Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Economics and Management
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Management

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Assessment of maturity level of applying lean construction tools in construction industry

Master's thesis in Project Management
Supervisor: Olav Torp
June 2020

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Preface

This study has been conducted in fulfilment of my master's study in the field of project management at NTNU in fall 2019. Construction has not still reached perfect condition due to existing numerous causes such as cost and time overrun, low quality of material, low efficiency, the huge amount of waste, etc. in which result in low productivity, poor safety, and insufficient quality. It is incumbent on academics to find an innovative solution to turn this situation around. Many believe that failing in adopting new philosophies and technologies, fragmented value chain; extensive subcontracting, and coping with complexity are contributory factors to exacerbate the situation.

Lean Construction has been introduced as one of the efficient methods to ameliorate this situation. The lean construction is composed of an advanced set of tools for maximizing the performance from the customer perspective by eliminating non-added value activities as much as possible. Recently construction managers put a lot of attention to values; they tend to provide the highest values for the owner while increase net profit.

In general, when we implement lean tools in construction projects we supposed to achieve the following goals: easier to control, a higher degree of safety, smoother implementation, accomplish sooner, more cost-effective and improved quality. However, embedding lean construction tools in the organizations and companies is difficult and challenging due to introducing new strategies both in the cultural and operational levels. This research struggles to evaluate the maturity of lean construction tools among all construction companies and organizations.

It was approximately 10 months ago that I was expected to choose a topic for a master thesis. Based on my academic background and experiences I decided to assess the development of lean construction tools in the construction companies, and what are the challenges during the implementation of lean. The main idea arose when I was studying the suggested topics by faculty and I understood lean management is aligned with my desire and knowledge.

I would like herby to show my great gratitude toward people who gave me their unconditional support during doing my master's thesis. My special thanks go to Olav torp my supervisor, and I sincerely believe that working under Olav's guidance is one of the best moments that I experienced in Norway.

Finally, I am thankful to my family: my father and mother who provided everything in order to fulfil my goals.

SUMMARY

The construction industry is always struggling with chronic problems such as time and cost overrun and having proper quality. Contractors are always worried about uninterrupted decreasing in margin profit and sustainable development in the competitive market. Therefore, there is a high eagerness among construction companies to embrace one of the newest construction philosophies called “lean construction” instead of a traditional management approach.

The lean construction approach is derived from the lean production concept, which its purpose is contributed to achieving the highest efficiency and effectiveness by reducing, not necessarily eliminating, all waste or non-valuable activities throughout the whole process. Two different visions exist about the ways we could get the most advantage of lean construction. The first interpretation is about the application of lean production methods in the construction industry. Second, consider lean production as a basis to formulate a constructive methodology for the construction called lean construction. Transformation, Value, and flow are considered the basic principles of lean construction (Koskela, 1992).

Sustainability of construction was the issue that led to paying more attention to lean construction tools due to concentrating on the removal of waste. This priority helped to lean construction tools to evolve faster than the past. The objectives of this study were to measure the integration level of lean construction tools in organizations and companies. Moreover, this study struggles to identify the significant challenges for successfully implementing lean construction.

Although it is really hard to distinguish the extent of lean thinking’s effect on the project outcomes, this study tries to address research questions by carrying out an in-depth literature review and interviews.

Keywords

Construction industry, Waste, Lean construction, Challenges.

Abbreviation

AEC	Architecture, Engineering and Construction
CE	Concurrent Engineering
CIFE	Centre for Integrated Facility Engineering (CIFE)
ICT	Information and communication technology
IP	Involverende planlegging
GM	General Motor
LC	Lean Construction
TPS	Toyota Production System
TDV	Target Value Design
TVF	Transformation-Flow-Value
LPDS	Lean Project Delivery System
LPS	Last Planner System
PDCA	Plan Do Check Act
UM	Uncertainty management
VSM	Value Stream Mapping

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1 INTRODUCTION

This section will show the framework of a study that illustrates the pathway and background for the Master thesis. The first part of the chapter starts with a general background. The problem statement will be presented further, followed by research objectives. Lastly, the chapter ends with an overview of the master thesis.

1.1 Background

The Construction industry can be counted as one of the historical industries since human beings started to civilize. As it is clearly seen this industry involves large numbers of other industries, using huge amounts of raw materials from different resources (Goldhaber, Jha, & Macedo, 1977). We should pay attention there is a trend that shows construction projects tend to be more complicated and risky recently. Complexity is an instinct characteristic of a construction project. Many key factors such as cost inflation, safety issues, newly strict demands and standards, shortage of skilled labour, cutting-edge technologies, etc. are contributed to increasing the complexity of projects. Empirical data, which has been revealed recently, shows high interaction between arising complexities and project cost. A deep understanding of complexity is vital for all contractors because it could affect project planning and control and simultaneously influence project organisation. (Li et al., 2008).

The construction industry is inherently project base, where repetition can not be beneficial and contractors try to avoid it as possible. The construction site is like a low volume but a high variety environment in which equipment, workforce, and materials should be brought on it since the final product is ready for delivery. (Errasti et al., 2009) Therefore, Construction Companies need to find a reliable solution to guarantee their progress in this competitive market.

However, there are some common problems in all construction projects such as low productivity, poor safety, inferior working conditions, and insufficient quality. Low productivity demotivated companies to start new projects. The inferior working condition leads to the shortage of workforce. Construction projects were traditionally optimized by each activity and presumed client value is highly dependent on the design phase and could be maximized that stage.

Many solutions had been developed to improve effectiveness and productivity but it was Koskela's idea that made a huge change in this industry. Koskela believed construction should be considered as production process. The idea was that the construction site is the same of temporary production line and it shows lean construction. In simple words, Koskela used the

concept of production philosophy to the construction industry. The main goal of this attitude is defined as decreasing losses by improving the control system during all processes. Moreover, management could be applied not only in the overall state of project but also in detailed subtasks. "Lean production" prepared uninterrupted progress in the production process by eliminating different kinds of waste. Different types of waste could be seen in projects such as time, cost, reworking, transportation, improper decision, making defected products. (Lee 1999, Koskela 1992). However, a few of waste were addressed or defined properly by construction management during construction phases. There are underlying reasons to justify the mentioned problem, but uncertainties and lack of appropriate tools to identify waste played substantial roles. Traditional ways are not effective to differentiate between value-adding and non-value adding activities. With applying of lean construction approach, results regard to management and deliverables were improved in the way that they were tangible and considerable (Koskela and Howell, 2002).

1.2 Research objective

Hypothetically, many lean construction tools are contributed to solving chronic problems of construction. These problems could be originated from two significant causes. The first reason returns to having a traditional approach regarding designing, production and implementation. The second reason refers to organization and management. The decisions made on the early stage of the project life cycle could affect much more than during later stages, as shown in figure 1-1. Project sponsors or owners take these decisions often; therefore, the necessity for involving all stakeholders is essential for transferring from a traditional approach into modern methods.

The main goal of lean thinking is to define the waste first and after that isolating them in the further process. To address the mentioned issue, this research aims to evaluate to some degree lean principle, thinking and tools contribute to construction projects and analyse previous researches about the application of lean construction tools during construction projects. Plus, five interviews have been conducted to highlight the role of lean construction tools in the construction industry. However, lean tools are not as means just for eliminating a group of actions or procedures, and simply believe that we are doing lean management. Creating change without considering a whole system brings about more waste. Thus, taking a deeper look into the efficiency and consequences of lean techniques could enable us to handle better lean construction tools.

