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POSSIBILITIES OF APPLICATION OF LM METHODS AND TOOLS IN THE CONSTRUCTION INDUSTRY – LEAN CONSTRUCTION – THEORETICAL CONSIDERATION

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Purpose: The study aims to present the possibilities of using the methods and tools of the LM concept in the construction industry. The potential impact of the LM solutions used on the implementation of the construction process was determined in terms of improving the organization and safety of work, workflow (employees, materials, information), timeliness of work performed, and employee involvement. Attention was paid to the possibility of eliminating or limiting activities that do not add value to the construction process, which is the main goal of both Lean Manufacturing and the Lean Construction approach.
Design/methodology/approach: Based on the analysis of literature related to the researched topic, LM methods and tools were identified, the implementation and use of which in construction may translate into improved implementation of the construction process in its various aspects.
Findings: Based on the analysis, it was found that the methods and tools of the LM concept can be used in the construction industry. The eight LM solutions most frequently mentioned in the literature, which can improve the functioning of the construction process and eliminate losses, were analyzed. The selection and use of a given tool will depend on the problems occurring in the construction project, as well as on the awareness of the work organizers/managers about the possible benefits that these solutions can bring to construction workers and all project stakeholders. Attention should also be paid to barriers that may hinder the use of lean practices in construction processes, including resistance to change, non-compliance with applicable standards, lack of awareness, lack of commitment of employees and people supervising the process, and lack of communication.
Originality/value: The article attempts to determine the potential impact of LM methods and tools on improving the construction process. The use of LM solutions in construction may indicate the direction of improvement activities for supervisors and organizers of work on the construction site.
Keywords: Lean Manufacturing tools, Lean Construction, construction industry.
Category of the paper: literature review.

1. Introduction

The Lean Manufacturing concept (LM) was based on the Toyota Production System, developed by T. Ohno and S. Shingo in the 1950s (Pavanskar et al., 2003; Ohno, 1998). The system has developed methods, tools and techniques that improve production processes by eliminating activities that do not add value, known as losses (jap. muda). The LM concept has gained traction worldwide with principles focusing on loss reduction, continuous improvement, and increased efficiency (Olu-Lawal et al., 2024). It has been used by companies in various industries for many years (Utami et al., 2023), bringing many benefits, including eliminating errors, reducing inventories and costs, reducing Lead Time, improving productivity, quality and work safety, and changing the work culture (Melton, 2005; Gupta, Jain, 2013; Al-Qayoudhi, 2022; Oleksiak et al., 2023).

LM solutions are also used in the construction industry. Based on the model used in the automotive industry, in 1992 L. Koskela introduced the Lean Construction approach to the construction industry (Koskela, 1992). He stated that the construction industry should adopt a new production philosophy that will improve competitiveness by identifying and eliminating activities that do not add value to the process. Lean Construction (LC) involves designing a production system to minimize losses of materials, time and effort to generate maximum value for the final product (Koskela, 1992). As the construction industry struggles with low productivity rates, inefficient work practices, high costs, on-time performance, and low safety levels (Demirkesen, 2022; Bajjou, Chafi et al., 2020; Bajjou et al., 2017a) the use of LM solutions may reduce existing losses and improve flow.

The study aims to present the possibilities of using the methods and tools of the LM concept in the construction industry. The impact of the most frequently used LM solutions on the implementation of the construction process was determined in terms of improving work organization and safety, workflow (employees, materials, information), timeliness of work, and employee involvement. At the same time, attention was paid to the possibility of eliminating or limiting activities that do not add value to the construction process, which is the main goal of both Lean Manufacturing and the Lean Construction approach.

