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# From Lean Manufacturing to Lean Construction: How Principles, Tools, and Techniques Evolved

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## Abstract

Lean manufacturing first emerged in the automotive industry. However, low productivity and low efficiency in production are major problems for the majority of industries relying on a heavy workforce. Being one of these, the construction industry suffers from low productivity rates along with inefficient work practices. To prevent those, the industry has shifted its focus from the traditional approach to a more innovative one, which is called Lean construction. Lean construction aims to maximize value while minimizing waste. Therefore, it intends to create safer, smoother, and more efficient processes to eliminate waste. This chapter focuses on Lean construction and highlights the generic Lean tools and techniques practiced in the construction industry indicating its historical journey from Lean manufacturing. The chapter aims to raise awareness towards the efficiency of Lean methods in the construction industry with respect to practices observed in manufacturing.

**Keywords:** lean manufacturing, productivity, efficiency, lean construction, lean methods

## 1. Introduction

The foundation of Lean thinking dates back to the 1900s, when Henry Ford, founder of Ford Motor Company, came up with an entire production process relying on interchangeable parts with standard work and moving conveyance for creating a flow production [1]. Melton [2] defines Lean as a revolution indicating that Lean is not just utilizing tools and techniques or making a few changes in processes, rather he defines Lean as a complete change in businesses to observe supply chain operations, managerial decisions, and daily work of employees in an organization. The authors of the book named “The Machine that Changed the World”, which is one of the most influential books implied that the Lean way results in better products at a lower cost as well as encouraging employees to overcome challenges in production processes [3]. Even though Lean manufacturing has first found its roots at Ford, it was later investigated by Toyota Motor Company. The Japanese engineer Taiichi Ohno, who had several visits to Ford factories to observe production processes. However, Taiichi Ohno found some methods implemented at Ford as needing improvements. Therefore, Sakichi Toyoda, his son, Kiichiro Toyoda, and Taiichi Ohno came up with the concept of Lean Manufacturing, which was first called just-in-time (JIT) production [4]. Taiichi Ohno was responsible for implementing

the new ideas that evolved into the Toyota Production System (TPS). Then, Taiichi Ohno hired Shigeo Shingo to work on the setup reduction problem at Toyota. Shingo later named this successful process the famous Single Minute Exchange of Dies (SMED) system. This is how production ideas evolved at Toyota leading to technical innovations.

The lean manufacturing concept was first articulated as a shop floor practice to reach higher efficiency in processes being implemented with JIT and Toyota Production System (TPS) [5, 6]. It was also mentioned that Lean manufacturing in the 1980s rather focused on shop floor techniques and inventory reduction as well as value-added processes in the supply chain [7, 8]. Lean manufacturing is now implemented as a popular manufacturing practice in various countries and industries [9]. The ultimate goal intended by Lean organizations is to have a high-quality organization responsive to customer demands with no waste. On the other hand, most manufacturing organizations fail to realize the transformation for Lean due to a range of challenges faced [6]. The majority of the previous studies implied that even though most Lean organizations aim to implement Lean in the best way, they fail at some point as a matter of fact [10, 11]. However, the organizations are still seeking ways to improve their Lean approach and effectively practice Lean methods.

The success of Lean thinking in the manufacturing industry positively affected the construction industry. However, the construction industry is a conservative and fragmented industry, which makes innovations less welcomed by industry practitioners [12]. On the other hand, low productivity rates and intentions to improve workforce efficiency led the construction industry to implement innovative technologies.

The term 'Lean Construction' was first articulated by the International Group for Lean Construction (IGLC) in 1993. Glenn Ballard and Greg Howell, the two construction practitioners who first considered Lean in construction projects, started the Lean Construction Institute (LCI) in 1997 to provide and share information about the management of construction projects in the most effective way. They observed that only 50% of the tasks on weekly work plans in construction projects are completed on time by foremen in a given week [13–15]. They proposed that construction practitioners can avoid these problems with active management of variability, starting with the structuring of the project (temporary production system) and continuing through its operation and improvement" [16]. This indicated that the construction industry is facing similar challenges to the manufacturing industry. Hence, the principles of the TPS and methods of Lean productions started to have been practiced in the industry by adapting them for construction.

Considering the similarity of challenges and need for improvement in both manufacturing and construction, the Lean methods have evolved with the methods for implementing. Hence, the main purpose of this chapter is to provide the background of Lean thinking in both manufacturing and construction along with presenting a bunch of Lean methods, which are widely practiced by industry practitioners. The chapter also mentions how Lean methods in production have changed when they are being implemented in the construction industry.

## **2. Background of lean production and lean construction: Interaction in terms of tools, techniques, and methods**

Due to the quick industrialization after the industrial revolution, the world has become a place, where natural resources are unconsciously consumed and environmental problems increase. All these negative conditions have caused the run out of natural resources, distortion in the ozone layer, decrease in biodiversity, increase in

environmental contamination, and global warming. Therefore, the removal of all these problems and negative conditions is one of the most important challenges of today's world. This leads to a considerable increase in the number of studies regarding the prevention of environmental problems, conscious use of natural resources, and a cleaner and healthier environment to be inherited by the next generations. In this context, Lean is a newly emerging concept for the majority of industry encouraging the effective use of resources. One of the major challenges of today's world is to execute projects more efficiently with respect to project objectives. At this point, Lean thinking aims to minimize waste while maximizing value to the customer.

