba Walk	[50]	-
8	Visual Management (VM)	[2], [25], [47]	[2], [35], [36]
9	Daily Huddle Meeting (DHM)	[79]	[25]
10	Target Value Design (TVD)	[22]	-
11	First-Run Studies (FRS)	[50], [64]	-
12	Standardization	[22]	-
13	Collaborative Meetings	[47]	-
14	Kaizen	[50]	-
15	Fail Safe for Quality (FSQ)	-	[50]
16	Kanban	[2], [31]	-
17	Conference Management	[50]	[35]
18	Plan-Do-Check-Action (PDCA)	[47]	-
19	Poka-Yoke	[47]	-
20	Last Planner System (LPS)	[22], [28], [40], [47], [71]	[27], [29], [35], [36]
21	Process Mapping	[46]	-
22	Continuous Flow	[38]	-
23	Teamwork and partnering	[50]	-
24	Just In Time (JIT)	[2], [22], [38], [46], [69]	[35]
25	Total Quality Management (TQM)	[40], [50]	-
26	Total Productive Maintenance (TPM)	[31], [38]	[2]

When examining studies that address 25 LTTMs impacting construction site process, it has been determined that these research findings can be used to achieve goals such as managing waste, ensuring sustainability, enabling stakeholders to work together in an integrated manner, increasing information sharing, preventing delays and time losses, ensuring continuous improvement, increasing value, ensuring sustainability, facilitating problem-solving, and strengthening control systems in the construction and construction site process of construction projects. In studies focusing on 9 LTTMs impacting OHS process, it has been emphasized by researchers that these LTTMs are effective in reducing work accidents and improving safety conditions. Like the pre-construction processes, it has been found that LTTMs can be used independently in construction processes, or their integrated use can have a significant impact on the entire construction process, as revealed by the analysis of the studies.

Although there are very few studies on LTTMs that can be used in the post-construction processes, the 8 LTTMs discussed in these studies are shown in Table 3. In 7 of these studies, the impact of LTTMs on operational processes is emphasized, while the impact of 3 of them on demolition process is addressed. When examining studies addressing LTTMs that can be utilized in the post-construction process, it is generally understood that these LTTMs contribute to reducing delay factors, increasing productivity, minimizing waste, and ensuring sustainability. On the other hand, as shown in Table 3, research has identified that both 5S and LPS have an impact on both operational and demolition processes.

LTTMs have been addressed in considerably fewer studies during the post-construction process compared to the pre-construction and construction processes. The main reasons for this may include the more detailed analysis of time, cost, and quality parameters during the pre-construction and construction processes, which creates a greater need for new and lean approaches to improve the management of these processes. Furthermore, operation and demolition processes within the building life cycle have recently gained increased importance due to the growing emphasis on circular economy approaches and resource management. Therefore, research in these areas is relatively recent and emerging, which is likely to explain the limited number of studies focused on LTTMs in the post-construction process.

However, the post-construction processes involve a multi-stakeholder structure, including users and various maintenance companies responsible for different functions, which may complicate the integrated adoption of lean principles by all stakeholders using LTTMs in these processes. After applying lean approaches during the pre-construction and construction processes, construction companies can improve the operation and demolition processes that encompass the post-construction processes by considering user feedback and employing lean principles.

Table 3. LTTMs used in the post-construction processes

	Lean Tools, Techniques and Methods (LTTMs)	Operation Process	Demolition Process
1	5S	[47]	[40]
2	Information and Communication Technologies (ICT)	[47]	-
3	Value Stream Mapping (VSM)	[47]	-
4	Visual Management (VM)	[47]	-
5	Plan-Do-Check-Action (PDCA)	[47]	-
6	Poka Yoke	[47]	-
7	Last Planner System (LPS)	[47]	[40]
8	Total Quality Management (TQM)	-	[40]

Furthermore, new LTTMs tailored to the nature of the construction industry, like those developed for the pre-construction and construction processes, could be introduced and their implementation and outcomes discussed for the post-construction processes. Considering that the post-construction processes are also critical processes within the building life cycle, it is believed that it should be addressed more extensively in both practical applications and academic research, as with the pre-construction and construction processes. This approach would be highly beneficial for the holistic improvement of the building life cycle and the lean transformation of the construction industry. Therefore, focusing future studies on the post-construction processes is deemed crucial for enhancing the overall efficiency of the building life cycle.

