Exploratory Analysis on Lean Construction Practice in the Lebanese Construction Industry

by

Kamal Metlej

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Graduate Supervisory Committee:

David Grau Torrent, Chair
Samuel Ariaratnam
Thomas Czerniawski

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ABSTRACT

The fact that the lean construction approach, a project-based production management approach, is considered as a best practice in the construction industry and a key solution to alleviate the implications of various forms of waste on the construction projects performance in general, and the Lebanese ones in particular, motivates the author to conduct a study to evaluate it as a strategic option. For that to happen, a bibliographic analysis has been developed to serve the key project objective. The bibliographic analysis is expected to help construction professionals to deepen their knowledge in Lean philosophy and its applications in the construction industry.

After developing a solid background of understanding of Lean Construction, a survey to collect information from construction companies within the Lebanese territory has been conducted, followed by analysis and interpretations of the findings to examine lean construction inside the Lebanese construction Industry; that has been achieved in terms of understanding and analyzing the suitability, acceptability, and applicability of lean construction principles, tools, and techniques by Lebanese construction firms.

Performed Revision has been crowned with a detailed explanation of the lean construction approach accompanied with an applicable lean construction implementation guideline. Besides that, survey results showed a wide acceptance of most lean construction principles (namely, waste elimination and continuous improvement) by Lebanese construction professionals. It has been shown as well, that lean construction tools and techniques are applied by a major portion of the Lebanese construction firms due to the significant impact these tools and techniques have on the project quality, schedule, and cost. However, all analyzed results confirm one main conclusion, that a

significant portion of the Lebanese construction industry lack that adequate knowledge and understanding of lean construction philosophy, which necessitates the development of “Lean Construction Education Programs” as a principal enabler for successful lean construction adoption.

This paper has been developed mainly to guide Lebanese construction professionals, especially project and construction managers, towards understanding and adopting lean construction as a mean to deliver projects of value and to inform Lebanese construction industry leaders about the current state of lean construction inside the Lebanese construction Industry.

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CHAPTER 1

INTRODUCTION

Construction management is a field of applied science that is dedicated to helping project and construction managers to discover and examine new practices and methodologies to deliver successful projects. According to Clough and Sears (1994), the construction management field of study is "the judicious allocation of resources to complete a project at budget, on time, and at desired quality”.

Based on a quick overview, it is clear that the conventional approach to managing projects is the prevalent one. Delivering long, complex, and uncertain construction projects within time, cost and quality constraints based on the typical approach ends up with unsatisfactory results, according to Ballard and Howell (1994). That is represented by the fact that only 50% of the planned work is accomplished by the end of the workweek (Ballard and Howell, 2003) (at the project level), and by the decline in the aggregate productivity rate across the construction industry (at the industry level).

Analyzing the potential reasons behind unsatisfactory performance in construction projects reveal that activities that did not add value to the overall construction process (i.e., non-value adding activities) consume 57% of the project schedule, according to the lean construction institute (2014). Taking that and the current status of the construction industry into consideration, moved the focus of the construction management field of study from the results-focus mantra, “On time, within budget, and at desired quality”, to a mean-focus mantra that focuses on eliminating root causes that block satisfactory results.

Lean philosophy has been shown to provide the manufacturing industry with satisfactory results that the construction industry is looking for. Lean philosophy is a set of principles that control the production system to create a stable and reliable flow of work (i.e., the flow of tasks, resources, and information) through the identification and elimination of various forms of waste. That makes lean philosophy be considered as an alternative approach to deliver construction projects based on lean production principles.

The scope of this paper involves developing an educational guideline for construction professionals about Lean Construction, a construction management approach developed as an extension of Lean Production, besides providing local construction professionals with an understanding of the status quo of Lean construction implementation in the Lebanese Construction Industry. These objectives have been approached through a research methodology that is discussed in detail in chapter 3.

Besides these key objectives, the author needs to mention that this study may contribute to the development of a well-refined productive lifestyle. The author considers Lean Philosophy a universal truth that shows an understanding of human nature; Readers can get the most out of implementing this philosophy, not only in the manufacturing or construction processes but in the life aspects where productivity is a key to their progress. For instance, building a system of daily habits needs first developing a list of habits to acquire, pulling one habit per time, anchoring the pulled habit (keep doing it for certain period), and then pulling the next habit. In this simple life aspect example, we may see how the Pull system - that will be discussed later on - works; Habits are only pulled when the person building his/her system is ready to acquire a new habit, and when the pulled habit is workable, which means the scope of the habit, the size, and any of its pre-requisites are achieved. This simple example is the manifestation of another truth, that we only led ourselves by the simplest concepts, not by the complex ones.

CHAPTER 2

RESEARCH SCOPE AND OBJECTIVES

This research aims, in its way to answer the research question, "Is Lean Construction considered a strategic option for the Lebanese Construction Industry", to develop an educational guideline on lean construction as a construction management approach to be used by construction professionals to deliver construction projects as they meant to be. This study involves surveying to assess the implementation of lean construction inside the Lebanese Construction Industry in terms of its suitability, acceptability among professionals, and applicability across construction projects as a strategic option. The key objectives to fulfill the scope of this study are as follows:

A. DEVELOP A LEAN CONSTRUCTION EDUCATIONAL BACKGROUND.

To explore major outlines of the lean Construction field of study, a bibliographic analysis of the lean construction field of study followed by an analysis of findings have been conducted. The objectives for the first aim of this study are as follows:

- Develop an introduction to lean production, the applicable approach in the manufacturing industry.
- Develop an introduction to lean construction, as an extension of lean production, in terms of its features, characteristics, and forms of waste it addressed.
- Find out key drivers/motivators for lean construction adoption and implementation.
- Highlight lean construction principles that constitute the essence of lean philosophy.

- Construct a harmonized methodology of application of lean principles to attain desired output.
- Find out lean tools and techniques created to fit in the construction industry.
- Synthesize a 4-stages framework for lean construction implementation by new adopters, and that integrates lean construction practices, guidelines, and recommendations.
- Discuss the key performance indicators of lean construction implementation that monitor the cost, schedule, quality, value, and waste aspects of construction projects.

B. ASSESSING LEAN CONSTRUCTION IMPLEMENTATION IN THE LEBANESE MARKET.

To investigate the status quo of lean construction inside the Lebanese Construction Industry, an industry-wide questionnaire survey has been conducted; The survey analysis objectives are as follows:

- Assess the significance of the major reason behind considering lean construction a strategic option.
- Assess the acceptability of human resources of lean construction in terms of its principles and subprinciples.
- Assess the applicability of lean construction principles along with lean construction tools and techniques.
- Identify key drivers and key barriers for lean construction implementation.

Highlight gaps in the implementation methodology of lean construction by the Lebanese construction firms to get filled and for the process to get refined.

Figure 1 shows a summary of the bibliographic analysis, where figure 2 and indicates how the findings motivate the author to understand the extent of maturity of the Lebanese Construction Industry to adopt new construction management (CM) approach like Lean Construction (LC).

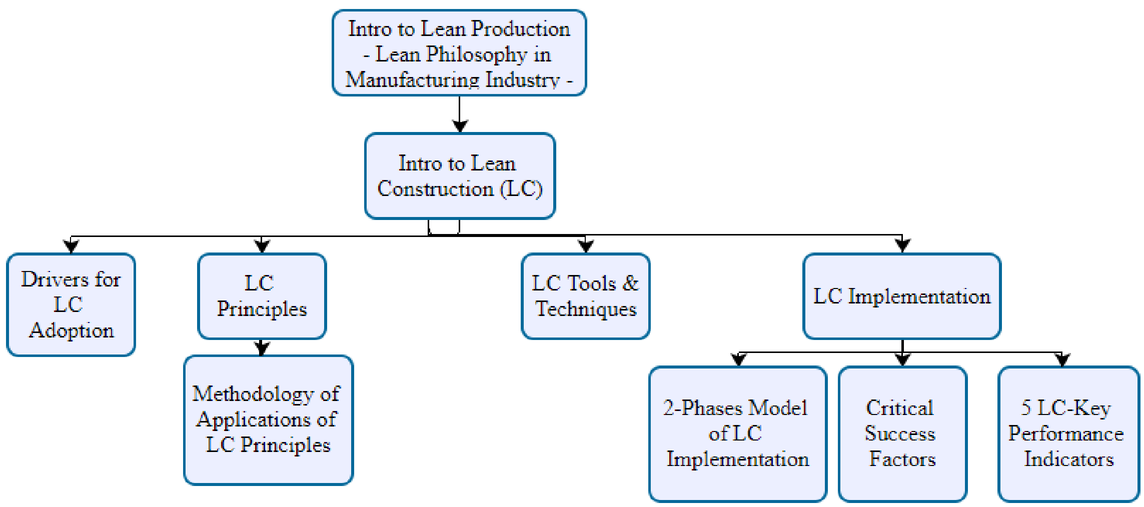

Figure 1. Bibliographic Analysis

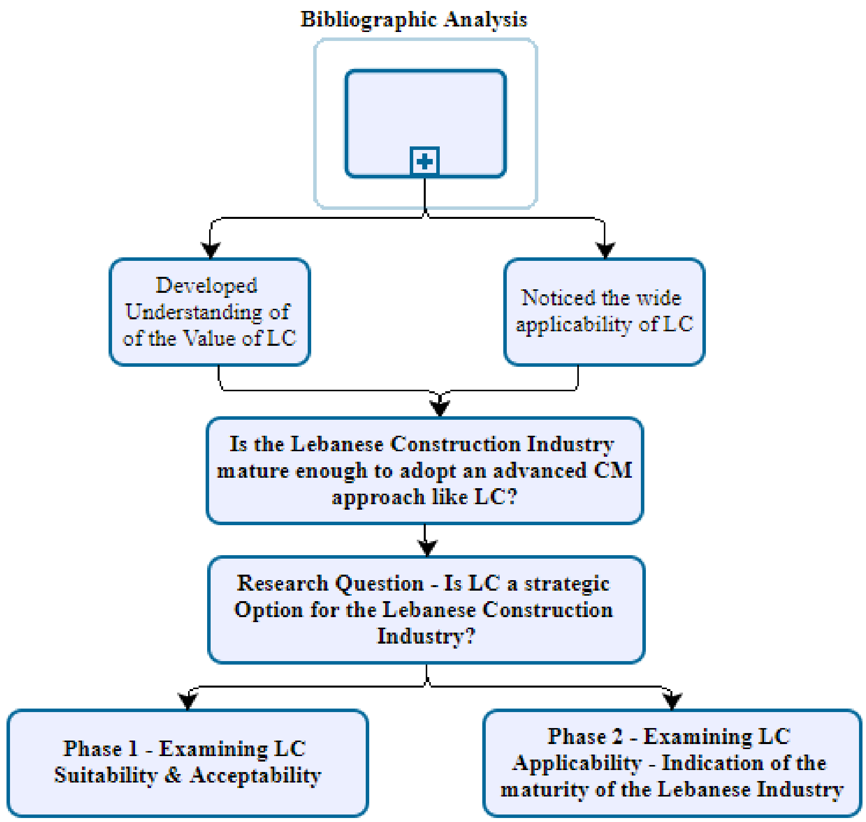

Figure 2. Bibliographic Analysis' Findings Motivate the Examination of the Maturity of the Lebanese Construction Industry.

CHAPTER 3

RESEARCH METHODOLOGY

A. MOTIVATION

Waste is the outcome of the non-effective use of the company's resources while delivering value. That makes waste the biggest enemy for projects in general, and construction projects in particular, because of its impact on projects' performance. Knowing that the traditional project management approach adopted in the Lebanese Construction Industry makes companies attain a reactive approach when dealing with waste. The traditional approach deals only with the implications of the various forms of wastes on the project performance, i.e., cost and schedule variance, instead of handling the sources of wastes, which is the case of the Lean construction management approach. Based on the status-quo of management practices of local Lebanese construction firms, it becomes clear that a change at the project and company level is needed to handle the situation. The change that is discussed throughout this paper is the implementation of "Lean Construction", as a construction management approach, amongst local Lebanese construction firms. To consider Lean construction as the ultimate solution for the "waste" problem in Lebanese construction projects, the first step would be to examine it as a strategic option towards achieving a higher level of productivity.

A research methodology was developed to attain the objectives outlined in the previous chapter. Such objectives are (1) Developing an educational guideline that construction professionals could refer to develop the right understanding of Lean Construction Philosophy and (2) Examining Lean Construction suitability, acceptability, and applicability within the Lebanese Construction Industry, amongst contracting firms from all sectors.

The methodological steps followed through this paper included (1) Definition of such objectives and scope, (2) Bibliographical analysis - which contributed to refining the objectives and scope and inform the survey to be conducted, (3) Survey Design, (4) Data Collection, (5) Results Analysis, and (6) Conclusions and Recommendations. Each of these steps is discussed in detail.

B. BIBLIOGRAPHIC ANALYSIS

Extensive bibliographic analysis has been carried out to serve the previously stated objectives. It served the educational objective by developing the context of an educational guideline that consists of the key aspects of the Lean construction philosophy. Aspects covered by the bibliographic analysis are (1) Introduction to Lean Construction theory, (2) Key drivers to adopt lean construction, (4) Principles, and their applications, (4) Tools and techniques, (5) Implementation guideline, and (6) Key performance indicators of the lean construction approach.

The bibliographic analysis served as well to inform the survey design. It helped the author to identify the 24 forms of waste addressed in the first section of the survey, core principles of lean construction in the form of 34 statements addressed in the second section of the survey, and the lean tools and techniques, key drivers, and key barriers for lean construction adoption at the company level addressed in the third section of the survey.

Theoretical papers, conceptual papers, and case studies have been reviewed from lectures, and journals, such as Journal of Construction Engineering and Management, International Group for Lean Construction (IGLC), Lean Construction Institute (LCI), International Journal of Lean Six Sigma, and others. A three-stage strategy has been followed for the analysis: In the first stage, more than 152 articles were selected by the relevance of the article’s title and keywords to the context of this study. For the second stage, further filtration has been done by going through articles' abstracts, introductions, and conclusions of all articles to examine the value they may add to this study. In the last stage, 74 articles were kept for further analysis based on the perspective they provide for one or more chapters of this study.

C. SURVEY DESIGN

As mentioned before, the design of the survey has been informed by the bibliographic analysis. The survey’s goal is to evaluate the adoption of lean construction implementation as a strategic option for all construction sectors of the Lebanese construction industry. That has been done by addressing three major components in the conducted survey: (A) Suitability of lean construction; Participants were asked to select and identify the frequency of each of the 24 forms of waste in the Lebanese construction industry with no sector in particular. (B) Acceptability of lean construction by construction professionals; Participants were asked to rate their conformance to 34 statements that represent Lean construction core principles. The last component addressed by the survey is (C) Applicability of lean construction principles; that has been addressed by assessing participants' familiarity with lean construction tools and techniques and by analyzing key drivers and key barriers for lean construction implementation.

D. DATA COLLECTION

A survey has been created using Google forms. Sixteen Lebanese construction companies and 182 Lebanese construction professionals who worked for local Lebanese construction firms have been identified and contacted using the LinkedIn professional platform. Only 10 filled surveys were obtained and qualified for analysis, to end up with a rate of response of 5.49%.

Survey participants belong to various firms' sizes that provide various construction services. The distribution of participants' firms based on the company size is as follow, 10% Small companies (less than 50 employees), 30% Medium companies (50 - 500 employees), 40% Large companies (500 - 2000 employees), 20% Enterprises (more than 2000 employees). Distribution of participants' firms based on the construction services they provide – knowing that most companies provide more than one genre of construction services – are as follows: Industrial facilities (20%), Institutional facilities (20%), Commercial facilities (40%), Engineering facilities (80%), and Residential facilities (50%).

E. ANALYSIS OF RESULTS

Data collected have been analyzed based on the frequency, mean, and standard deviation statistical measures. Mean values that exceed 3.00 imply that participants agree with the given statement or choice, as a whole, while mean values which are less than 3.00 imply the opposite. The standard deviation value is used, for the second section, to highlight the width of variation of participants' agreement upon the lean statements. Findings have been analyzed in the light of the Lebanese construction industry, mainly.

F. CONCLUSIONS AND RECOMMENDATIONS

At the end of the research paper, findings of both the bibliographic analysis and the survey analysis have been discussed in terms of their implications and their contributions to the field of lean construction implementation, on one hand, and to the readers' areas of knowledge, on the other hand. Besides that, some recommendations for future researchers have been developed. Recommendations consist mainly of highlighting the examination and further development of the 4-Stages Implementation Model – developed in chapter 9 – as an area of research.

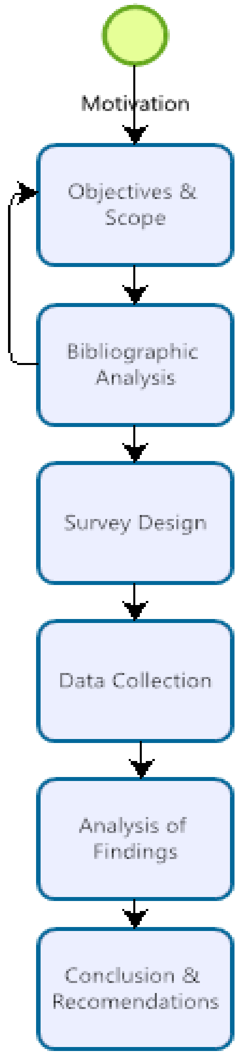

Figure 3. Research Methodology

CHAPTER 4

INTRODUCTION TO LEAN PRODUCTION

Lean production is a production management philosophy that is concerned with controlling the tight dependencies between tasks and the high variations (internal, customer's, and supplier's variations) within a workflow using a flexible planning and control system. Lean production is an integration between the lean philosophy – a system of shared thinking and behaviors - and the production concept – the chain of events that converts raw materials into products (Diekmann, et al, 2004; Ballard et al., 2007). Lean production theory has been developed by Taiichi Ohno, an engineer in Toyota firm, to optimize the performance of the production system as a whole instead of optimizing the craft production at the activity level.

Lean production aims to reduce the flow activities and maximize the efficiency of conversion activities (Farrar et al., 2004). Lean production theory considers that activities in a production system are either "conversions" or "flows"; Conversions are the activities that add value to the product, while the flows are the activities that move the production between the conversions. The lean goal is manifested through developing a production system design that is capable of delivering custom products instantly without maintaining intermediate inventories. Hence, a lean production system is driven by a set of value-based principles: (1) identifying customer requirements and delivering "value" (through eliminating waste, non-value adding activities), (2) developing a reliable and continuous workflow (through a decentralized decision making, transparency strategy, pulling production control, and managing uncertainties along with the flow of work), and (3) pursuing perfection (through adopting a continuous improvement mentality) (Koskela 1992). Those key principles are applied along the value stream through a set of actions.

Lean production is an applied philosophy where a set of actions have been developed to apply lean principles. According to Womack and James (1996), Mason (2002), and Koskela (2004), lean production is driven by the following applicable procedure:

1. Identify and specify the value of the product through understanding the customer's needs and expectations, i.e., objectives, requirements, deliverables, and acceptance criteria; That ends up by establishing a value statement, in collaboration with the customer, to resolve potential conflicts along with the project.
2. Map the value stream, in the form of a chart, by visualizing how and where value is generated. Value stream mapping is essential to identify who is responsible for what and how decisions should be made. It raises the possibilities to optimize system performance and to highlight the non-value-adding activities to be either reduced or eliminated.
3. Create a continuous flow of work by eliminating (or minimizing) the various forms of wastes, and by removing bottlenecks – the work stages at which tasks get stacked because of capacity shortage. The continuous flow of work ends up with a predictable workflow, that helps the product manager to understand "when a product is done" and to maximize the throughput (i.e., number of produced items within a standard period).

4. Create a pull system as a means to raise workflow reliability. This means that work is started only when there is a customer demand for it and team capacity to achieve it. A pull system is performed along the production line by (a) asking workers to pull tasks from queues (high priority tasks) only when they can work on these tasks, (b) harmonizing and aligning the rate and sequence of delivery (or the work done by a station) with the rate and sequence of installation (or the work done by the following station) to improve performance efficiency and minimize materials or products inventories, (c) raising the level of transparency by making the production line information and progress visible by people involved in the production process, and (d) decentralizing the decision making by allowing people to make decisions that support the system objectives and to stop the production line whenever quality defects are detected.

   The pull system focuses on avoiding multitasking, context switching, interruptions, or overburdening. That ends up with a stable workflow, optimized use of resources, over-production avoidance, and higher production quality (as the worker focuses on one task at a time instead of multi-tasking which damages the crew/team productivity).

   Along the production line, production efficiency is measured using two Key Performance Indicators (KPIs), (1) Cycle time – time taken to produce one item or to complete one task, and (2) Throughput – number of tasks accomplished in a predefined time frame. The higher the throughput and the lower the cycle time, the better the performance is.

5. Adopting a continuous improvement mentality (Kaizen) by developing a lean leadership style. Integrating Continuous improvement in the company culture transforms it into a continuous learning firm. For that to happen, the right leadership style, i.e., lean leadership, needs to get adopted. Lean leadership is about the continuous involvement of all employees along with the following continuous improvement processes: (1) identifying problems or obstacles (within the employees' scope of work), (2) suggesting potential solutions in daily meetings, and (3) taking ownership of their tasks to "increase their independence”.

Applying all these principles along the production line necessitates the identification of various forms of waste to be reduced or eliminated.

A. FORMS OF WASTE IN THE PRODUCTION SYSTEM

Waste elimination, a core objective of lean production, is essential to maximize delivered value and to establish a continuous and reliable flow of work. Waste per lean perspective is defined as the process or activity that consumes resource but add no value from the customer's perspective. Ohno looked at the production process as a flow of materials and information where value-added activities need to be optimized and non-value adding activities need to be minimized (or eliminated) for the workflow to be smoother and more efficient (Howell, 1999; Womack & Jones, 1996; Womack et. al, 1990). Ohno did not focus on reducing production cost since production profitability will be automatically optimized as a direct consequence of optimizing the production process (eliminating wastes) (Abdelhamid et al., 2008). Lean aims to provide the customer with a product of value through the identification and elimination of waste along the delivery process (Ansah et al., 2016). Hines and Rich (1997) have classified production activities into (1) Non-value adding activities (NVA), which are considered as pure wastes, i.e. activities of no advantages to the production process and harm the flow of work, (2) Necessary but non-value adding activities, i.e., activities that do not generate direct value for the customer but support the production process (i.e., Quality control is a necessary waste), and (3) value-adding activities, which are the activities that transform raw materials (or semi-finished products) into the final product. To eliminate non-value-adding activities, it is essential first to identify to which categories they belong for the right strategy could be adopted.

Wastes are grouped into three main categories: (1) Muda (wasteful activities), (2) Muri (overburden), and (3) Mura (unevenness) *(The Wastes of lean & The Importance of Value, n.d.)*. Mudas represent the various forms of wastes that end up with a slower cycle time, damaged quality, extra resources, or reduced production profitability. Muda involves seven forms of waste, namely (1) *Transportation* - moving non-necessary parts and materials from one place to another, (2) *Inventory* (Storage) - excessive inventory to meet unexpected demands or to avoid production delays, which increases storage and depreciation costs, (3) *Motion* - Unnecessary movement of the worker that may cause injuries and extended production time, (4) *Waiting* – for instance, equipment waiting to be fixed, document waiting for executives' approval, or waiting for the next production step, (5) *Overproduction* - production that exceeds the customers' demand which triggers the six other forms of waste to appear, (6) *Over-processing* - Spending a lot of time on a given task; Overprocessing activities are the ones that bring no additional value or bring value more than required by the customer, and (7) *Defects* - inspection and fixing efforts.

Further forms of waste are “Mura” and “Muri. Mura is the alteration between overburdening company resources and underutilizing the same resources over time. Eliminating Mura helps to establish a stable pace of production and a more predictable workflow. For Muri's category of waste, it happened when the management push tasks to the team in a way that exceeds the team’s full capacity. That places the team under pressure. Muri lead to extra work hours, which causes a reduction in team productivity, occupational burnout, hurting the team's morale, and damaging the “health” of the work process. Some of Muri’s reasons in a work process are (1) setting unrealistic deadlines, (2) overdemanding (as a result of a push system), (3) lack of training (team works on a task longer than necessary), (4) lack of communication, which lead some people not to realize their responsibilities till the very last day, and (5) lack of proper equipment and tools. In this sense, Management should try to use the optimal team capacity instead of utilizing its full capacity to reach a level at which system parts deliver results in an aligned form (without creating extra work).

Having all these in mind and noticing the similarity of the manufacturing industry with several other industries arises the question of the acceptability and applicability of lean philosophy in other industries, namely the construction industry.

CHAPTER 5

INTRODUCTION TO LEAN CONSTRUCTION

Construction projects are a set of systems and work processes that exhibit various forms of waste and where meeting customers' requirements is a major constraint that drives project performance. These facts, besides (1) the dynamic nature of the construction industry and (2) its openness to change (Demirkesen and Bayhan, *2019),* make the construction industry suitable to adopt lean philosophy as it aims to eliminate wastes and maximize delivered value to the customer. Additional reasons that raise the acceptability level of lean adoption inside construction companies include (1) the inability of traditional planning systems (i.e., critical path method (CPM) and Earned Value Management (EVM)) to produce a predictable and stabilized workflow, and (2) the lack of clear understanding of system productivity that is governed by "The Whole is more Important than the parts" mentality instead of traditional management's activity-centered mentality *(Tang et al., 2014; "Lean Construction", 2020).* All these reasons end up adopting lean philosophy inside the construction industry under a management approach named "Lean Construction".