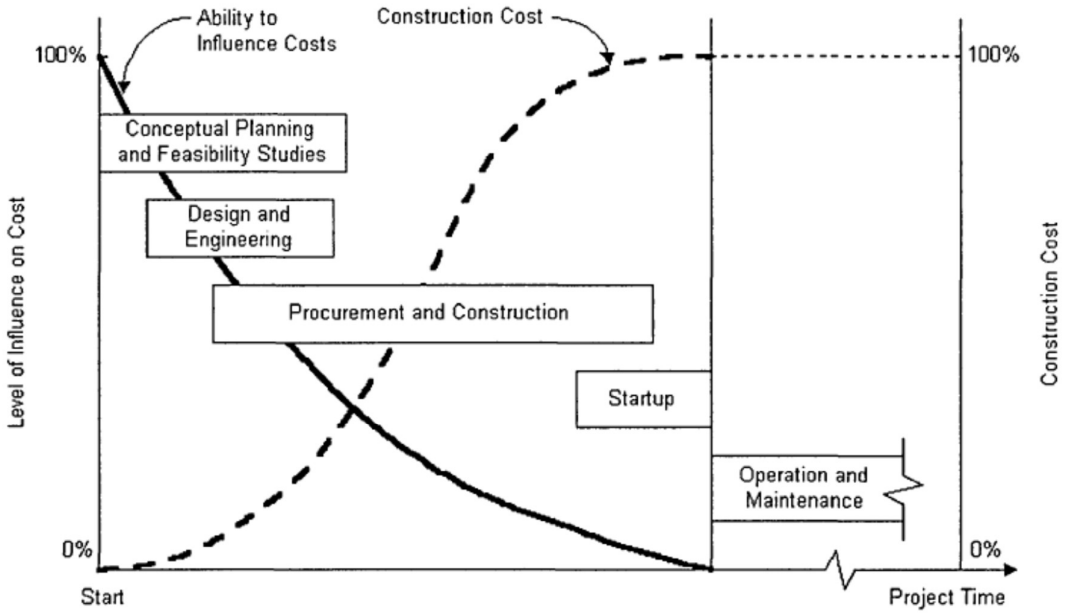

Figure 1-1 Ability to influence cost over time (Hendrickson, Chris,2000)

The main question that this research is looking forward to answering is:

To what extent construction companies are mature when it comes to implementing lean construction tools? In light of this, how we can evaluate the current level of lean construction in the construction industry?

1.3 Research questions

In order to respond to the above question, it will be converted into different questions.

1- What is meant by lean construction? Can LC concept be utilized as a conceptual solution to minimize waste?

2- What are the most common used lean construction tools, and how they affects the project performance?

3- Which types of waste we have in the construction industry and how they are produced?

4 What are the challenges for implementing lean construction tools?

5- Have the construction companies adopted lean construction techniques in their routines?

1.4 Hypothesis and delimitations

Based on the research goals, this study should set some assumptions. First of all, due to restricted semester duration, this study tries to narrow down the best articles and choose more relevant information to the main subject. Secondly, it was assumed all the collected information from different sources are unbiased, valid, and accurate.

This research just considers companies that are located in Norway; therefore, results are based on their specific working environment and rules. The result of this study does not represent all the projects and companies in Norway which lean thinking has been executed because of time and place constraints.

As it is clear, competitions between construction companies are increasing. Therefore, every company is supposed to use many techniques like Lean construction tools, BIM, agile, etc. which leads to having synergic effects in reality. The unique contribution of this study attempts to provide insight into the impact of lean construction tools on the project performance. Overall, the synergic effects of other techniques will be neglected and this study just focuses on lean construction tools.

1.5 Master's thesis structure

In the following, a short overview has been provided to get a better understanding of chapters.

Chapter 1 shows an initial introduction for the subject, motivation, problem, and research question. In addition, the research gap and the importance of study are stated shortly.

Chapter 2 will represent a theoretical body of knowledge, related literature review for lean construction and its root that originated from TPS. Next, it identifies different kinds of waste in construction and various types of lean techniques. Furthermore, it indicates the application of lean tools in reducing waste in construction projects.

Chapter 3 refers to an adapted research methodology for thesis and how suitable is it for the desired answer. It also contains the research questions, the validity of assessment and limitations.

Chapter 4 is devoted to the collected data of interviews in which the significant contents are summarized, and it includes tables to demonstrate tangible information. The dominant purpose of this chapter is to answer the sixth and seventh research questions.

Chapter 5, in particular, presents discussion regard to all findings and assemble all the outputs together. Lastly, obtained data elaborately interpreted and this study addresses all the research questions briefly.

Finally, the drawn conclusion and recommendations for future work, based on the analysis of obtained data will be presented in **chapter 6**.

2 Literature review

2.1 Brief History of lean

The severe problem in the Middle East led to a serious energy crisis from 1967 until 1979. The oil price experienced unprecedented high jump caused a shock to the global market. The global recession was one of the consequences of increased oil price. Actually, the Japanese economy experienced stagflation and went on the verge of bankruptcy. Whiles, there was not any clue for breaking down Toyota Company, on the other hand, prosperity was the thing that attracted the attention of other companies. This disparity between Toyota and other companies made other company's bosses be inquisitive about the incredible growth of Toyota (Ohno, 2013).

Before this slump, signs began to appear, no company was interested in manufacturing technology and production system of Toyota Company. However, after that they changed their minds to the Toyota approach. They surprisingly decided not only to alleviate the economic crisis but also to get the most benefit. The main question is what differs Toyota from other companies in this economic crisis. The answer is simply the Toyota production system (Ohno, 2013).

2.2 Toyota production system

It just began by the late 1940s, when the Japanese industry needed to rebuild after world war II. Japanese industries suffered from financial and skilled worker crises, which are well-known as subtle initial motivations for the Toyota production system. After finishing the war, Toyota continued with 3000 persons without any desirable condition for workers. Although the financial crisis obliged Toyota Company to lay off (Liker, Der Toyota Weg, 2014).

Simultaneously Toyota's labour union started to strikes in late 1949 in order to postpone laying off. Undoubtedly, if there was not an agreement between labour union and Toyota company, this situation would have been worsened; probably caused bankruptcy for Toyota. Eiji Toyoda (a cousin of Kiichiro Toyoda) who was newly chief executive officer after resignation of his cousin arranged a searching journey with company's managers to the USA for visiting and assessing production site of General Motor (GM) and ford to take advantage of their success factors in order to improve own production system (Liker, Der Toyota Weg, 2014).

They understood the production system had not been improved since 1930. They did not decide to copy their production system, actually, they wanted to analyse what is going on in those companies. The numerous amount of intermediate products that had been piled in a specific

way. For example, they found many disruptions during production procedure that led they had a lot of material be stored in bad condition. The defected products could not be easily identified due to overproduction in those companies. This investigating team saw a huge amount of resource waste within manufacturing (Ohno, 2013) (Liker, Der Toyota Weg, 2014).

Toyota motor company introduce a new method for its production system after World War II in order to revive in the competitive automobile market (Womack, Jones, & Roos, 1990). For example, one of the measures that Ohno implemented is: Instead of having a foreman and normal workers, he divided workers into the different teams and assigned team leaders for each of them. Workers have been told how to collaborate to get the best results and team leader was responsible for coordinating and assembly job. Also, each team had been given housekeeping, repairing and quality- checking tasks. Ohno motivated the team to think deeply about how they could improve mass production by identifying errors and tracing them to eliminate. Truly, he understood the importance of stopping rework in terms of rectification work and time. Toyota Company managed to rebuild its structure with TPS faster than other companies in Japan after global recession due to the oil crisis in 1973. This made Japanese government paid more attention carefully to this company for discovering reasons for prosperity.

“The machine changed the world” published by Womack, Jones, & Roos (1990) introduced world to the word of lean, which focused on studying of TPS. Unnecessary movement, excessive transport, Overproduction, additional processing, extra inventory, Waiting time, newly ineffective employee and defects were specified as seven waste in TPS. Having quality service which leads to customer satisfaction was the aim of TPS.