Based on the findings presented in Tables 1, 2, and 3, the LTTMs that are most frequently evaluated by researchers in the literature and found to be effective in the main and sub-processes of the building life cycle are summarized in Table 4 as an overview of the key findings of this study. To illustrate, when considering the LTTMs that can be used in the pre-construction processes, which include planning and design processes in Table 1, it has been determined that LPS is most emphasized in 17 sources, BIM in 10 sources, VSM in 7 sources. In Table 2, which includes LTTMs used in construction processes covering construction sites and OHS processes, it has been found that 5S is highlighted in 13 sources, LPS in 9 sources, and JIT in 6 sources. In the post-construction processes covering operation and demolition processes, shown in Table 3, 5S and LPS are emphasized in 2 sources.

When the findings related to the pre-construction process are evaluated collectively, it becomes evident that these processes—where fundamental project decisions are made and collaboration among numerous stakeholders is essential—benefits significantly from certain LTTMs. Specifically, the use of the LPS for developing work plans, BIM for facilitating coordination among teams through digital models, and VSM for identifying waste, developing preventive measures, and eliminating inefficiencies within and between processes, all contribute to the effective management of planning and design processes. Consequently, these LTTMs support the efficient completion of the building life cycle process.

As shown in Table 4, LPS, BIM, and VSM are the LTTMs most frequently emphasized by researchers in relation to their impact on planning processes. The use of LTTMs in planning is of great importance for the successful completion of the building life cycle. This is because the planning process is where the most fundamental decisions regarding time, cost, and quality are made for the entire building life cycle, where integration among stakeholders is ensured, and where a feasible work plan must be developed. LPS supports the creation and monitoring of weekly and monthly plans.

Table 4. The most preferred LTTMs in the building life cycle processes

	Pre-Construction Processes		Construction Processes		Post-Construction Processes	
1	LPS		5S		5S, LPS	
2	BIM		LPS		-	
3	VSM		JIT		-	
	Planning Process	Design Process	Construction Site Process	OHS Process	Operation Process	Demolition Process
1	LPS	BIM	5S	5S	5S, LPS	5S, LPS
2	BIM	LPS, TVD, IPD, SBD	LPS,VSM, BIM, JIT	LPS	ICT, VSM, VM, PDCA, Poka-Yoke	TQM
3	VSM	VSM	VM	VM	-	-

On the other hand, BIM contributes to the development of digital models that allow stakeholders to work within shared data, thereby enabling the completion of the building life cycle at the planned cost and with higher quality [39]. On the other hand, VSM can contribute to identifying waste that may arise throughout the project life cycle and to ensure that planning processes are carried out in a more disciplined, realistic, transparent, and sustainable manner. Additionally, these LTTMs facilitate improved communication and coordination among stakeholders involved in the building life cycle. The findings of this study are supported by existing literature, which highlights the contributions of LPS, BIM, and VSM to the successful completion of planning processes, improvements in time, cost, and quality performance, early identification and prevention of activities that may negatively affect environmental performance, reduction of errors and waste originating from planning, and enhancement of coordination among stakeholders [39, 70].

In the design processes, BIM, LPS, TVD, IPD, SBD, and VSM were identified as the most frequently emphasized LTTMs by researchers. BIM contributes to the visualization of design decisions through the creation of digital models of projects, allowing for the optimization of non-value-adding designs. LPS supports project managers in developing feasible work schedules, while TVD facilitates the design of activities that deliver value to the client in accordance with specific design criteria such as time, cost, and quality [33]. Moreover, IPD involves the inclusion of all stakeholders from the beginning of the design process through to project delivery, thereby enhancing collaboration among stakeholders. Similarly, SBD facilitates the identification of the optimal solution alternative for problem-solving [41]. As in the planning processes, the use of VSM in design processes enables the identification and management of waste within the process through the utilization of visual maps [42]. Therefore, the use of BIM, LPS, TVD, IPD, SBD, and VSM in design processes enables the inclusion of clients and other stakeholders from the beginning of the design process. It allows for the early identification and improvement of design decisions that may negatively impact stakeholders. By modeling design decisions, it facilitates the refinement of those that could lead to errors, waste, or affect time, cost, and quality. Additionally, it supports the development of the most appropriate solutions to problems arising during the design processes, thereby ensuring the efficient completion of these processes.

According to Table 4, when the findings obtained for the construction process are evaluated collectively, 5S, LPS, and JIT are considered the most extensively studied LTTMs for this process. These LTTMs contribute to the efficient completion of construction processes by promoting planned and systematic progress, ensuring site organization and cleanliness, improving safety conditions, and reducing workplace accidents.