2. Lean Manufacturing concept

The concept of "lean" was first used in 1988 by J. Krafcik in the article "Triumph of the Lean Production System" (Krafcik, 1988). In 1990, scientists from the Massachusetts Institute of Technology (J. Womack, D. Jones, D. Roos) published the book "The Machine That Changed the World", giving the concept of "lean" a special meaning. The book was the first to present Japanese production methods compared to traditional mass production systems and highlighted the excellent results of Toyota Motor Corporation with the implemented management system - TPS. After years of observations, the authors concluded that TPS was the first working lean production system, called Lean Manufacturing (Womack et al., 1990). Production in this system is called lean because it uses fewer resources compared to mass production in half the time. Its main goal is to eliminate activities that do not add value to processes, defined as losses, which include (Ohno, 1998; Melton, 2005; Bicheno, Holweg, 2016; Furman, Małysa, 2021; Al Bashar, Taher, 2024): overproduction, excessive inventory, over-processing, waiting, unnecessary motion, unnecessary transportation, defects, and unused employee creativity. By continuously identifying and eliminating losses and focusing on activities that create value, one strives to obtain an excellent value stream (Thangarajoo, Smith, 2015), which has been defined as the principles of Lean Thinking (Figure 1) (Womack, Jones, 1996).

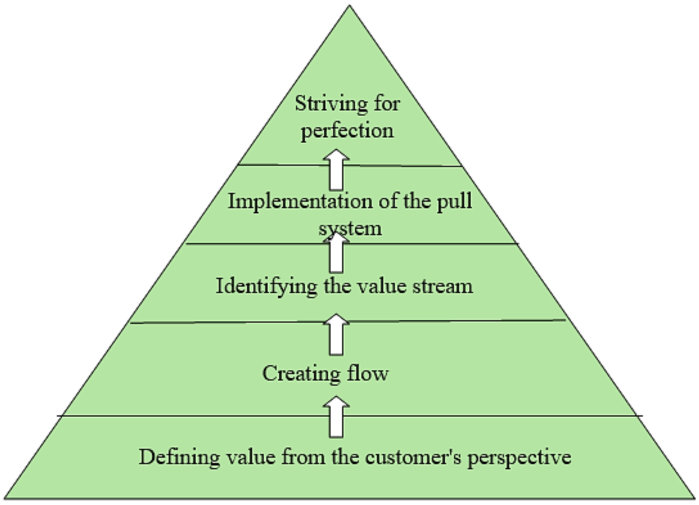

Figure 1. Lean Thinking principles.

Source: Own elaboration based on (Womack, Jones, 1996).

The practice of LM is considered to be one of the most effective methods used by manufacturers worldwide to improve their competitiveness. By emphasizing continuous improvement and eliminating waste, one seeks to maximize performance in terms of productivity, quality, turnaround time, cost, and customer satisfaction (Al-Qayoudhi, 2022). Enterprises can achieve this by using LM methods and tools tailored to their needs. The most frequently used solutions include (Al-Qayoudhi, 2022; Furman, Małysa, 2023; Al Bashar, Taher, 2024; Pawlak, 2024; Wolniak, 2024): the 5S method, Visual Management (VM), Standardization, Value Stream Mapping (VSM), Just in Time (JiT), Poka-Yoke, SMED, TPM, Kaizen, and quality management tools for solving problems (e.g. Ishikawa diagram, 5Why analysis, PDCA).

3. Lean Construction approach

Since the mid-1990s, Lean Construction has emerged as a new concept in the discipline of construction management and the practical sphere of construction. There are two interpretations of LC: one talks about the application of lean production methods in construction, and the other - sees lean production as a theoretical inspiration for the formulation of a new theory, based on construction methodology, called Lean Construction (Koskela et al., 2002).

L. Koskela began implementing the Lean approach in the construction sector, which resulted in his work "Application of a new production philosophy in construction" (Koskela, 1992). In this work, he argued that production should be improved by eliminating material flows and that conversion activities would improve its efficiency. The theoretical foundations of Lean Construction proposed by Koskela assume the perception of production in construction as a process of transformation, flow and value generator (the T-F-V theory), therefore the goal of LC is to create production systems that allow for the optimization and elimination/reduction of flows to improve delivery times. In this sense, LC is a new way of thinking in construction project management, aiming to reduce sources of loss and generate maximum value for the client using the least amount of resources (Bajjou et al., 2017; Ahmed et al., 2021; Garces, Pena, 2022).

In 1997, G. Ballard and G. Howell created the Lean Construction Institute to develop and disseminate new knowledge in the field of construction project management, and TPS principles began to be applied in the industry, adapting them to construction (Demirkesen, 2021). There are eight categories of losses in LC, presented in Table 1. It is believed that ignoring these losses is the main cause of problems related to cost overruns and delays in the construction industry (Bajjou et al., 2017), and may also negatively impact on safety and work organization.