The following picture designed by Fujio Cho, shows Toyota production house that consists of roof, pillars and base. Every part assists other elements. Just in time and jidoka are two pillars for the house, where levelled production, stable and standardized processes with visual management provide a base for the house. TPS includes a group of lean techniques such as just in time, 5S, etc. that emphasize on the persons and every element of the system to increase ceaselessly values of the procedure.

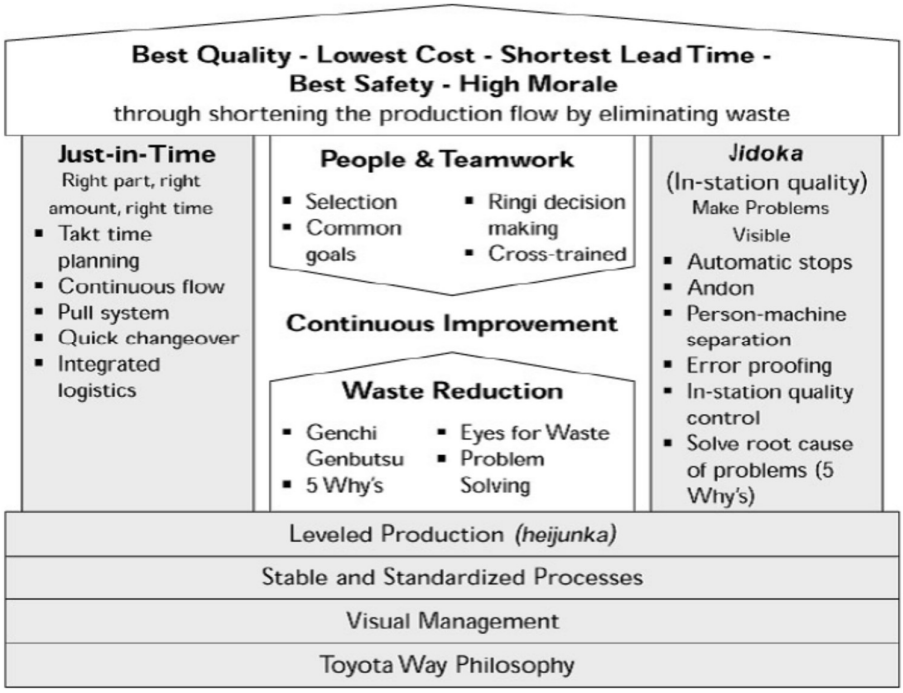

Figure 2: Toyota production system house (Liker , 2004, p. 49)

2.3 Lean thinking

Lean thinking derived its name from the bestseller book called "The Machine That Changed the World" The Story of Lean Production (by Womack, Jones, & Roos ,1990). This book wrote down the history of transferring automobile manufacturing to mass production and finally lean production. It chronicles how Henry Ford regulated car elements and assembly techniques; therefore, cheap cars were made by amateur labours and advanced machines. The book tells a story about how mass production provide a better base for the cheaper cars but unfortunately faced overcrowding workers in different sections such as engineering, management, etc. Then the book shows how Toyota Company took advantage of mass production to stabilize its position in the recession period. It should be considered that Toyota Company utilized this method first when japan was struggling with a huge demolition after world war II.

Five substantial principles of lean thinking were presented by James P. Womack, Daniel Roos, and Daniel T. Jones in their book as the following:

- Specify the desired value from the customer perspective
- Mapping the value stream. The value stream is about all necessary actions should be done to provide product for customer with considering antidote for waste.

- ❖ Make the value flow continuously by eliminating non-valuable activity and adding valuable activities
- ❖ Implement Pull
- ❖ Pursue perfection

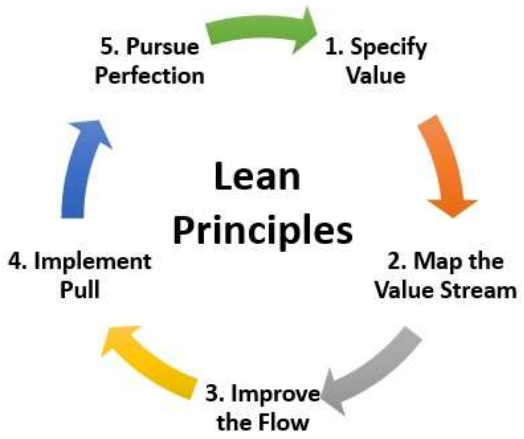

Figure 3: 5 Principles of lean thinking

The five key lean principles are assumed as an important recipe to ameliorate the efficiency of the workplace. In the subsequent sections prepare a detailed overview of each principle:

2.3.1 Value

The first and most vital lean principle starts with a detailed understanding of value. Value is always clarified by the needs of the customer. Womack and Jones stated that values could be identified by the end customer and it is only understandable in which they are defined as a product. The value is the thing that a customer is willing to pay to get it. They could be like services, goods or both in one, which meets the customer's need with limited price at a particular time(Womack and Jones, Lean Thinking, 16).

This principle encourages manufacturer to find who the real end-user are and what those customers consider as value. This specific view is different from the traditional approach where values are defined by the department, organization and engineering standpoint. Conducting value helps an organization to make a top-down target cost. Therefore, companies could concentrate on eliminating waste to increase value for the final customers. It is largely common that sometimes customers are not able to envision what they really are looking for or need especially when it comes to innovative technology and modern tools. There are obviously many

techniques to help to find values for customers such as doing interviews with people, surveys, analyzing the data and estimations. According to the above definition, activities could be divided into two parts: value-added activities and non-value added activities. Value-added activities as endeavors invest in converting inputs to outputs that customers need. On the other hand, non-value added activities are related to endeavors spend on converting but they do not bring value for outputs in the customer's standpoint.

2.3.2 Value stream

When the unique value has been defined, in the next step, all the potential processes that are engaged from concept to delivering the final product to the customer should be mapped. Activities that do not add any value to the final product are regarded as non-valuable activates. The value stream mapping is the most efficient procedure that refers to conducting the minimum number of value-added activities and without any non-value added activities. The activities that do not add value to end customers are considered waste. Actually, the non-value added activities could be spilt into two parts: non-valued added but necessary and non-value & unnecessary. The last one is totally waste and should be eliminated whilst the other one could be decreased as possible. The value stream is " specific activities required to design, order and provide a specific product from concept to launch, order to delivery, raw material into the hands of the customer" (Womack and Jones, Lean Thinking, 311). The value stream allows the lean team to find out how value runs through the project and more beneficial, where it gets stuck.

2.3.3 Flow

The third principle is called flow, after eliminating all the waste from the value stream, the following step is to guarantee that all remaining actions flow smoothly without any delay, interruption, and bottlenecks toward the end-users. It could happen through precise analysis and rational measure such as having a cross-functional view through all departments, excellent work break down, masterfully distributed workload, etc. this process should be checked by the manager to prevent possible delays, bottlenecks and lead to a more efficient and effective process. Some of the add-value activities could be appended to ameliorate the process.

2.3.4 Pull

One of the biggest challenging issues for the waste is inventory in all production processes. Many organizations use a push system that leads to stockpiling to meet the future needs of the customer.

On the other hand, the pull system has been paid a lot of attention in lean thinking. This principle helps to ensure that nothing will be produced ahead of time by prediction until the costumer order it. The pull is identified as “a system of cascading production and delivery instructions from downstream to upstream activities in which nothing is produced by the upstream supplier until the downstream customer signals a need” (Womack and Jones, Lean Thinking, 311). In the pull system, tasks should be analyzed and put in an order to implement, probably a priority list could be considered as an upward step for queuing. At the end, products do not be made in advance as well as materials for stockpiling. Toyota Company applied this manner during the recession period. Therefore, they managed to save money for all stakeholders.