In construction processes, ensuring sustainability, preventing occupational accidents, managing waste, achieving team integration, enhancing information sharing, facilitating material flow, preventing delays, and strengthening control systems are of great importance. Table 4 identifies the top three most researched LTTMs in the construction process, with a total of six LTTMs recognized due to four different LTTMs sharing the second position equally in the number of studies. Accordingly, when examining the results obtained for construction processes, it has been determined that 5S [39], which facilitates the elimination of unnecessary elements to organize the construction site and increase efficiency; JIT [22], which ensures the successful flow of materials; BIM [39], which enables the creation of detailed digital models and thus improves the understanding of activities to be implemented during construction; LPS [47], which contributes to the prevention of delays; VSM [78], which maps value-adding activities for the customer, visualizes the flow of information within the construction process, and provides a visual representation of processes and their durations; and VM [2], which aims to visualize all work performed as much as possible and alerts authorized personnel through audio-visual devices in case of any errors in the construction process, all contribute to better management of construction sites. Studies in the literature demonstrate that 5S, LPS, VSM, BIM, JIT, and VM contribute to cost reduction, shortening delivery times, facilitating material flow, and improving site safety, thereby supporting the findings of this study [22, 39, 78].

For OHS processes, the use of 5S, LPS, and VM has been emphasized more frequently compared to other LTTMs in the literature. This finding aligns with studies indicating that 5S contributes to the control of critical areas and facilities on construction sites and the reduction of environmental impacts, VM significantly improves safety management on construction sites through the use of visual tools such as safety warnings, and LPS enhances safety management by enabling teams to work in a planned manner on construction sites [35]. Accordingly, the application of 5S, LPS, and VM in OHS processes will contribute to maintaining order and cleanliness on construction sites and improving safety conditions.

When the findings related to the post-construction processes, which include operation and demolition processes, are examined, it is observed that 5S, used for organizing and improving the work environment, and LPS, commonly applied in planning processes, are more frequently addressed in relation to their impact on operation and demolition processes compared to other LTTMs (Table 4). Consistent with these findings, the literature also includes studies that identify the positive effects of 5S and LPS on reducing waste and promoting sustainability in the post-construction processes, like their contributions during the construction processes [40]. 5S contributes to maintaining a clean and organized environment in operational processes of buildings and demolition activities, ensuring that required materials can be accessed efficiently at the right place and time. Moreover, due to the involvement of users and various maintenance companies in the post-construction processes, there is a need for interdisciplinary coordination during these processes. So, LPS can contribute to the effective planning of periodic maintenance and repairs, as well as to the organization of demolition processes, by enhancing coordination and planning among stakeholders. Therefore, the use of LTTMs in the post-construction processes, which include operation and demolition processes, can support the completion of these processes in a planned, safe, and transparent manner.

When examining Table 4 overall, it was determined that the LPS can be commonly applied in both the pre-construction and construction processes. This may be due to LPS's contribution to the development of a feasible work plan and its facilitation of coordinated collaboration among different disciplines during the pre-construction and construction processes. For the construction and post-construction processes, 5S and LPS were identified as commonly used LTTMs. This is attributed to the critical importance of organization, cleanliness, and safety in both processes. The reason why the LPS is considered the only LTTM that can be commonly applied across the pre-construction, construction, and post-construction processes—specifically in planning processes—is that various stakeholders throughout the building life cycle need to work in an integrated, coordinated manner within a defined schedule. Through the implementation of LPS, it is possible to ensure that all processes progress in a coordinated and planned way, to identify potential disruptions in advance, and to develop early solutions. In this way, LPS contributes to the efficient completion of the building life cycle.

The top three most frequently studied LTTMs, as identified in Table 4 and based on the results of this study, were compared with the findings of similar studies in the literature [48-50] as presented in Table 5. As shown in Table 5 and stated in the introduction of this study, Singh and Kumar [48] identified 14 LTTMs applicable to the construction industry by using the SLR method. Although these researchers did not classify the identified LTTMs—determined using different keywords and covering the years 2008 to 2018—within the context of building life cycle processes, their study was included among the comparative works due to its similarity in scope to the present research.