The theory of Lean Construction is based on five main principles (Howel, 1999; Bajjou, Chafi, 2020):

1. Identification of value from the client's perspective.
2. Mapping the value stream - determining how value is created, when it is delivered, and where improvements need to be made; process mapping is a key tool because it allows for a better understanding of the process and the detection of waste, enabling decisions on improvements to be made.
3. Ensuring the uninterrupted flow of value - the main goal is to achieve continuous flow by reducing unnecessary movement, defects, queues, and waiting.
4. Applying the pull system in the process - necessary materials or information must be delivered to the next customer (the next stage in the supply chain) as quickly as needed.
5. Striving for perfection - continuously improving the process by eliminating losses and increasing transparency on construction sites.

Table 1.
Categories of losses in construction

Type of losses	Loss characteristics
Overproduction	Overproduction requires more materials, employees, and equipment than necessary to meet customer requirements, resulting in an increased amount of production.
Unnecessary transportation	The inefficient workflow includes work-in-progress, finished products, or parts being moved over significant distances between workstations.
Unnecessary motion	Any unnecessary movement performed by employees during their daily work (e.g., walking, searching, arranging tools, parts).
Excessive inventory	Excess at any stage of the workflow (work-in-progress, raw materials, finished products) results in excessive storage and transportation costs.
Waiting	The result of waiting is the inability to immediately perform a task due to shortages (of labor, materials, information, equipment) or due to downtime, delays, and bottlenecks.
Defects	Inspection, production, repair, replacement, or disposal of defective products or parts means a loss of time and costs and directly impacts the efficiency of the construction process.
Over-processing	Inefficient processing leads to shortages while over-processing leads to unnecessarily high quality; both are considered losses.
Unused employee creativity	Underutilization of employees' potential, loss of skills, ideas, and improvement opportunities constitute a major source of losses for construction companies.

Source: Bajjou et al., 2020; Demirkesen, 2021.

The most frequently used tools within Lean Construction include: Last Planner System (Ballard, 2000), Building Information Modeling (Garces, Pena, 2022) and Prefabrication (Bajjou et al., 2017), as well as solutions taken from the Toyota Production System, i.e.: 5S method, Visual Management (VM), Value Stream Mapping (VSM), Poka-Yoke, Just in Time (JiT), Gemba Walk, Daily Meetings, Root Cause Analysis (5Why analysis, Ishikawa diagram) (Bajjou et al., 2017, 2017a, 2017b; Abdelkhalek et al., 2019; Ahmed et al., 2021; Demirkesen, 2021; Yazan, 2022; Musa et al., 2023; Unnikrishnan, Sudhakumar, 2024)

It is believed (Unnikrishnan, Sudhakumar, 2024) that Lean tools and methods should be used already at the design stage of construction works, taking into account various factors, e.g. requirements, geographical conditions of the system location, types of waste generated, size of the workplace, labor productivity and safety procedures.

4. The use of LM methods and tools in the construction industry

Based on the analysis of literature on the topic discussed, Table 2 summarizes the LM methods, tools and techniques most frequently used in the construction industry.