Lean Production was the term coined by [17] to refer to Toyota's offering of high value, low-volume, and cost-competitive production to best address customer desires [18]. After the success of lean production in the automotive industry [19], Toyota's Lean thinking was applied in other industries. The construction industry produces more waste than any other industry in the entire world [20]. The waste oftentimes occurs in the form of workforce loss, safety breaches, material waste, and low efficiency. To avoid these, Lean construction has proven to be an effective means of production management for project delivery, i.e., designing and building capital facilities. Lean Construction is important in that it adopts the principle of minimizing waste and maximizing value while improving the total project performance per customer expectations. The need behind Lean construction comes from the failure of mass production and the persistence of craft-based production in the construction industry. Due to the changing needs of the customer, Lean construction is essential to provide the desired variety. To minimize waste and maximize value, researchers have previously focused on several different Lean construction methods. For example, it was implied that modular construction is effective in reducing waste and achieving resource efficiency [21]. This study also demonstrated that modular is reusable, which evidences the essential function of modular construction. In another study, it was indicated that there are several waste factors in mid/high-rise building projects and the determination of those waste factors is essential [22]. Therefore, Lean construction has proposed an opportunity for estimating the impacts of waste on overall project performance [23].

Sacks et al. [24] implied the importance of Lean production management systems in reducing waste in construction. Kalsaas [25] highlighted that measurement of waste and workflow is essential for the achievement of continuous improvement in construction projects. El-Reifi et al. [26] emphasized that Lean thinking is essential in the briefing process, where the design team develops their designs with respect to clients' desires. Fullalove [27] provided that the use of Lean techniques resulted in significant benefits such as an increase in return on investment and efficiency savings in UK road constructions. Marhani et al. [28] indicated that the application of Lean thinking into the construction industry provides a tremendous opportunity for the reduction of waste and an increase in production. Zhao and Chua [29] demonstrated that the reduction of non-value adding activities has a significant contribution to the construction productivity improvement. Aziz and Hafez [30] concluded that lean projects are safer, easier to manage, completed sooner, cost-effective, and are of better quality by referring to the impact of lean in minimizing waste in construction. Boyce [31] investigated the aspects of Lean thinking and concluded that it helps to improve the design phase of complex projects by emphasizing the essential function of a collaborative planning process in highway design. Going Lean is needed for the defective processes in mass production and craft production. Hence, Lean is an effective approach for customer satisfaction and enhanced project performance as previously implied by several studies [32, 33]. However, there is still a need for more effective Lean techniques to be applied in the construction projects especially given that the industry generally is reluctant to embrace and slow to adopt change.



Given this background, this chapter presents the most applied methods of Lean in the construction industry with inference to Lean production. The construction industry is utilizing most of the Lean techniques developed for manufacturing. Hence, it is essential to present these tools and techniques to guide industry practitioners for the proper implementation of the methods.

### 3. Lean methods: how tools and techniques are evolved

Lean methods have been heavily implemented in the manufacturing industry. Over time, the efficiency and reliability of the methods have been proven. This encouraged other industries to benefit from Lean methods. Since the construction industry relies on a heavy workforce, it is essential to utilize safer, reliable, and efficient methods and technologies.

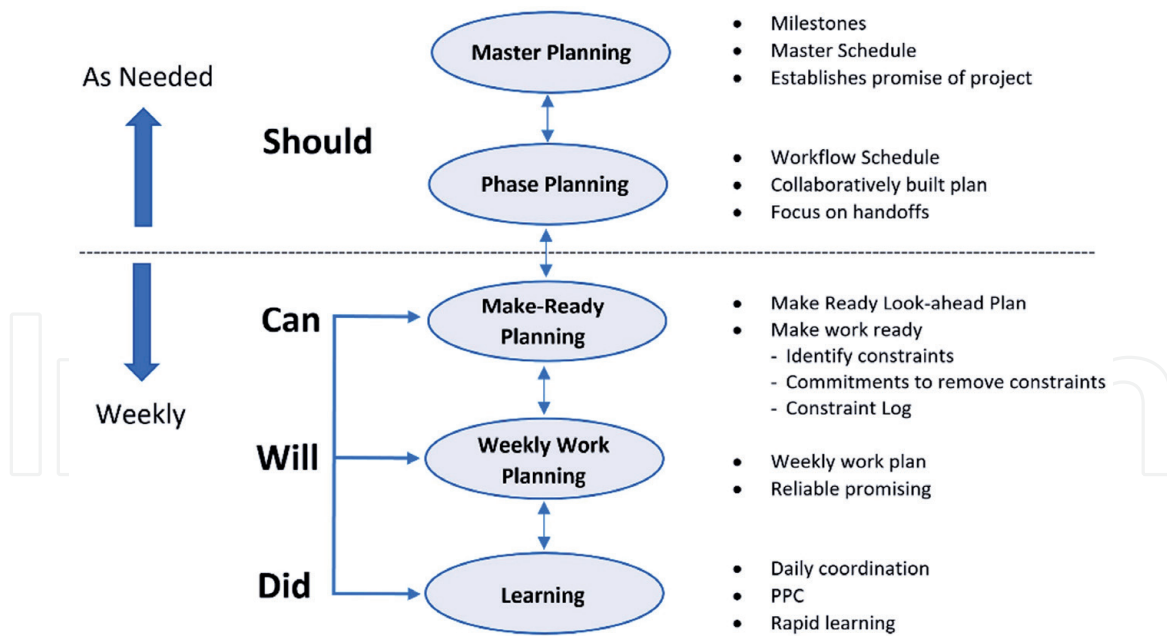
In production, it is of utmost importance to eliminate 'waste'. Waste or 'muda' in Japanese is simply defined as anything other than the minimum amount of parts, materials, equipment, and work time specific to production [34]. There are seven waste types defined as overproduction, waiting time, transportation, inventory, processing, motion, and product defects. Lean manufacturing aims to manage processes without waste. However, it was evidenced that several companies are still challenging with staying Lean [35]. Kongguo [36] implied that Lean thinking helps conceive the Lean principles better, which first starts with realizing the customer value and continues with identifying value-added activities, generating flow, implementing the pull system, and sustaining continuous improvement. To improve the efficiency in those, various Lean methods and techniques are developed and practiced in manufacturing organizations. Some of them have been more effective in other industries such as construction.

Below are the widely implemented Lean techniques that have evolved and be used in the construction industry.