2.3.5 Perfection

The idea behind perfection is constantly improving and implementing meaningful change, which is integrated with organizational culture. In this step, employees should put a lot of effort into optimization while delivering the output to the customer. In practice, these substantial lean principles act as a cycle. As the lean team strives to perfection, they seek to analyze each process to increase value and eliminate waste. Perfection can blossom in an organization if every employee has a commitment to his or her duties.

2.4 Different types of waste in production

Lean Production is a systematic manufacturing operation utilize for eliminating waste during the process. Lean production is about to reduction of waste in terms of all aspects of production not only materials. The waste could be reduced consists of waste time due to procedure, for example, they take longer than necessary and implementing time. However, eliminating waste is not the only goal of lean, but also increases the speed and quality that are engaged with lean production.

Taiichi Ohno(1988) introduced seven types of waste within the value stream study. The seven waste is originated from Japan, where waste is called “Muda”. In the following, they categorized waste in TPS in seven types:

- **Overproduction:** With regarding, that waste is not anything that customer is going to pay for it; it is simply understandable why overproduction is Muda. Overproduction normally happens when there is no demand from customer and manufacturing exceed of demand that has been asked which finally leads to extra cost. Actually, there is obviously clear that overproduction implicates in the other six types. Hence, if there occasionally is an imperfection during overproduction, it means whole reworks should be done.
- **Inventory:** it is hard to think that excessive inventory is seen as waste because in accounting it is observed as assess and often suppliers provide a discount for bulk buying. In such cases, companies overstock themselves in order to meet unpredicted demand, any potential production delay, etc. although it should be considered that every extra inventory leads hidden costs for the organization. It includes: increasing lead-time, occupied more productive space and maintenance costs.
- **Defect:** It happens when the products do not work or fit properly. This common issue results in either throwing away or rework. In addition, inspection is done at the end of the production process that is too late for detecting. Thus, quarantining inventory, rework, reschedule and resource waste lead to extra cost for the customer without any add-value activities.
- **Transportation:** unnecessary moving of resources (people, equipment, inventory, etc.) do not bring add-value activities for customers. Excessive transport just results in damaged products, deterioration and time-consuming. Often waste of transportation obliges organizations to cost more for time, storage and machinery.
- **Motion:** the waste in motion involves unnecessary motion of the workforce or machinery to leave their work and bring material or reach what is needed to complete their task. For instance, it includes: walking, bending, reaching, lifting to get material or search in documents and files.
- **Waiting:** when products and goods do not move and wait until other processes finished; the waste of waiting occurs. On the contrary, the flow of production should be continuous and smooth.
- **Over-processing:** it refers to using inappropriate techniques, expensive machinery and doing more work than what is required by the customer. It means adding extra value to the product that a customer does not pay for it.

After utilizing lean thinking in the Toyota Company, the benefits were easily seen. Especially after the recession period in early 1980, all the companies tried to adopt this paradigm to eliminate waste and increase productivity.

With growing waste and decreasing the profit margin in the civil industry, Koskela decided to take advantage of Lean thinking in order to solve these chronic problems.

"Application of the New Production Philosophy to Construction" Published by Koskela (1992) that shows the application of Lean thinking and TPS in civil projects and the necessity of embracing the lean concept in the civil industry.

2.5 Lean construction

Emerging of a new philosophy in TPS was the initial base for revealing lean construction. In contrast to other methods, that were introduced for manufacturing in the civil industry earlier but refused because of being ineffective, Lean construction managed to gain positive results.

The transition of lean principle and adapting into construction industry began in the early 1990s through studies by Koskela (1992), Ballard and Howell (1994).

Koskela understood that there is hidden potential for using fresh managerial philosophy in development to ameliorate the outputs in the AEC industry. In 1992, when Koskela was working in the Center for Integrated Facility Engineering (CIFE) at Stanford University introduced the basic first Lean construction as well as classifying weakness of traditional construction management into three groups, Ignoring quality control, fragmented control and sequence of project realization, and assert that recent managerial model is unfruitful.

Koskela indicated the following eleven principles as a foundation for lean construction that they contribute to heighten efficiency for flow process design and improvement. Koskela states that they have a connection with each other and finally show them in one word, value-added activity.

1. **Reduce the share of non-value adding activity:** non-value adding activity includes activities that just use time, money, place and resources without bringing any advantage for the whole project. therefore, deducting in non-value adding activities could be a forward step in improving efficiency and ameliorating the flow process.
2. **Increase output value through systematic consideration of customer requirements:** costumer needs could show values. Thus, the organization should put a lot of effort to meet the customer needs in order to increase effectiveness.
3. **Reduce variability:** variability is the intrinsic nature of construction projects.

Outsourcing, especially from different countries, other imported high techniques are the paradigm of variety in civil construction. Reducing the variability definitely helps to better project performance and achieve a reliable workflow.

4. **Reduce the cycle time:** measuring the cycle time is easy and understandable. Koskela introduces the following method for estimating the cycle time:

   Cycle time = Processing time + inspection time + wait time + move time (Koskela, 1992)

   By compressing cycle time through different approaches such as eliminating work-in-progress, etc., reduction in cost is clearly tangible. In the following figure, it is depicted:

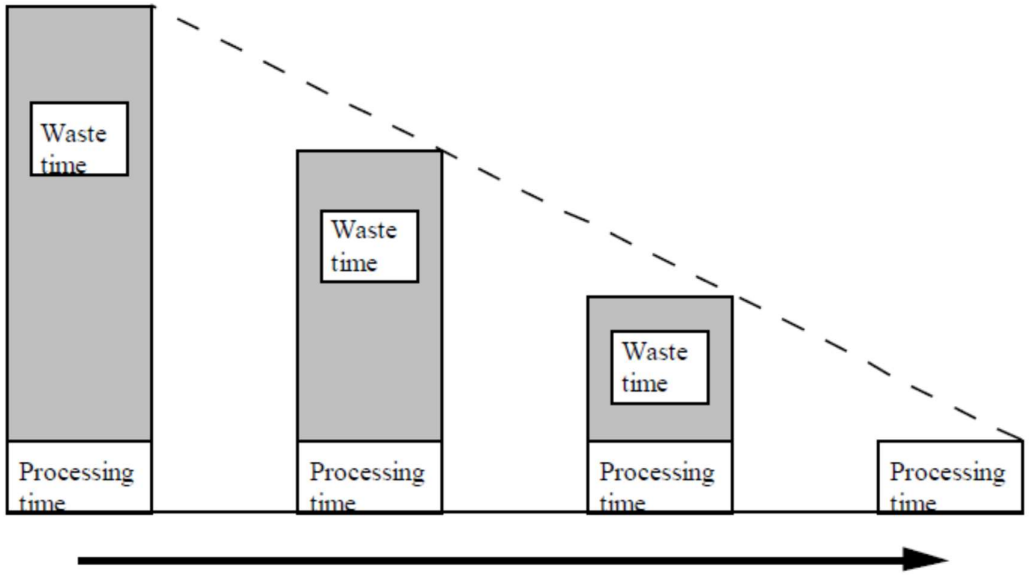

Figure 4: Cycle time compression (Koskela, 1992, Figure 4, page 20)

5. **Simplify by minimizing the number of steps and parts:** there is a direct correlation between the complexity of the procedure and rising cost. The more complex is a process, the more difficult it is to realize the whole parts and flow. In this situation, probably utilizing WBS is a smart technique to simplify the ongoing processes and eliminating non-add value activities.
6. **Increase output flexibility:** Koskela (1992) stated that utilizing modularized product design, decreasing the hardship of transition and setups; in addition, training a multitasking labor helps to increase the flexibility.