In brief, lean construction is a construction management approach that has been inspired by lean production principles. It is the result of applying "flow-based production management approach" (lean approach) to construction processes after perceiving construction projects as "temporary based production systems" (i.e., large operation) that adhere to certain constraints (to be delivered on time, within budget and meet specified quality requirements) *(Ansah et al., 2016; Howell, 1999).* Koskela developed a paradigm for the project-based production system, named "TFV Production theory", where production in construction projects has been conceptualized in terms of Transformation (T) of raw materials into a delivered structure, Flow (F) of resources and information along with the production processes, and Value (V) optimization through waste eliminating or reduction (Abdelhamid et al., 2008).

A remark to add in this context before moving on with the discussion of the various aspects of Lean construction philosophy is that what is meant by "crews" throughout this paper are the "workplace crews"; that would help the reader to develop a better understanding of the physics of Lean Construction on the job site.

A. LEAN CONSTRUCTION FEATURES AND CHARACTERISTICS

Adopting lean philosophy in construction projects provides the last with significant features that would be hard to realize otherwise. Some of the feature lean construction add to construction projects are (1) the involvement of downstream players into upstream processes (i.e. planning process), (2) mobilization of construction work to off-site, (3) increasing resources utilization and maximizing collaboration between all project participants (Owner, A/E, Constructors, Facility Managers, End-user) along the project timeline, (4) standardization of construction work processes, (5) minimizing variations that interrupt the flow of materials and information, (6) adoption of a pull system in planning, (7) execution and material delivery onsite when needed (Abdul Rahman et al., 2012), and (8) integration of the design and the execution phases in a harmonized manner, that are usually separated due to specialization, to improve the flow of value from the design to the production phase *(Ballard, 2006; "lean construction", 2020)*.

Besides that, lean construction, as a system-based mentality, focuses on the flow between construction processes. Lean construction aims to manage & optimize the interaction between construction activities in terms of their dependencies - dependence of the production rate of an activity to the production rate of the predecessor activity - and variations, where a variation in the productivity rate of activity lead to a queue (if rate increases) or to a waiting time (in case of rate decreases) *(Howell, 1999)*. For that sake, i.e., optimizing activities interactions, a new form of production planning and control system has been adopted, namely the Last Planner System. The "planning" aspect of that system consists of (1) producing workable work packages and (2) releasing work from one crew – i.e., workplace crews - to another in a predictable manner; While the "control" aspect involves taking corrective actions to conform to the actual performance to the planned one. Adopting that new form of project planning and control system ends up changing the traditional functionality of master project plans.

All these lean construction features and aspects are derived from a core aspect of lean adoption in construction, which is waste reduction. To address wastes effectively, a need to recognize various forms of waste exhibited by construction processes, sources of these wastes, and their implications on project performance.

B. FORMS OF WASTE IN THE CONSTRUCTION INDUSTRY

According to Ansah et al. (2016) and Abdul Rahman et al. (2012), the same forms of waste exhibited by manufacturing processes are exhibited by the construction processes. From the construction industry perspective, the seven forms of waste, their sources, impacts, and suggestions to minimize their impacts are explained as follows:

1. *Transportation*, i.e., unnecessary transportation of material or equipment to perform onsite tasks. Unnecessary transportation is mainly caused by the lack of site layout and of the unsuitable working environment (lack of adequate equipment and suitable pathways states) which led to numerous workflow interruptions, waste of workers' efforts (worker's hours), onsite spaces, and energy. From a value-based perspective (lean perspective), "every movement ought to have a reason" as it incurs a certain amount of the total cost.

2. *Inventory* (Storage waste). Excessive and unnecessary inventories prompt material loss (because of unsuitable stock conditions, vandalism, robbery, and deterioration), "fiscal losses because of the capital being tied up" (Ansah et al., 2016), and additional incurred costs. Adequate resource planning and detailed estimation of required materials are actions that reduce inventory waste drastically.

3. *Motion*, i.e., the movement of people more than what is required to perform the process. The reason for the unnecessary movement is caused by (1) poor working environment (long distances, bad states of onsite pathways), (2) poor methods to accomplish onsite assignments, (3) lack of adequate equipment, or (4) poor arrangement of the work area. An unnecessary movement leads to an increased level of accidents and injuries which incur additional costs. Motion waste is reduced

through improving the reasons mentioned before besides improving the housekeeping strategies.

4. *Waiting* for the availability of material or release of work from predecessors. Waiting or idleness is caused by the lack of (1) alignment of the rate of work between crews, and (2) leveling of material flowing onsite. Idleness is shown while waiting for materials arrival, engineering designs, quality inspections, engineering approval to work that has been submitted for approval. Idleness time could be reduced significantly by (1) identifying and modeling all onsite processes, (2) connecting them, and (3) creating a stable and continuous flow of work along with these processes.

5. *Overproduction*. Production that exceeds the actual demand; that led to misuse of worker hours, equipment, and materials. Adopting a pull strategy system will control the production rate to match the demand.

6. *Overprocessing*. Occurs when value-adding activities either don't add the expected value or add value more than expected (as per the client's perspective). That is usually associated with quality issues, i.e., rework, where the same work efforts need to be spent again. Some of the tools that would be of use to reduce quality issues are the 5-Whys root cause analysis and Poka-yoke (mistake-proofing technique) (tools will be discussed in detail later on in a separate section).

7. *Correction of Product Defects*. Occurs when the end-product did not adhere to the quality requirements identified by the client; That prompts rework and use of additional resources (human efforts, materials, and equipment work hours).

The 8th form of waste

Macomber and Howell (2004) identified the 8th type of waste as the underutilization of workforce abilities, skills, and capabilities or what has been called (8) the "*waste of human potential*" by Burton and Boeder (2003). Waste of human potential is considered as a cause of some of the seven forms of waste (i.e., Over-processing, defects) more than as a waste form by itself. For Womack and Jones (2003), "the design of goods and services" that does not meet the end user's needs has been considered as the eighth form of waste; however, for Koskela et al. (2013), "Making-do" waste form, where the task may begin without all required input to perform, is considered as the eight and most important form of waste.

Based on what had been discussed and according to Senaratne & Wijesiri (2008) and Serpell et al. (1995), wastes are caused at (1) the "flow" activities level (Lack of resources and information), (2) the "conversion" activities level (inadequate methods, poor planning, poor quality), (3) the management level (bad decision making, i.e., poor allocation and resource distribution), (4) environmental level, or at the (5) external flows level.

Raed Al-Omar (2012) in his article "A lean construction framework with Six Sigma rating" have identified and categorized 27 wastes in the construction industry into the seven forms of waste identified by Ohno, as shown in table 1:

Table 1

Categorization of 27 Construction Wastes (Al-Omar, 2012).

Correction	**Over-processing**	**Waiting**	**Inventory**	**Transportation**	**Overproduction**	**Motion**
Repair Work	Long Approval Process	Late Work Delivery	Damaged Material	Transport Time	Idle periods	Labor Moves
Equipment Breakdown	Clarification Needs	Activity Start Delays	Excess Materials	Material Handling	Excessive Space	
Work Defects	Excessive Safety	Work Interruptions	Pilferage			
Rework/ Re-run	Excessive Training Time	Ineffective Work				
Design Errors	Excessive Supervision					
Execution Errors	Excessive use of Equipment					
Retest Work	Overqualified Resources					
Uncompleted Work						

Impact of wastes

Wastes in flow processes cause a significant amount of cost. According to Koskela (1992), “product defects” (or Correction) type of waste consumes 12% of the total project cost; The lack of adequate material management lead to 10% - 12% of total labor cost; Time used to perform non-value adding activities consumes 2/3 of total project time, and safety incidents account to 6% of the total project cost. These significant losses in delivered value display the need to reduce the various forms of waste.

CHAPTER 6

DRIVERS FOR LEAN CONSTRUCTION IMPLEMENTATION

Key drivers for lean construction implementation are derived from the value lean construction implementation provides. A business driver is “a component, condition, process, resource, or rationale that is vital for a business to thrive" (Market Business News, 2019); The Company’s driver to adopt lean construction is the ability of lean construction approach to optimize resources utilization, reduce waste, enhance the level of commitments, establish more efficient communication channels, complement the project management methodology through developing and designing a production system, and reduce safety accidents through minimizing non-value-adding motions and process steps (Dehdasht, 2020). All that makes the key drivers for lean implementation fall within one main aspect, “maximum value realization”; However, that does not mean that all companies have the same drivers to adopt lean construction, where identifying identify key drivers has been recommended as an essential step to start lean construction adoption journey.

Identifying key drivers before adopting the lean construction approach has many advantages. According to Dehdasht (2020), identifying key drivers that motivate organizations, stakeholders, decision-makers, and employees to adopt lean construction is a feasible approach to overcome implementation barriers. In plus, recognizing key drivers (1) help the company to be able to recognize what efforts are needed to achieve successful results, which efforts need to be improved, and where to focus these efforts, (2) provides managers and decision-makers in a company with an insight to identify the best strategies and approached to implement lean construction, and (3) helps management to acquire required support and resources for the implementation process. In short, identifying key drivers help construction companies to approach their goals faster.

Based on results collected from various case studies, it has been shown that companies who delivered their projects using the lean construction approach (1) reduce their projects' costs by 25% - 50% (Alarcón and Mardones 1998; Dobbs et al. 2013), (2) make their construction projects three times more likely to get completed ahead of schedule and two times more likely to be completed under budget (Dodge and Analytics data, 2016), (3) reduce their projects' durations by 6% - 25% (Ballard and Kim, 2007; More et al., 2016; Erol et al., 2017), (4) save cost by 5% - 50% (Ballard et al., 2007), (5) increase productivity by 5 - 50% (Locatelli, 2013; Dallasega, 2016), (6) decrease the rate of safety accidents in the ratio 1:3 in comparison with projects where lean construction has not been applied, according to MTH, a Danish Contractor (Thomassen 2002).

Therefore, and due to the significance of key drivers' identification, below is a detailed discussion of key motivators for lean construction adoption.

A. LEAN CONSTRUCTION OVERCOME THE TRADITIONAL PROJECT MANAGEMENT APPROACH

According to Glenn (2007), effective and efficient project management helps the project team to meet or even exceed customer's requirements and hidden expectations, maximize resource usability, and meet project constraints (Ahead of schedule, under budget, quality meets project specification). Even though both project management approaches, lean construction and the traditional approach, are common in their goal to meet customer's expectations and reduce waste, lean construction overcomes the traditional approach as it is founded on a production management philosophy that functions more efficiently in complex and uncertain projects (Howell, 1999).

According to Abdelhamid (2004) and Ansah et al. (2016), models used in the traditional construction management approach, i.e., critical path method, earned value management (EVM), and Work Breakdown Structure (WBS) has been failed to meet the "Efficient & Effective project management" criteria. That is mainly caused by not considering the importance of certain production system indicators, i.e., throughput, cycle time, and Work in Progress (WIP), which impact the construction processes' productivity. At this point, the reader may ask, why construction managers and project managers should be interested in these factors? In other words, what value can these factors provide?

Projects constraints (budget and schedule) are built upon productivity assumptions, which makes these assumptions “Constraints” to be met. In other words, meeting project constraints at the macro-level means that construction processes meet productivity constraints at the micro-level. These factors indicate whether expected (i.e., planned) productivity performance has been met or not.

The traditional project management approach did not consider these "direct" productivity indicators in monitoring project performance; the sole technique used to monitor performance is the Earned Value Management, where its three factors - Earned Value (EV), Planned Value (PV), and Actual Cost (AC) - are manifestations and not real indicators of productivity performance.

Based on the productivity principle "What we cannot measure we cannot improve", and since the traditional approach does not consider these kinds of indicators, actual productivity performance cannot be monitored effectively.

Lean construction integrates project management and production management approaches, as their interactions are inevitable for a project to succeed (Ansah et al., 2016). Production management adopted by lean construction is performed through (1) focusing on reducing waste in construction processes (within and among activities), and (2) maintaining a continuous and reliable flow of work (Abdul Rahman et al., 2012).

Lean construction focuses on optimizing the system as a whole through managing the dependency and variation (in terms of released work and resources arrival) among activities; where the traditional approach focuses on sub-optimization, i.e., optimizing productivity at the activity level which ignores waste due to the dependency and variation among activities (Koskela, 1992).

Lean construction overcomes traditional project management at the level of its control aspect, as well. For lean construction, project control is a proactive mode, for instance, quality is built-in since the starting stage; For the traditional approach, project control is a reactive mode, i.e., reactions are taken when variances from the planned or expected performance are detected *(“Lean Construction”, 2020)*.

In plus, lean construction adopts a pull system to control the flow of materials, info, and tasks into construction processes after removing associated constraints, while the traditional approach adopts a push system to push info, materials, and work regardless of crews’ readiness for production (Ballard, 2000).

B. KEY DRIVERS FROM LITERATURE REVIEW

An extensive literature review, done by Dehdasht (2020), reveals 63 drivers to adopt lean construction as a project delivery approach. The classification of the 63 drivers shows that drivers for lean construction implementation could be classified into three aspects, namely (1) social, (2) economic, and (3) environmental, and into seven groups, namely (1) financial, (2) management, (3) resource, (4) technical, (5) awareness and education, (6) people, and (7) culture, as shown in Figure 4.

Please note that readers can refer to the explanation of each driver of the 63 identified drivers in Appendix I.

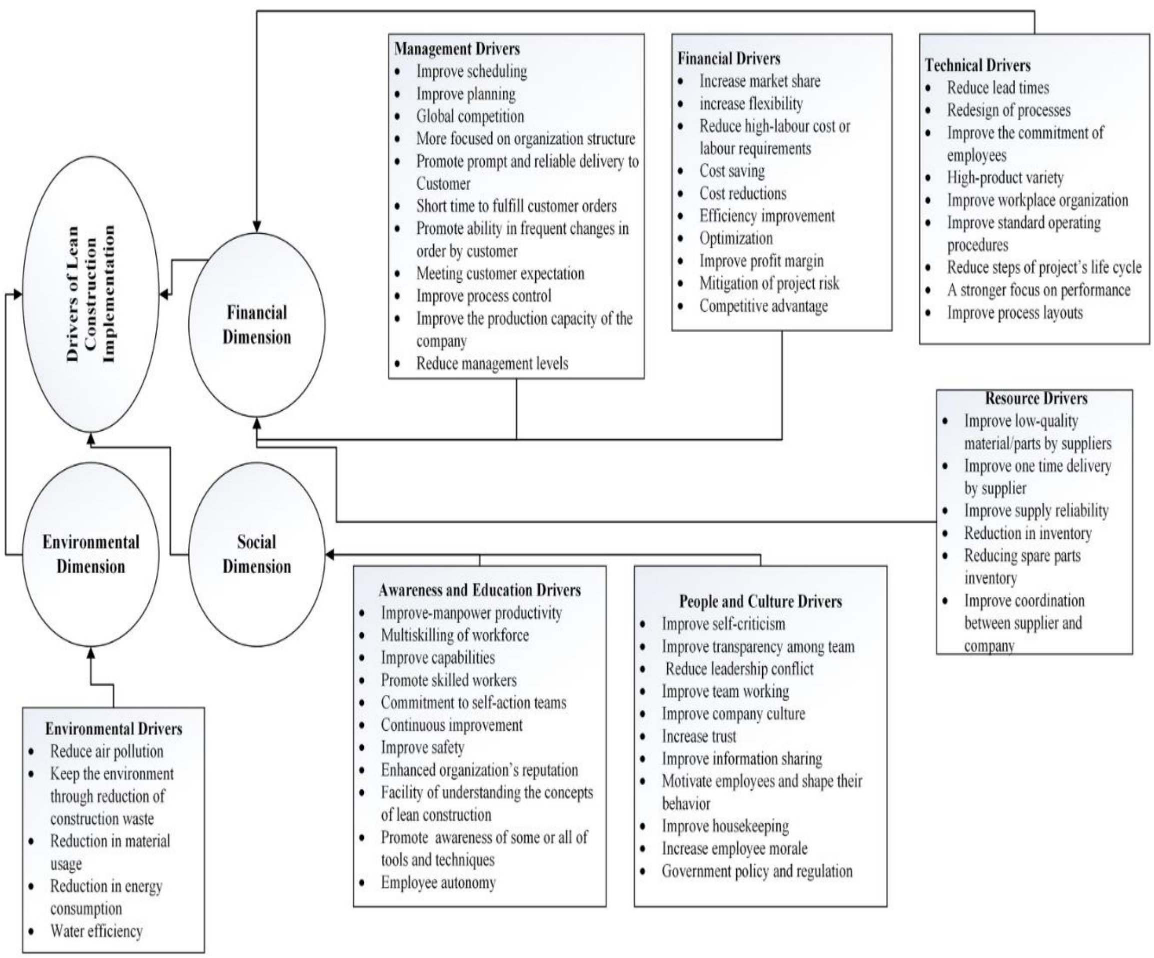

Figure 4. Classification of 63 Drivers (Dehdasht, 2020).

Key drivers have been ranked in their order of importance, as shown in Figure 5, and have been categorized into the seven mentioned categories, as shown in Figure 6.

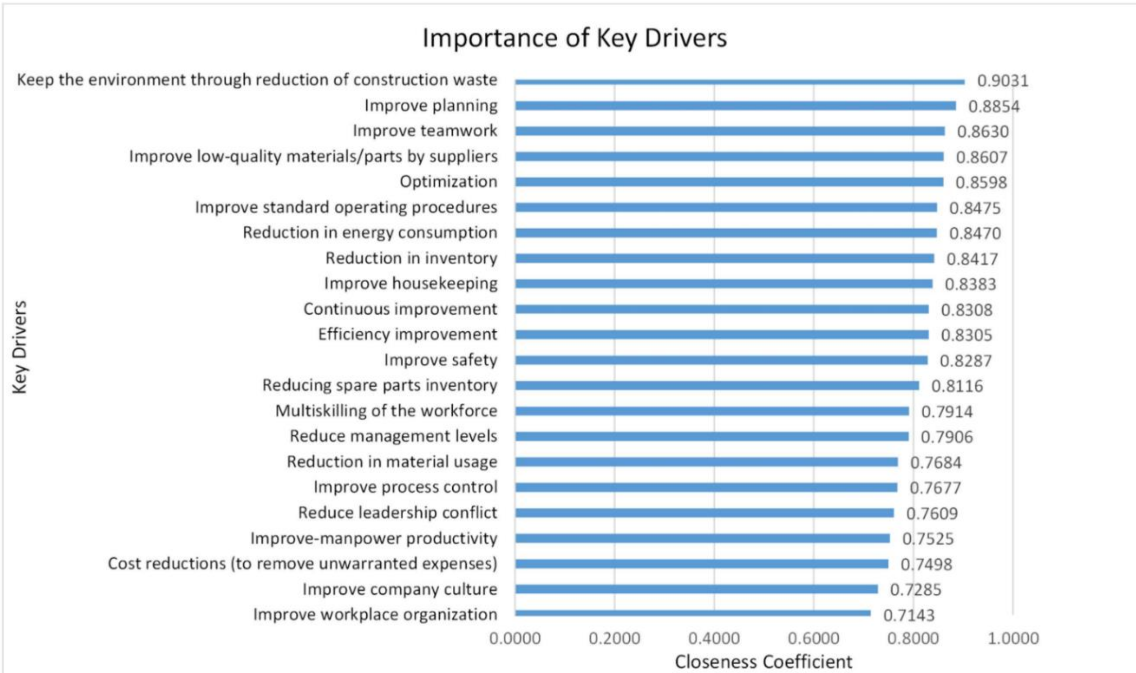

Figure 5. Ranking Of Key Drivers for Successful Lean Construction Implementation (Dehdasht, 2020).

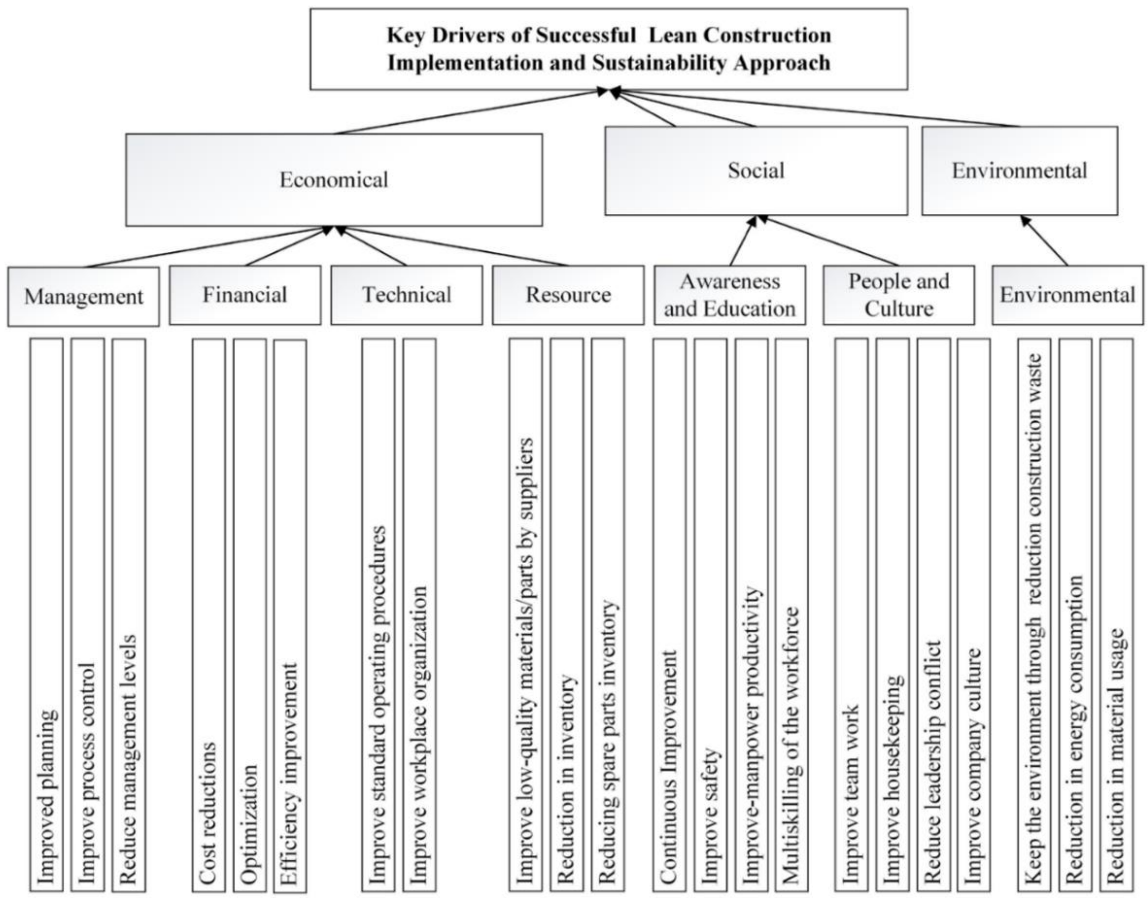

Figure 6. Key Drivers for Successful and Sustainable Lean Construction Implementation (Dehdasht, 2020).

CHAPTER 7

LEAN CONSTRUCTION PRINCIPLES

Lean construction principles govern the overall implementation process of lean construction. Farrar et al. (2004) and Seneratne and Wijesiri (2008) consider that the core principle of lean construction is mainly to eliminate waste (Mudas), the foundation upon which a continuous workflow is established. In the “Application of the New Production Philosophy to construction” article, Koskela (1992) presented 11 principles for lean construction, namely:

(1) Reducing the non–value-adding activities ((i.e., Mudas, or the 7 forms of wasteful activities),

(2) Maximizing output value by considering customers' needs, requirements,

(3) Reducing variability along the workflow,

(4) Reducing the cycle time;

(5) Simplifying construction processes through standardizing work processes and reducing the number of steps within these processes;

(6) Increasing the flexibility of the output;

(7) Increasing transparency of the work progress;

(8) Controlling the whole process, not the parts (i.e., activities);

(9) Improving the work processes continuously;

(10) Balancing the improvement of flow with that of the conversion activities (activities that add value to the end-product); and

(11) Benchmarking.

A. LEAN CONSTRUCTION PRINCIPLES AS DEFINED BY THE CONSTRUCTION INDUSTRY INSTITUTE (CII)

CII Research Team 191 collected all lean construction principles and actionable items, then organized them, in a harmonized manner, under five core concepts. The following principles could be used as a guide to transforming an organization into a Lean organization (Ballard et al., 2007).