#### 3.1 The last planner system (LPS)

LPS was originally developed by Glenn Ballard in 1993 in accordance with Lean construction principles. LPS is a Lean construction tool that focuses on increasing productivity by creating weekly work plans. The weekly plan includes tasks related to work and the individuals executing these tasks are called the Last planners [13]. LPS allows quick monitoring of the work-related issues for all construction personnel. LPS also provides an environment, where mistakes are visible. However, problems might occur, and timely actions are not taken in traditional construction management leading to late delivery of projects [36]. The Last planner is the person, who directly supervises the work. This person is usually responsible for production capability. The Last planner can be anybody like a project engineer, department manager, or foreman [37]. **Figure 1** presents the Last Planner System.

The tasks are split into two as needed and weekly. As needed tasks involve 'should' tasks, whereas weekly tasks include 'can', 'will', 'did' tasks. In 'should', the tasks include work to be done to reach the determined milestones according to the project plans. These tasks are created from different data such as customer demands, project goals, and information, planner stuff's former experiences. In 'can', the fundamental tasks are reflecting the actual work that is executed with respect to the constraints of the project. In this process, the required materials and labor are ready, where the previous project stage is completed. In 'will', the tasks ensure the work to be completed after all constraints are assessed. In 'did', the tasks refer to completed work [39].

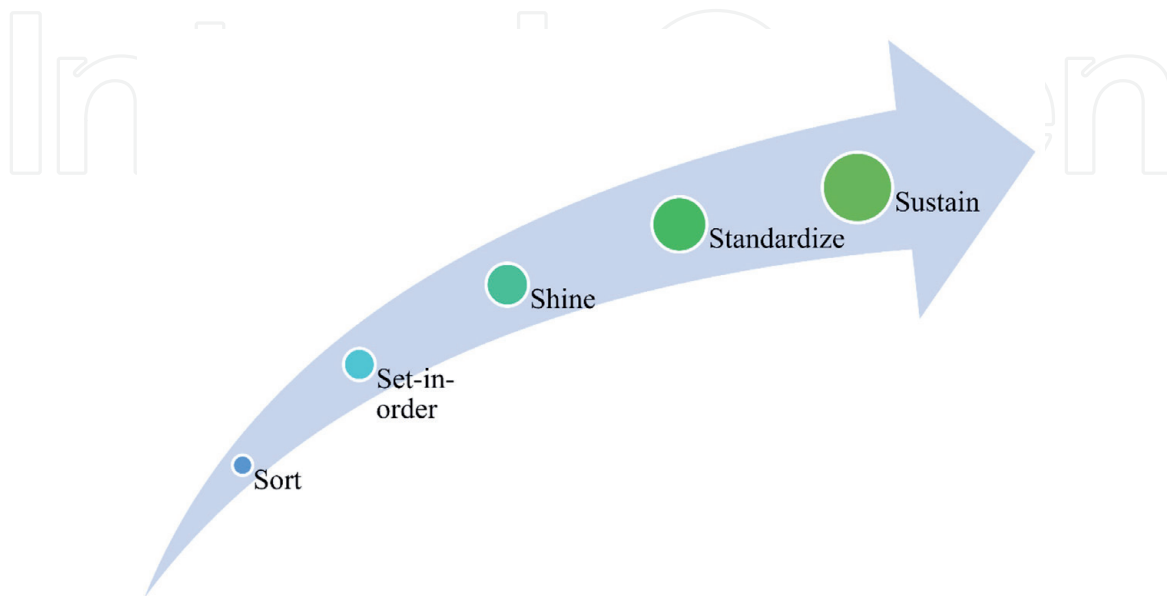


**Figure 1.**  
*Last planner system (adapted from [38]).*

3.2 5S method

5S is a Japanese method of organizing the workspace in a clean, efficient, and safe manner to create a productive work environment. The 5S is a starting point for any company aiming to be recognized as a responsible and reliable producer [40]. In Japanese, the 5S methodology represents 5 different words, which all start with the letter S. **Figure 2** presents these five steps, respectively.

**Sort (Seiri):** Sorting is the first stage of 5S. It is the process of sorting out (separating) materials and equipment needed or unneeded. This process might result in fewer complaints, improved communication among employees, and an increase in the quality and efficiency of production. This process allows workers to take the next steps such as tagging the items.



**Figure 2.**  
*5S stages.*

**Set in order (seiton):** This stage refers to make all equipment needed for production accessible and prepared for use. This step also refers to organize all equipment and material for easy access and facilitation for production. This step requires the work area to be organized for production. A map can be drawn to represent station and equipment places.

**Shine (seiso):** This step refers to cleaning polluted equipment and work area. Pollution can be detected by sense organs and this might help find out the problem before it occurs. This stage also refers to sweeping everywhere cleanly and taking all kinds of unwanted objects away from the working environment. Thus, abnormalities can be noticed immediately, and the decision to clean materials after separation becomes easier.

**Standardize (seiketsu):** This stage refers to cleaning and maintaining the arrangement and standardizing that. The main purpose of this step is to fully meet 3S requirements and to detect and eliminate the root cause of problems. The way to ensure these is to constantly check the environment and detect deficiencies.

**Sustain/self-discipline (shitsuke):** This step encompasses all stages. It includes checking the existing system, training the employees, establishing good communication, and rewarding. The main purpose of this step is to get into the habit of maintaining the correct procedures [41].