7. **Increase process transparency:** this step can be executed with process organization, to make sure being understandable and observable for all of the employees. Knowing about the control process and its implementation is vital in every project. The goal of this principle is to assure that the construction process is transparent and distinguishable to facilitate overseeing and develop employee's skills.
8. **Focus control on the complete process.** It is advised by permitting the independent group to supervise all the procedures, and making fruitful cooperation with suppliers and team building will optimize the overall workflow.
9. **Build continuous improvement in the process.** The effort to improve the product through a continuous investigation is highly recommended in the lean principle. Actually, lean thinking encourages manger to search always for fault or find a way to smooth the process than before. Doing this principle results in eliminating waste and increase add-value activities.
10. **Balance flow improvement with conversion improvement:** hereby conversion means utilizing cutting-edge technology and new techniques that need new investment. There is a direct correlation between conversion and flow. Because the optimized flow leads to better control in order to apply conversion technology simply. Therefore, all of the alternatives for developing flow should be assessed and then continues with optimizing through conversion.
11. **Benchmark:** this concept involves understanding weakness, strength, threats and opportunity of organization. In this approach, you are completely familiar with your processes and attempt to find the best one in the market to compare with. Everything could be compared with the competent such as leaders, performance, progress, incorporating, etc.

All of the above principles will be used for a gradual improvement framework to evaluate the production system. For every concept, which is introduced lately, should be defined as a set of complementary measurements that helps to implement the whole idea completely. These measurements could be divided into two parts: one is suitable for actual status and the other is related to the future. A quick look into traditional measurement demonstrates their weaknesses:

1- Continuous improvement is ignored and does not prepare indirect cost means that change concentrating point (Koskela, 1992, (Johnson & Kaplan, 1987)).

2- Data collection is a big problem specifically when it comes to using in the computerized system (Koskela, 1992, (Plossl, 1991, p. 189)).

3- Measurement acts as local improvement more rather than global (Koskela, 1992, (Umbel & Srikanth, 1990, p. 270)).

However lean is highly interpretive, it can be observed its measurements were built based on more than cost and time aspects and evolved to support the core idea of lean. The measurements should be easy to understand and result in a better flow process. In the following, measurements will be includes:

- Frequency of all main and peripheral processes
- Various kind of waste and effectivity of solution in order to deduct waste
- Concentrating on the initial reason instead of outputs
- Insist on the transparency during the whole process to get fruitful feedback at both local and global levels.
- Identifying variability and attempt to decrease it
- Decreasing non-added value works and if it is possible to add value activities
- Continuous monitoring of performance to detect any entropy in workflow

In order to better integration and implementing lean philosophy, the following key factors should be considered: Having open-minded persons in the top management and they are eager to utilize new techniques, Employee engagement, Evolving and estimable focus on the improvement.

2.6 Waste in construction

Construction waste is commonly defined as solid waste that includes surplus materials from new construction, refurbish and demolition of buildings and other structures (Kofoworola and Gheewala, 2009). Obviously, a huge amount of waste, which is derived by the construction industry, has brought about a negative effect on the economy and environment. Almost waste are been produced through the whole lifecycle of construction. Around 35 % of industrial waste belongs to construction waste (Solís-Guzmán, J., 2009).

Based on the estimation of the US Environmental Protection Agency (EPA), approximately 136 million tons of construction were produced in 1996 (Esin, T., Cosgun, N. 2007). With the emerging new construction philosophy, the definition of waste changed. Not only in lean

construction, solid waste is counted waste but also non-added value activities over the construction period are considered waste. In other words, these types of waste (non-added value activities) occur through the construction process. Koskela and Alsehaimi (2008) indicated that weak project management was the substantial and main cause for the delay in construction projects.

Totally, a huge amount of waste or non-added value activities has been discovered but it is very demanding to estimate and measure it precisely. Figure 5 compares percentage of time waste in manufacturing and construction (Aziz, Hafez, 2013).

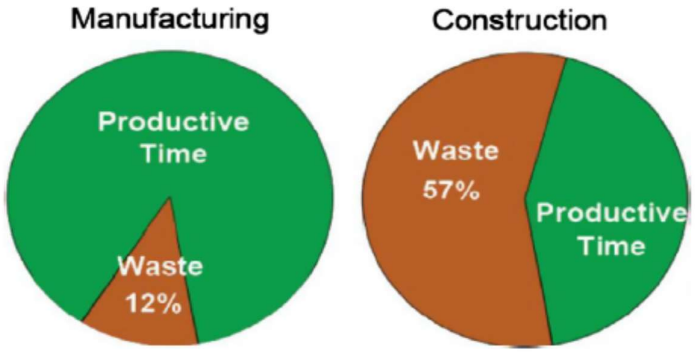

Figure 5: Percentage of time waste in manufacturing and construction (Aziz, Hafez, 2013)

Formoso et al. (1999) asserted that it seems that people, who work in construction industry, assume that waste is related to collected losses, which throw out of the site and disposed in the landfill. In addition, they believe it is the result of being easy to look and estimate.

Alarcon categorized waste in three distinct groups, which are contributed to management, conversion and flows activities.

2.6.1 Types of waste

Polat et al. analyzed different roots of waste related to the Turkish construction industry and ranked them. They divided waste into 7 groups and consequently identified 34 factors that associate with waste generation.

waste group	waste factors	Overall ranking	Importance Level
Design and contract documents	Errors in contract documents	21	M
	Design and construction detail errors	2	H
	Design and detailing complexity	19	M
	Frequent design changes and change orders	1	H
	Selection of low quality materials	10	H-M
waste group	waste factors	Overall ranking	Importance Level
Procurement	Purchasing materials not complying with specifications	15	H-M
	Suppliers' and/or shipping errors	25	M
	Mistakes in quantity take-offs	11	H-M
	Over allowances (i.e., difficulties to order small quantities)	6	H-M
Handling	Damage during transportation to site/on site	23	M
	Materials supplied in loose form	27	M
	Unnecessary material handling on site	32	M
Storage	Improper storing methods	17	H-M
	Inappropriate site storage area leading to damage and/or deterioration	18	M
Workers	Damage caused by workers due to lack of experience	9	H-M
	Workers' mistakes during construction (i.e., poor workmanship)	7	H-M
	Too much overtime for workers (i.e., time pressure)	29	H-M
	Use of incorrect materials resulting in their	4	H-M

Site management and supervision	disposal		
	Unused/leftover materials and products on site	13	H-M
	Waste from cutting uneconomical shapes	2	H
	Scarcity of equipment	26	M
	Inappropriate construction methods	8	M
waste group	waste factors	Overall ranking	Importance Level
Site management and supervision	Congestion of the site	21	M
	Poor lighting of the site	34	M
	Delays in passing information on types and sizes of materials to be used	14	H-M
	Lack of supervision	5	H-M
	Lack of on-site material control	31	M
	Lack of waste management plans	33	M
	Lack of environmental awareness	20	M
	Damage caused by subsequent trades	30	M
External	Weather conditions	15	H-M
	Unpredictable local conditions	24	M
	Damages caused by third parties	28	M
	Theft and/or vandalism	12	H-M

Table 1: Suggested categorizing and ranking of waste (Polat et al., 2017)

2.7 Lean techniques and tools

Undoubtedly, implementing lean construction approach in practice without any organizational knowledge and adequate perception about lean principles is not practical. However, it is substantial to note that there are many construction firms, which try to achieve their goals by implementing the lean principles. Different types of lean techniques and tools have been proposed after introducing TPS. The lean techniques and tools play an important role to identify and reduce waste in construction projects. Each of them has specific features that affect positively on the process and workflow. Ideally, a set of lean techniques should be applied to facilitate achieving the highest level of performance in construction projects.