1) Customer Focus
    a) Meet customer requirements
    b) Define value from the viewpoint of the customer (project)
    c) Use flexible resources and adaptive planning
    d) Cross-train crew members to provide production flexibility
    e) Use target costing and value engineering
2) Culture/People
    a) Provide training at every level
    b) Encourage employee empowerment
    c) Ensure management commitment
    d) Work with subcontractors and suppliers
3) Workplace Organization/Standardization
    a) Encourage workplace organization and use 5S
    b) Provide visual management devices
    c) Create defined work processes
    d) Create logistic, material movement, and storage plans

4) Waste Elimination

   a) Minimize double handling and worker & equipment movement

   b) Balance crews; synchronize flows

   c) Remove material constraints, use kitting, reduce input variation

   d) Reduce difficult setup/changeover

   e) Reduce scrap

   f) Use total productive maintenance

   g) Institute just-in-time delivery

   h) Use production planning and detailed crew instructions, predictable task times

   i) Implement reliable production scheduling, short interval schedules

   j) Practice the last responsible moment, pull scheduling

   k) Use small batch sizes, minimize work-in-process inventory (WIP)

   l) Use decoupling linkages, understand buffer size and location

   m) Reduce the parts count, use standardized parts

   n) Use preassembly and prefabrication

   o) Use preproduction engineering and constructability analysis

5) Continuous improvement and built-in quality - Built-in quality concept is of high importance to ensure no value loosed occur as value is flowing down.

   a) Prepare for organizational learning and root cause analysis

   b) Develop and use metrics to measure performance, use stretch targets

   c) Create a standard response to defects

   d) Encourage employees to develop a sense of responsibility for the quality.

B. APPLICATIONS OF LEAN CONSTRUCTION PRINCIPLES TO ESTABLISH A PRODUCTIVE WORKFLOW

Lean Principles among industries are the same, but their applications are not. For instance, "Stopping the line" in manufacturing (to ensure the built-in quality) has been replaced by weekly assignment planning in construction to make sure no defects have been released downstream (Ballard and Howell, 1998a).

Each stage in a process needs to accomplish a required amount of recurrent within a target amount of time, which is hard to accomplish in the case of construction projects. In order not to end up with a schedule variance, as the actual performance did not meet the planned (target) amount of time for each stage, the traditional method considers a push system to control the project schedule. In a push system, tasks are released without considering neither the readiness of the downstream players to do the work, nor the availability of ingredients (instruction, labor, material, equipment, and space) (Ballard et al., 2007); In plus, "each activity passively waits for its ingredients" to get released from predecessor activities to get started; In the case that some ingredients are available while some others are not, available ingredients will wait in a queue for the availability of the whole set of ingredients for the activity to start (Thomas et al. 1989; Howell et al. 1993).

"The key to a healthy and productive Flow is the absolute minimum interruption to the process. The work has to stream through it freely powered by the Pull power" (Ballard et al., 2007).

Based on the quote just mentioned, it is clear that a productive flow is established by (1) reducing interruptions, and (2) developing a pull system. Interruptions are unexpected events that happen and that causes discontinuity in the flow of work, i.e., material delivery delay, equipment breakdown, defects, etc.; That makes interruptions are forms of variations in the working conditions from what has been expected while developing the work schedule. Therefore, it would be better to restate the concept of establishing a productive workflow by considering "Reducing variations" instead of "reducing interruptions”. Ignoring introducing the pull approach and starting immediately with reducing variation using the buffer concept will end up with excess in inventories, as the work process has not been harmonized, which enforces the act of pushing tasks for further processing. Elimination or reduction of inventory volume ends up with fewer WIPs, which is tied to a reduction in the cost of design changes and the working capital *(Howell, 1999).*

Pull Technique

The pull technique is applied when the downstream players pull work from the upstream players to assure the readiness of the first (Ballard et al., 2007). Therefore, to apply the pull system on a construction project, there is a need to (1) adopt a new project delivery method, i.e. The Integrated Project Delivery, to ensure that project participant is willing to respond to each other's need to optimize project performance (Ballard et al., 2007), (2) to understand when and how to pull (Tommelein, 1998), (3) reduce lead time to acquire what is needed from the upstream as soon as downstream players ask for, to (4) extend the duration assigned to the repetitive task to ensure readiness to work on the newly pulled task, and (5) to reduce interdependencies among tasks; Accomplishing that ends up with a more stable workflow (Ballard et al., 2007).

A mean to control the pull system is to limit WIPs (limiting tasks that are in progress in each stage); that will create a smooth workflow, identify problematic parts along the process, and help crews to focus on one task at a time; drawing crews' attention to focus on a single task brings the following advantages to construction processes *(Kaizen, n.d.)*:

- Quickly adapt to changes that may occur in the work process,
- Scale the optimal capacity of the crews,
- Increase crew productivity and deliver work items much faster,
- Reduce waste of resources (reduce waiting time and other Mudas),
- Improve flow efficiency,
- Be more predictable when planning future work – Being more predictable can be achieved by collecting historical data about the workflow and the average cycle time of tasks, and forecasting how much work can be processed in a period using forecasting techniques such as the Monte Carlo simulation.

a. Pull Technique Application in Project Planning

Pull technique application in project planning is manifested in the form of the Last Planner System (LPS), a production planning and control technique that shields on-site crews from various forms of uncertainties. Uncertainties mean the lack of certainty, variability, and ambiguity of factors that will impact project performance, i.e., the scope of work, weather conditions, estimated durations. A Major outcome of LPS application is the establishment of a reliable workflow free of uncertainties in terms of activity delay (fabrication, transportation, or installation delay, the likelihood of rework (quality defects that need a rework, i.e., delay). Therefore, a pull planning system helps to maintain a continuous and reliable workflow (Howell and Ballard, 1996; Howell and Ballard, 1997).

b. Pull Technique Application in Material Supply

In the case of material supply, the pull technique is the proposed solution for uncertainties in supplying materials (Tommelein, 1998), and it is manifested in the form of Just-In-Time (JIT) delivery. JIT helps to minimize the waiting time of resources in queues by making resources available only when they are ready to be used (Tommelein, 1998). The pull technique suggests real-time feedbacks sent from the downstream worker to upstream (supply chain, designers, fabricators) to control or adjust the quantity, quality, and specs of materials supplied to the project site before they are supplied, so they meet onsite requirements (Tommelein, 1998). The feedback loop concept is used as a basis for continuous improvement (Berg and Reed, 2020).

Reduce Variation

After applying a pull technique to control the flow of work tasks, a need to balance the capacities of work stages to avoid process bottlenecks. A process bottleneck is a stage in the work process that gets more work requests than it can handle at its maximum capacity; That leads to workflow interruptions and production delays. Below is a proposed methodology to detect process bottlenecks *(Kaizen, n.d.):*

1. Visualize the workflow (using the Value Stream Mapping technique). To visualize tasks to be processed (in queues) and tasks that are processed.
2. Detect stages at which bottleneck appears. A bottleneck appears when the queue grows significantly faster than the activity stage processes work (i.e., tasks are waiting too much in a queue before getting processed).

3. Measure Cycle Time per Stage. Some stages need more time to process a single task than other stages, therefore, measuring cycle time at every stage helps to build a database that identifies cycle time per stage.
4. Identify stages in which tasks spend a significant amount of time to get processed longer than the measured cycle time of that stage. If it is found that these stages are the ones where queues happen, then these stages are the bottlenecks.

c. *Buffer, A Technique to Handle Bottlenecks and Variations*

According to Schonberger (1986), "Variability is the universal enemy". Variability in construction processes is manifested when the crew works at variable production rates and resources are supplied at varying delivery rates *(Howell, 1999)*. Variabilities in construction processes are caused by (1) material and equipment late delivery, (2) equipment breakdowns, (3) labor strikes, (4) tool malfunctions, (5) underutilizing crew capacity, (6) change orders, (7) non-effective design of the production system, (8) design errors, (9) environmental effects (i.e., weather), (10) physical demands of certain activities, and (11) accidents (Abdelhamid & Everett, 2002). Reducing variability will end up with increasing workflow reliability and customer satisfaction besides reducing cycle time and non-value adding activities (Koskela, 1992).

Lean works to eliminate variations in processes by isolating crews from variations in the rate of supplied materials. Crew isolation is done by providing an adequate backlog, i.e., a resource or capacity buffers, so the crew can speed up or slow as conditions dictate *(Howell, 1999)*. Buffers can alleviate dependencies (from other resources), idle time otherwise incurred in the process (Howell et al. 1993), and achieve a continuous workflow with minimum interruptions (Farrar et al., 2004). Buffers may be considered as an unproductive asset (in terms of the value-added in comparison to their added cost) but if they are used in the right amount, in the right place, and at the right time, they add value by providing cushions that support workflow efficiency and smoothness (Grau, 2020); That makes balancing buffers-added costs to the cost of risk of inadequate buffer, a necessity (Grau, 2020).

Buffers take the form of (1) surge piles (raw or processed materials), (2) plan buffers (work backlog), and (3) flexible capacity (use of cross-trained workers to accomplish various kinds of jobs or by underutilizing crews' capacity, intentionally) (Ballard & Howell, 1998). Therefore, for the buffer to absorb variation, a need first to select the right buffer type (capacity, inventory, time, or contingency), (2) locate buffer in the process (Stages at which bottlenecks exist), and then to (3) size the buffer based on the queue size in the bottlenecks (Ballard, 2008).

To place all these principles into practice, several lean tools have been adjusted and developed to fit in the construction processes.

CHAPTER 8

LEAN CONSTRUCTION TOOLS & TECHNIQUES

Due to the difference between the construction and the manufacturing industry in terms of the nature of operations, planning, and execution (Paez et al. (1995), the need to develop a set of lean tools that fit in the construction industry has been aroused. Researchers provide the construction industry with a set of tools and techniques that are in conformance with lean principles and aid their applications.

The below is a discussion of the most widely known lean construction tools and techniques based on the performed bibliographic analysis.

A. LAST PLANNER SYSTEM (LPS)

First, it is essential to understand the reason behind developing a new planning system knowing that a traditional planning and scheduling system already exists. Hence, an overview of the traditional planning system in terms of its values and shortages has been conducted.

Traditional Scheduling Techniques – Perceived Values and Shortages

The conceptual models used to control project performance, i.e., Critical Path Method (CPM), Work Breakdown Structure (WBS), and Earned Value Management (EVM), show their limitations in delivering a project within budget, on time, and by the desired quality (Abdelhamid 2004); In plus, they failed to stabilize workflow along with the construction processes (Koskela and Howell 2008). Analysis of project plan failures indicated that "normally, only about 50% of the tasks on weekly work plans are completed by the end of the plan week", as stated before. That indicates that the typical methodology followed in managing construction projects has failed *("Lean Construction", 2020)*.

The traditional project management approach's tools, i.e., WBS and CPM, are used for more than what they are capable of. Work Breakdown Structure is considered as the best technique to establish a Master Schedule; however, in construction projects, WBS has been employed to develop project schedule and project budget which ends up with significant variations from what has been planned since WBS looks at activities in an independent manner without considering the interdependency between them *("Lean Construction", 2020)*. The Critical Path Method is a technique that helps project managers when administering contracts and provides them with a detailed representation of the project in terms of the project activities' durations, resources allocation, and relationships among activities; However, CPM proves its inadequacy in production planning and control as it (1) doesn't consider the abilities of those doing the work (Choo et al., 1999), and (2) allocates resources to project activities, but it did not check resources availability before starting the work; which ends up with a variation between the actual and the anticipated available resources (presented by CPM). That deviation, that is caused by the two mentioned reasons, has been gently described by Choo et al. (1999) when they said "The plan (WILL) typically is developed without knowing what CAN be done, and it is left up to the production crews to find out what intersection exists between the two when they try to execute the plan".

Introduction To LPS and Features

The Last Planner System (LPS) is an implementation mechanism of lean construction (Ballard 1997; Ballard 2000). LPS is a collaborative scheduling approach to improve the predictability of design and construction schedules, i.e., "work completed as and when promised" *(“Lean Construction”, 2020)*. Last Planner System consists of building a schedule based on the last planners' input to get team buy-in of the schedule *(Esgar, 2013)*; Team buy-in is essential as it helps to (1) develop realistic schedules, (2) reduce variability (i.e., increase outcome predictability), and (3) behave proactively to avoid any sources of schedule delay.

Last Planner is based on one main principle, the shorter the forecasts, the more predictable they are. According to Duncan, Edkins, and McCallin (2020), all long-term plans are forecasts, the longer the forecasts and the more detailed they are, the more wrong they are. Therefore, the Last Planner System doesn’t plan for activities further than the lookahead period, which ends up with accurate and predictable results.

The Last Planner System helps project participants to improve project performance continuously. The right implementation of LPS helps project managers in (1) detecting problems in a "blame-free environment", (2) analyzing root causes, (3) developing countermeasures, (4) monitoring how countermeasures impact processes’ outcomes, (5) taking corrective actions in the form of outcome-based modifications, (6) standardizing modified processes (Tillmann et al., 2014), and (7) deepening the learning process. Therefore, LPS supports management (1) to control (to prevent bad changes), and (2) to breakthrough (to cause good changes), which are completely two different processes (Juran, 1964).

Quality Plans

LPS is a means to stabilize workflow, the key factor to achieve continuous improvement. LPS is considered as a "crew-level planning system" that releases quality plans and assignments that shield onsite workers from uncertainties and workflow disruptions (ambiguities in engineering drawings, fabrication errors, shipment delay, damages while handling, etc.) (Choo et al., 1999).

Quality plans are outcomes of the plans developed to execute the right scope of work within the limit of available resources. (Ballard, 1994). Plans are considered effective (i.e., Quality plans) when released assignments meet the following quality requirements - recommended by Ballard and Howell (1998):

(1) Definition. By specifying the scope of tasks, so required resources (human, material, equipment, etc.) could be collected and task completion could be identified,

(2) Soundness. By making sure that the work is ready before the week in which the work starts. That is done by ensuring the availability of resources and engineering drawings, the applicability of work, and the accomplishment of the pre-requisite tasks,

(3) Sequence. By ensuring that selected tasks adhere to a priority and constructability order, and by ensuring the availability of quality low-priority assignments (workable backlog) in case crew productivity exceeds set expectations,

(4) Size. By ensuring that selected assignments match the production capability of crews and can be done within the planned period,

(5) Learning. By tracking the un-accomplished tasks and finding the reason for the deviation.

Below are the five forms of constraints that need to be addressed before releasing a quality assignment (Choo et al., 1999):

(1) Contracts Constraints - addressed by making sure that the released work package (set of work tasks to be executed) belongs to either the project scope (as defined by the contract) or to a newly issued and approved change order.

(2) Engineering Constraints - addressed by ensuring that (1) all submittals and shop drawings have been turned in and approved, (2) RFIs have been addressed properly, (3) decisions regarding means and methods have been taken, (4) assembly drawings have been received, and (5) required permits have been secured.

(3) Materials - addressed by making sure that (1) fabrications designs have been issued, (2) materials sources and requirements have been identified, (3) quotations requests (RFQ) have been sent, (4) materials have been purchased or fabricated, (5) delivered, and (6) allocated.

(4) Labor and Equipment - addressed by ensuring that (1) activities durations have been estimated and (2) required labor and equipment along the duration of the work are available.

(5) Pre-requisites (tasks and site conditions) - addressed by ensuring that (1) pre-requisite tasks have been accomplished, (2) work-areas used by previous tasks have been cleared and cleaned, (3) adequate workspace to stage materials in are available, (4) site is accessible and (5) weather forecasts are consonants with tasks requirements.

Percentage Promises Completed (PPC)

PPC works as a measure of the planning system quality and performance, and as an indicator of workflow predictability and reliability *("Lean Construction", 2020)*.

Associated benefits of applying PPC measures support the monitor and control, production, and informative aspects of the production management system. From Monitoring & Controlling Perspective, the PPC equation involves a comparison between an integrated baseline of different control aspects of the project (schedule, budget expenditure, and quality constraints represented by the total number of planned tasks) and the actual performance (represented by the total number of completed tasks) upon which variances are detected and corrective actions are taken (Ballard, 1994). From a production perspective, PPC value is an indication of the planning efforts' quality (quality of released plans) (promises have been accomplished with the assigned resources), which impacts workflow reliability significantly. And from an information perspective, weekly monitor and analysis of PPC values reveal weak areas in weekly planning, root causes of schedule variance, and provide opportunities for continuous improvement. Therefore, PPC, as it could be applied at any organizational level, works as the center for any breakthrough initiatives (Ballard, 1994).

Besides these advantages, PPC has certain limitations. One limitation is that the PPC value did not consider the amount of time needed to accomplish assigned tasks, which means that the PPC metric could not be used as a cost/duration forecasting tool where time-sheets and cost reports need to be kept besides PPC reports. Another limitation is that the PPC value does not present a detailed idea about crew productivity, which calls for another technique like the Activity Analysis technique to check actual versus targeted production rate (Metlej, n.d.).

It has been shown that PPC values are correlated with productivity rates and safety incident rates. According to studies by Ballard et al. (2007), PPC values were found to be positively correlated with productivity rates at a 95% confidence level, only when the ratio of workload to capacity falls in a moderate range; That correlation gets weakened when (1) underloading - ends up with higher PPC value and lower productivity, and (2) overloading - ends up with reduced PPC values, reduced flexibility to cope with breakdowns and variation (due to the lack of capacity buffers), and with no significant impact on productivity; For instance, if assigned tasks exceed crew capacity, PPC value (task completion rate) decreases. In plus, as PPC increases, safety incident rates decrease; Danish Research shows that the number of accidents and sickness absents has been decreased drastically after adopting LPS for planning and controlling project performance *("Lean Construction", 2020)*.

Implementation Guideline of Last Planner System Technique

The pull technique is found in the heart of the LPS as work tasks, information flow, and materials deliveries are planned based on requests (or “pull”) from downstream players. That ends up with a controlled flow of resources and a reduced batches’ size (Grau, 2020).

LPS consists of four planning Levels: (1) Should, (2) Can, (3) Will, and (4) Did. “What WILL be done (hopefully) is the result of a planning process that best matches WILL with SHOULD within the constraints of CAN" (Ballard, 1994). For the Will (What will be done next week) to get matched with the Should (What is on the schedule), the last planners’ (the real doers) inputs need to be received, and obstacles and constraints must be identified and removed before the work started.

The below guideline provides the reader with an introduction to the four phases of the system and a bullet-point format procedure to facilitate LPS implementation at each of these stages, based on the lectures presented by Esgar (2013), Berg and Reed (2020) at Arizona State University.

Figure 7. Phases of the Last Planner System (Esgar, 2013)

1. Should.

The level that represents what should be done to execute the job, and consists of the following 2 stages:

a. Developing a Master Schedule that consists of key milestones and deadlines; Each milestone is represented by a tag during the planning process.
b. Pull Planning (or Phase Scheduling) that consists of scheduling one milestone per time. Here is the implementation procedure for Phase scheduling:
    i. Pull 1 key milestone from the master schedule,
    ii. Bring in subs & foreman associated with the milestone,
    iii. Start Backward planning with the milestone deadline in mind. Backward planning is to plan activities based on the following thinking pattern: “For that to happen, what needs to happen in advance?”

1. For each pull session, ask the following: “how to complete this milestone by the milestone finish date as specified by the master schedule,
2. Find the milestone Start date. Based on the end date, work backward to know when we need to start that milestone to finish that milestone on time.

iv. Develop a schedule baseline that consists of the defined activities, start & finish dates of each activity.

v. Represent activities on a whiteboard.

1. Each activity is represented by a tag where the tag (or sticky note) color represents a trade.
2. The tag includes (1) Activity Owner, (2) duration, and (3) constraints.

While phase scheduling, BIM is considered as a tool of high importance; BIM Modeling helps to take a look at the model in the 3D perspective, to look at things in a detailed way, then to think about potential approaches to deliver the project in adherence to the best constructability practices.

2. Can | Lookahead Planning

Lookahead Planning is to schedule a work plan for a few weeks in advance (6 weeks, usually). It is about looking ahead for the following 6 weeks to (1) look for possibilities to use prefabrication of some parts and pieces, (2) get prepared for any risk, (3) understand what activities will be accomplished, (4) find out potential constraints (i.e., crew setup, material security, equipment used, and (5) assign a person to remove the obstacles before the starting date of these activities (to achieve a smooth flow of work). An efficient practice while looking ahead is the use of “Make-Ready Process”, as shown in table 2:

Table 2

Make-Ready Table for The Design Phase (“Lean Construction”, 2020).

MakeReady: Design

project

Stage

area

week

prepared by

date prepared

ref	task description	date req'd	responsible party	Constraint			can do	notes
				Directive	Pre-req	Resource		

3. Will | Weekly Work Planning (WWP).

WWP is done in collaboration with correspondents’ subcontractors and foremen at the start of each week), during which meeting participants identify (1) activities to be done by next week (seen as promises by last planners), (2) the daily number of people needed to accomplish each activity, (3) weekdays to accomplish the work, (4) resources needed, and (5) tracking metrics to measure activities completion. Daily work is represented by a tag (so a 3-days activity will be represented by 3 tags). A sample of the WWP sheet is presented in table 3:

Table 3

WWP ("Lean Construction", 2020).

Weekly work plan

project ____________________ Week commencing ____________________

Stage ____________________ Company ____________________

area Prepared by ____________________

Date prepared

ref	Task description	Final MakeReady needs		Period to perform the task							PPC analysis		
	Criteria for release of assignments: defined, sound, ordered, sized	Work that must and can be performed prior to the release of this task	who will do work	M	T	W	T	F	S	S	Y	N	Reasons for incomplete*

Figure 8. The Promise Cycle (After Fernando Flores) ("Lean Construction", 2020)

Figure 8 shows that, once the task is completed, the responsible party (the last planner) declares its completion; that declaration acts as a request for the site management to ensure that work has been accomplished per the project specs and as a request for the next trade to start working on its task.

4. Did | Learning

The learning phase consists mainly of evaluating the last planners' performance for the last week and identifying opportunities for improvement. For accomplished activities during the previous week, last planners approve activities' completion and cross them out; In plus, last planners are required to:

a. Move uncompleted tasks to the next week,

b. Identify reasons behind their non-accomplishment (allow the problems and issues to show up) using the 5-Whys Root Cause Analysis Technique,

c. Develop a Pareto chart to display reasons for tasks un-accomplishments and the frequency of each identified root cause,
d. Plan to solve similar issues in the future by finding solutions for the highly-frequency root causes,
e. Calculate PPC value (target value ranges between 80% and 90%)
    i. 1 Promise = 1 day or 1 tag
    ii. PPC = (No. of promises made / No. Of promises kept) x 100 = % Promises Kept,
f. Update Issue Log (a log to be used to archive problems faced and potential solutions that helps in continuous improvement and tracking solutions effectiveness),
g. Graph the variance along a red line that marks the targeted PPC value, and
h. Update the master schedule.

Therefore, and based on the above guideline, two kinds of meeting need to be done for the right implementation of the LPS technique: (1) A Baseline Pull Meeting – an introductory meeting, and (2) a Weekly Pull Meeting.

(1) Baseline Pull Meeting

An introductory meeting where (1) meeting goals are defined, (2) pull planning technique is introduced, (3) instruction for using labeling is provided for participants, and (4) a pull session is done (to practice what has been learned).

(2) Weekly Pull Planning Meeting - Consists of:

1. Evaluating last week performance & detecting variances,
2. Updating the master schedule,
3. Pulling a milestone (either at the beginning of the project execution or after accomplishing a project milestone and before starting the next one),
4. Developing 6 weeks look ahead plan, and
5. Developing a weekly work plan for the work to be done by next week.

Below is the procedure that is recommended to be followed by the Weekly Pull Planning meeting facilitator:

1. Identify Milestone to pull – Scope of current work
2. Select associated trades (the last planners)
3. Send out meeting agenda that constitutes of:
    i. Current Milestone / Scope of work,
    ii. Anticipated Milestone Date,
    iii. Meeting date, time, location, and timeline,
    iv. Meeting objective – identify activities required to get completed,
    v. General notes.
4. Procure Materials / Setup The room
    i. Get in Sharpies, colored sticky notes (number of colors = number of trades), and boards (each board represents 1 week)
    ii. Graphic / Drawings
    iii. Pull Plan Boards - 4’x8’ With Grid (7 Squares Wide)

iv. Pull Tags - 4" Plain or Custom that includes Activity description summary, Duration, and Constraints

v. Room Setup:

a) Remove obstacles/tables from the middle –

b) Take the chairs out of the room to help in active involvement

5. Place tags in rows in sequential order, as shown in Figure 9:

i.

ii. Each trade has its row

iii. Show logic between tasks

iv. Make sure predecessors/constraints are happening before the corresponding tag.

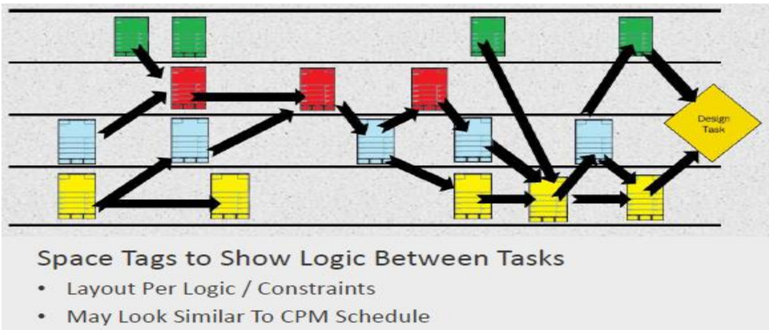

Figure 9. Swim Lanes Diagram (After connecting tasks)

Based on what has been discussed so far, it is clear that the Last Planner System and the Critical Path Method complement each other; for using them effectively, it is required to understand when to use each of them, where the CPM tool should be used while planning for the project (to serve as a good representation of what SHOULD be done) while the LPS should be employed while execution (Choo et al., 1999).