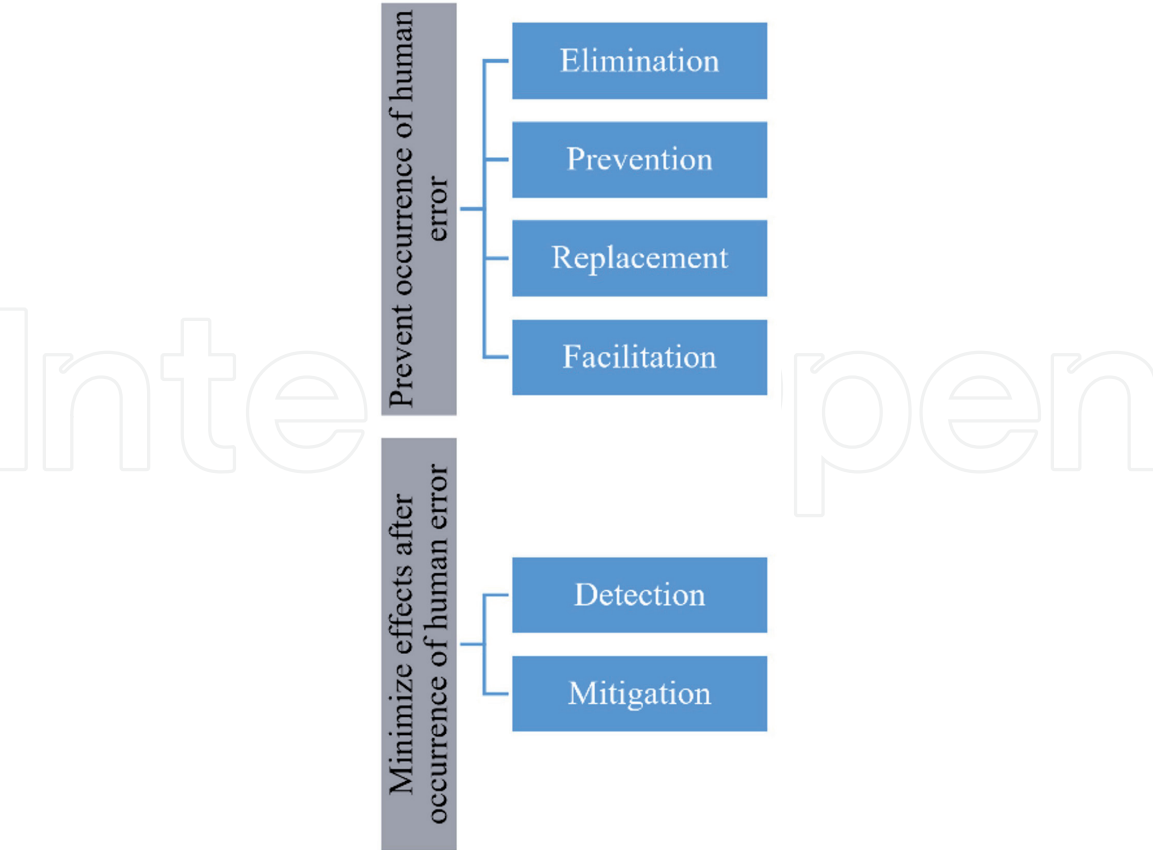
### 3.3 Mistakeproofing (Poka yoke)

“Mistake proofing, or its Japanese equivalent poka-yoke (pronounced PO-ka yo-KAY), is the use of any automatic device or method that either makes it impossible for an error to occur or makes the error immediately obvious once it has occurred” [42]. Mistake proofing is an effective quality control technique to avoid human error, which might cause mistakes or defects [43]. Shingo [44] defines three inspection techniques for quality control, namely the judgment inspection, informative inspection, and source inspection. Judgment inspection is for discovering defects, whereas informative inspection is used to lower defect rates by controlling the process and prevent defects. Source inspection rather searches the conditions that exist for an error-free action.

Poka yokes might be grouped into three as shutdown poka-yoke, control poka-yoke, and warning poka-yoke in terms of their functions. The poka-yoke devices check different and important parameters and detect whether the process has an improper action. This check allows detecting whether the product manufactured has defects or not. The shutdown of poka-yokes constitutes an important part to prevent defects eliminating the possibility of error. The control poka-yoke is built into the production equipment and works as a redactor. When the device finds an unwanted condition that occurred during manufacturing processes, it signals production to avoid defects. The warning poka-yoke warns the operator with either visual symbols or sound signals for errors. The warning poka-yokes rely on human factors, where it is not quite certain to avoid defects in the production processes [45].

Mistake-proofing has six principles namely elimination, prevention, replacement, facilitation, detection, and mitigation. The first four principles intend to prevent the occurrence of human error, whereas the last two principles are to minimize the effects after the occurrence of human error. **Figure 3** presents these six principles along with their tasks.

The use of mistake-proofing devices also provides various advantages in terms of safety at the workplace [46]. It is possible to create fail-safe approaches in manufacturing with the use of such tools and devices. Considering the high accident rates in the construction industry, the use of mistake-proofing devices is also effective means of enhancing safety performance and avoiding human errors leading to work-related accidents.