Table 2.
LM methods, tools and techniques used in the construction industry

Authors	LM tools and methods	Characteristics
Bajjou et al., 2017 Bajjou et al., 2017a Ahmed et al., 2021 Demirkesen, 2021 Yazan et al., 2022 Musa et al., 2023 Unnikrishnan, Sudhakumar, 2024	5S/6S	A method aimed at creating a well-organized, orderly and safe workplace, e.g. through designated tool storage zones and material storage at the construction site. 5S/6S simplifies the production flow on the construction site, improves ergonomics and work safety, and limits excessive movement of workers.
Bajjou et al., 2017 Bajjou et al., 2017a Abdelkhalek et al., 2019 Ahmed et al., 2021 Demirkesen, 2021 Yazan et al., 2022 Musa et al., 2023 Unnikrishnan, Sudhakumar, 2024	VM	Tools facilitating communication on the construction site and providing employees with key information regarding quality, safety and work organization, e.g. light and sound signals, boards, pictograms, color coding. VM improves the organization, transparency and safety of construction works.
Bajjou et al., 2017 Bajjou et al., 2017a Bajjou, Chafi, 2020 Ahmed et al., 2021 Unnikrishnan, Sudhakumar, 2024	Poka-Yoke	Technical solutions that prevent the possibility of an employee making a mistake and, as a result, prevent quality errors or accidents at work.
Bajjou et al., 2017 Bajjou, Chafi, 2020 Ahmed et al., 2021 Demirkesen, 2021 Musa et al., 2023 Unnikrishnan, Sudhakumar, 2024	VSM	A graphical tool used to present the flow of materials and information in the construction process. VSM aims to simplify the process and its sequence by identifying losses, and thus creates opportunities for process improvement.
Ahmed et al., 2021 Yazan et al., 2022 Musa et al., 2023 Unnikrishnan, Sudhakumar, 2024	JiT	JiT monitors inventories and ensures the delivery of the necessary materials and equipment in the required quantity and precisely on time for a given stage of construction works. JiT reduces flow time and improves safety (eliminating congestion at the construction site).
Bajjou et al., 2017a Demirkesen, 2021	Gemba Walk	Gemba walks help highlight problems on a construction site and provide opportunities for improvement by identifying the root cause of the problem. They also enable the identification of problems related to work safety.
Ahmed et al., 2021 Szkolnicki et al., 2017 Demirkesen, 2021 Musa et al., 2023 Unnikrishnan, Sudhakumar, 2024	Daily Meetings/ Daily Huddle Meeting	Short, daily team meetings to discuss the results of the previous day's work, the current work plan, and emerging problems (including those related to health and safety). It is a tool that allows to monitor the progress of construction works and improves communication within the team, engaging employees in solving problems before they affect the progress of the project.
Ahmed et al., 2021 Demirkesen, 2021 Unnikrishnan, Sudhakumar, 2024	Root Cause Analysis (5Why, Ishikawa diagram)	Tools for determining potential causes of problems in construction work (Ishikawa diagram) and for identifying the root cause (5Why).

Source: Own elaboration.

The 5S/6S method is considered one of the first steps to be taken when implementing LC. By implementing five or six stages (selection, systematics, cleaning, standardization, self-discipline, and safety), the method allows for a well-organized, transparent and safe workplace on the construction site. This can be achieved by removing unnecessary items from the construction site, designating and describing storage areas for materials and tools, and introducing cleanliness standards, which ensures better accessibility, improves organization and work safety, and reduces losses related to excessive movement of workers and the possibility of accidents (falls, trips). It is believed that implementing and maintaining 5S/6S conditions can promote a health and safety culture and workforce productivity (Bajjou et al., 2017, 2017a; Ahmed et al., 2021; Demirkesen, 2021; Yazan et al., 2022; Musa et al., 2023; Unnikrishnan, Sudhakumar, 2024).

Visual Management (VM) is a communication tool that informs how work should be done and whether the way it is done deviates from the established standard. It involves presenting key information for employees and all stakeholders in a simple, clear and understandable way, which makes the construction process transparent, simple and safe. As part of VM, the following solutions can be used on the construction site: color coding, labels of material storage zones, hazardous areas, transport paths, paths for employees, safety boards and signs, digital billboards (with key information about the process), light and sound signals. The use of various forms of VM improves the efficiency of production planning and control (information display), and helps increase employee involvement in the improvement process by visualizing current and target performance indicators. It also allows for the identification of the arrangement of workstations, materials and tools, which limits excessive and risky movement of employees around the construction site. Light and sound signals, safety signs inform about threats (work in progress, unfinished work, falling objects) (Bajjou et al., 2017, 2017a; Abdelkhalek et al., 2019; Ahmed et al., 2021; Demirkesen, 2021; Yazan et al., 2022; Musa et al., 2023; Unnikrishnan, Sudhakumar, 2024).

The use of Poka-Yoke solutions allows to prevent errors made by employees that may affect the quality of production, productivity and work safety (these errors may result, for example, from the monotony of work, lack of attention or lack of experience). In construction works, systems are used to identify errors, where the process is automatically interrupted and/or a light and sound signal appears informing the employee about an error or danger, e.g. entering the area of falling objects from a height, concrete drying zone (Bajjou et al., 2017, 2017a; Bajjou, Chafi, 2020; Ahmed et al., 2021; Unnikrishnan, Sudhakumar, 2024).