B. TARGET COSTING

During the typical design processes, designers work with clients to figure out their requirements, and then they develop designs that deliver to the clients the value they are looking for. After that, cost estimation is done; usually, the estimated cost is found to be more than what the client is willing to pay, which requires a review and adjustment of the design to get its cost estimated again in a cycle of design-estimate-adjust (or rework); A wasteful cycle that reduces the value received by the clients. Therefore, a more value-based approach to delivering designs that meet clients' budget constraints is needed.

According to Ballard et al. (2007), target costing is a management practice that constrains the design and construction cost of a capital facility to a target cost (maximum cost). Target costing is based on the production-oriented business management philosophy that imposes artificial necessity to drive continuous improvement; that philosophy could be articulated by Taiichi Ohno's concept, "lower the river to reveal the rocks" (Ohno, 1988); in other words, a need to reduce capacity, budget, and time buffer that absorbs variations to reveal areas that need improvement throughout the design process.

Implementing target costing using the artificial necessity concept consists of the sequential order of steps. The answer to the "Can a facility be designed and constructed in a way that allows the client to achieve their purposes within the limits of their constraints?” question will decide in a go/no-go decision. If that results in a “Go” decision, then, firstly, a need to define capital facilities functionalities and properties; secondly, reduce the available amount of money dedicated for facility design and construction; and finally, increase the minimum required/acceptable ROI or increase properties and functionalities of the delivered facility in comparison the attributes that could be delivered for a similar available budget. By providing some incentives to the project team, the process will end up boosting designers’, builders’, and suppliers’ innovation. This methodology could be applied in case clients have limited available funds or in case of projects with financial risk.

C. SET-BASED DESIGN (SBD)

Set-Based Design is a design execution strategy at which design alternatives and criteria for evaluation (extracted from all design levels) are applied along the development process (Ballard et al., 2007). The typical design practice (Point based Design) consists mainly of identifying available design alternatives then narrowing them down to a single option, "quickly" upfront; however, SBD is about moving forward (throughout the development stage) until the last responsible moment with a set of design alternatives; overtime, design alternatives that don’t meet requirements are eliminated after being tested and validated, till ending up with one validated design alternative.

D. INTEGRATED PROJECT DELIVERY (IPD)

Integrated Project Delivery is a relational contracting approach that enables the implementation of lean construction ideals. In the case of traditional contracting strategy, the competing interests of project participants end up sub-optimizing their areas of work independently of the loss of interest (i.e., additional work) they may cause for the downstream players. IPD aligns all key project stakeholders' interests and project objectives to foster a collaborative relationship among project key partners, namely project owner, Engineer, and Contractor, using legal tools (i.e., contracts) (Ballard et al., 2007; *"lean construction", 2020)*. Hence, project partners are bound together and share the profit and risk as a whole, which ends up optimizing the whole (the project performance) not the parts (individual interests).

E. FIRST RUN STUDIES

(Salem et. al, 2005; Abdelhamid et al., 2008):

First Run Studies is a technique used to redesign repetitive and critical construction processes and assignments. It aims to increase crew productivity while accomplishing creatin tasks by examining the current way of doing the work and seeking more productive alternatives; that is done using photos, video files, and graphics to illustrate steps followed to accomplish certain operations, in parallel with the PDCA (Plan-Do-Check-Act) model that consists of:

(1) *Planning*, by (a) Identifying which work processes to study (critical and repetitive processes), (b) examining involved steps, (c) brainstorming simpler alternatives to

accomplish the work (by reducing the number of steps), and (d) checking quality, productivity and safety aspects of the developed alternative.

(2) *Doing,* by trying out the developed alternative.

(3) *Checking,* by measuring the crew performance while accomplishing the work according to the newly developed method.

(4) *Act*, by standardizing the change if it shows a positive impact on system performance, or start over from the plan step with better information if the change shows ineffectiveness.

F. VISUAL MANAGEMENT

(Mastroianni & Abdelhamid, 2003; Ballard et al., 2007; Abdelhamid et al., 2008; Demirkesen and Bayhan, 2019).

Visual management is a management approach that provides visual clues to facilitate the flow of information and to identify everyday work tasks. Visual Management Tools include:

- Increased visualization tool. A tool that is used to communicate key information to onsite laborers; usually consists of posting schedule, quality, and safety-related labels and signs on the construction site. The labels could represent performance targets, required actions, or mapped workflow.
- Logistics Plan. A plan that addresses site logistic issues and that is communicated to subcontractors, posted onsite, and updated along the construction process. Site logistics issues to be addressed through the site logistics plan involves:

1. Organization of stored material and equipment that reduces waste, searching time, transportation time and lay down space,
2. Site water (snow or rain) management to facilitate transportation, equipment, and people motion and material handling,
3. Work areas of project subcontractors,
4. Resources movement, and
5. Physical waste generation and clean-up.

Figure 10 provides the reader with an example of a Logistics Plan.

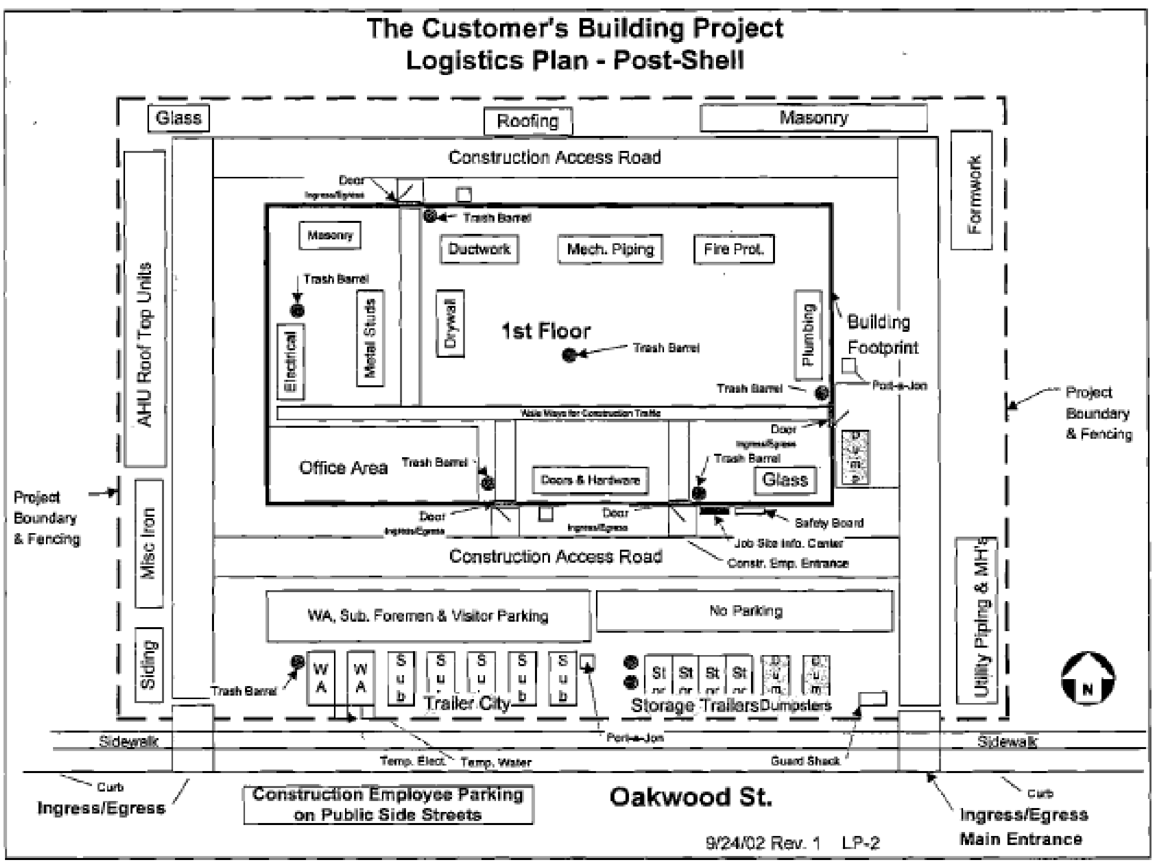

Figure 10. Example of Site Logistics Plan (Abdelhamid et al., 2008)

G. 5S (HOUSE-KEEPING OR VISUAL WORK PLACE)

(Abdelhamid et al., 2008; Demirkesen and Bayhan, 2019)

The 5S is a system used to optimize workspace for maximum work efficiency by ensuring that is clean, safe and by eliminating non-useful resources. The 5S technique is about “Having a place for everything and having everything in place”. A primary implementation pre-requisite of 5S is to have a material layout since 5S is an "area-based system of control and improvement" that indicates the location of materials and equipment (Spoore, 2003). The 5S application improves safety, quality, set-up time, productivity teamwork, and reduces lead times.

The 5S refers to five house-keeping levels, namely:

(1) Seiri (Sort). Separate useful tools, materials, and parts from the non-useful ones (trash),
(2) Seiton (Straighten). Set tools to facilitate their use,
(3) Seiso (Shine). Clean up the workspace,
(4) Seiketsu (Standardize). Standardize the first 3Ss as a work process, and
(5) Shitsuke (Sustain). Develop the habit of conformance to the rules.

H. CROSS-FUNCTIONAL TEAMS

(Ballard et al., 2007)

The cross-functional team technique is about engaging key stakeholders (including laborers) in the decision-making process. For example, if the foundations Engineering team has a meeting to consider and analyze available foundation designs, the foundation contractor, structural engineer and suppliers would participate in that meeting to end up with a decision all project participants agree upon.

I. MISTAKE-PROOFING | FAIL-SAFE FOR QUALITY AND SAFETY (POKA-YOKE)

(Abdelhamid et al., 2008; Demirkesen and Bayhan, 2019; Demirkesen and Bayhan, 2020; *Kaizen: Pursuing Continuous Self-Development, n.d.)*

Traditional Quality management consists mainly of a quality control process that is based on inspecting a sample size after products have been processed, a completely different strategy than that adopted by Poka-yoke. Poka-yoke is a tool (or a system) that prevents accidental errors, reduces system errancy, and correct defects before moving downstream within the operating process to turn into quality defects in the product. That ends up providing zero-quality control, reduced set-up time, and lower safety incidents (Shingo, 1986). To apply Poka-yoke in construction processes, it is needed first to (1) select activities with potential quality defects, (2) identify potential reasons behind quality defects, (3) investigate each of these reasons, (4) develop alternative solutions, and (5) apply the most applicable and feasible alternative. Poka-Yoke ensures that the right conditions exist before a process step is executed, and thus preventing defects from occurring in the first place. Where this is not possible, Poka-Yoke performs a detective function, eliminating defects in the process as early as possible.

J. 3D MODELING (BIM)

According to (Ballard et al., 2007), BIM has not been reported as a lean tool, but as a tool that facilitates lean construction implementation. BIM helps contractors to improve visualization of the project to be delivered (Aslam, 2020), identify materials type and quantity that are in need (Ballard et al., 2007), which facilitates Just-In-Time material delivery, and integration of efforts of various involved areas of specialties and expertise. According to Aslam (2020), the use of the Integrated Project Delivery system along with BIM modeling has been identified as an effective means to implement lean construction successfully.

K. VALUE STREAM MAPPING (VSM)

(Demirkesen and Bayhan, 2019; *"Lean Construction", 2020)*

Value Stream Mapping is a flow optimizer technique (not a process optimizer) that visualizes the production system in terms of the flow of material, information and people, in the form of a process model. VSM is done by representing each stage the product pass by, visually. It helps to identify stages at which value is generated, non-value-adding stages (to be considered for elimination), and hand-offs (where bottlenecks may occur causing waiting time). Visual Stream Mapping, Last Planner System, And Integrated Project Delivery are techniques that facilitate implementing lean construction ideals.

L. MODULARIZATION & PRE-FABRICATION

(Demirkesen and Bayhan, 2019)

Modularization is a technique used to improve onsite construction productivity and reduce health and safety risks. That is achieved by turning a construction site into an assembly location to assemble delivered structural elements after being fabricated off-site.

M. JUST-IN-TIME (JIT) MATERIAL DELIVERY

(Ballard et al., 2007; Demirkesen and Bayhan, 2019)

Just-In-Time is a material delivery technique that ensures that materials are delivered to their final locations for installation at the right time (just before installing them) and in the right amount, to minimize storage cost, lead time, and demand variability.

N. WORK STANDARDIZATION

A technique used to standardize repetitive work processes in an organized manner (Demirkesen and Bayhan, 2019).

O. PULL SYSTEM

Discussed previously.

P. DAILY HUDDLE MEETINGS (TOOL-BOX MEETINGS)

(Abdelhamid et al., 2008; Demirkesen and Bayhan, 2019)

Daily huddle meeting is a two-way communication technique. Daily huddle meetings are performed by holding an early meeting by the project manager or site manager with onsite crews and foremen for workers to share their performance, assigned tasks status, any problem that has been raised since the previous day's meetings. In plus, daily meetings help workers to get engaged in the continuous improvement process (through identifying and solving problems), and to get useful training. Daily huddle meetings are means to achieve quick responses to onsite problems and to create a sense of growth, self-esteem, and job meaningfulness for employees.

Q. LEAN TOOLS FOR CONTINUOUS IMPROVEMENT (KAIZEN)

(Demirkesen and Bayhan, 2019; Kaizen: Pursuing Continuous Self-Development, n.d.)

Kaizen is a Japanese philosophy that means continuous improvement. Kaizen is more than just a technique; it is a mentality used to improve processes continuously in terms of improving efficiency and productivity. Kaizen is the mentality that fosters continuous improvement through self-development; it is the result of questioning and criticizing the status quo, holding accountability for someone's self, and having the courage to change the way things used to get done even when actual performance meets what has been planned to be.

Kaizen optimizes work processes by optimizing value-adding activities and eliminating or minimizing wastes in their three forms, namely Muda, Mura (unevenness), and Muri (Overburden). For that to happen, a set of Kaizen tools and techniques need to be used, as discussed below.

Plan-Do-Check-Act (PDCA)

PDCA is known as the Deming circle (named after its founder, the American engineer William Edwards Deming). PDCA is a never-ending cycle that aims to help to carry out changes and to improve further based on achieved results. PDCA model requires a certain amount of time, and it may not be appropriate for solving urgent issues. Below is a bullet-point format to implement PDCA:

1. PLAN - Planning What needs to be done
    a. Plan for improvements by (1) setting goals (i.e., baselines to compare achieved results against), and (2) establishing processes necessary to achieve defined goals.
    b. Answer some essential questions before moving on, as:
        i. What is the core problem that needs to be solved?
        ii. What resources are required and which ones are available?
        iii. What is the best solution for fixing the problem with the available resources?
        iv. In what conditions will the plan be considered successful (i.e., define success criteria)? What are the goals?
2. DO – to place the developed plan into action.
3. CHECK (Check the Plan Efficiency)
    a. Monitor the impact of implemented changes on the performance,
        i. Measure & analyze results against developed baselines
        ii. Identify problematic parts of the current process,
        iii. Find the root causes of raised problems.

In case the analysis shows that performance is worse than before, it is better to keep the previous standard of work.

4. ACT: If changes show intended benefits, standardize the improved method and communicate it to the parties; if results are not as expected, start the cycle over, i.e., prepare a new plan by analyzing the process, understand the reason behind its ineffectiveness in the precedent trial, and develop a set of corrective actions.

5 Whys: The Ultimate Root Cause Analysis (RCA) Tool

5Whys is a technique used to reveal the root cause behind a problem. According to Taiichi Ohno, “the basis of Toyota’s scientific approach is to ask why five times whenever we find a problem. By repeating why five times, the nature of the problem as well as its solution becomes clear”. One of the key factors for successful implementation of the technique is to make an informed decision, i.e., to give people with practical experience the right to provide management with information regarding any problem that appears in their area of expertise. Something to remember is that “5” is just a number, therefore, it is recommended to keep asking “why” as long as it is applicable. Below is the implementation procedure for the 5-Whys technique:

1) Form a cross-functional team (members are representatives of different departments) to receive unique points of view, collect info, and make an informed decision.
2) Define the Problem. Discuss the problem with the team and make a clear problem statement that defines the scope of the issue.

3) Ask Why. Empower one person to facilitate the whole process by asking "Why" as many times as needed until the team can identify the root cause of the initial problem. It is recommended to take the advice below into consideration:
    a. Ask Why only to find the root cause and avoid ending up with tons of unreasonable suggestions and complaints.
    b. Sometimes there could be more than one root cause. In these cases, the 5 Whys analysis will look more like a matrix.
4) Take Corrective Action(s)
    a. Find the best solution,
    b. Assign a team member to be responsible for applying the right actions and observing the whole process,
    c. After a certain period, the team needs to meet again and check if their actions had a positive impact. If not, the process should be repeated. (The cause is considered a root one only if the final negative effect is prevented for good after the cause is removed)
    d. The case should be documented and sent across the organization to achieve Knowledge Sharing.

Applying Lean Kanban

Kanban is a system for improving the workflow efficiency of the production process. It helps to identify what needs to be improved by visualizing the flow of work. The Kanban rules that govern its implementation are as follows:

1) Visualize the flow of work using a whiteboard (a Kanban board).
    a. Kanban board consists of 3 columns: Requested, in progress, Done.
    b. For each task to be done, it needs to be hosted on a Kanban Card and to pass through all the stages of the workflow.
    c. Kanban Board helps to (1) show the amount of work that every team member has to prevent overburden (Muri) and to (2) create a feedback loop so people can understand who is doing what at any time.
2) Eliminate interruptions - By limiting the work that can be in progress simultaneously, i.e., limit WIP (eliminate multitasking that harms productivity).
3) Manage flow by alleviating the bottlenecks in the process.
4) Make process policies explicit to encourage the team to take more responsibility and take ownership of their process.

Gemba Walk (GW)

Gemba Walk's initial purpose is to allow managers and leaders to observe the actual work process, get engaged with employees, build relationships with them, gain knowledge about the work process, and explore opportunities for continuous improvement. Some of the important aspects to consider while going for a Gemba walk are:

1) Ask Why. Gemba walk's main objective is to explore the value stream in detail and locate its problematic parts through active communication; for that to happen, the person having the walk needs to be eager to listen rather than talk (to collect info).

2) Respect people. Gemba walk is not a "boss walk", so it is recommended to avoid pointing fingers, blaming people, judging, and reviewing results. Gemba walk is about focusing to find the weak spots of the process and find solutions collaboratively.

Below is a Gemba walk's implementation procedure:

1) Pick a theme to focus on while having a Gemba walk (i.e., productivity, cost efficiency, safety)
2) Prepare a list of questions relevant to the selected theme.
3) Prepare workers so they understand that Gemba walk is a common process where the final destination is continuous improvement. That will make them feel more comfortable and willing to collaborate.
4) Focus on the process, not on people. The main purpose is to observe, understand, and improve the process while focusing on people who will end up facing resistance.
5) Follow the value chain to identify areas with a high potential for waste activities.
6) Record observations (everything that grabs attention) and avoid making suggestions during the walk as it is recommended to keep analysis for post-Gemba (to be more precise by having all facts available).
7) Invite a colleague from a different department and who is unfamiliar with the process to invest in his fresh perspective and ask a different question.

8) Follow-up. Share with crews what has been learned and the actions planned to involve. Otherwise, workers will only have the feeling of being watched.

Below is a list of certain recommendations to consider by the Gemba-walker after performing the Gemba-walk process:

1) Take some time to organize thoughts and notes before taking any actions based on the GW observations,
2) Sit down with the leadership team and carefully analyze the situation
3) Avoid Early feedback (directly after the Gemba-Walk)
4) Invite some of the workers who have been observed (the ones who gave the most insightful information).
5) Hold a meeting after each Gemba-Walk that may include a few participants from different departments to make the best decision. Here, it is essential to endure that the decided action is applicable
6) Implement actions in the observed process(es).

A3 Problem Solving

The A3 methodology is a lean thinking process where the problem owner (the person who has been assigned to solve the problem) should go through the model's steps to find out a proper solution to be implemented. The A3 implementation process consists of the following seven steps:

1. Clarify the problem and briefly describe it
2. Clarify current situation: (1) Describe the current situation in the area where the issue appears and map the different processes that exist around the problem area to see the bigger picture and identify the root cause.
3. Set targets/goals. At this stage, the full picture is not clear, yet. Therefore, it is recommended to go back to this stage to add more details to the defined goals after going through steps 4 and 5.
4. Analyze root cause analysis using the 5-Whys technique.
5. Develop Countermeasures (Corrective actions/Solutions)
6. Implementation. Develop an implementation plan that includes a list of the actions that will be applied to get the countermeasures in place, and assign responsible individuals for each task to be done by the due date.
7. Monitor the efficiency/effectiveness of developed countermeasures. Measure the actual results and confirm the effect of the developed countermeasures. If the actual results differ from the predicted ones, a need to modify the plan, re-implement it, and follow-up; however, if countermeasures improve the process, it is recommended to share it with others and to standardize the process.

To sum up, to achieve continuous improvement at the project and organizational levels, a need to (1) establish a communication channel that involves all relevant stakeholders (top and mid-level managers and field supervisors) in the process of recognizing problems, analyzing, and having an agreement on their root causes, brainstorming possible solutions, and committing to work collaboratively towards solving the problem; (2) develop a "Decision-making system" that involves where decisions are made by consensus, and (3) foster team commitments to strive for improvement at every aspect (Tillmann et al., 2014).

LEAN CONSTRUCTION TOOLS SELECTION

One of the essential steps to achieving a successful lean construction implementation is the selection of the right lean construction tools and techniques. According to *"The Application of lean construction Tools in United Kingdom construction Organizations: Findings from A Qualitative Inquiry"*, Bashir et al. (2013) considered that an essential criterion for tools selection is the identification of the company's driver to adopt lean construction. The article's authors, and based on interviewing various construction companies, have developed a matrix that matches the company's driver to the correspondent set of lean construction tools to assist the company to attain expected advantages out of this implementation. Matrix is displayed in Table 4:

Table 4

Comparison Of Drivers to Lean Construction Practice and Tools Applied In The Organizations (Bashir et al., 2013)

Drivers to lean construction practice	**Lean construction tools & techniques applied**
▪ Reduce project duration, ▪ Explore cost benefits, ▪ Improve efficiency, ▪ Improve the quality of end product, ▪ Reduce defects, ▪ Enhance site conditions, improve safety and image/presentation.	▪ Standardization of teams, products, designs, and materials; ▪ Offsite manufacturing; ▪ Early elimination of un-controllable risks; ▪ Problem-solving tracker; ▪ Daily task objective charts; ▪ Just in time.
▪ Deliver value for your clients, ▪ Become Leading-edge, ▪ Increase revenues and profits (internally).	▪ Sharing Knowledge and lessons learned; ▪ Risk reduction; ▪ Kaizen (continuous improvement).
▪ Client satisfaction, ▪ Economize resources, ▪ Best practice.	▪ Collaborative Planning; ▪ Short term planning; ▪ Process Mapping; ▪ Continuous Improvement of processes.
▪ Improve efficiency in processes, ▪ Reduce cost, ▪ Reduce time on site.	▪ Collaborative planning
▪ Make more money, ▪ Clients' satisfaction, ▪ Improve quality, ▪ More efficient, ▪ Reduce cost, ▪ Smooth project delivery, ▪ Health and safety ▪ Make a difference, ▪ Government reports.	▪ Visual management (Pareto chart); ▪ Root cause analysis (fishbone diagram); ▪ Collaborative planning; ▪ 5whys (Root cause analysis); ▪ 5S/5C (house-keeping); ▪ Workers' empowerment.
▪ Improve efficiency, ▪ Reduce cost, ▪ Market competition.	▪ Design management; ▪ Root cause analysis; ▪ Collaborative planning; ▪ Integrating planning, ▪ Programming, and procurement; ▪ Weekly work plan (Last planner).
▪ Improve product and services quality, ▪ Improve productivity, ▪ Deliver value to clients, ▪ Eliminate wasteful activities, ▪ Competitiveness, ▪ Government reports.	▪ 5S (house-keeping); ▪ Signs; ▪ Collaborative planning; ▪ Workers' empowerment; ▪ Daily huddle meetings; ▪ Suppliers' involvement in decision making; ▪ 5 Whys.

Since lean construction tools and techniques are at the core of the implementation process (Demirkesen and Bayhan, 2020), Ballard et al. (2007) have developed a lean construction implementation framework that is based mainly on a set of implementation recommendations and identification of what lean construction tools to apply at what project phases. The framework is displayed in Table 5:

Table 5

Lean Construction Implementation Framework - Developed By Ballard Et Al. (2007).