**Figure 3.**  
*Mistake proofing principles.*

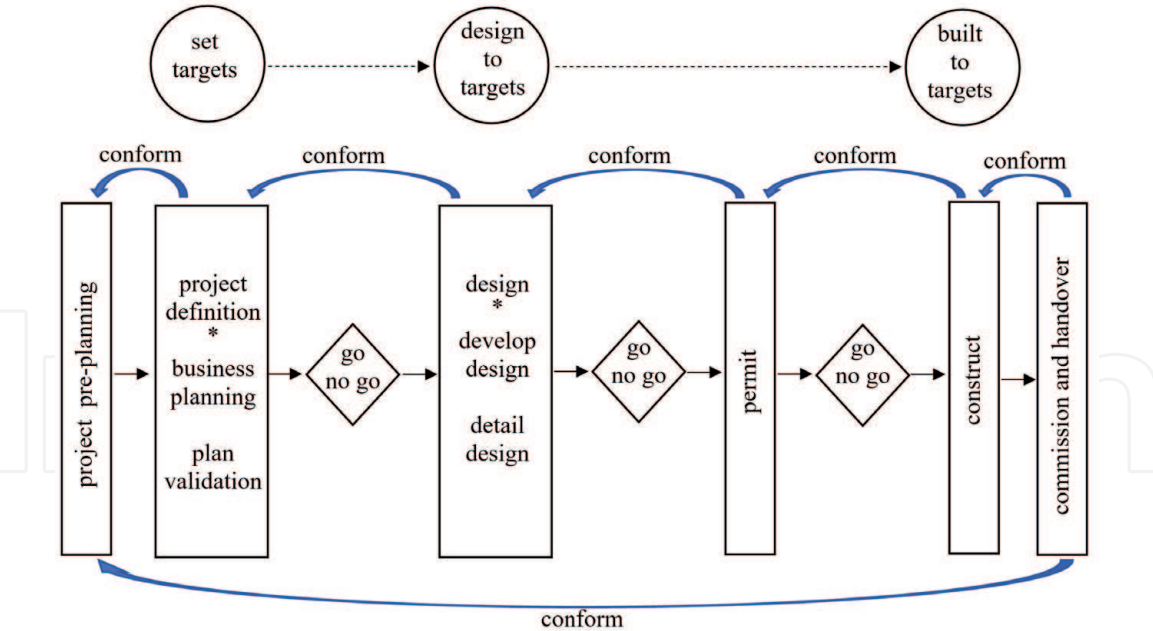
### 3.4 Visual management

Visual management is a broadly implemented Lean technique in the manufacturing industry. This technique helps to make information visible for all showing the information through visual signals [47]. Visual management has recently been used as a system enabling employees to better understand their role and contribution with respect to organizational values and customer needs. Nevertheless, the critical role of visual management has not yet been understood well by the construction industry. For example, two types of visual means such as 3D and visual planning are utilized in construction design [48]. Visual management helps increase communication, transparency, and stakeholders’ capabilities [49, 50]. Therefore, construction companies must make use of these techniques to provide a better environment for their employees increasing efficiency and productivity.

### 3.5 Target value design (TVD)

Target Value Design (TVD) is simply defined as “a management practice that steers the design and construction of the project to the customer’s constraints while maximizing the value delivered within those constraints” [51]. TVD is an emerging practice in the U.S. construction industry for cost predictability during design, construction, and delivery. It is adapted from the Target Costing method of manufacturing, which first appeared as a profit planning and strategic management approach in the 1930s [52]. This technique is promising for several benefits for the construction industry, where the companies are still struggling with project constraints such as cost, quality, and time. Therefore, TVD is an effective means of collaborative Lean approach in terms of reducing construction costs [53]. It was further indicated that





**Figure 4.**  
*TVD process scheme [53].*

the systematic application of TVD resulted in significant improvement in project performance based on 12 construction projects, where TVD was introduced.

**Figure 4** presents the TVD process with respect to construction project phases.

### 3.6 Value stream mapping (VSM)

Value Stream Mapping is an essential tool to identify and comprehend the productive stream focusing on the identification of waste sources, such as waiting for products and inventories, rework, information lost in the process, non-value-adding activities besides the identification of opportunities for improvement [54]. With VSM, it is possible to improve the information stream in the design process through the inclusion of alternative methods of control. This creates a base for incentives and future actions to generate value [55].

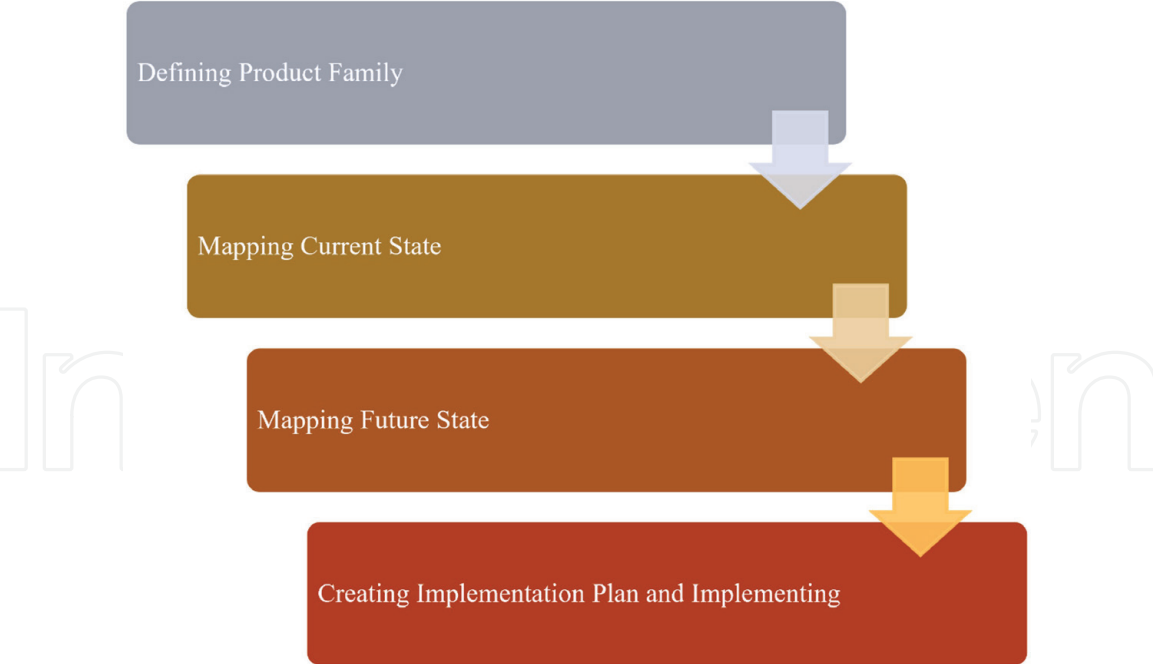
VSM helps visualize the whole rather than isolated parts of the process as well as monitoring the products, documents, and information. It also allows simultaneous visibility of streams of materials and information; visualization of indicators such as throughput time, percentage of value aggregation, lots size, and cycle time for the performance of activities [56].

VSM consists of several steps such as mapping activity for a family of products, defining the current state map of the value stream, and creating the future value stream map, where improvement takes place based on the proper identification of problems [54, 56]. **Figure 5** presents the steps for VSM.