Table 5. Comparison between existing studies and this study

Building Life Cycle Processes		This study	Determining LTTMs used in the construction industry [48]	Determining LTTMs used in supply chain management [50]	Determining LTTMs used in the construction industry [49]
		Number of identified LTTMs & The most preferred LTTMs			
Main Processes	Sub processes	42	14	32	32
Pre-Construction Processes	Planning Process	LPS BIM VSM	-	LPS VSM SS Work structuring and scheduling Benchmarking	LPS Pull planning DHM VSM Poka-Yoke SS
	Design Process	BIM SBD IPD TVD LPS VSM	-	VDC IPD CE BR Standardization	CE VDC TVD BR IPD Prefabrication and Modularization
Construction Processes	Construction Site Process	5S BIM VSM LPS JIT	-	Conference Management Teamwork Gemba Walk TQM Kaizen	JIT VM TQM Teamwork 5S
	OHS Process	5S VM LPS	-	FSQ	Planning the conditions and working environment FSQ Health and safety improvement management
Post-Construction Processes	Operation Process	5S ICT VSM VM PDCA Poka-Yoke LPS	-	-	-
	Demolition Process	5S LPS TQM	-	-	-

The findings of the two studies were compared only in terms of the number of identified LTTMs, and no evaluation was made based on life cycle processes. Similarly, as stated in the introduction of this study, Babalola et al. [49] identified LTTMs implemented in building and infrastructure projects by reviewing studies published between 1996 and 2018. As a result of this review, 32 LTTMs identified as applicable to building and infrastructure projects were classified within the context of building life cycle processes. In addition, the findings of this study were compared not only with those of similar review studies presented in Table 5, but also with the study by Le and Nguyen [50], who analyzed LTTMs applicable to supply chain management processes in construction projects and classified them according to building life cycle processes. The study conducted by the researchers, which examines supply chain management in terms of its impact on the pre-construction, construction, and post-construction processes, was included in the comparison due to its consideration of LTTMs within the context of building life cycle processes.

As shown in Table 5, the number of LTTMs identified in the compared studies differs from the number identified in this study. Although the scopes of the compared studies are generally similar [48, 49], the differences in the number of LTTMs identified can be attributed to variations in the publication years of the analyzed studies, the use of different keywords, and the employment of different databases. While this study was conducted within the framework of the pre-construction, construction, and post-construction processes, the study by Le and Nguyen [50] was carried out within the context of supply chain management influencing these processes, which also contributed to the variation in the number of LTTMs identified.

As shown in Table 5, the LPS, which contributes to the development of work schedules and the execution of a smooth workflow, is identified in three studies as the most important LTTM applicable to planning processes. When the LTTMs identified for the design process in this study are compared with those in previous studies, it is observed that TVD and IPD are commonly identified in the study by Babalola et al. [49], while IPD is also identified in the study by Le and Nguyen [50]. Therefore, the use of LPS, TVD, and IPD in the pre-construction processes can support successful supply chain management, enhance coordination among stakeholders during early project processes, facilitate the development of feasible work schedules, and enable the design of value-adding activities aligned with specific design criteria. Within the scope of the building life cycle examined in this study, BIM was identified—unlike in the other studies—as the most frequently addressed LTTM.

When all studies related to the construction processes are evaluated collectively, no common LTTMs were identified for these processes. However, only the use of JIT and 5S on construction sites was found to be shared with the study conducted by Babalola et al. [49]. Similarly, when comparing the findings related to OHS processes, no common results were observed across the three studies. In this study, the recurring identification of BIM as a preferred LTTM in construction sites is interpreted as an indication of the strong interrelationship between construction and design processes. Although the scopes of the studies are relatively similar, the inclusion of infrastructure projects in Babalola et al.'s [49] research, and the focus on supply chain management in the study by Le and Nguyen [50], along with the differences in the years the studies were conducted, have contributed to the identification of different LTTMs for the construction process.

When the findings related to the post-construction processes are evaluated, it is observed that, as shown in Table 5, this study is the only one that addresses LTTMs applicable to the management of post-construction processes. This evaluation indicates that research focusing on the post-construction processes has only recently begun to attract attention. Considering that post-construction processes are an integral part of the building life cycle, future studies addressing the impact of LTTMs on the management of these processes will significantly contribute to the efficient completion of the building life cycle.

4. Conclusion

4.1. Conclusion

For the lean thinking approach to be applied in construction projects, it is essential that all stakeholders correctly understand the principles and guidelines of lean thinking, adapt these principles to the entire building life cycle process, and manage projects accordingly. At this point, identifying the most suitable LTTMs for effectively managing building life cycle processes, testing and developing them in a way that suits the nature of the construction industry is highly valuable for the lean transformation of the construction industry.

The main contribution of this research is the identification of LTTMs that can be more effective in the pre-construction, construction, and post-construction processes of the building life cycle for lean construction, through a SLR method. The findings of this study are expected to assist many companies aiming to optimize building life cycle processes, stakeholders involved in these processes, and other construction industry stakeholders seeking to initiate lean transformation.