Pre-project Phase	Structure the project contractually and organizationally for the pursuit of the *lean ideal*, using *relational contracts* and *cross-functional teams*.
Project Definition Phase	Align ends, means, and constraints
	Set targets for scope and cost based on aligned ends, means, and constraints
	Set other targets for experimentation and learning
Design Phase	Make workflow predictable through *reliable promising* and lean production control
	Follow a *set-based design* strategy
	Design to *target scope and cost*
	Design product and process simultaneously; design for sustainability and constructability, including safe and defect-free fabrication and assembly
	Produce product specifications, fabrication instructions, installation instructions, and system specifications from an integrated database
Supply Phase	Make workflow predictable through *reliable promising* and *lean production control*
	Prefabricate and preassemble
	Apply appropriate lean tools and methods in fabrication shops; e.g., *5S, value stream mapping, point of use (materials and tools), cellular manufacturing*
	Fabricate at the *last responsible moment* to reduce the risk of design change
	Produce assembly packages by *kitting* fabricated materials with commodities not maintained in site stores
	Deliver *assembly packages* to site just-in-time
Assembly Phase (Execution)	Implement the principle of providing materials and tools at the point of use through site stores and assembly packages.
	Maintain commonly used and relatively small items (safety equipment, small tools, consumables, fasteners, etc.) in site stores. Replenish using Kanban or vendor-managed inventory.
	Do *first run studies* to improve the safety, quality, time, and cost of operations (placing concrete, pulling cable, setting equipment), involving craft workers in operation design, testing, and improvement.
	Achieve *Built-in quality* through preparation, detection, correction, and prevention.
	Get feedback on the effectiveness of production management and suggestions for improvement from craft workers through surveys and interviews.
	Apply other appropriate lean tools and methods in site assembly; e.g., layout for minimal travel time and 5S.
Use Phase	Use commissioning and start-up to verify delivery to requirements
	Transfer information (model, as-built, equipment manuals) to operators for use in operations and maintenance
	Conduct a post-occupancy evaluation to verify understanding of the purpose of requirements and the fitness for purpose of design and construction.
	Collect feedback from members of the project delivery team and other stakeholders on lessons learned.

CHAPTER 9

LEAN CONSTRUCTION IMPLEMENTATION

There are four different levels of change: (1) Event level, (2) Behavioral level, (3) System or procedural level, and (4) Mental level (Senge et al. 1994). Introducing lean construction philosophy into an organization is considered a change at the mental level, as it is a shift from an activity-centered mentality to a system-centered mentality. Changes at the mental level, as opposed to other changes the construction industry is adapted to, is a continuous development process where each new action will reveal further opportunities for further changes and improvements, which ends up with a unique implementation and improvement path for every organization. Therefore, with time, the number of possible changes increases after each step of implementation, which makes the implementation journey far away from being a step-by-step process (Howell, Ballard, 1998).

The right implementation plan is a set of actions that are shaped by the deep understanding of lean construction principles, not just by being familiar with lean construction tools and techniques. An implementation attempt that is based only on the implementation of some tools and techniques will end up failing as it lacks a complete understanding of lean construction principles. Besides that, it is essential to remember that "Lean is a journey, not a destination", and pursuing lean ideals will never end (Ballard et al., 2007).

Having all that in mind, developing an implementation plan is based on a set of guidelines that are discussed along with the following pages.

A. LEAN CONSTRUCTION IMPLEMENTATION GUIDELINES

Phase 1 - Lean Construction Framework Selection

To frame the implementation of the lean construction approach, it is essential first to adopt a lean construction framework. Adopting a lean construction framework emphasizes lean thinking at every stage of project delivery through optimizing the effectiveness and efficiency of these stages while reducing wastes along the project delivery process (Al-Aomar, 2012). Some of the most important lean construction frameworks that have been found after a bibliographic analysis are discussed briefly.

Numerous and respectful efforts have been done by construction researchers and practitioners to come out with a lean construction framework that facilitates the implementation of lean mentality inside the construction industry. One of these frameworks has been discussed in the previous chapter - Table 5, which is mainly based on matching different Lean tools to the different project phases. Table 6, prepared by Gao and Low (2014), provides a brief description of the most widely published lean construction framework in terms of (1) Objective, the driver for utilizing the developed framework, (2) Topics covered, issues that are covered/addressed by the framework, and (3) Research methodology, identifies how data has been collected.

Table 6

Comparison Of Lean Construction Models (Gao and Low, 2014)

No.	Author(s)	Model name	Objectives	Topics covered	Research methodology	Where applied
1	Ballard (2000)	Last planner system™ (LPS)	To produce more reliable schedule	• Four levels of scheduling: master plan, phase plan, look-ahead plan, and weekly plan • Reliable matrix: percent plan complete • Daily huddle meeting: remove potential barriers	Case studies	USA
2	Diekmann et al. (2004)	Lean construction wheel	To assess the extent to which an organisation conforms to lean ideals	• Elimination of waste • Standardisation • Culture/people • Customer focus • Continuous improvement	Questionnaire and case studies	USA
3	Green and May (2005)	Not mentioned	To evaluate the existing model of lean construction from policy makers' point of view	• Model 1: waste elimination • Model 2: partnering • Model 3: structuring the context	Industry-wide Interviews	UK
4	Johansen and Walter (2007)	Not mentioned	To investigate the application of, and to understand lean concepts and techniques	The conceptual model investigates eight areas in an organisation, including design, procurement, planning/control, supply, installation, collaboration, management, and behaviour	Questionnaire	Germany
5	Koskela (1992, 2000)	Three views of construction production	To build theoretical foundation for lean construction	• Transformation model • Flow model • Value generation model	Model development Case studies	Nordic countries
6	Paez et al. (2005)	Lean construction as socio-technical design	To reveal that both lean manufacturing and lean construction are rooted in common human and technical elements	• Human system and technical subsystem	Model development	Not mentioned
7	Salem, Solomon, Genaidy, and Minkarah (2006)	Lean assessment framework	To evaluate the implementation of each lean tool within the proposed framework	Six lean tools are identified in four scopes, namely • Flow variability (i.e. last planner) • Process variability (i.e. fail safe for quality) • Transparency (i.e. 5S) • Continuous improvement (i.e. huddle meeting)	Case study (one)	USA
8	Santos (1999)	Application of Flow model in construction industry	To develop the heuristic implementation approaches of the flow model	Influenced by Koskela's (1992) work, the model developed by Santos (1999) contains four principles: • Reduction of process cycle time • Reduction of variability • Increase of transparency • Continuous improvement	Case studies	The UK and Brazil

a. The Toyota Way Model for Lean Construction Implementation

The Toyota Way Model has been developed initially to guide lean implementation in the manufacturing industry. According to Ballard et al. (2007), the Toyota Way Model, as it is shown in figure 11, is based on 14 management principles that are categorized into 4 sub-models, namely (1) the philosophy sub-model, a set of lean concepts that drive the organization to be developed as a continuous improvement organization that can adapt to market changes and to survives; (2) The process sub-model, a set of tools and techniques that have been developed to reach one-piece flow ideal, i.e., to achieve “the best quality at the lowest cost with high safety and morale" ideal; (3) Developing partners & people sub-model, focuses on people development and continuous improvement in parallel with process improvement to confront business problems professionally; and (4) Problem-solving sub-model, as a mean for continuous learning through identifying problems, analyzing root causes, developing and monitor the effectiveness of countermeasures to prevent similar problems to occur later on.

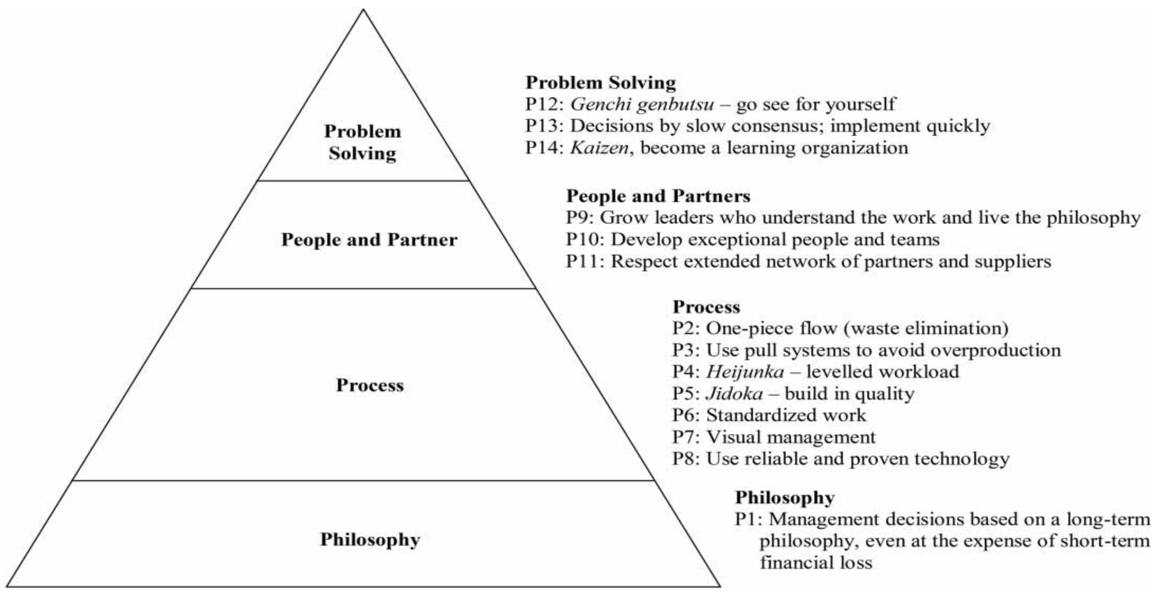

Figure 11. The Toyota Way Model (Source: Liker, 2004).

Gao and Low (2014) noticed that out of the frameworks mentioned in table 6, only three frameworks, namely Diekmann et al. (2004), Paez et al. (2004), and Green and May (2005) consider the soft aspect lean approach, i.e., human resources, while other frameworks are seen as "process-focus" (i.e., technical-focus) approaches. Based on that, and to equally value the soft (people) and the process attributes within a lean construction framework, and since the Toyota Way Model succeed to achieve that balance in the manufacturing industry, Gao and Low (2014) customized the Toyota way Model in a way to fit in the construction industry. Customization has been done by extracting actionable attributes out of the elements that lie inside each of the 14 principles, to fit in the construction context, while keeping the "conceptual" aspect of the model, i.e., the four layers, the 14 principles, and sub-principles, with no change.

The reader can refer back to the article written by Gao and Low (2014) *“The Toyota Way model: an alternative framework for lean construction”* for detailed explanations, or to Appendix II for a brief explanation of each of the four sub-models, the 14 principles, the correspondent elements of each principle and the extracted practices out of these elements.

b. Lean Project Delivery System

Lean Project Delivery (LPDS) is a lean construction implementation framework that has been developed by the lean construction Institute (Ballard, 2008). LPDS considers the relationship between the various phases of project delivery. Ballard broke down the project delivery process into four phases as shown in figure 12, namely (1) Project Definition (Pre-project Planning), where customer's and stakeholders’ values (Ends), conceptual design (Means), and constraints (Design Criteria) are generated and aligned; (2) Lean design phase, where conceptual designs generated earlier are transformed into processes and products designs, design alternatives are analyzed using the "set-based" strategy, and one alternative that is consistent with design criteria, constraints and project scope is selected; (3) Lean supply, where designed products are released to be fabricated and delivered; and (4) Lean assembly (execution) phase that ranges from the installation of supplied resources to the commissioning stage.

For detailed information about the lean Project Delivery system, the reader can refer to *"The last planner system of production control"*, Ph.D. Dissertation developed by Balllard (2000).

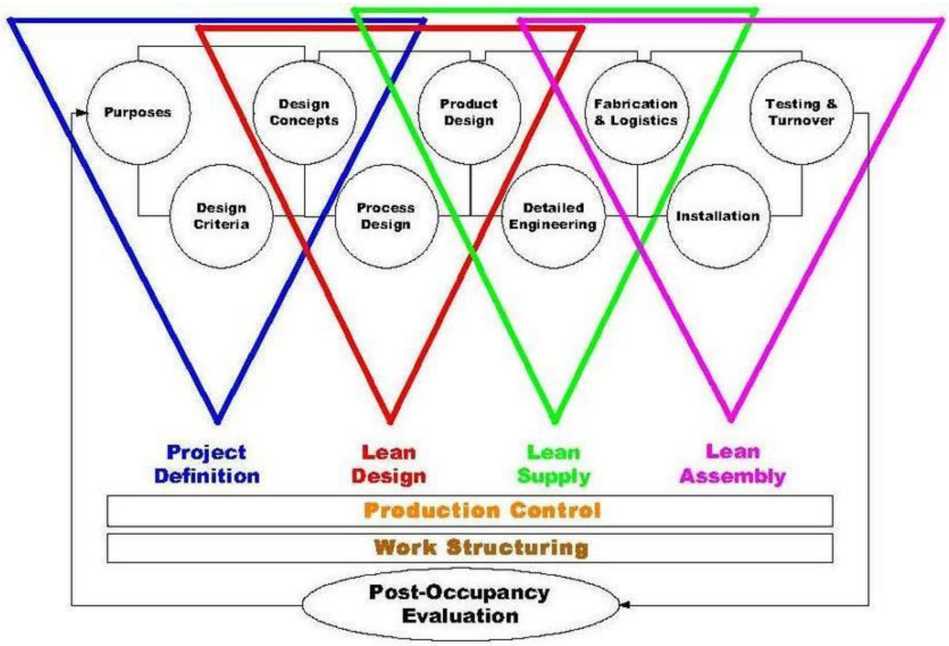

Figure 12. Lean Project Delivery System (LPDS) (Ballard et al., 2007).

After adopting a lean construction framework, a need to integrate lean construction practices into the selected framework to develop a transformational roadmap or guideline, which will be discussed along with the following pages.

Phase 2 - Lean Construction Implementation Guideline

Below is a proposed guideline for lean construction Implementation. It has been created by integrating various guidelines, recommendations, and perspectives developed by Womack and Jones (1996), Farrar et al. (2004), Ballard (2006), Ballard et al. (2007), Abdelhamid et al. (2008), Tillmann et al. (2014), and Aslam (2020). The Guideline consists of four stages as represented in figure 13.

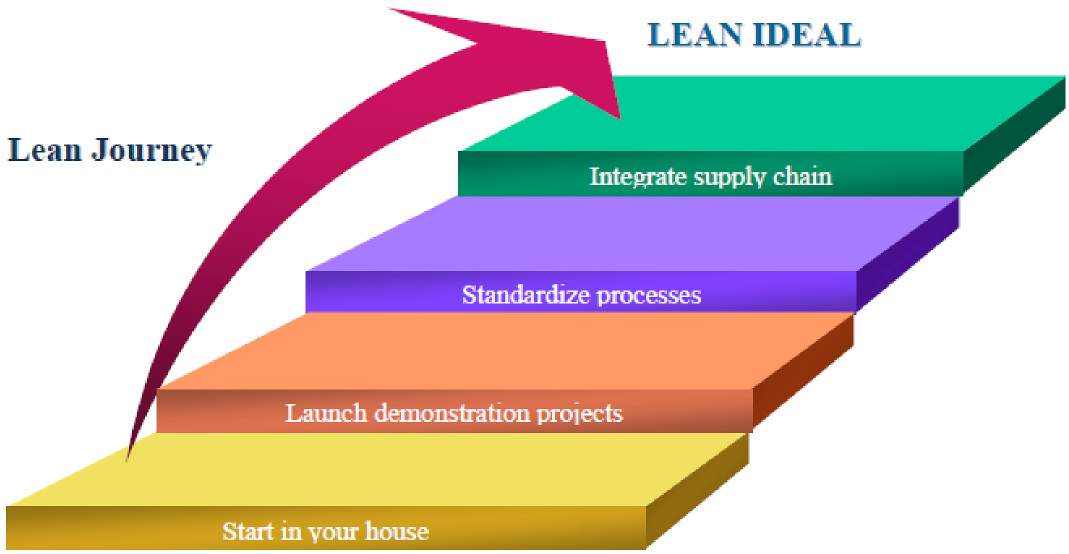

Figure 13. Lean Journey - Extracted From Ballard Et Al. (2007).

a. Stage I - Start in House

The first stage is about educating oneself and employees about lean, applying principles and tools on processes within direct control, and preparing people for a change at the company culture and behavioral levels. That is done systematically according to the following methodology:

A. Identify key drivers of lean construction implementation by decision-makers (top management).

B. Assign a Change agent (Implementation Champion) to (1) guide the change, (2) cause actions that are principles driven (for instance, decentralization of the decision making), (3) stand against those who resist lean construction implementation (as they may consider that a loss in their influence and power), and (4) engage people in the changing effort, and (5) mentor them to embrace a culture of shared leadership.

C. Get external help from consultants, trainers, facilitators, and mentors to guide the lean journey in terms of supporting the change agent's implementation strategies and developing educational and training programs.

D. Deepen lean Knowledge and develop essential lean behaviors

   1. Get enough knowledge to start implementing lean (i.e., Production management basics) then continue refining gained knowledge and adopting lean behaviors by doing, since changing behaviors cause a change in thinking and understanding. Some of the essential lean behaviors are (1) focusing on learning not on blaming, (2) ability to collaborate, and (3) ability to release reliable promises.

   2. For the onsite workforce (field managers, foremen, Field engineers), some of the proposed methodologies to deepen their lean knowledge are video sessions, collaborative classrooms, continuous improvement workshops held by mentors, and followed by job training to practice what they learned.

E. Implement lean thinking in the middle of a well-run project or from the start of a project in collaboration with a good project team to reveal the value provided by implementing lean thinking and to identify weaknesses of the current management system. Along with the pilot implementation, the below application methodology is recommended:

1. Map the value stream of a project to reveal any redundancy and waste forms, using the value stream mapping technique.
2. Select construction processes for lean construction intervention. It is recommended that these processes are within the organization's control in case adjustments to the processes and systems are required.
3. Select lean construction tools based on their compatibility with lean construction implementation key drivers and selected construction processes [1].
    a. Use BIM tools to integrate project designs and construction processes and to improve visualization.

4. Stabilize the production system. The first step to implement lean on construction projects is to create a reliable and stabilized workflow. That is done through:
    a. Using the Last Planner System to design a production planning and control system [2].
    b. Stabilize onsite workflow, based on the following methodology of work:
        i. Classify activities within a construction process as value-adding (VA) and non-value-adding activities (NVA); Value Adding activities are the activities that convert resources into products that serve the customer's needs (Koskela, 1992).
        ii. For non-value adding activities

- Focus on one activity at a time and start with the activity with the highest impact on process performance or highest consumption of resources.
- Find out practical solutions to reduce the time and resources an NVA activity takes as a first step towards eliminating it from the construction process completely (if that seems to be applicable along the continuous improvement journey).

iii. Apply Just-in-time technique to improve the material delivery process, i.e., the right material to deliver the right place at the right time (i.e., zero-time delivery) and in the right amount (to be utilized 100%);

iv. Introduce Pull driven system to control the flow of tasks (reduce multi-tasking through pulling a task only when a crew has available capacity)

v. For Value-adding activities. Optimize VA activities continuously using A3 problem-solving methodology (as discussed before).

vi. Introduce buffers to absorb variation created as a result of (1) improvement of the production process, and (2) difference in production rates among linked activities (unbalanced activities); Then eliminate shared resources among linked activities to create a balanced system and reduce dependency among activities.

c. Measure, analyze, and evaluate performance using the right KPIs (throughput, Cycle time, Work in Progress), and avoid expecting cost or time reductions immediately as that may destroy lean construction implementation initiative), and take corrective actions as needed.

b. Stage II - Launch Demonstration Projects

Apply lean principles and Stage I methodology to deliver a project from the very beginning at which application of lean tools are spread from processes that are under the direct control of the organization to processes that involve interfaces with one other stakeholder (customer or supplier), then to processes that involve multiple interfaces.

c. Stage III - Standardizing Processes

A. Engage people in process improvement and standardize improved processes by integrating them into the organization’s operating procedures.

B. Make results visible and share lean construction implementation success stories among stakeholders and employees. That would help to reinforce management-buy-in and convince people who opposed lean implementation that lean construction deserves the effort to be implemented.

C. Expand the scope of change to reach all corners inside the organization and support people to make changes in the workplace they are responsible for, as the change rate is the key lean metric;

D. Improve processes continuously. An ongoing step to be in paralleled with every step of the proposed methodology.

d. Stage IV - Integrate Supply Chain

Develop an environment where stakeholders are actively engaged collaboratively to provide inputs along with the project phases. That is done by:

A. Using the relational contracting technique to involve other project participants in delivering a lean project. It is essential to align interests among project participants in a contractual manner that will facilitate lean implementation and to pursue lean ideals after developing a solid start and expansion of lean implementation into multiple projects (Ballard et al., 2007).

B. Moving backward along the supply chain to improve planning reliability of suppliers and reduce lead time after improving the organization's planning reliability; To achieve that, forming a long-term alliance with preferred suppliers is a recommended strategy. (Ballard et al., 2007).

Based on what has been discussed, it is essential to remember two main issues before starting the lean journey. First, there is no unique detailed roadmap for an organization to become lean as each organization has its own unique and tailored roadmap. Second, organizations need to have an initial implementation success to sustain later and wider initiatives for lean construction implementation; That will raise the morale of employees and faster the transformation phase of organization culture into a lean culture (Aslam, 2020).

Implementation Methodologies Remarks:

[1] It is recommended to implement selected lean tools and techniques based on a collaborative project delivery system.

[2] Lean construction Institute recommends starting implementing the Last Planner System in the early phase of the lean construction implementation journey. Applying LPS will reveal many problems the company needs to address systemically and in a prioritized manner. With time, encountered problems will move beyond the company's scope of influence to key stakeholders along the supply chain. From there on, the only way to deepen the learning of lean implementation and to optimize the outcomes is through developing strategic alliances and knowledge sharing.

B. CRITICAL SUCCESS FACTORS OF LEAN CONSTRUCTION IMPLEMENTATION

Critical Success factors are the factors that need to be considered in the implementation plan to achieve a better, easier, and successful lean implementation in construction projects, and to get the best advantages out of it. Critical success factors are considered as enablers or as strategies to address various challenges that may be encountered along the lean construction implementation journey.

Lean construction implementation is a wide topic that could not be covered in one paper. Therefore, and in order not to duplicate existing work, success factors will not be discussed in this paper as they have been studied by various papers. One of these articles where a serious effort has been made is *"A lean Implementation Success Model for the construction Industry"* a paper written by Demirkesen and Bayhan (2020).

Demirkesen and Bayhan (2020) made respectful efforts to identify, explain and categorize 27 critical success factors for lean construction implementation into seven groups, namely (1) Financial, (2) Technical, (3) Culture, (4) Management, (5) Workforce, (6) Government, and (7) Communication factor groups. Along with the article, the authors discussed the reasons or the need to address each of these seven groups; For instance, it is necessary to address (1) The financial factor group to boost and reveal the financial benefit of applying lean practices, (2) The technical factor group (i.e., availability of lean tools, techniques and software systems) to build a lean-friendly environment, (3) The culture factor group to handle cultural barriers and establish a better working environment, (4) The management factor group to establish an incentive-based type of relationship to increase commitment for lean implementation, (5) The workforce factor group to create a shared environment that is open to learning and new opportunities, (6) The government factor group in terms of incentivizing lean initiatives and support lean culture growth, and (7) The communication factor group to set an effective commination channel that leads to a more efficient implementation of lean practices. Table 7 lists, defines, and categorizes each of the 27 success factors into the correspondent factor group.

Table 7

Lean Implementation Success Factors for The Construction Industry (Demirkesen and Bayhan, 2020)

Cluster	Code	Factor	Description
Financial	F1	The existence of a clear marketing strategy	A visionary market strategy enhances Lean implementation
	F2	Long term profit of implementing Lean tools	Implementing Lean tools brings profit for the companies in the long term
	F3	Willingness to invest in Lean practices	Investing in Lean tools and practices facilitate the implementation of Lean
	F4	Market share	Growth and increase in market share lead to improvement in Lean implementation
Managerial	M1	Management commitment	Commitment by top and middle management in Lean practices facilitate Lean implementation
	M2	Incentive mechanisms	Incentive mechanisms are the catalysts for Lean Implementation and improve process efficiency
	M3	Creating awareness for Lean	Enhancing awareness for Lean leads to a collaborative and effective structure in Lean implementation processes
	M4	Customer satisfaction	Adopting customer satisfaction as the firm policy ensures the success of Lean implementation
Technical	T1	Lean training	Lean training leads to a more definite scheme of Lean implementation process resulting in the desired success
	T2	Availability of Lean tools and techniques	Available resources in Lean and familiarity with Lean techniques facilitate Lean implementation
	T3	A clear understanding of technical requirements in Lean practices	The clarity in Lean terms definition and identification of best practices are of paramount importance to Lean implementation success
	T4	Morning huddles for Lean	Daily meetings and morning huddles reinforce Lean learning and improve technical skills in Lean implementation
	T5	The effectiveness of Value Stream Mapping	Value Stream Mapping helps to visualize the Lean implementation process and provides a graphical representation of steps to be used
Workforce	W1	A supportive environment for workforce efficiency	Workforce efficiency reduces waste in Lean practices leading to successful Lean implementation
	W2	The existence of certified and qualified Lean personnel	Lean certified personnel are more able to come up with better implementation strategies knowing the terms to be applied
	W3	The efficiency of human resource management activities	The effectiveness of human resource management activities including selecting best fitting personnel for the projects promotes Lean practices and affects Lean implementation positively
	W4	Availability of consulting team members in Lean	Lean consultancy and an available consulting team matter for the success of Lean implementation for resolving conflicts in processes
Culture	CU1	Adopting a Lean culture	Adopting a Lean culture helps people conceive the importance of Lean practices leading potentially to safer practices in the workplaces
	CU2	Lean as a firm strategy	Making Lean part of firm culture increases the familiarity with Lean practices leading employees with the practices along with shorter application durations in Lean implementation
	CU3	Lean leadership	Availability of Lean leaders and managers supporting Lean activities ensure satisfactory operations in Lean implementation
	CU4	Employee morale	Employee morale is a driver for the successful operation of Lean practices
Government	G1	Supportive nature of governmental regulations in Lean	Government support such as launching regulations enabling Lean practices is essential for the success of Lean practices and Lean implementation
	G2	Government incentives	Government incentives (i.e. tax exemptions, rewards mechanisms) increase the likelihood of Leaner practices leading to successful Lean implementation
	G3	Availability of resources for Lean	Making Lean resources available by government parties such as government-funded Lean associations and projects help Lean initiatives perform better
Communica-tion	CO1	The existence of clear roles in Lean	Identifying roles in Lean prevents conflict of interest and results in increased performance in Lean operations
	CO2	The existence of Lean research groups and initiatives	Lean research groups and initiatives have the power to influence Lean activities leading to success in Lean implementation
	CO3	The existence of communicating Lean practices	Dissemination of knowledge in Lean practices is essential to communicate different groups in terms of gaining best practices in Lean implementation

C. LEAN CONSTRUCTION KEY PERFORMANCE INDICATORS (LC-KPIS)

Key Performance Indicators of lean construction need to be derived from the key measures of construction project performance, which include Quality, Cost, Schedule besides some other lean construction measures, namely Value and Waste.