Many authors carried out researches to evaluate and compare the efficiency of lean techniques. Salem et al. (2006) conducted a study to find out differences between lean construction tools and lean manufacturing tools. In addition, they suggested a method to evaluate each technique precisely, so they provided a checklist that consists of many criteria for tracking improvement in projects. Li et al. (2017) tried to measure the extent level of implementing lean tools in two different chines firms; they examined 6 types of lean tools and 26 factors. Value is been known as one of the most significant principles between other principles in lean thinking. Generally, lean techniques and tools are being utilized to detect value activity and eliminate waste (Tyagi, S, 2015).

Salem et al. (2006) approved the positive influences of implementing lean techniques in construction. They showed project was accomplished three weeks earlier than due time and under a specified budget. In addition, stakeholders were more pleased with their relationships. Moreover, they introduced an assessment tool for tracking improvement for all projects.

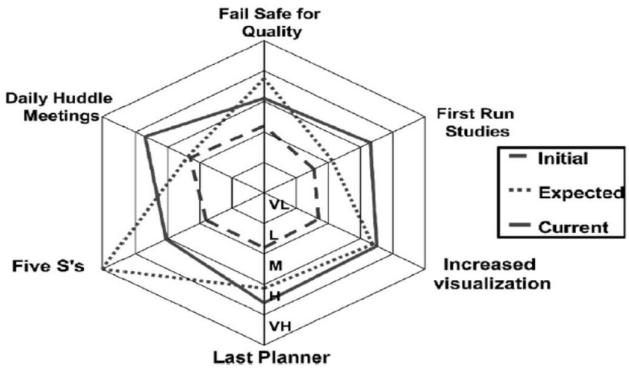

Figure 6: lean assessment tool (Salem et al. 2006)

In this respect, a number of tools that are commensurate to this study including the project delivery system, last planer system, etc. will be explained in the following.

2.8 Lean project delivery system

Glenn Ballard introduced the lean project delivery system (LPDS) in 2000. It sounds like philosophy, not only helps customers to understand better decision and operation but also supports end-users to find what really they are looking for. Aziz et al. (2013) stated the Lean Project Delivery System is a set of interdependent functions, rules of decision-making, procedures for execution of functions, and as implementation aids and tools, including software when appropriate, and is a conceptual framework developed by Ballard to guide the implementation of lean construction on project-based production systems. Ballard decided to design four main phases for this system: Project definition (what they want to accomplish and limitation to achieve goals), lean design (performing designing from initial concept to decision for the fund or no), lean supply (receiving approved design and providing measures to run the project), lean assembly. Ballard based on his personal experience related to failing in realizing the goal of project decided to add another phase, which is named lean use. The last phase includes end-users value.

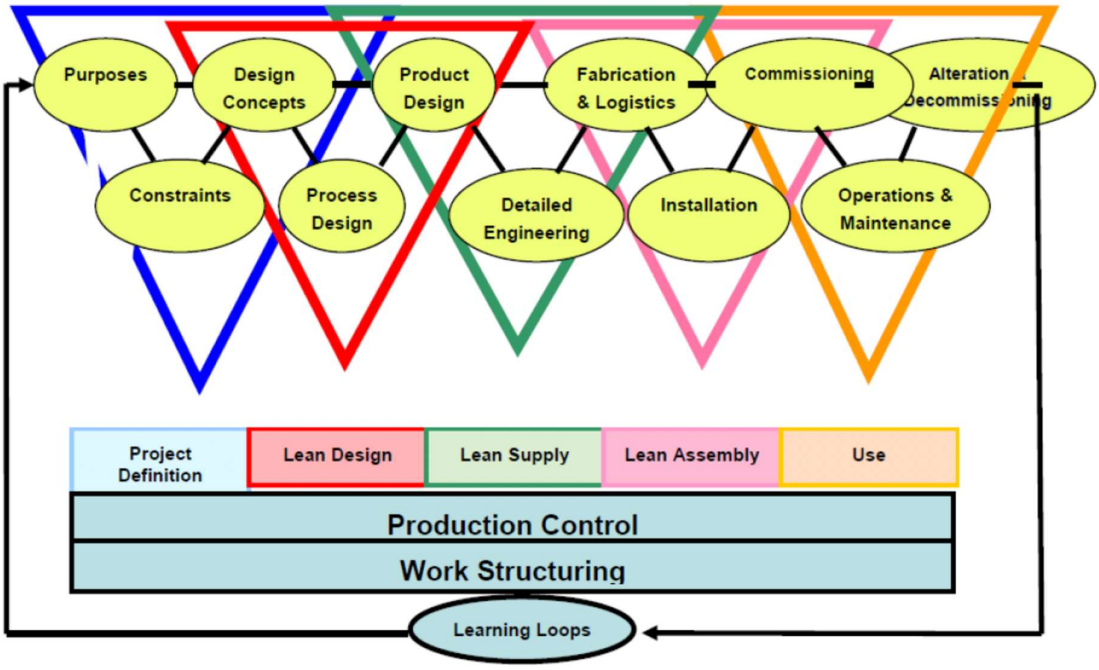

Figure 7: Lean Project Delivery System (Ballard, 2008)

Every project phase gets involved with work structuring and production control. Work structuring means breaking works into the small tasks to assure being smooth workflow. Production control emphasizes on the following workflow to manage sub-work professionally.

Therefore, some features that contribute to characterize LPDS will be declared in the following:

- The project is organized and administrated based on generating value.
- Early engagement of final customers to frond-end phase through cross-functional team
- On the contrary to the traditional system, a pull system is used to elicit information and procurement
- Alternatives should be used to guarantee streaming production system

2.9 Last planner system

Last planner system of production control is the full name of this technique and last Planner® is a registered trademark of the Lean Construction Institute. The last planner system is lean techniques for improving tight scheduling and controlling detailed complex plans. It is a holistic managerial approach, that helps to run construction projects efficiently. The principles of this tool make sure that each stakeholder such as contractors or subcontractors are able to accomplish their task completely based on the schedule and this technique emphasizes accountability. Simply as its nickname suggests, a system that gets all the last planners, the people who are specifically responsible to accomplish their task, involved to collaborate to avoid any potential risk that acts as a bottleneck.

The last planner system was created and developed by the founder of lean construction institute, Glenn Ballard and Greg Howell, in the 1980s.

LPS is made up of five levels:

1. Master Scheduling
2. Phase Scheduling
3. Look Ahead Planning
4. Commitment Planning
5. Learning

2.9.1 Master scheduling:

The first step in LPS starts as soon as possible that should create a professional schedule that shows workflow through the entire project. It includes:

- Milestone: the deadline for delivering each project phase
- Master planning: each task and deliverable will be connected to a special day
- Defining the goals of the project

2.9.2 Phase Scheduling

In the second step of the last planner system, a detailed plan for executing a particular phase of the project be defined. This is normally conducted a few months before the implementation phase. Often pull techniques will be used to accomplish this phase, in other words; work is planned based on the customer's need.

The project's workflow is described and the planning process will be done through a collaboration involving last planners and determine how long each task will take to be delivered based on their complexity. Therefore, we have more concrete planning at this stage.

2.9.3 Look Ahead Planning

The third part of the last planner system focus on making work-ready. In addition, last planners check each task to ensure a responsible person has enough necessary resources to complete them. In addition, they identify barriers and limitations in advance to remove obstacles. The 'look-ahead planning' meeting happens for the deliverable, which is supposed to be completed four to six weeks from the date of the meeting.