Another tool is VSM, which allows for graphical presentation and analysis of the flow of materials and key information in the construction process. VSM helps identify activities that add value for the customer and identify losses, which is the basis for taking improvement actions. When used skillfully, VSM can simplify the flow of the construction process (Bajjou et al., 2017; Bajjou, Chafi, 2020; Ahmed et al., 2021; Demirkesen, 2021; Musa et al., 2023; Unnikrishnan, Sudhakumar, 2024).

The use of Just in Time in the construction process is intended to monitor inventories and ensure the delivery of materials and other necessary resources exactly on time and in quantities necessary for a given stage of the process. This organization of production ensures uninterrupted flow and also affects the work safety on the construction site - timely deliveries of materials eliminate the formation of excessive inventories that create congestion that may cause accidents at work (Ahmed et al., 2021; Yazan et al., 2022; Musa et al., 2023; Unnikrishnan, Sudhakumar, 2024).

The use of Gemba Walk in the construction industry is important due to the possibility of continuous, regular observation of the process by superiors. Gemba Walk makes it possible to identify losses and problems (including those related to work safety) and collect data that is necessary to determine the root causes and take improvement actions. The literature also mentions Safety Walks, during which the work and behavior of employees are monitored in terms of compliance with occupational health and safety rules and 5S/6S (Bajjou et al., 2017a; Demirkesen, 2021). Daily Huddle Meetings also have a similar importance as regular team meetings play a key role in planning and discussing ongoing work/tasks to be performed, monitoring construction work progress, discussing problems, and paying attention to hazards. This tool improves communication and influences employee involvement in improvement processes (Ahmed et al., 2021; Szkolnicki et al., 2017; Demirkesen, 2021; Musa et al., 2023; Unnikrishnan, Sudhakumar, 2024).

It is worth emphasizing the importance of using Problem-Solving tools to determine the potential causes of losses/problems in the project and determine the root cause. The most frequently mentioned in the literature on the subject are the Ishikawa diagram and the 5Why analysis. Using them in everyday work can improve the construction process in terms of quality, timeliness and safety (Ahmed et al., 2021; Demirkesen, 2021; Unnikrishnan, Sudhakumar, 2024). Problem-solving is an integral part of the continuous improvement process and the basis of TPS.

5. Possibility of influencing selected LM methods and tools on the construction process

The analysis conducted on the use of LM methods and tools in the construction industry allowed to determine the potential impact of these solutions on improving various aspects of the construction process, as presented in Table 3. Eight LM methods and tools most frequently mentioned in the literature were selected.

In terms of improving work safety/safe working conditions on the construction site, it is possible to use seven LM methods and tools (Table 3). 5S/6S and VM are solutions that can significantly improve work safety. The use of visual markings, labels and signals informs and warns all employees about the threat. Similarly, Poka-Yoke, through technical and visual solutions, prevents errors leading to accidents. The application of JiT principles also improves work safety, because the delivery of materials in the right quantity and time prevents the formation of congestion that can cause accidents at work (falls, trips) and impede the movement of employees. Regular Gemba Walks allow to identify and respond to threats occurring on the construction site on an ongoing basis, and discussing and solving safety problems during Daily Huddle Meetings can reduce the possibility of accidents at work (using Problem-Solving tools).

Table 3.
Possibility of influencing LM methods and tools on the construction process

Area of improvement	5S/6S	VM	Poka-Yoke	JiT	VSM	Gemba Walk	Daily Huddle Meetings	Root Cause Analysis
Work safety/safe working conditions	+	+	+	+		+	+	+
Safe behaviors	+	+	+			+	+	+
Organization of work/workplace	+	+				+	+	
Workflow (employees, materials, information)				+	+			
Timeliness of work				+	+		+	
Increased employee involvement	+	+					+	+
Elimination/ limitation of losses	+	+	+	+	+	+	+	+

Source: Own elaboration.