Al-Aomar (2012) proposed the following five KPIs to assess the effectiveness and efficiency of lean construction are as follows:

Sigma Rating (SR)

Six Sigma's concept aims to improve quality and reduce variability in production processes (Pheng and Hui, 2004). That makes six sigma, on one hand, plays a complementary role with the lean concept in the construction context by reducing quality-based Mudas (i.e., rework), and on the other hand, lean concept complements six sigma focus (i.e., quality improvement) by reducing variability and stabilizing the flow of work (George, 2002).

Sigma Rating (SR) is a quality measure that quantifies defects at the end of each lookahead period, i.e., after reviewing performed work by the subcontractors, and then compared to a benchmarked value. Sigma Rating is Calculated according to the following process, as illustrated by (Al-Aomar, 2012):

a. Count the number of defects (ND) in the performed work units (WU); WU is the number of quality checks (or samples taken) performed at each work package (structure, internal finishes, electrical work, mechanical work) performed by the contractor, i.e., packages).

b. Compute the % Yield based on equation 1:

$$\%Y = 100\% - \left(\frac{ND}{WU}\right) \quad (1)$$

c. Convert % Yield into Sigma rating (SR) based on the following Excel equation (2):

$$SR = NORMSINV(\%Y) + 1.5 \quad (2)$$

SR value will determine quality performance done by the contractor, so the contractor acknowledges the need for further quality improvements.

Project Schedule & Cost Effectiveness

Schedule Variance (SV) and Cost variance (CV) are performance measures developed by the Earned Value Management System (EVMS) to represent project performance. SV and CV quantify variance, i.e., deviation from planned performance, to determine the need to take corrective actions accordingly. SV and CV are determined based on three factors (1) Planned Value (PV) - budgeted cost for work scheduled, (2) Earned Value (EV) - budgeted cost for work performed, and Actual Cost (AC) of work performed (Kerzner, 2009); SV and CV are calculated as per equations 3 and 4:

$$SV = EV – PV \quad (3)$$

$$CV = EV – AC \quad (4)$$

Remark: SV and CV can be expressed in dollar value or hour. A negative value is an indication of schedule delay (for SV<0) or cost overrun (for CV<0).

Estimating cost and schedule effectiveness from a lean perspective using CV and SV measures requires the computation of CV and SV at the end of the Lookahead period based on the value of PV, EV, and AC during the same period. For this sake, Schedule

Performance Index (SPI) and Cost Performance Index (CPI) to be computed as per equations 5 and 6:

$$\text{CPI} = \frac{EV}{AC} \quad (5)$$

$$\text{CPI} = \frac{EV}{PV} \quad (6)$$

Remark: Indices values below 1.0 indicate a schedule delay (SPI<1.0) and cost overrun (CPI<1.0).

Waste and Value Indices

Waste and Value indices are essential to measuring the impact of lean construction implementation in terms of reducing material waste, inventory levels, and movement of materials and labor.

a. Waste Index

According to Thomas et al. (2002), the project waste index (WI) could be used to reflect the waste in materials or during working hours. To measure material waste, a need to compare the amount of procured materials (P) to the used amount (U) and estimated amount (E) (in the case of measuring material waste) for the same lookahead period. The waste index is calculated as per equation 7:

$$\text{WI} = \frac{(P-U)}{E} \quad (7)$$

(P, U, and E are represented by the correspondent material type unit).

The lower the index the better it is; Values of Waste Index have various indications: (1) the lower the value is an indication of high frequent application of JIT delivery and low inventory levels, (2) zero-value indicate that "lean supply of material results in procuring only the amount needed", while a (3) positive value means that the difference between what has been procured and used materials end in the inventory to be carried out to the next lookahead period (Thomas et al., 2002).

b. The Value index (VI)

The Value index compares the conversion time (i.e., duration of effective work or value-adding activities) to the total duration of the lookahead period. By tracking the conversion time (CT) and the flow time (FT) during the lookahead period, VI is computed as per equation 7:

$$\text{VI} = \frac{CT}{(CT+FT)} \tag{8}$$

Based on the presented equation, VI is a higher-the-better index.

To guide the improvement of the company performance, a need to (1) set a benchmark (a threshold) for each Lean Construction-KPI, and (2) link each of the 5 KPIs to the seven types of Mudas. Benchmarks values are in function of (1) company level of sophistication and proficiency, (2) level of company's willingness to meet customer's expectations (even the hidden one), and (3) the efficiency of the adopted risk management approach. Table 8 provides a set of threshold values for each Lean Construction-KPI, where each KPI is linked to the correspondent Muda type it impacts.

Table 8

Examples of Lean Construction-KPIs Threshold Values for a Hypothetical Project

Waste Category	LC-KPI	Threshold Value
Defects/Errors	SR	≥ 3.0 (99% of work is defect free)
Delay/Ineffectiveness	SPI	≥ 1.10 (10%-time buffer is maintained)
Overproduction		
Overprocessing/Cost effectiveness	CPI	≥ 1.15 (15% cost buffer is maintained)
Conveyance	VI	≥ 0.75 (A maximum of 25% conveyance & movement)
Movement		
Inventory/ Material	WI	≤ 5% (no more than 5% ending inventory)

CHAPTER 10

EXAMINING LEAN CONSTRUCTION SUITABILITY, ACCEPTABILITY, AND APPLICABILITY IN THE LEBANESE CONSTRUCTION INDUSTRY USING SURVEY ANALYSIS

The fact that adopting lean construction ends up minimizing or even eliminating cost-consuming activities (i.e., flow activities) necessitates the consideration of lean construction implementation as a strategic option. Evaluating lean construction as a strategic option before implementing it in a particular environment is recommended. Evaluation is performed in terms of a Suitability test, Acceptability test, and Feasibility test, as proposed by Johnson and Scholes (1999). The suitability test examines the effectiveness of an option within a particular circumstance, to address a major challenge faced by an organization or an industry. In the case of the Lebanese Construction Industry, the Suitability of Lean Construction has been addressed by evaluating the existence of various forms of waste. The acceptability test evaluates whether the adoption of lean construction will gain support or will be opposed; Acceptability of lean construction has been examined by examining participants' level of support and acceptance of the lean construction principles. The feasibility test evaluates the company's ability to implement lean construction successfully.

For the sake of examining lean construction adoption as a strategic option in the Lebanese construction industry, a survey has been developed to address the suitability and acceptability of lean construction in the Lebanese construction industry; and since carrying out the feasibility test at the industry level is difficult (as it is recommended to be carried out at a company level), the survey examined instead the "Applicability" of lean construction in the Lebanese construction industry; Applicability of lean construction has been tested by examining familiarity of participants with the lean construction principles, tools and techniques applications, drivers and barriers of lean construction adoption.

The survey consists of four sections. In the first section, participants were asked to check the existence of 24 types of wastes, collected throughout an extensive bibliographic analysis, in the construction industry, and, if they exist, participants were asked to determine the frequency of existence of each. The second section of the survey inquired opinions of construction professionals regarding their acceptance of the core principles of Lean construction. The third section collected information about the familiarity of the Lebanese construction firms with Lean construction concepts, tools, and techniques. In plus information was collected to find out what (1) lean construction tools and techniques have been applied by lean implementers firms, (2) key drivers of lean construction adoption, (3) barriers lean implementers have faced, and (4) barriers expected to be faced by non-lean implementers when they decide to implement lean construction.

Data collected have been analyzed based on the frequency, mean, and standard deviation statistical measures. Mean values that exceed 3.00 imply that participants agree with the given statement or choice, as a whole, while mean values which are less than 3.00 imply the opposite. The standard deviation value is used, for the second section, to highlight the width of variation of participants' agreement upon the lean statements.

Sixteen Lebanese construction companies and 182 Lebanese construction professionals who worked for Lebanese construction firms have been contacted to fill in the survey; Only 10 filled surveys were obtained and qualified for analysis. This small sample size means that results are anecdotal, i.e. cannot be validated, and increases the margin of errors; Some other factors that contribute to the anecdotal nature of the results are (1) the uncertainty of the participants' level of expertise, (2) the wide range of construction sectors addressed by the survey, and (3) the economic situation in Lebanon in the time of conducting the survey; The Lebanon economic and financial crises caused Lebanon's GDP to drop from US$55 billion in 2018 to a projected US$20.5 billion in 2021, besides a deterioration of the exchange rate with the US$ by 68% to LPB 19,800/US$ between March and August 2021, and an inflation rate averaged 131.9% over the first six months of 2021 (World Bank, 2021). Overall, such a small sample size implies that the results of the survey should be considered anecdotal or indicative but by no means valid since a larger and more homogenous sample would be required.

The potential reasons behind having a very low participation percentage even though it was made clear that the survey is confidential and results will be disclosed only in an aggregated form are (1) the financial crisis in Lebanon – just discussed - which lead to companies' shutdowns from different industries, including the construction industry, either temporary and permanent, which lead to frustration among Lebanese construction professionals, (2) lack of awareness of the value that lean construction approach provides the construction industry with, which is associated with a lack of interest, and (3) sensitivity to disclose detailed information about the projects they worked on.

Survey participants belong to various firms' sizes, as shown in figure 14, which provide various construction services, as shown in figure 15.

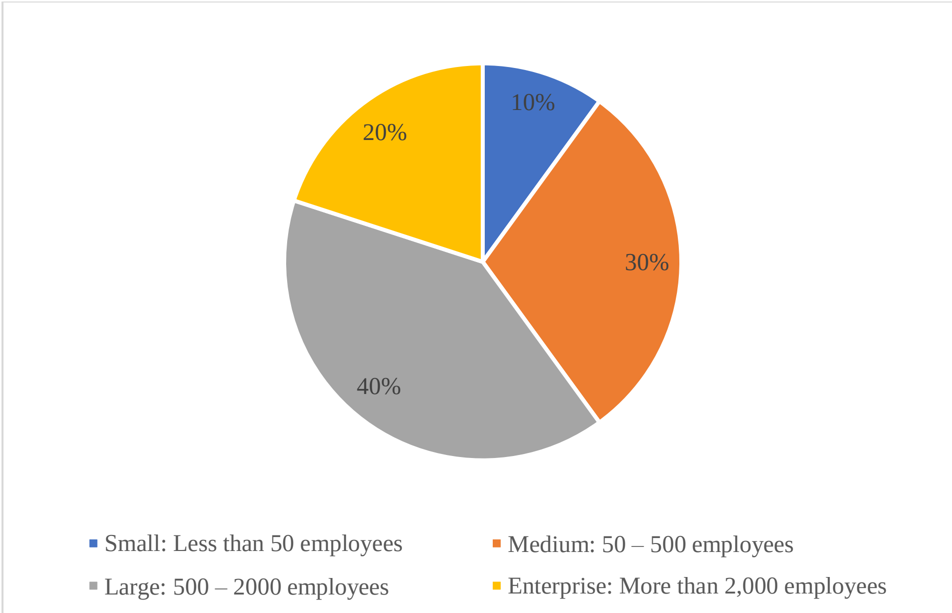

Figure 14. Sizes Of Companies That Survey Participants Belong To.

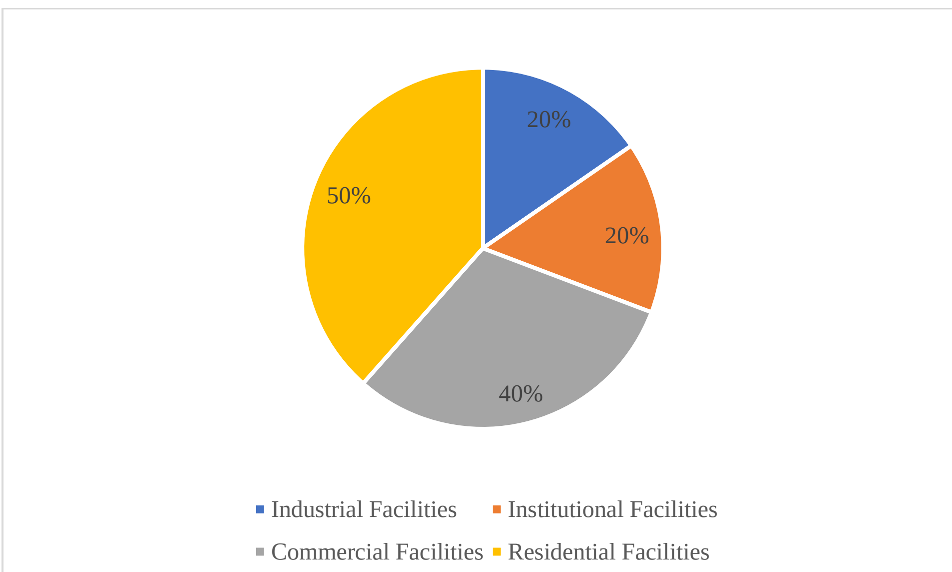

Figure 15. Types Of Industries That Best Describe the Construction Services Participated Companies Provide.

A. LEAN CONSTRUCTION SUITABILITY

A strategic option is suitable as long it can provide an industry (or a company) with the right means to overcome a weakness. In the case of the construction industry, wastes exhibited by construction processes are considered as a major weakness, which makes lean construction, based on its core objective to maximize value and minimize waste, a suitable strategic option.

That conclusion would be tested by asking construction professionals to check for the availability of 24 types of construction wastes, and to identify the frequency of existence of each type of waste on a scale from 1 to 5 (1 – Rarely exists; 5 – Always exists) in Lebanese construction projects. Results have been displayed in Figure 16.

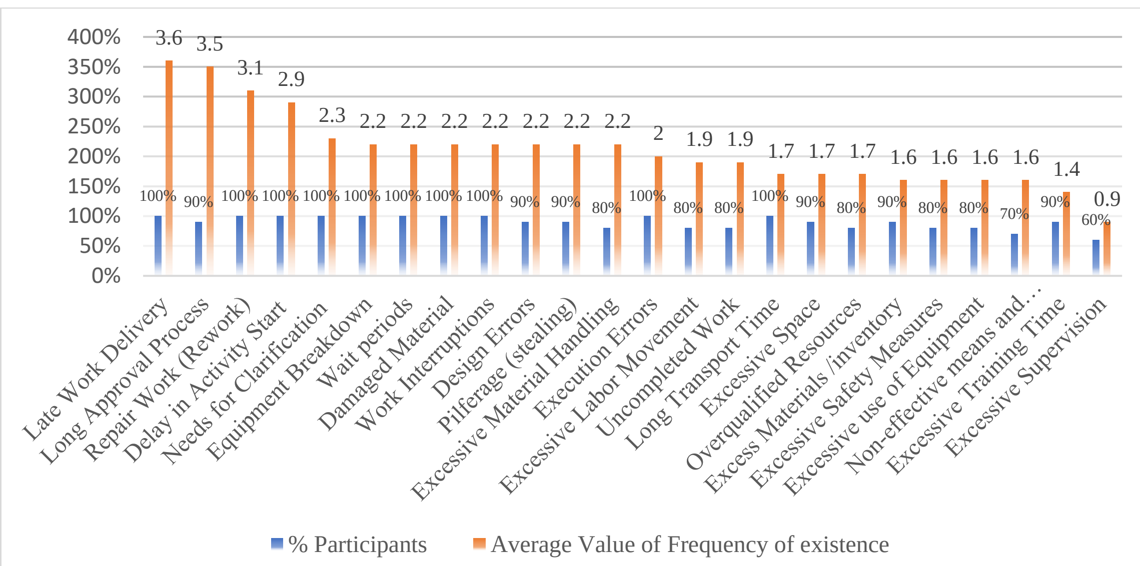

Figure 16. Pareto Diagram Showing the % Of Participants Who Agreed On the Existence Of the 24 Types Of Wastes and rhe Average Frequency Of Existence Of Each.

Figure 16 shows two measures, the % of participants who agreed on the existence of certain types of wastes, and the mean-value frequency of existence of each type of waste (ranges between 1 and 5). Remarkably, ranking these factors based on mean frequency values doesn’t match with the % participants-based ranking. That may be because participants (1) are of different positions (ranging from the CEO position to site engineering position), and (2) belong to companies that build various forms of facilities. Position-wise, higher-level positions enable construction professionals to notice a wider range of construction wastes, and industry-wise, different types of construction projects imply different types of construction wastes.

Since a mean value of a waste type that exceeds 3.0 implies that survey participants are in agreement with that type of waste, and based on collected results, it seems that (1) Late work delivery, (2) Long Approval Process, and (3) Rework are identified as the most frequent types of waste in the Lebanese construction industry.

Therefore, it would seem that lean construction is a suitable approach to be adopted by the Lebanese construction industry, due to the high frequency of existence of various forms of wastes.

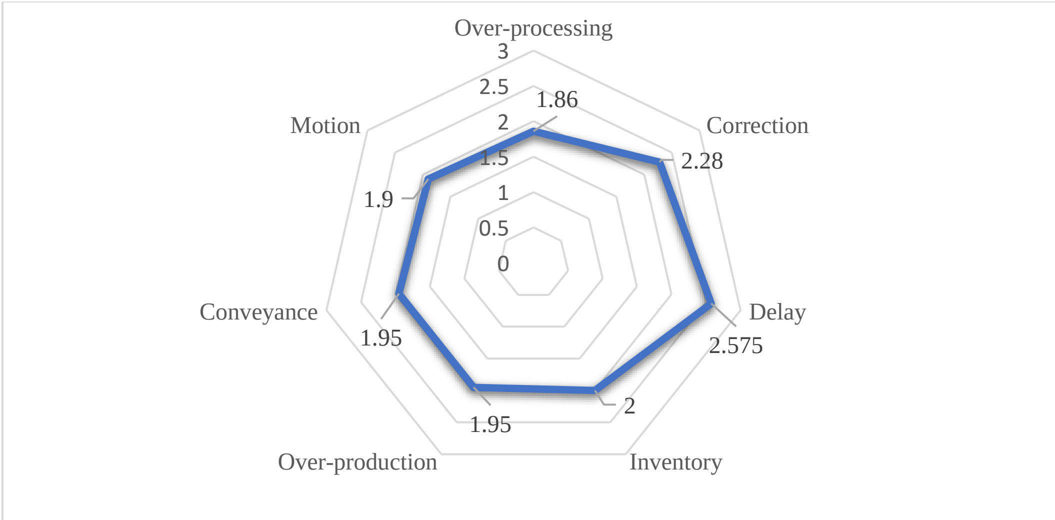

Figure 17. Mean-Value Frequency of Existence of Each form of Waste.

After categorizing all types of wastes into the seven forms of wastes previously addressed, figure 17 shows the mean-value frequency of each of the seven forms. Remarkably, the “Delay” form of waste is the form of waste that exists frequently in the Lebanese construction industry, even though no one form of waste has complete agreement among participants, which may be due to the difference in construction services provided by participants’ companies.

B. LEAN CONSTRUCTION ACCEPTABILITY

People will accept the adoption of a new philosophy at work only if they accept the principles upon which that philosophy stands, according to the management theorist, Carnall (1990). Therefore, people's acceptance of lean construction principles has been tested.

Participants were asked to mark their acceptance, on a scale from 1 (Strongly disagree) to 5 (Strongly agree) against 34 statements that represent the core principles of lean construction (Koskela, 1992); 19 out of 34 statements evaluate participants' acceptance of the need to eliminate waste, while 15 statement test participants' acceptance of Kaizen mentality (i.e., continuous improvement mentality). Results of Acceptability to lean construction principles are displayed in Table 9[3].

Table 9

Acceptability of lean construction Principles Results

Statement No.	Statement	Mean	Standard Deviation
Factor 1	**Wastes, non-value-adding activities, should be eliminated**		
1	A majority of earlier mentioned wastes consume significant cost	3.4	1.35
2	A majority of earlier mentioned wastes consume a considerable amount of time	3.2	1.40
3	Almost all of the earlier mentioned wastes can be eliminated	3.4	1.65
4	All the above wastes should be eliminated	3.9	1.69
5	The earlier mentioned wastes add no value to the final product	3.6	1.94
6	Most of the above-mentioned causes of wastes are controllable	3.7	1.16
7	When a company eliminates the above wastes, it will increase the output value	3.9	0.88
8	The earlier mentioned causes will give rise to more types of wastes in future	2.8	1.72
9	Trying to find the causes of these wastes and eliminating them is of value and deserve serious efforts	3.8	1.14
10	I have many ideas which can contribute to eliminating these wastes and causes	3.3	1.58
Factor 2	**Company-wide acceptance for 'elimination of flow wastes'**		
11	I can help the company to eliminate these wastes	3.1	1.85
12	I think my subordinates will support the company to reduce these wastes	2.8	1.81
13	My peers (who are working at the same level of the organization) will help to reduce these wastes	3.3	1.87
14	Trying to eliminate these wastes will not harm my position in the company	3.4	1.84

Factor 3	**To increase output value (through the elimination of flow wastes), systematic consideration of customer requirements is essential**		
15	Adding value to the customer is the prime intention of every activity in the construction process	2.9	1.60
16	Giving more attention to customer requirements will minimize the above-mentioned wastes.	2.5	1.78
17	Systematic consideration of customer requirements will increase the output value	2.4	1.71
18	These wastes reduce company profits considerably	2.7	1.80
19	Even though these wastes are eliminated, I will not be benefited	2.1	1.45
Factor 4	**The mentality of Continuous Improvement**		
1	Each person in an organization can contribute to improving the activities of his/her workplace	3.8	1.81
2	All activities of the organization/site can be continuously improved	3.6	1.59
3	All activities of the organization/site should be continuously improved	3.7	1.58
4	Not a single day should go by without some kind of improvement being made somewhere in the organization/site	3.3	1.77
5	Continuous improvement will reduce/eliminate non-value-adding activities of an organization/site	3.5	1.65
6	I am willing to search for ways of continuously improving the work I do	2.9	1.90
7	Trying to improve every work activity continuously is of great importance	3.4	1.84
8	I like to seek ideas and learn from many people to improve myself	3.7	1.77
9	There is no end to improvement	3.4	2.01
10	I do have anything new to learn or improve	3.6	1.90
Factor 5	**Company-wide acceptance for Kaizen (Continuous Improvement)**		
11	A company's corporate culture should be one that where everyone can freely admit 'problems' and suggest improvements	3.5	1.90
12	'Quality' should be the priority, not 'profit'	3.4	1.51
13	I believe my peers are willing to continuously improve the work they carry out	3.1	1.62
14	I believe my subordinates are willing to continuously improve the work they carry out	3.0	1.50
15	From my experience, I believe that a majority of the workforce in the Lebanese construction industry are willing to continuously improve the work they do	2.5	1.65

[3] Responses included “I am not sure” have not been considered in the response analysis. Only responses with a rating from 1 to 5 have been included to analyze Lebanese industry acceptability of lean construction Principles.

For the first three factors, and based on table 9 results, it is noticed that (1) participants agree with factors' 1 and 2 statements that represent the need to eliminate waste from construction processes to maximize generated value, while a less degree of agreement has been achieved for the statements of the third-factor that exhibit the need to meet customer requirements to maximize value. Based on the displayed results, it would seem that participants comply with the fact that value is maximized by reducing wastes, while they don't completely agree that the same goal, value generation, could be reached by considering customer requirements. Factor's 3 results point out that some construction professionals in Lebanon may lack the understanding that value is evaluated from the customer's perspective, which makes the value directly linked to meeting customers' requirements.

For the Kaizen mentality statements (Factors 4 and 5), it has been shown that participants agree with the Kaizen mentality and their companies have a wide acceptance for a continuous improvement mentality.

The equals of the mean values of factor no. 1 and factor no. 4, as shown in figure 18, indicates that participants agree with the fact that both approaches, i.e., waste elimination and continuous improvement, are the keys to maximizing value.