In this study, a preliminary literature review was conducted to generally identify the LTTMs used in the life cycle of construction projects and the processes in which these LTTMs are applied. Subsequently, the building life cycle processes were re-evaluated as main and sub-processes. These include the pre-construction processes, encompassing design and planning processes; the construction processes, covering the construction site and OHS processes; and the post-construction processes, involving operation and demolition processes. The LTTMs most frequently addressed and studied by researchers in the literature were examined through a SLR method and classified in this study according to the main and sub-processes of the building life cycle.

In literature, the most frequently examined LTTMs by researchers for the pre-construction processes are LPS, BIM, and VSM, while for the construction processes, they are 5S, LPS, and JIT. For the post-construction process, 5S and LPS have been identified. Furthermore, LPS, which is effective in planning and control processes, has been found to be the only lean method commonly applicable across all three pre-construction, construction, and post-construction processes. Compared to the pre-construction and construction processes, a significantly smaller number of studies have addressed a limited range of LTTMs in the post-construction processes. Therefore, it is considered highly important to focus on post-construction processes to enhance the overall efficiency of the building life cycle.

As in other industries, achieving lean transformation in the construction industry requires a holistic approach that considers all stakeholders, all processes, all lean principles, and LTTMs collectively. However, in terms of identifying a prioritized solution approach for optimizing the main processes of a building life cycle as well as their associated sub-processes, the findings on LTTMs presented in this study may prove to be beneficial.

This study is expected to enhance awareness of waste-free, value-driven, and process-oriented management in processes such as design, construction site, planning, OHS, operation, and demolition by identifying the LTTMs that can contribute to the more effective management of building life cycle processes in construction companies. It is believed that this study will provide valuable insights both for construction industry professionals and for academic research. Furthermore, the classification of LTTMs according to the processes they influence is highly beneficial for construction companies aiming to manage building life cycle processes more efficiently.

4.2. Limitations and future studies

The study encompasses research that includes specific keywords, retrieved from selected databases within a defined time frame, based on the presented findings and evaluations. However, lean transformation efforts in the construction industry have increased the demand for further research in this area due to the accompanying search for solutions. Nowadays, the number of such studies is steadily increasing, and databases are being updated accordingly. While this situation poses a limitation for the present study, it is believed that the findings and scope of this research will benefit future studies.

In future studies, research and evaluations conducted using systematic literature reviews or alternative review methods with different databases and keywords may contribute to updating the findings of this study. Additionally, LTTMs identified as necessary under future conditions can be compared with the current findings, enabling an examination of the construction industry's development, transformation, and emerging needs from this perspective. However, one of the limitations of this study is that the identified LTTMs were not distinctly classified as lean tools, lean techniques, and lean methods. Furthermore, explanations and discussions regarding each LTTM were not specifically adapted to the context of the construction industry. Therefore, future studies could focus on classifying LTTMs according to these categories. Additionally, field research could be conducted to investigate which LTTMs, either individually or in an integrated manner, are most effectively applied to specific processes within the construction industry, and the findings could be compared with the results of this study.

The findings of this study will enable construction companies aiming for lean transformation to raise awareness of lean thinking, principles, and LTTMs, allowing them to prioritize and identify the most suitable LTTMs for related building life cycle processes and thereby take faster action to optimize these processes. It is of great importance to validate the identified and process-classified findings of this study through case studies in different contexts to demonstrate their prevalence and applicability. By examining various processes of projects at different scales, geographical regions, and facility types such as different project types, a better understanding can be gained of how LTTMs perform individually or in an integrated manner. This will allow for necessary adjustments to be identified and enable the development of LTTMs tailored to the nature of the construction industry.

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Author Contributions

E. Demircioğlu: Conceptualization, Methodology, Formal analysis, Investigation, Visualization, Writing - Original Draft, Writing - Review & Editing. G. Can: Conceptualization, Methodology, Visualization, Writing - Original Draft, Writing - Review & Editing.

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Data Availability Statement

No new data were created or analyzed in this study.

Ethics Committee Permission

This study was developed based on a Turkish-language master's thesis entitled "Analysis of Design Process Waste Causes and Lean Tools and Techniques Based on AHP-TOPSIS Integration (AHP-TOPSIS Entegrasyonuna Dayalı Tasarım Süreci İsraf Nedenleri ile Yalın Araç ve Tekniklerin Analizi)" completed in 2024 by researchers (the author and the advisor) affiliated with Istanbul Medipol University. The aforementioned thesis served as the primary foundation for this research. Ethical approval for the thesis was granted by the Istanbul Medipol University Social Sciences Scientific Research Ethics Committee (Date. 09.02.2023; No. 16).

Conflict of Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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