2.9.4 Commitment Planning

During the fourth stage, all last planners have to regularly meet and discuss weekly upcoming work. During the meeting, every responsible person should confirm that every work will be done on due time and if there is a problem, all the last planners try to tackle the issues and refine the program as it is possible. Tracking the expectation probably could be as a success factor in this stage.

2.9.5 Learning

Basically, it occurs immediately after the completion of work. The teams argue about how they achieve their goals and what were the challenges during implementation, what they have been

taught and how they take advantage of it in the next step, for example, how much time should be allotted to tasks in order to accomplish them.

The following figure shows the result of applying LPS in the construction project in which it obviously illustrates the improvement in term of productivity and cost-effective.

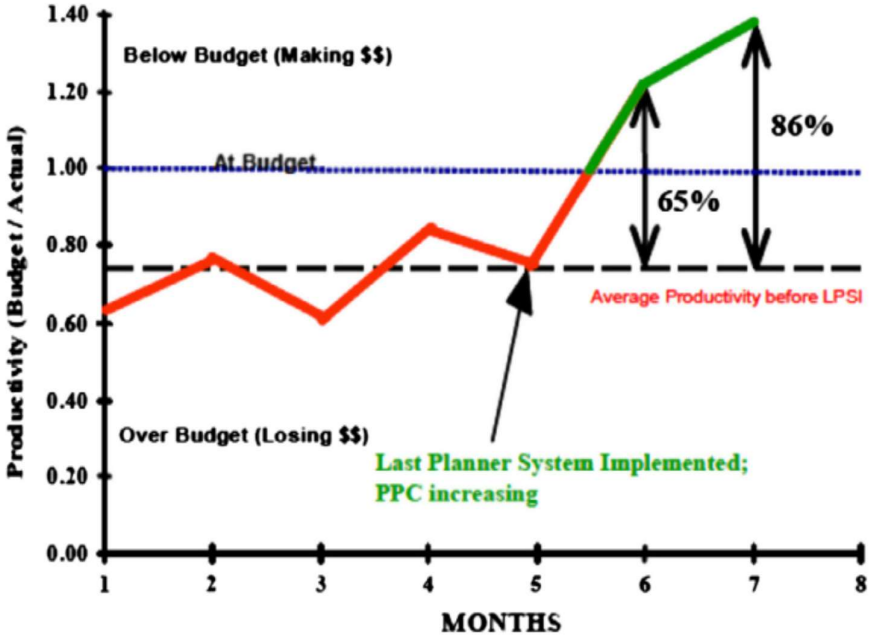

Figure 8: Productivity improvement using LPS (Aziz, Hafez, 2013).

2.10 5S system

The 5s system is described as a lean manufacturing tool that helps to have a better visual workplace in terms of cleaning, organizing and safety, so work can be done efficiently, effectively and optimized. It refers to five Japanese words Seiri (Sort), Seiton (Set in order), Seiso (Shine), Seiketsu (Standardize) and Shitsuke (Sustain).

- **Seiri**: distinguishing between required tools, materials and parts and unnecessary things. Moreover, classifying necessary tools based on the frequency of use brings about more efficiency and save time.
- **Seiton**: the practice of neatly storage materials, data and equipment, so they could be easily used as much more than before. As a suggestion, it could be more productive if all the needed things placed with respect to ergonomic location because of easy access.
- **Seiso**: it refers to having a clean, tidy and well-organized workplace without trash, dust

and grease. It includes basic cleaning and maintenance. Cleaning emphasizes on the dusting, mopping, sweeping and wiping out surfaces while maintaining focus on planning in advance to check machinery in order to prevent an ongoing problem.

- **Seiketsu**: introducing a set of rules and principles for procedures and organization in order to have a neat and clean workplace.
- **Shitsuke**: sustain refers to keep implementing processes of 5s continuously and every person should be got engaged. If these tools should be performed in the long-term, sustain must be an inherent culture of the business.

2.11 TFV theory

The Transformation-Flow-Value generation, a new unique theory, introduced by Koskela. The TVF theory can be described as the following:

Transformation: in economic concept is to transforming from input to output.

Flow: material and information flow in the production process.

Value generation: everything that makes customers satisfy and fulfil their needs is value.

There is two interpretation of production (Koskela, 2005); the first one is that be named flow model (Production is a flow of time and space of material towards the output), and the second one refers to value generation model (production is the change of customer needs to the product that meet them).

Item	Transformation	Flow	Value generation
Conceptualization of engineering	As a conversion of requirements into product design	As a flow of information, composed of conversion, inspection, moving and waiting	As a process where value for the customer is created through fulfillment of his/her requirements
Main principles	Hierarchical decomposition, control and optimization of decomposed activities	Elimination of waste (non conversion activities), time reduction	Elimination of value loss (achieved value in relation to best possible value)
Methods and practices	Work breakdown structure, critical path method, organizational and responsibility chart	Rapid reduction of uncertainty, team approach, tool integration, partnering	Rigorous requirements analysis, systematized management of flow down requirements, optimization
Practical contribution	Taking care of what has to be done	Taking care that what is unnecessary is done as little as possible	Taking care that customer requirements are met in the best possible manner.
Suggested name	Task management	Flow management	Value management

Figure 9: TFV Principles (Koskela, 2000)

2.12 Concurrent engineering

Concurrent engineering is a well-known method that aims to minimize overall production time and decrease the final project budget by overlapping activities, which are normally done sequential way. Concurrent engineering (CE) is described as the parallel execution of different development tasks in multidisciplinary teams with the aim of obtaining an optimal product with respect to functionality, quality, and productivity (Rolstadås, 1995). If it administrates perfect, it brings about a reduction in product time, time to market and total time. CE embodies two approaches: integrated product development and simultaneous engineering.

The concurrent engineering is based on five principles:

- Process
- Multidisciplinary team
- Integrated design model
- Facility
- Software infrastructure

Construction activities are regularly fragmented into sequential activities that they are referred to variant types of professionals, which result in a limitation on workflow and unintentionally increase project time.

In the traditional construction procedures, each discipline works independently and contractor was the responsible person to facilitate this process. A schematic traditional process is shown in figure 9.

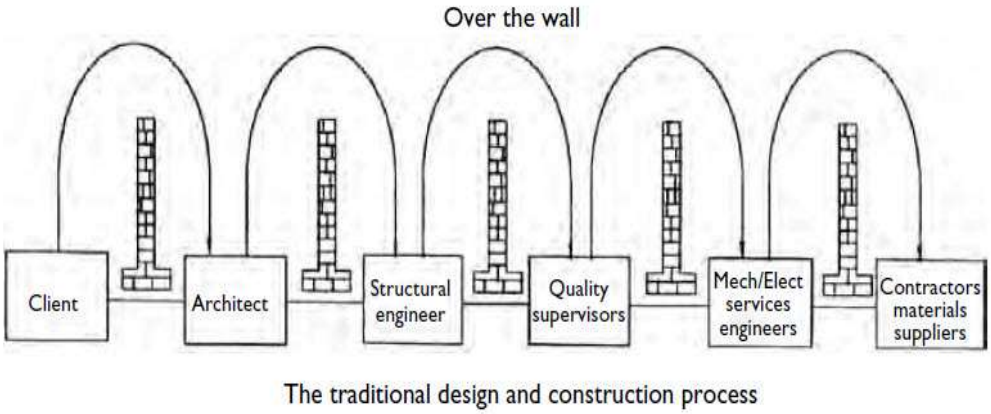

Figure 10: The traditional design and construction process (Anumba et al., 2007, p 36).

This traditional process includes some drawbacks:

- Fragmentation nature of work leads probably to misunderstanding and misinterpretation.
- Fragmentation of design process results in errors and arguments.
- Possible future change causes to rework of all discipline and impose cost again.
- Without a comprehensive life-cycle analysis of project result in instability and lack of synchronization.