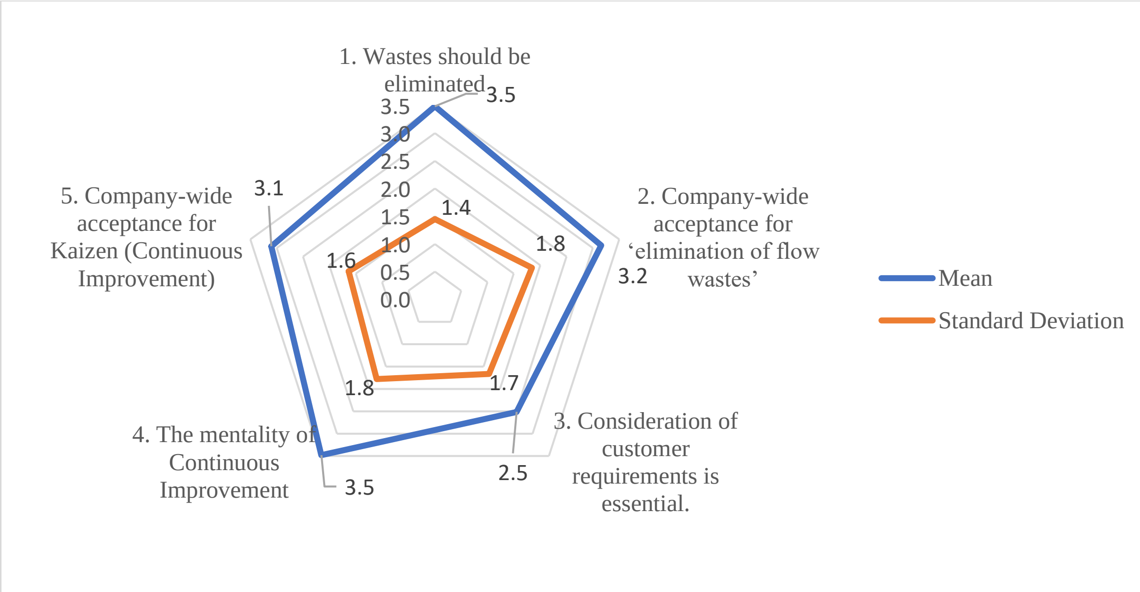

Figure 18. Mean Value of The Factors Representing the Lean Construction Principles.

Trying to analyze the indication of the resulted standard deviation values that exceed one complete point, as shown in table 9, it seems that some construction practitioners agree upon certain statements, while others disagree with the same statements. These results indicate that a significant percentage of construction professionals who work for Lebanese firms may accept adopting the lean construction mentality as an approach to deliver construction projects, while another significant percentage may not. Based on that, it could be said that we are quite uncertain whether there would be an industry-wide acceptance of lean construction principles or not.

To sum up, these results imply the need to make the workforce knowledgeable and aware of the value they gain by delivering construction projects using a lean construction approach.

C. LEAN CONSTRUCTION APPLICABILITY IN THE LEBANESE CONSTRUCTION INDUSTRY

To analyze the applicability of lean construction in the Lebanese construction industry, the familiarity of participants with lean construction concepts, tools, and techniques has been assessed. Based on collected results, it would seem that 90% of participants are familiar with lean construction Principles, 80% are familiar with lean construction tools and techniques, and 70% of participants are familiar with how lean construction works for construction firms that experimented with lean construction implementation.

Results show that 57% of construction firms that implement lean construction (i.e., lean construction implementers) adopt lean construction for 10 years and less, 29% for 5 years and less, and 14% for less than a year.

Besides that, this section will analyze key drivers of the Lebanese construction industry to adopt lean construction, Tools and Techniques Analysis, and lean construction implementation barriers analysis from the perspective of lean construction implementers and non-implementers firms.

Analysis of Key Drivers for Lean Construction Implementation

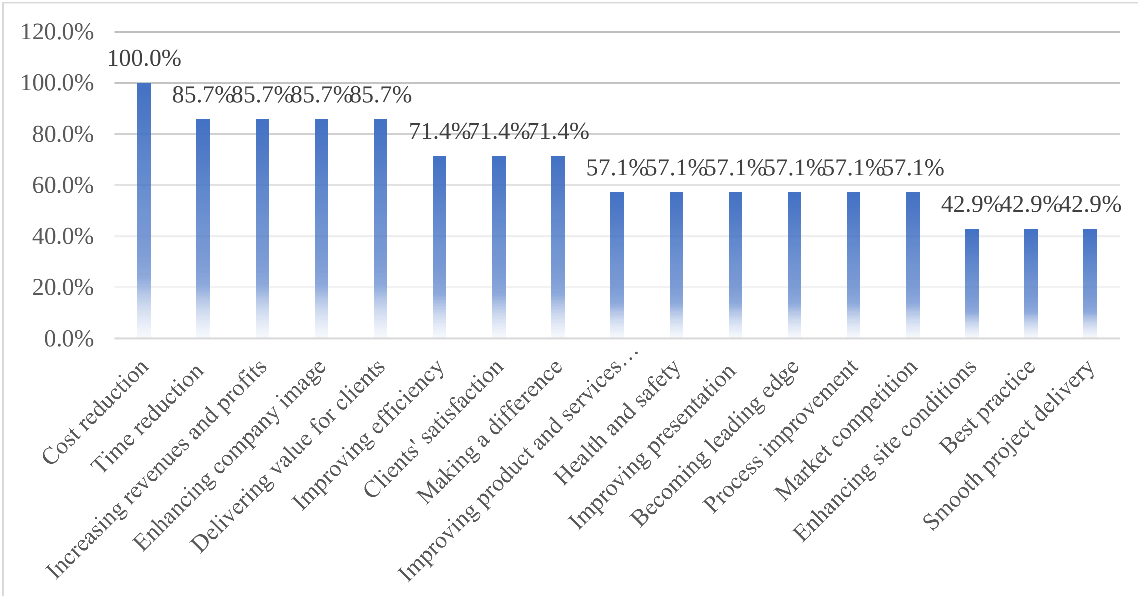

Figure 19. % Frequency Of Key Drivers of the Lebanese Construction Firms

Participants who are working or worked for construction firms that adopt lean construction in their delivery process (i.e., lean construction implementers firms) were asked to list the key drivers for lean construction adoption. Based on Figure 19, it is clear that "cost reduction" is the top driver for lean construction implementation by the Lebanese construction industry. All barriers, namely "Time reduction", "increasing revenues and profits", "enhancing company image", and "delivery value to the client", fall as the top second driver for lean adoption.

Besides the remark indicated in figure 19 - that the Lebanese construction industry is cost-driven, one may wonder about the reason that makes cost reduction frequency exceeds that of time reduction. In the Lebanese construction industry, when the contractor is late in delivering the project to the owner (behind the deadline), often, both parties, the contractor and the owner, agree upon the exemption of the contractor from the liquidated damages for an extended duration of time. That does not happen over all the Lebanese construction projects, but in many of them, and that will clarify the reason behind the difference in ranking between cost reduction and time reduction drivers.

Analysis of The Lean Construction Tools & Techniques Adopted by Lebanese Construction Firms

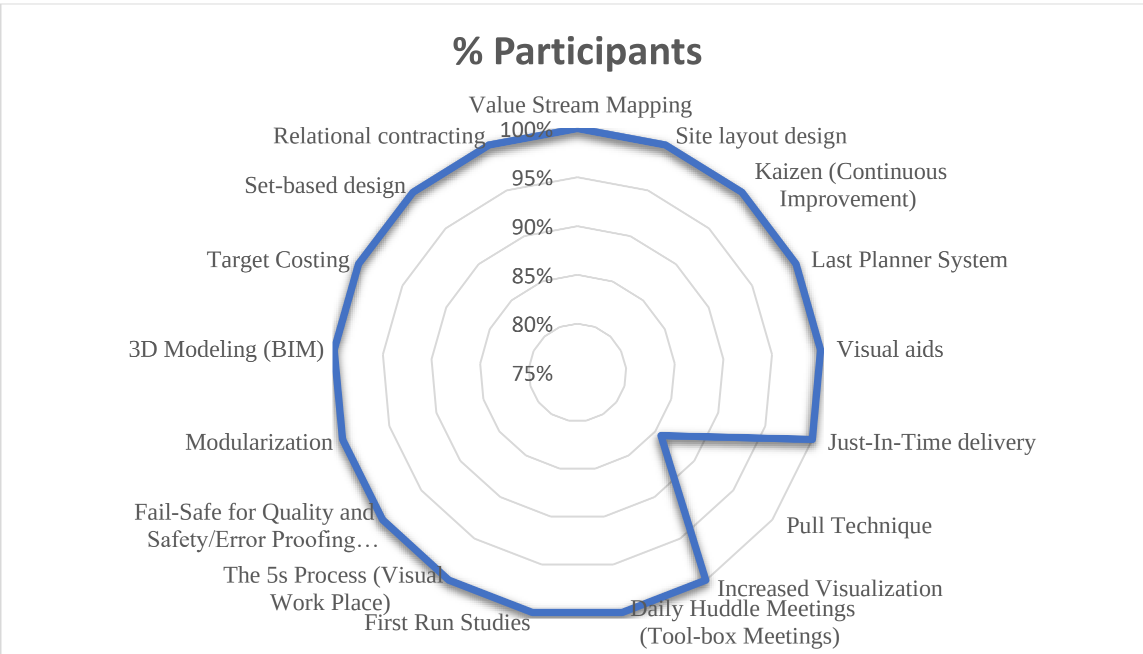

Figure 20. % Frequency Of Lean Construction Tools and Techniques.

Participants who work (ed) for lean construction implementers were asked to list what lean construction tools and techniques were used by their companies. Based on figure 20, it is clear that 16 tools out of 17 listed tools and techniques are implemented by all Lebanese construction firms, and the least implemented technique is the "pull" technique (86% of participants). The pull technique is considered as a foundation upon which lean construction implementation stands; in other words, implementing the pull technique represents the company's understanding of Lean Philosophy. Even though only 14% of participants did not implement the Pull technique as the main technique along their lean construction implementation journey, but that small percentage is seen as a representation of a small portion of the Lebanese construction industry who considers that adopting lean construction could be done only by applying lean construction tools and techniques and ignoring lean concepts and principles; however, following that methodology in LC implementation ends up with disappointing results.

Participants are then asked to identify the application frequency of each lean construction tool and technique in their construction projects. Participants' responses are displayed in figure 21.

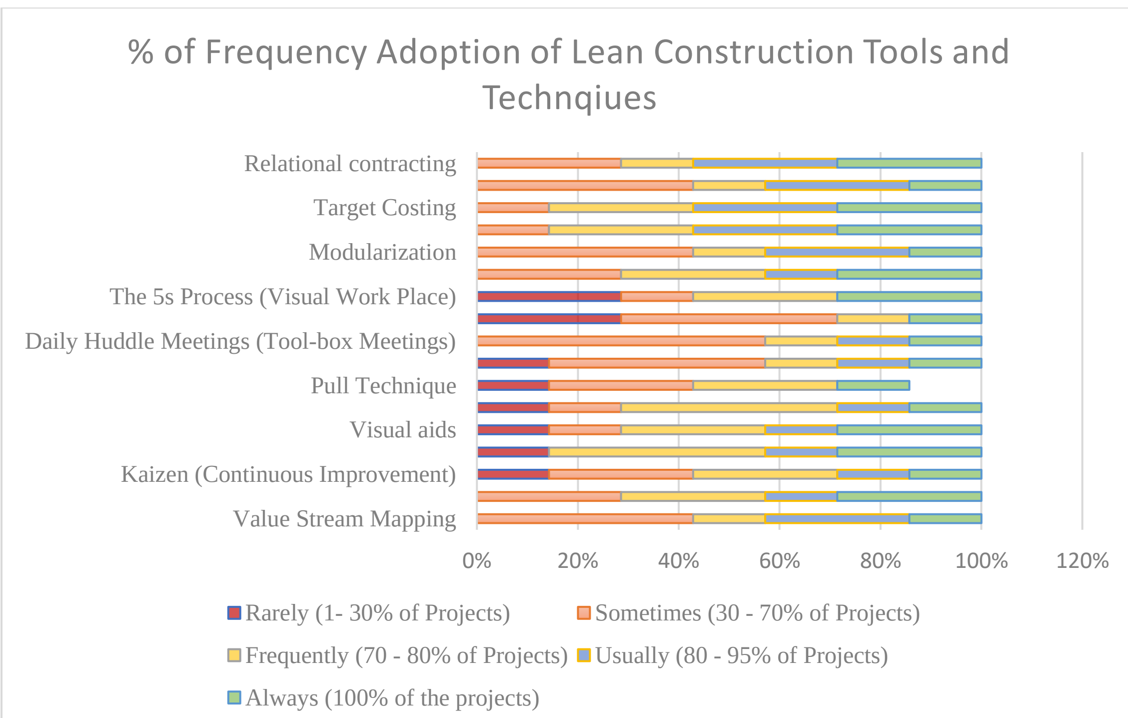

Figure 21. % Frequency Adoption of Lean Construction Tools and Techniques.

Results displayed in Figure 21 show that (1) Site layout design, (2) Last Planner System, (3) Visual aids, (4) The 5S process, (5) Poka-yoke, (6) BIM, and (7) Target Costing are the tools and techniques that are applied to all construction projects by 29% of survey participants. In plus, it is shown that (1) Pull technique, (2) Kaizen, (3) Last Planner system, which is considered as the foundation for lean construction implementation are rarely applied by some construction companies, which emphasize the fact that some companies are implementing lean construction tools without prior understanding of lean construction philosophy and principles. However, there is a need to mention that, due to the impossibility to statically validate the collected data, these data could be overestimated or underestimated, which means no exact interpretations could be drawn regarding the current status of the application of Lean application construction tools in the Lebanese Construction Industry. Results are anecdotal and could (or not) be indicative of underlying trends.

Participants were then asked to assess the impact of each of their applied lean construction tools and techniques on the project performance in terms of the project cost, schedule, and quality. Results are displayed in Figure 22:

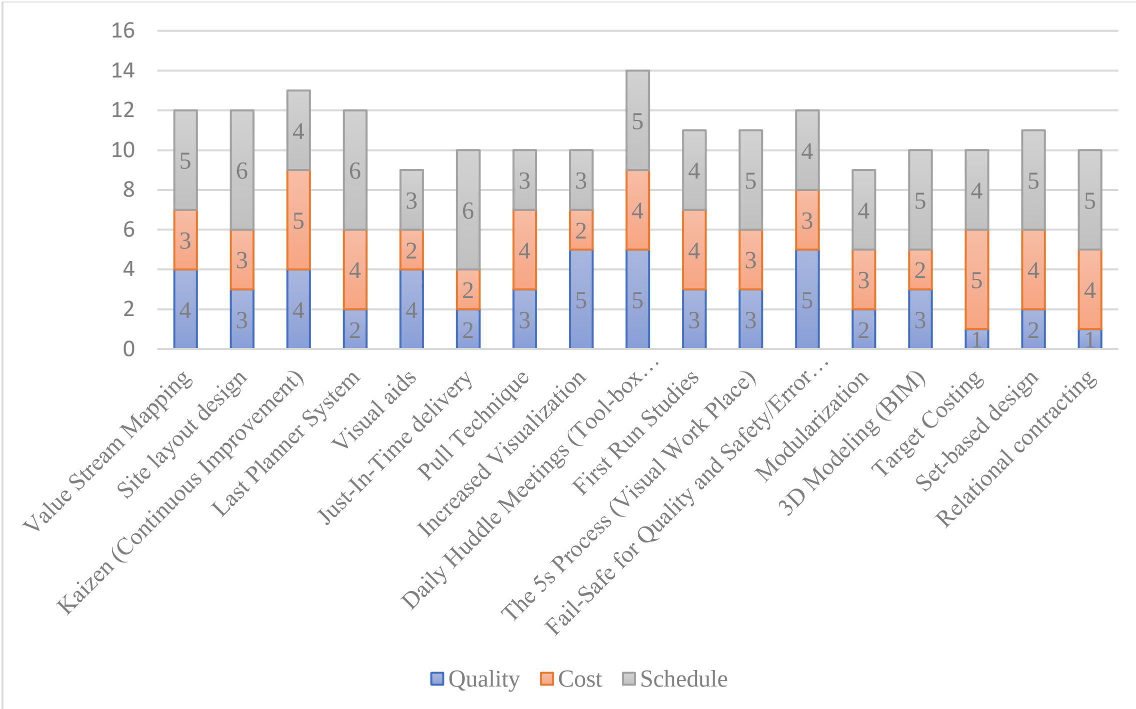

Figure 22. Impact Of Lean Construction Tools & Techniques on Project Quality, Cost, and Schedule.

Based on collected results, it has been shown that (1) Increased visualization, (2) Daily Huddle meetings, and (3) Poka-Yoke techniques mainly, impact project quality significantly; Project cost is seen to be highly impacted mainly by (1) Kaizen and (2) Target Costing techniques which emphasize the ability of both techniques to save costs. For the project schedule, it is seen as highly impacted by (1) Value Steam mapping, (2) site layout design, (3) LPS, (4) JIT, (5) Daily huddle meetings, (6) 5S process, (7) BIM, (8) set-based design, and (9) relational contracting. Based on collected results, it is shown that 9 out of 17 lean construction tools and techniques have a high impact on project schedule, which makes lean construction implementation a schedule-optimizer approach in the first place.

Analysis Key Barriers of Lean Construction Implementation from The Perspective of Lean Construction Implementers and Non-Implementers

In the final section of the survey, participants that work (ed) for lean construction implementer and non-implementer firms were asked to identify the key barriers they faced (for implementers) or may face (for non-implementers) when the decision of lean construction implementation has been taken (or will be taken). Results are displayed in figure 23 and figure 24, where barriers have been categorized into five barrier groups. Remark: The Symbol between the brackets in figure 23 represents the barrier group to which each identified barrier belongs.

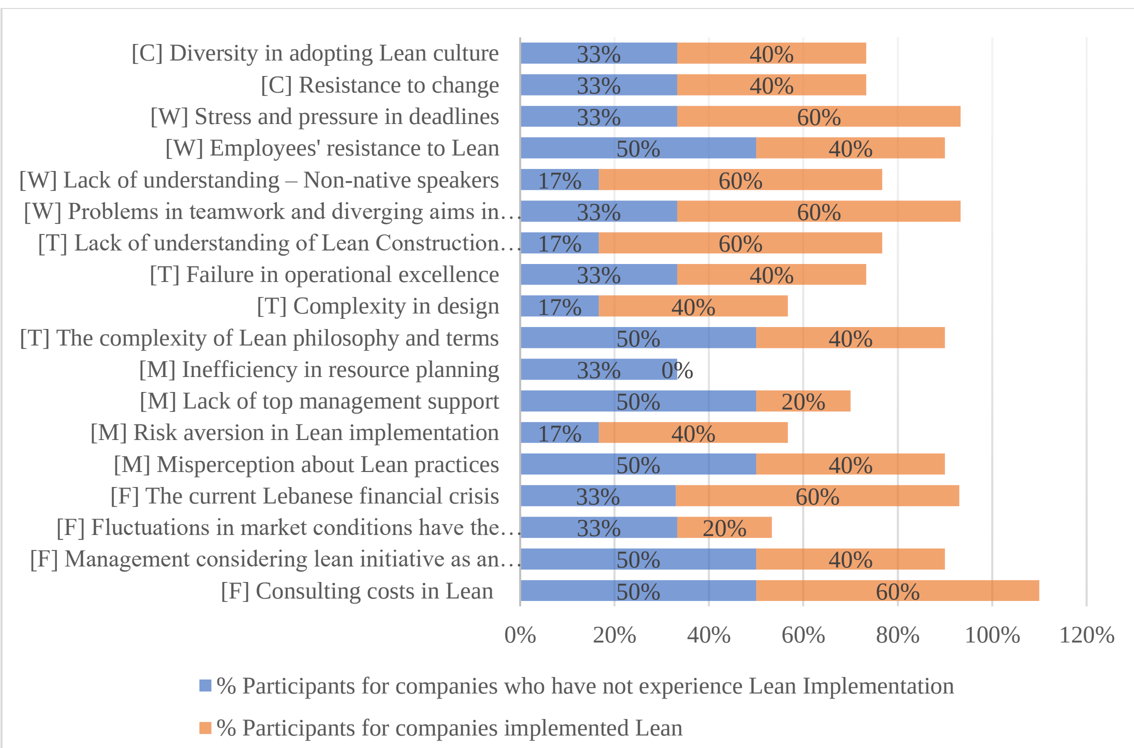

Figure 23. % Frequency Of Key Barriers from the Perspective of Lean Construction Implementers and Non-Implementers.

Based on collected results, it is shown that for some barriers, i.e., diversity in adopting lean Culture and resistance to change, both groups, implementers' and non-implementers participants, agreed upon as key barriers; for some other barriers, non-implementers participants have underestimated the impact of some barriers on the lean implementation journey, i.e., lack of understanding non-native speakers, lack of understanding of lean construction tools, etc.; while for some other barriers, non-implementers groups over-estimate the impact of some key barriers on the lean implementation journey, i.e. employees' resistance to lean, the complexity of lean philosophy ad terms, and inefficiency in resource planning.

Mainly, and as shown in figure 24, underestimation is found critical in the workforce and technical barrier groups, while overestimation is found critical in the managerial barrier group. These results should motivate non-implementers, first, to deepen their knowledge, (so any complexity in lean construction implementation is clarified and simplified), and secondly, to ask for external help from lean construction professionals to guide them along the lean implementation journey, acknowledge critical barriers they need to face, and to develop the right strategies to address each of them.

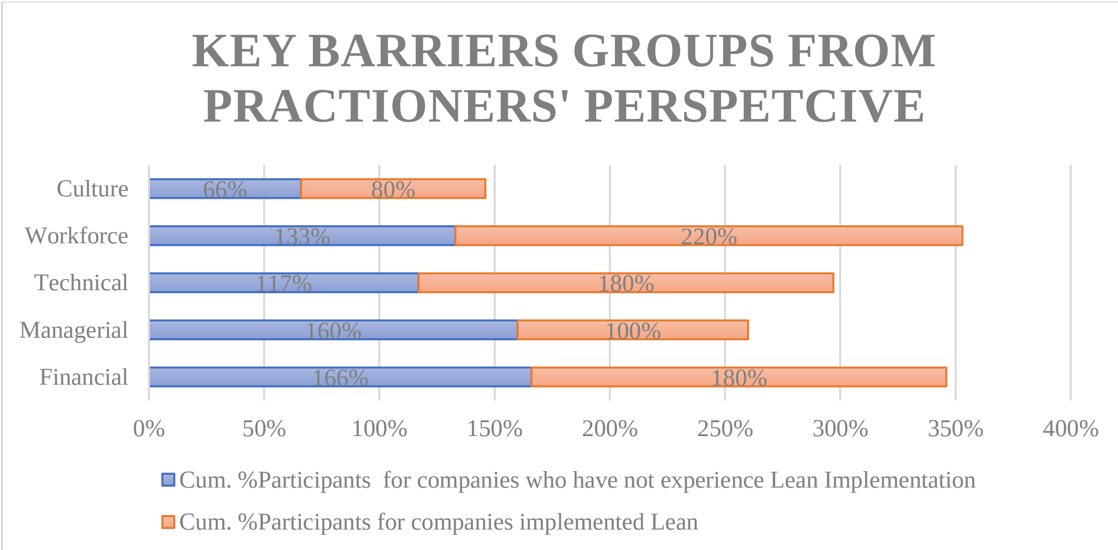

Figure 24. % Frequency Of Key Barriers Groups from The Perspective of Lean Construction Implementers and Non-Implementers.

To sum up, it is clear for now that the lean construction implementation exists in the Lebanese construction industry, as it is considered a mean to address waste-reduction and continuous improvement issues; however, a portion of the Lebanese construction firms lacks enough knowledge about the lean construction implementation, the fact that is manifested by adopting certain lean construction tools and techniques before developing the right level of awareness and understanding of lean construction philosophy, concepts, and principles. That makes raising the awareness and education level about lean construction a priority by the Lebanese construction firms who are willing to develop a competitive edge inside the Lebanese market.

CHAPTER 11

CONCLUSION & RECOMMENDATIONS

This study has major contributions in the domain of assessment of Lean construction adoption in the Lebanese Construction Industry and the domain of Lean Construction Implementation. In plus, it has significant implications towards addressing the lack of sufficient knowledge and familiarity with Lean Construction philosophy for construction professionals in general, and the Lebanese ones in particular, as has been revealed in the conducted survey.

This paper provides Lebanese leaders in the construction sector with an anecdotal assessment of Lean construction inside the Lebanese construction Industry through surveying to collect data, analyze, and assess Lean as a strategic option. Knowing that collected results cannot be statistically validated because of the small sample size in addition to additional factors (i.e., different levels of expertise of participants, no targeted sector in particular, and the economic crisis in Lebanon), the conducted survey helps leaders to have a basic understanding of the level of maturity of this philosophy within the Lebanese context, and how they could move forward in broadening its range of usability. It revealed that the lack of the right level of understanding of Lean principles and how they could be applied (i.e., the methodology) is the major gap of Lean implementation strategy followed by Lebanese firms. Results are anecdotal and could (or not) be indicative of underlying trends.