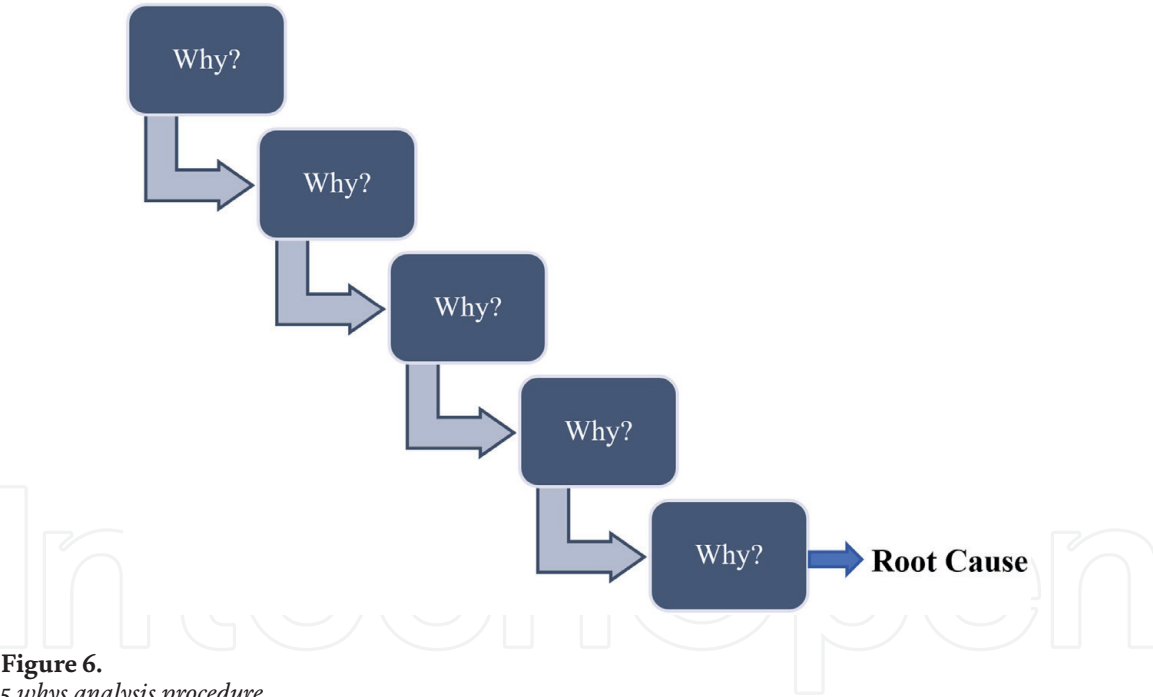
### 3.7 5 whys and root cause analysis

5 Whys is a quality management tool of problem-solving aiming to find the root cause of an event [57]. It directs that one needs to ask five times repeatedly to identify the root cause of a problem for the fact that the solution is clear. This procedure aims to eliminate the root cause to prevent its recurrence [58]. **Figure 6** shows the 5 Whys procedure for finding the problem's root cause.

Considering the risky nature of construction projects, it is of utmost importance to determine the root cause of the problems leading to unwanted situations. Therefore, 5 Whys analysis is an essential method for preventing problems either



**Figure 5.**  
*VSM processes.*



**Figure 6.**  
*5 whys analysis procedure.*

from occurring or recurring. Therefore, utilizing the 5 Whys method might result in higher efficiency and productivity, where risky conditions are eliminated.

**3.8 Gemba walks**

Gemba is a Japanese word and it stands for the “actual place” [59]. For creating value in the organization, the actual place must enable employees to manufacture with less waste, fewer challenges, less overload, and less overproduction. At this point, Gemba walks are essential to go and see the current situation and understand the root cause of the problem. In the Lean construction context, walking means “go see, ask why, show respect” [60]. Gemba walks help making the problems visible and create improvement ideas with the proper consideration of the root cause.

It also allows collecting data regarding the root cause leading to problems. In the construction industry, it is clear that Gemba walks constitute an important part since the majority of the processes in construction need improvements and require the proper identification of the root cause for problems.

### 3.9 Daily huddle meetings

Daily huddle meetings take place, where team members are ready to share what they achieved and what they challenge. A huddle meeting can also be organized as a weekly work plan meeting highlighting the completion of assignments for the following week in addition to discussing the work to be done that day [61]. The huddle meetings enhance the job satisfaction of employees while strengthening two-way communication among the team [62]. Daily huddle meetings create an opportunity for employees to involve in discussions and indicate the positive and negative sides of their tasks. The employees also find room for solving problems together during those meetings. These meetings also help detect the causes of accidents, which are associated with poor communication and coordination [63]. Hence, daily huddle meetings must be organized, and employees are encouraged to speak up on the tasks listing good and bad sides.

## 4. Conclusions

This chapter presented the historical evolution of Lean management and how Lean is adopted in the construction industry. The study presented the core principles of Lean along with the most widely adopted practices. According to the information presented in this chapter, one may advocate that the construction industry still struggling with the adaption of various Lean manufacturing practices into construction. Therefore, it is apparent that more research has to be conducted to provide a guideline for the industry practitioners in terms of benefitting from Lean practices at maximum. On the other hand, the methods, tools, and techniques presented in this chapter are expected to lead industry practitioners in terms of scrutinizing Lean concepts and evaluate those in the context of project conditions. As future work, the efficiency of Lean methods both applied in manufacturing and construction might be compared based on different operating processes.