In terms of improving safe behavior, it is possible to use six LM methods and tools. Applying and respecting the 5S/6S and VM rules and using Poka-Yoke solutions in construction works shape the safe behavior of employees, build awareness, and promote a safety culture among employees. A key role in this respect is played by supervisors, who observe employee behavior and react to deviations from health and safety regulations (as part of Gemba Walk) and discuss problems related to work safety and possible hazards during Daily Huddle Meetings. Safe behaviors can also be shaped by involving employees in solving health and safety problems and analyzing the causes of their occurrence (5Why analysis, Ishikawa diagram).

In terms of improving the organization of work/workplace in the construction process, it is possible to use four LM methods and tools: 5S/6S, VM, Gemba Walk, and Daily Huddle Meetings. Maintaining order on the construction site, designating places to store materials and tools, and using visual markings have a positive impact on the organization of tasks and make work easier. Observation of the process by superiors and paying attention to any deviations during Gemba Walk may affect the organization of work and maintaining the 5S rules. Moreover, discussing the current work plan and existing problems related to work organization during Daily Huddle Meetings also affects the discussed aspect (drawing attention to the problem before it disorganizes the process).

In terms of improving the workflow and timeliness of construction work, it is possible to use JiT and VSM. Organizing the delivery of materials to the construction site in the right quantity and time (JiT) allows to improve the efficiency of work by shortening the flow time in the process and the response time of suppliers. The assessment of the current state of the process, based on mapping (VSM), allows to identify areas of loss and take action to improve the flow of materials and information. VSM and JiT can therefore be an effective tools to achieve uninterrupted workflow. In terms of improving the timeliness of work, it is also possible to use Daily Huddle Meetings, to discuss current tasks to be performed, monitor work progress, and solve problems that may make it difficult.

The use of four LM solutions (5S/6S, VM, Gemba Walk, Daily Meetings) can increase the involvement of all construction workers. Compliance with the 5S/6S principles, compliance with the introduced VM tools, compliance with work and safety standards, identifying irregularities related to quality and health and safety, and solving problems during meetings - all this may translate into an increase in commitment to continuous improvement.

All LM methods and tools listed in Table 3 can eliminate or reduce losses occurring in construction works:

- excessive movement of workers on the construction site (5S/6S, VM, Gemba Walk),
- unnecessary movement during searching for tools/materials and during avoiding congestion on the construction site (5S/6S, VM, JiT, Gemba Walk),
- excessive transport of materials (JiT, VSM, Gemba Walk),
- creation of excessive inventories (JiT, VSM, Gemba Walk),
- waiting for materials or the next process stage (JiT, VSM, Gemba Walk),
- defects caused by workers' errors (Poka-Yoke, VM).

Each loss should be discussed during Daily Huddle Meetings and analyzed to determine the root cause.

6. Summary

Based on the analysis, it was found that the methods and tools of the LM concept can be used in the construction industry. The eight LM solutions most frequently mentioned in the literature were analyzed and presented in Table 3. It was found that they can improve the functioning of the construction process in various aspects:

- in terms of improving work safety/working conditions – the impact of 5S/6S, VM, Poka-Yoke, JiT, Gemba Walk, Daily Huddle Meeting, Root Cause Analysis,
- in terms of shaping safe behaviors – the influence of 5S/6S, VM, Poka-Yoke, Gemba Walk, Daily Huddle Meeting, Root Cause Analysis,
- in terms of improving the organization of work/workplace – the impact of 5S/6S, VM, Gemba Walk, Daily Huddle Meeting,
- in terms of workflow – impact of JiT, VSM,
- in terms of timeliness of work – the impact of JiT, VSM, Daily Huddle Meetings,
- in terms of employee involvement – the impact of 5S/6S, VM, Gemba Walk, Daily Huddle Meeting.

Attention was also paid to the possibility of eliminating or reducing losses in the construction process - in this aspect, all LM methods and tools listed in Table 3 can be used and support management in taking improvement actions.

The choice and use of a given tool will depend on the problems occurring on construction sites, as well as on the awareness of the work organizers/managers about the possible benefits that these solutions can bring to construction workers and all project stakeholders. Attention should also be paid to barriers that may hinder the use of lean practices in construction processes, including: resistance to change, non-compliance with applicable standards (including occupational health and safety), lack of awareness, lack of commitment of employees and supervisors, and lack of communication.

The conclusions from the analysis may guide construction companies that take actions aimed at eliminating losses and increasing the efficiency of the process.

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