This paper contributes to the field of Lean construction Implementation by elaborating the integrated 4-stages Lean Construction Implementation Journey combined with a set of five keep performance indicators to assess the impact of Lean construction on project performance in terms of the project cost, schedule, quality, value, and waste.

In plus, it provides a step-by-step guideline for carrying out the Last Planner system technique for production planning and management. This tool has been discussed in terms of what should be done in each of its four stages (The Should, The Will, The Can, and The Did), and how to be done. This turns this paper into more of a technical paper to be used by new lean adopters.

RECOMMENDATION FOR FUTURE RESEARCH

The developed implementation guideline discussed in this study in Chapter 9 is the result of the integration of a set of practices, recommendations, and methodologies.

Therefore, future research is needed to examine this guideline as a mean to optimize it, using a Kaizen tool, like the Deming Cycle. For that to happen, a future researcher needs to (1) Place this guideline in the context of real projects, (2) Collect data regarding the impacts caused by this methodology of application, (3) Compare collected data with the recorded impacts of Lean Construction implementation on project performance (discussed in Chapter 4 - Key Drivers for Lean construction Implementation), (4) Refine the process either by adding, removing, or adjusting the sequence of actionable items or used tools and techniques, (5) Examine the adjustments made by place the guideline again into real projects, to end up with (6) standardizing it as an organizational methodology.

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APPENDIX A

KEY DRIVERS FOR LEAN CONSTRUCTION IMPLEMENTATION

Table 10

Key Drivers for Lean Construction Implementation (Dehdasht, 2020)

NO	**Drivers**	**Definition**
1	Improve scheduling	Scheduling promotes a decision that defines when and who will do the job or activity. Lean through principles (like Flow, value stream, and perfection) and techniques (like the Last Planner System) can improve the scheduling.
2	Improve planning	Planning is a decision for what, how and time estimate for a job. Planning of a job should be done before Scheduling a job or activity. Lean through principles (like Flow, value stream, and perfection) and techniques (like Last Planner System) can improve the Planning.
3	Global competition	Lean construction improves standards, quality, decrease in total cost, and shorten the project duration, helps the companies to be active in international markets.
4	More focused on organizational structure	Lean through the standardization, Improve the typically hierarchical arrangement of lines of authority, communications, rights, and duties of an organization.
5	Promote prompt and reliable delivery to the customer	Reliable delivery is the ratio of the number of deliveries made without any error (regarding time, place, price, quantity, and/or quality) to the total number of deliveries in a period. Lean can reach this objective through improving standardization and reducing waste via different tools such as JIT, LPS, First Run studies, etc.
6	Short time to fulfill customer orders	Implementing Value stream, Flow, and Pull principles lead to the company making the process flow, reducing inventories, and reducing the waiting time of products between the single steps of the production line
7	Promote ability in frequent changes in order by customers	Implementing Pull and Perfection principles can make a company flexible regarding the demand of the customer.
8	Meeting customer expectation	The principle of Perfection pursues to deliver exactly what the customer desire with regards to quantity and quality, at the right time at a cost-effective and with minimum waste, in which the real goal is zero waste.
9	Improve process control	Last Planner System (LPS) and Fail-Safe for Quality and Safety are effective tools of lean construction in improving process control within construction projects.
10	Improve the production capacity of the company	Lean construction through principles and techniques helps the project to reach the maximum level of output possible. Lean construction increases the production capacity by increasing efficiency and productivity. Efficiency improvements can often reduce utilization as more output is achieved with fewer resources in less time.
11	Reduce management levels	Lean construction attempts the structure of an organization to become flattered by reducing or eliminating the hierarchy which leads to a business encouraging better information sharing across the organization. Limiting the hierarchy also closes the traditional gap between management and workers, which reduces the friction that usually accompanies that gap. Rather than fixating on how to secure a promotion, workers spend their energy on maximizing their professional skills.
12	Increase market share	Market share represents the percentage of an industry or market's total sales that is earned by a particular company over a specified period. This advantage can achieve through price competition. Lean helps to increase market share through cost reduction.

13	Increase flexibility	Lean construction can increase the flexibility of the company through principles and tools wherein the company can respond to potential internal or external changes affecting its value delivery, in a timely and cost-effective manner.
14	Reduce high-labor-cost or labor requirements	lean decreases labor requirement by automation, improving process, standardization, etc.
15	Cost savings	Cost Savings are actions and methods that will result in the fulfillment of the objectives and at a cost lower than the historical cost. Lean Construction through perfection principle and also thorough the tools such as First Run Studies, Concurrent Engineering, KAIZEN, and LPS help in cost saving.
16	Cost reductions	Cost reduction is the process of looking for, finding, and removing unwarranted expenses from a process to increase profits without harming the product quality. The lean process helps to cost reduction through the elimination of non-value-adding activities.
17	Efficiency improvement	Efficiency is the comparison of what is actually produced or performed on what can be achieved with the same consumption of resources (money, time, labor, etc.). Improving efficiency is one of the main objectives of the lean process.
18	Optimization	Lean can improve optimization through finding an alternative with the most cost-effective or highest achievable performance under the given constraints, by maximizing desired factors and minimizing undesired ones.
19	Improve profit margin	Profit margin is part of a category of profitability ratios calculated as net income divided by revenue, or net profits divided by sales. Lean can improve profit margin by finishing the project on time, removing the wastes, improving efficiency, etc.
20	Mitigation project risk	The Last Planner System is an effective way that helps in mitigating risks. All possible risks can be identified through pre-planning and long-term planning and effectively treat risks during the project.
21	Competitive advantage	Lean can help the organization to be competitive by providing the same value as its competitors but at a lower price, or charging higher prices by providing greater value through differentiation. Competitive advantage results from matching core competencies to the opportunities
22	Improve-manpower productivity	Manpower productivity is the rate of output per worker (or a group of workers) per unit of time as compared to an established standard or expected rate of output that should be improved. Labor productivity can be improved through improve flow, improve planning, and standardization. Improving labor productivity leads companies to use less amount of manpower.
23	Multi skilling of the workforce	Promotes workers who have a range of skills or knowledge for working on several different projects, which may or may not be a part of the worker's technical job description. Lean through the training increase the multi-tasking of workforces which lead to improved flow, labor cost savings, reduction in required workforce, and increase in average employment duration.
24	Improve capabilities	Capability is the measure of the ability of an entity (department, organization, persons, and systems) to achieve its objectives, especially in relation to its overall mission. Standardization is one of the best ways to improve this capability.
25	Promote skilled workers	Lean through Training of workers affects them to become knowledgeable about a specific skill or profession.

26	Commitment to self-action teams	Lean philosophy attempt to remove problems without referring to management through discussion and exchange of views within members of the team in or direction to where the team goes. This is an effective way that helps managers to focus more on important problems.
27	Continuous Improvement	Continuous improvement is defined as a culture of sustained improvement targeting the elimination of waste in all systems and processes of an organization. Continuous improvement is a core component for implementing the perfection principle.
28	Improve safety	Lean construction can improve safety through different principles and tools such as Value Stream Mapping, Flow, Perfection, 5S, LPS, Fail-Safe for Quality and Safety, etc.
29	Enhanced organization reputation	Organizational reputation has been defined as the ability of the company to deliver improving business results. Lean construction through perusing value-adding, meeting customer expectations, removal of waste, on-time delivery, etc. can promote organization reputation.
30	Facility of understanding the concepts of lean construction	Understanding the concept will cause a positive effect over time and enhance the management process of the projects. Throughout the concept, waste elimination and value enhancement in a construction project will be defined. This approach can make the process of implementing activities in the project in a systematic, organized, and effective manner.
31	Promote awareness of some or all of the tools and techniques	Being well-informed about tools and techniques helps in choosing the right tool, in the right place and at the right time that seeks to accomplish project goals.
32	Employee autonomy	Autonomy in management is allowing a great deal of freedom to employees to control their work situation. A manager who allows the employees to have autonomy generally lets the employee decide the best way to achieve the project goal. Lack of employee autonomy led to staff members feeling dissatisfied. Traditionally, only employees in upper management have much autonomy, but lean process through standardized work procedures, improved organization structure, and reduced or eliminated hierarchy has helped to improve employee autonomy.
33	Improve Low-quality material/parts by suppliers	Lean construction through defining supply planning and controlling, and standardized work procedures can ensure the quality of materials.
34	Improve on-time delivery by the supplier	The efficiency of the supply chain process is measured by on-time delivery. This advantage can be achieved by the specification of the resources and supply planning; issuing and transmission of purchase requests; transport and receipt of the goods at the construction site; maintenance of the supply forecast in the planning (control and reprogramming), Improve Value Stream Mapping, using Kanban tools, and close commitment with supplier.

35	Improve supply reliability	Confidence in a supplier's ability to deliver an acceptable product at the required time that will satisfy the customer's needs. This can be achieved by defining supply planning, standardizing the work procedures, commitment with a contract on a long-term run with long-term contracts, train suppliers, sharing of ideas between supplier and buyer, etc.
36	Reduction in inventory	This can be achieved through using Just in Time practice which suggests the delivery of raw materials at the exact time they are necessary, for the work in process or finished goods. This helps companies for better utilization of resources and reduces material inventories along with the production systems.
37	Reducing spare parts inventory	This advantage can be approached through a combination of some techniques such as Fail-Safe for Quality and Safety, Kanban, and JIT. Fail-Safe for Quality and Safety as a detective function that prevents defective in the process as early as possible, Kanban to demand-forecast, and JIT to deliver spare parts in the exact time that is needed.
38	Improve coordination between supplier and company	This can be achieved through training of supplier, Using Daily Huddle meeting techniques, supplier support by company; sharing of ideas between supplier and buyer; working in a rational framework with the supplier; etc.
39	Reduce lead times	Improve flow, improve value stream, improve planning and scheduling, using 5s techniques and concurrent engineering, etc. leads to decrease lag times.
40	Redesign of processes	First Run Studies use in projects to redesign critical assignment, are actually a part of the continuous improvement effort. This tool is based on productivity studies and reviews the methods of work by redesigning and streamlining the different functions involved
41	Improve the commitment of employees	Employee Commitment is the psychological attachment and the resulting loyalty of an employee to an organization. Improve commitment of employees, improve of team working and information sharing can be attained within the training. Moreover, improving the structure of an organization by lean process, reducing or eliminating the hierarchy, using Daily Huddle Meetings tools and continuous improvement can be effective in improving the commitment of employees.
42	High-product variety	Lean process through organizing the process, standardizing the work, improving efficiency and productivity can help the companies to be flexible in producing a high variety of products for customers.

43	Improve workplace organization	To improve workplace organization, 5S is the best tool which is also called the organization method. 5S presents how to organize a workspace for effectiveness and efficiency by detecting and storing the items used, maintaining the items and area, and sustaining the new order. Usually, the decision-making process is concentrated on standardization, which improves understanding between employees of how they should do the work.
4	Improve standard operating procedures	Standardization is a core element within lean construction which has been defined as a procedure specific to an operation that describes the activities necessary to complete tasks in accordance with industry or construction regulations, or even just the company's standards for running a business or project. Standardized work is a method of defining an efficient work process that is repeatedly followed by workers. An important goal of standardized work: eliminating wasteful motion and peruse continuous improvement.
45	Reduce steps of project's life cycle	Reducing steps of a project's life cycle is an effective way to reduce lead time and also reduce waste. Lean method through value stream mapping, standardized the work, eliminating non-value adding, improving planning, etc. can help to reduce the steps in projects.
46	A stronger focus on performance	The lean method attempts to improve performance at all levels of a construction project. The lean process tries to identify the key factors that affect project performance. All lean principles and tools have strong effects on performance.
47	Improve process layouts	The lean process can improve process layout through the value stream mapping principle and 5S tools. Improving layout help to improve flow within the project and decrease transportation waste and reduce lead time.
48	Improve self-criticism	Self-criticism means the action of finding one's faults and shortcomings. This led to a clear view of projected problems and the unlimited capacity to learn from errors since only part of the problem was perceived. Lean process attempts through training improve self-criticism among employees and decrease the hierarchy of authority within the projects.
49	improve transparency among team	Transparency has been defined as the ability of a production process to communicate with people. Lean construction through training and improve flow can help to promote transparency within the projects. In this regard, the tools such as 5S, Kanban, Daily Huddle Meetings, and Increased Visualization can help to improve transparency.

50	Reduce leadership conflict	Leadership conflicts are defined as friction or opposition between leadership resulting from actual or perceived differences or incompatibilities. The lean process can decrease this conflict through training, promoting standardized work, and improving team working and information sharing. Tools such as Daily Huddle Meetings and LPS are effective in preventing leadership conflicts.
51	Improve team working	Team working means a culture that workers or employees work collaboratively with a group of people to achieve a goal. Team working is a key component of lean construction. Team working can be achieved through training the employees, improving the structure of the organization, standardizing the work, and encouraging the employee to commit. The tools such as 5S, Daily Huddle Meetings, and LPS are effective for improving team working.
52	Improve company culture	Culture is a key component in the successful implementation of the lean method. Company culture can be defined as corporate culture pertaining to the beliefs and behaviors that determine how a company's employees and management interact, handle or overcome problems encountered. Generally, scholars claimed that implementing lean principles and techniques allows people to experience lean and act as a vehicle for the cultural shift of the whole organization (Bortolotti et al., 2015).
53	Improve trust	The meaning of trust is reliance on the integrity, strength, ability, surety, etc., of a person or group of people that lead to an improved team working. Implementing lean principles and techniques generally leads to improve trust within the employees and manager. Furthermore, lean training, standardized work, the structure of an organization, improving self-criticism, and improving communication helps to improve trust. The tools such as Daily Huddle Meetings are effective in communication and finally improve the trust.
54	Improve information sharing	Efficient information sharing is an effective way to increase the knowledge level of the entire organization. Information sharing also help to identify value through customer feedback and forward the information to the product company. The lean method aims to create a transparent organization so that everything can be seen by everyone. This is made possible by visualizing, like the visual planning tool which is the most effective way for communication, information exchange, and progress management. Furthermore, Value Stream Mapping (VSM) methodology is useful for the Flow of information.

55	Motivates employees and shapes their behavior	The lean method can improve motivation through the structural organization, organizational commitment, improve team working, and improve transparency. Furthermore, through training programs and carefully designed communication, it should be possible to manage employee motivation for and interest to Lean. In addition, the other factors that can help to improve motivation in implementing lean construction are self-criticism and Multiskilling of the workforce. 5s, Kaizen, and Daily Huddle Meetings are effective tools that can improve the motivation of employees.
56	Improve housekeeping	Lean process through the 5s can clean up an organization of the workplace. The 5s process (sometimes referred to as the Visual Work Place) is about “a place for everything and everything in its place”.
57	Increase employee morale	The lean method can improve employee morale through training, standardize the work structural organizations, organizational commitment, improve team working, and improve transparency. An intense focus on productivity can often lead to legal, moral, and ethical compromise.
58	Government policy and regulation	Government Policy and Regulation can encourage the company to implement lean construction (for example give loans for lean implementation) can help to meet up standards required in construction projects and also achieve sustainability.
59	Reduction air pollution	Lean process through improvement on the supply chain system, improve value stream, improve planning, leads to decrease life cycle of a project and decrease transportation and movement wastes. Decrease in transportation and movement waste means using less petrol and decrease in producing CO_2. In this regard, the JIT and prefabrication tool are influence tools for the reduction in motion and reduction in pollution.
60	Keep environment through reduction construction waste	The main goal of lean principles and techniques is waste reduction through enhanced planning and controlling, improve design, decrease the life cycle of projects, and improve the efficiency of the process. These practices help to reduce material usage and also reduce the reworks which lead to a reduction in construction waste that highly affected environmental pollution. In this case, prefabrication is an effective tool that helps to control construction waste.
61	Reduction in material usage	Lean construction is a “way to design production systems to minimize waste of materials, time, and effort to generate the maximum possible amount of value," (Koskela et al., 2002). Many material wastes are related to overproduction which the quantity is greater than required or earlier than necessary. In this case, the Pull principle and JIT tool are very effective in preventing the overproduction of wastes. LPS, 5S, prefabrication, and Kanban are other effective tools.

62	Water efficiency	Lean process improves the supply chain system, improves the efficiency of process, decreases the variability, decreases non-value-adding, improves value stream, improves planning lead to the decreased life cycle of a project. These practices tend to use less equipment, decrease process time, waiting for time, transportation, and movement wastes which cause less energy (fuel and electricity) consumption. Value Stream and Pull principle, JIT, LPS, 5S, prefabrication, and Kanban tools can be very effective.
63	Reduction in energy consumption	Lean principles and practices have a key role in reducing waste such as water-consuming during construction or workplaces. Lean construction through redesigning the process, improving the design, planning, and control, and using new methods within the construction try to decrease material usage such as concrete. Using less material means using less water. Pull principle, JIT, LPS, 5S, prefabrication, and Kanban are very effective in this matter.

APPENDIX B

THE TOYOTA WAY MODEL FOR THE CONSTRUCTION INDUSTRY

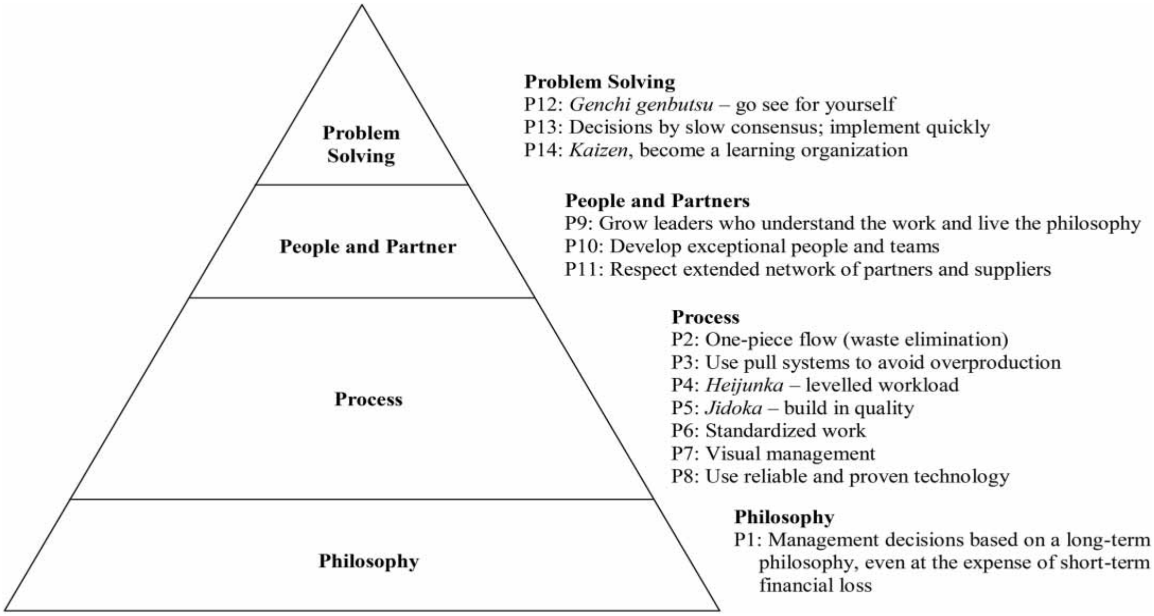

Figure 25. The Toyota Way Model (Source: Liker, 2004).

Table 11

Implementation Guidelines for Sub-Principles of The Toyota Way 'Philosophy' Model In Construction (Gao and Low, 2014).

Sub-principle	Implementation guidelines
P1: Management based on the long-term philosophy	
• Constant purpose	• Sustain a constant purpose, which aims to generate value towards employees, society, and customers
• Long-term perspective	• Develop a long-term vision and make a plan to achieve it • Long term philosophy supersedes short-term financial loss
• Self-reliance and responsibility	• Be self-reliant on core technology, and promote research and design for strong backup • Be responsible for what has been promised to employees, society, and clients
• Customer-focus	• Defining value from the viewpoint of customer • Contractor is often able to refocus and reorganise to meet changing customer requirements

Table 12

Implementation Guidelines for Sub-Principles of The Toyota Way 'Process' Model In Construction (Gao and Low, 2014)

Sub-principles	Implementation guidelines
P2. One-piece flow	
• Waste elimination	• Process optimisation • Efficient logistics plan • Material JIT delivery • Minimise double handling and workers and equipment movement • Reduce defects • Other forms of waste elimination using the remaining principles in this category
• Uninterrupted workflow (i.e. *takt* time, space utilisation, etc.)	• Synchronise the sequence and rate of material, components delivery with the sequence and rate of construction, installation, etc. • Ensure adequate working areas are always available • Balance crew members
P3. Use pull system	
• Pull from customer end (including both internal and external customers)	• Schedule material JIT delivery directly to the point of use
• Use *kanban* tool	• Using simple devices or tools to indicate the re-ordering level
• Pull planning methods	• Pull tasks through the schedule by determining what each sub-contractor/trade needs completed before the tasks commence • Ensure that tasks only commence when preceding tasks are completely completed and all necessary resources are available
P4. Level out the workload (*Heijunka*)	
• Level out the workload	• Use of the LPS: four levels of plans • Seek commitments from foremen or subcontractors to perform a given work task by a specified time • Huddle meeting: to remove constraints that would affect the evenness of workload
P5. Build-in quality	
• Stop and fix the problem	• An in-process inspection plan is in place to prevent rework • Reveal and solve problems at the source as they occur
• Use of error proofing	• Designers are encouraged to use standard design elements and feature • Suppliers are encouraged to make or modify products to facilitate error proofing • Construction firms are encouraged to standardise process
• Employee involvement and empowerment	• Cultivate the culture of 'build-in quality' by active employee involvement and empowerment • Motivate employees to take responsibility for quality
P6. Standardised work	
• Standardised operation procedure (SOP)	• Use of clear, easily accessed, and up-to-date written SOP on certain processes (i.e. define the content, sequence, terms, and expected results)
• Continuously improve standardisation	• Encourage engineers, foremen, and even workers to make contribution to the new standards of current process

Sub-principles	Implementation guidelines
• Standardised materials, components, etc	• Greater use of standardised material, components and pre-assembly
P7. Use visual control	
• Visual control systems to value-added work	• Use of visual tools to highlight schedule status, quality, safety, etc. to workers • Use of visual tools to highlight traffic logistics, material storage, working zone assignments, etc. to workers • The posted information should be regularly updated and visible to most workers
• Practice of 5-S	• Make the jobsite clean and organised and storage orderly • Tools and construction materials should be stocked and organised
P8. Use of reliable technology	
• Thoroughly test new technology	
• Technology must support people	
• Technology must improve the workflow	
• Technology must support the company values	• Construction firms should also follow this guidelines in adopting new technology, if any

Table 13

Implementation Guidelines for Sub-Principles of The Toyota Way People and Partner Model In Construction (Gao and Low, 2014).

Sub-principles	Implementation guidelines
P9. Leader and leadership	
• Leadership commitment	• Management must commit to live and understand the company's values
• In-depth knowledge	• Leaders must have in-depth understanding of work (at the project level) and have problem-solving skills
• Support the people doing the work	• Leaders must be able to constantly provide solutions to their subordinates
• Coaching ability	• Project personnel are encouraged to provide training sessions to help employees, suppliers, and customers
P10. Develop exceptional people and teams	
• People selection	• Meticulous screening system (i.e. vocational or technical training required) for recruiting excellent candidates
• Training	• Provide training at all levels and keep skills up to date, including: (1) pre-job training (2) on-the-job training (OJT) (3) off-job training (4) multi-skills training
• Work teams	• Employees coordinate their work with others to complete the whole task.
• Motivation	• Rewards for constructive ideas, feedback, and opinions that result in improvement
P11. Partner relations	
• Length and stability relationship	• Establish long-term and stable relationship
	• Achieve small base of suppliers
• Challenge	• Respect working partners by setting challenging goals, objectives, etc.
• Collaboration	• Work with suppliers, subcontractors, and owners to improve project effectiveness
	• Encourage suppliers'/subcontractors' early involvement in the design stage
• Communication and information exchange	• Timely and transparent information exchange and problem solving through suggestions

Table 14

Implementation Guidelines for Sub-Principles of The Toyota Way Problem-Solving Model In Construction (Gao and Low, 2014)

Sub-principles	Implementation guidelines
P12. *Genchi genbutsu*	
• Go and see for yourself	• Leaders must be committed to *genchi genbutsu* • Leaders must possess the skills to analyse and thoroughly understand the situation
• Based on personally verified data	• Think and speak based on personally verified data (i.e. through direct report)
P13. Decision-making and quick implementation	
• 5 'Whys'	• Ask questions multiple times until the root causes surface
• Alternative solutions	• Encourage workers to propose alternative solutions from the bottom up
• Practice of consensus	• Encourage workers to express their ideas, suggestions, and disagreements, and thus to achieve consensus
P14. Reflection (*Hansei*) and continuous improvement (*Kaizen*)	
• Attitude towards problems	• Management should see problems as opportunities for improvement
• *Kaizen* activities	• Conduct *kaizen* activities for better improvement
• Reflection	• Reflection on strengths and weaknesses of the current process, project, etc.
• Policy deployment	• Project manager sets clear and achievable goals that all the team member are working for