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## References

- [1] Lean Enterprise Institute (LEI) 2021. A Brief History of Lean. <https://www.lean.org/whatslean/history.cfm>
- [2] Melton T. The benefits of lean manufacturing: what lean thinking has to offer the process industries. *Chemical engineering research and design*, 2005, 83(6), 662-673.
- [3] Womack, J. P., Jones, D. T., & Roos, D. (2007). *The machine that changed the world: The story of lean production—Toyota's secret weapon in the global car wars that is now revolutionizing world industry*. Simon and Schuster.
- [4] Sorensen, Charles E., *My Forty Years with Ford*. New York: W.W. Norton, 1956.
- [5] Schonberger, R.J. (2007) 'Japanese production management: an evolution – with mixed success', *Journal of Operations Management*, Vol. 25, No. 2, pp.403-419.
- [6] Nordin, N., Deros, B. M., Wahab, D. A., & Rahman, M. N. A. (2012). A framework for organisational change management in lean manufacturing implementation. *International Journal of Services and Operations Management*, 12(1), 101. doi:10.1504/ij som.2012.046676
- [7] Womack, J.P., Jones, D.T. and Roos, D. (1990) *The Machine that Changed the World: The triumph of Lean Production*, Rawson Macmillan, New York.
- [8] Womack, J.P. and Jones, D.T. (1996) *Lean Thinking: Banish Waste and Create Wealth in your Corporation*, Free Press, New York.
- [9] Jaaron, A. and Backhouse, C.J. (2011) 'A methodology for the implementation of lean thinking in manufacturing support services', *International Journal of Services and Operations Management*, Vol. 9, No. 4, pp.389-410.
- [10] Fairris, D. and Tohyama, H. (2002) 'Productive efficiency and the lean production system in Japan and the United States', *Economic and Industrial Democracy*, Vol. 23, No. 4, pp.529-554.
- [11] Liker, J.K. and Hoseus, M. (2008) *Toyota Culture: The Heart and Soul of the Toyota Way*, McGraw-Hill, New York.
- [12] Shapira, A., & Rosenfeld, Y. (2011). Achieving construction innovation through academia-industry cooperation—Keys to success. *Journal of Professional Issues in Engineering Education & Practice*, 137(4), 223-231.
- [13] Ballard, G. and Howell, G. (1994a). "Implementing Lean Construction: Stabilizing Work Flow." *Proceedings of the 2nd Annual Meeting of the International Group for Lean Construction*, Santiago, Chile.
- [14] Ballard, G. and Howell, G. (1994b). "Implementing Lean Construction: Improving Performance Behind the Shield." *Proceedings of the 2nd Annual Meeting of the International Group for Lean Construction*, Santiago, Chile.
- [15] Ballard, G. and Howell, G. (1998). "Shielding Production: Essential Step in Production Control". *Journal of Construction Engineering and Project Management*, Vol. 124, No. 1, pp. 11-17.
- [16] Ballard, G. and Howell, G. (2003). "Competing Construction Management Paradigms" (PDF). *Proceedings of the 2003 ASCE Construction Research Congress*. Honolulu, Hawaii. Retrieved 31 March 2013.
- [17] Krafcik, J. F. (1988), "Triumph of the Lean Production system", *Sloan Management Review*, Volume 30, Issue 1,



- [18] Lean Enterprise Institute (2021), <http://www.lean.org/WhatsLean/History.cfm> (accessed April 17, 2020).
- [19] Womack, J. P., Jones, D. T., Roos, D., (1990), "The Machine that Changed the World", Harper Perennial, New York.
- [20] Meadows, D., (2011), "Designing out waste. Environmental Design & Construction", [http://www.modular.org/marketing/documents/DesigningoutWaste\\_EDC.pdf](http://www.modular.org/marketing/documents/DesigningoutWaste_EDC.pdf) (accessed July 29, 2020).
- [21] Alshayeb, M.J., (2011), "Lean Production Using Modular Construction", Master's Thesis, Engineering Management Program and the Faculty of the Graduate School, The University of Kansas, USA.
- [22] Khanh, H.D., Kim, S.Y., (2014), "Evaluating impact of waste factors on project performance cost in Vietnam", *KSCE Journal of Civil Engineering*, Volume 18, Issue 7, pp 1923-1933
- [23] Ali, S.A., Khadem, M., Seifoddini, H., (2008), "Efficacy of lean metrics in evaluating the performance of manufacturing systems". *International Journal of Industrial Engineering*, 15, pp.176-184.
- [24] Sacks, R., Radosavljevic, M., Barak, R., (2010), "Principles for Building Information Modeling based Lean Production Management Systems for Construction", *Automation in Construction*, Vol. 19 No. 5 pp. 641-655.
- [25] Kalsaas, B.T., (2013), "Measuring Waste and Workflow in Construction", 21th Annual Conference of the International Group for Lean Construction. Fortaleza, Brazil, 31-2 Aug 2013. pp 33-42
- [26] El.Reifi, M.H., Emmitt, S., Ruikar, K., (2013), "Developing a Conceptual Lean Briefing Process Model for Lean Design Management", 21th Annual Conference of the International Group for Lean Construction. Fortaleza, Brazil, 31-2 Aug 2013. pp 329-338
- [27] Fullalove, L.H., (2013), "Examples of Lean Techniques and Methodology Applied to Uk Road Schemes", 21th Annual Conference of the International Group for Lean Construction. Fortaleza, Brazil, 31-2 Aug 2013. pp 1057-1066.
- [28] Marhani, M.A., Jaapar, A., Bari, N.A.A., Zawawi, M., (2013), "Sustainability through Lean Construction Approach: A Literature Review", *Procedia - Social and Behavioral Sciences*, 8 November 2013, Pages 90-99
- [29] Zhao, Y., Chua, D.K.H., (2003), "Relationship between productivity and non value-adding activities", *Proceedings of the 11th annual conference of the International Group for Lean Construction*, Blacksburg, Virginia
- [30] Aziz, R., Hafez, S. (2013). *Applying Lean Thinking in Construction and Performance Improvement*. Alexandria Engineering Journal, 52, 679-695.
- [31] Boyce, E., Dainty, A., Thorpe, A. (2012). *A Novel Collaborative Planning Methodology for Complex Infrastructure Design Projects*. N. Thurairajah, ed. In: *CIB Joint Symposium, Management of Construction: Research to Practice*, Montreal, Canada, June 26-29.
- [32] Horman, M., Kenley, R. (1996). *The Application of Lean Production to Project Management*. *Proceedings of the 4th Meeting of the International Group for Lean Construction (IGLC)*, University of Birmingham, UK.
- [33] Khadem, M., Ali, S., Seifoddini, H., (2008). *Efficacy of lean metrics in evaluating the performance of*

manufacturing systems. *International Journal of Industrial Engineering*, 15 (2), 176-184.

[34] Rahman, N. A. A., Sharif, S. M., & Esa, M. M. (2013). Lean manufacturing case study with Kanban system implementation. *Procedia Economics and Finance*, 7, 174-180.

[35] Shahram, T., 2007. Lean manufacturing performance in China: assessment of 65 manufacturing plants, Vol.19, No. 2, p. 217-234.

[36] Kongguo, Z. (2014, May). Research on the emergence mechanism of Last Planner System of lean construction. In *The 26th Chinese Control and Decision Conference (2014 CCDC)* (pp. 3643-3646). IEEE.

[37] Ballard, G., Hamzeh, F. R., & Tommelein, I. D. (2007). *The Last Planner Production Workbook-Improving Reliability in Planning and Workflow*. Lean Construction Institute, San Francisco, California, USA, 81.

[38] Ballard, G., & Tommelein, I. (2016). Current process benchmark for the last planner system. *Lean Construction Journal*, 89, 57-89.

[39] Gao, S., & Low, S. P. (2014). The Last Planner System in China's Construction Industry—A SWOT Analysis on Implementation. *International Journal of Project Management*, 32(7), 1260-1272.

[40] Veres, C., Marian, L., Moica, S., & Al-Akel, K. (2018). Case study concerning 5S method impact in an automotive company. *Procedia Manufacturing*, 22, 900-905.

[41] Patel, V. C., & Thakkar, H. (2014). Review on implementation of 5S in various organization. *International Journal of Engineering Research and Applications*, 4(3), 774-779.

[42] ASQ (2020). "What is Mistake Proofing?" <https://asq.org/quality-resources/mistake-proofing>

[43] Grout, J. R. (1997). Mistake-proofing production. *Production and inventory management journal*, 38(3), 33.

[44] Shingo, S. (1986). *Zero quality control: source inspection and the poka-yoke system*. CRC Press.

[45] Tommelein, I., Demirkesen, S. (2018). *Mistakeproofing The Design of Construction Processes Using Inventive Problem Solving (TRIZ)*. CPWR-The Center for Construction Research and Training, CPWR Small Study Final Report, Silver Spring, MD

[46] Saurin, T. A., Formoso, C. T., & Cambraia, F. B. (2008). An analysis of construction safety best practices from a cognitive systems engineering perspective. *Safety science*, 46(8), 1169-1183.

[47] Singh, S., & Kumar, K. (2020). A study of lean construction and visual management tools through cluster analysis. *Ain Shams Engineering Journal*.

[48] Tjell, J., & Bosch-Sijtsema, P. M. (2015). Visual management in mid-sized construction design projects. *Procedia Economics and Finance*, 21, 193-200.

[49] Liker, J. K. (2004). The 14 principles of the Toyota way: an executive summary of the culture behind TPS. *The Toyota Way*, 14(1), 35-41.

[50] Tezel, B. A., Koskela, L. J., & Tzortzopoulos, P. (2010). *Visual management in construction: Study report on Brazilian cases*.

[51] De Melo, R. S. S., Do, D., Tillmann, P., Ballard, G., & Granja, A. D. (2016).

Target value design in the public sector: evidence from a hospital project in San Francisco, CA. *Architectural Engineering and Design Management*, 12(2), 125-137.

[52] Cooper, R., & Kaplan, R. (1999). *Design of cost management systems*. Upper Saddle River, NJ: Prentice Hall.

[53] Zimina, D., Ballard, G., & Pasquire, C. (2012). Target value design: using collaboration and a lean approach to reduce construction cost. *Construction Management and Economics*, 30(5), 383-398.

[54] Rother, M., & Shook, J. (1999). *Learning to See: Value Stream Mapping to Add Value and Eliminate Muda*. The Lean Enterprise Institute. Inc., Brookline, MA.

[55] Freire, J., & Alarcón, L. F. (2002). Achieving lean design process: Improvement methodology. *Journal of Construction Engineering and management*, 128(3), 248-256.

[56] Womack, J. P. (2006). Value stream mapping. *Manufacturing engineering*, 136(5), 145-156.

[57] Ansah, R. H., Sorooshian, S., Mustafa, S. B., & Duvvuru, G. (2016, September). Lean construction tools. In *Proceedings of the 2016 International Conference on Industrial Engineering and Operations Management Detroit, Michigan, USA*.

[58] Tsao, C. C. Y., Tommelein, I. D., Swanlund, E. S. and Howell, G. A. 2004. Work Structuring to Achieve Integrated Product-Process Design. *Journal of Construction Engineering and Management*. Vol. 130, Iss. 6. pp. 180-189.

[59] Imai, M. (2007). *Gemba Kaizen*. A commonsense, low-cost approach to management. In *Das Summa Summarum des Management* (pp. 7-15). Gabler.

[60] Womack, J. (2011). *Gemba Walks*. Lean Enterprise Institute.

[61] Zhang, L., & Chen, X. (2016). Role of lean tools in supporting knowledge creation and performance in lean construction. *Procedia Engineering*, 145, 1267-1274.

[62] Ogunbiyi, O., Oladapo, A. and Goulding, J. (2013), "A review of lean concept and its application to sustainable construction in the UK", *International Journal of Sustainable Construction Engineering and Technology*, Vol. 4 No. 2, pp. 82-92.

[63] Enshassi, A., Saleh, N., & Mohamed, S. (2019). Application level of lean construction techniques in reducing accidents in construction projects. *Journal of Financial Management of Property and Construction*.