Need to tackle mentioned problem obliged contractors to adopt new strategies that CE could be an effective tool.

2.13 Value stream mapping

Value stream mapping (VSM) is a lean tool that can be used to visualize the detailed process from product concept to delivering it to customers. Many lean users utilize VSM as a basic tool to identify waste, deduct cycle-time project, and develop procedures of production. It is noticeable to indicate that value is everything that end-user is willing to pay for it. There is no

doubt that some steps do not bring value for project but we should perform them to guarantee the success of product.

The main reason for using VSM is to find places that are capable to be improved. In the following, there are some examples that we are looking for:

- Delays in which postpone project progress.
- A limitation that acts as an obstacle to deteriorate workflow.
- Extra consumption of resources that incur more cost to project.

In figure 8, a good example of value stream mapping is shown. It provides a holistic view of all the procedures and steps. Moreover, it is a dynamic technique that means it could be updated as the processes are being ameliorated. Value stream mapping could decrease the most common risk in project implementation: financial, schedule, quality, safety, technical and environmental.

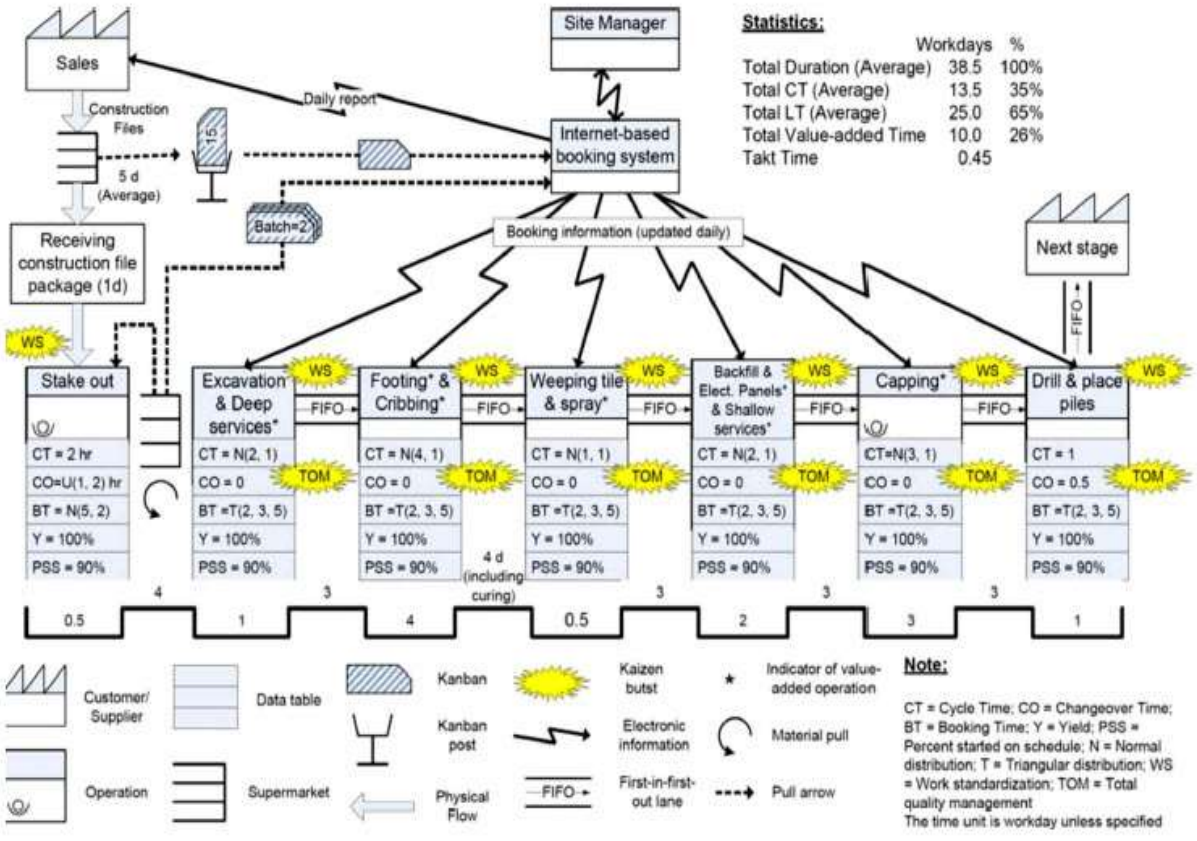

Figure 11: Future state map of home building process (Yu, H, 2009)

2.14 TVD

The idea of target value design has been applied by Japanese manufacturing for many years after that it started to spread out in different countries (Zimina et al., 2012). The primary concept of TVD is to achieve cost predictability in the construction industry. In other words, try to limit project budget up to maximum cost without decreasing project quality or extending lead-time. Target value design is target costing applied to build construction projects (Ballard, 2008).

In the traditional way, construction project was built based on the customer-architecture discussion, and after finishing designing, the final cost could be estimated. TVD tries to see cost as customer value and set up targets as a stretch to persuade team members to use smart and cost-effective methods (Ballard, 2008).In order to achieve goals of TVD, team members set target cost for designing and implementation. However, some of the experts believe that these limitations, introduced by a customer, are not related to cost, it could be time, location, etc.

Significant items should be considered while setting goals for TVD methods ((Zimina et al., 2012),(Ballard, 2008)):

- Choosing a target should be done based on the logic, feasibility and ability.
- Goals should be set by involving of team members and owners.
- Focusing on the entire project not just part of it.
- Using cutting-edge edge technology is highly recommended as valuable tools to minimize error during cost estimation.

2.15 Lean Six Sigma

2.15.1 Background of six sigma

As a data-driven problem-solving methodology, Six Sigma was implemented at Motorola in 1980s in the United States. The six sigma method concentrates to improve quality of goods or services by decreasing variance in the production system. Reducing output variability demand a careful inspection to find out deviations. The main goal of six sigma is to ensure to make an effective process with less than 3.4 defects per million opportunities. It indicates that a six sigma procedure includes 3.4 defects per million opportunities or less as a result. The six sigma adopts five different strategies to attain its goal: Define, Measure, Analyze, Improve and control.

Define: in this step, boundaries of desired performance are outlined from end-user perspective.

Measure: in this phase, existing performance of system is measured to 1) detect what factors most contributes to occur problem 2) evaluate the capacity of process to determine about ongoing real solutions.

Analyze: roots of causes will be analyzed with help of collected measure data in this stage. Statistical tools and metric techniques are utilized to ensure that roots of cause are not just a symptom.

Improve: as soon as roots of cause are detected, a suggested measure should be done in order to advance system.

Control: in this stage, quality performance of new system should be put under control, normally it is statistical control. Consequences of modified system must be evaluated and validated by rigorous scientific proof.

Figure 12: DMAIC Methodology

Lean six sigma is an integration of two managerial approaches, lean and six-sigma, that results in a succession of the business. In this approach, traditionally the lean tools try to remove the

waste and six sigma tools are utilizes to achieve continuous process improvement. The ultimate goal is to eliminate the waste and decrease variation.

In other words, lean and six sigma are complementary. In the following similarities and differences will be shown:

2.15.2 Similarities:

- Value, the thing that customer is ready to pay for it, has been focused on both methods.
- Mapping workflow as a tool to depict comprehensively procedures is been applied in both approaches.
- Both of them need reliable data to decide about future measures to improve performance.

2.15.3 Differences:

- A different way to recognize the problem of production, lean rely on the identification of waste and six sigma emphasize on the variation of process and deviation from desired state in manufacturing.
- Different kinds of tools to complete their mission. Lean mostly utilize visual tools to identify and eliminate waste while six sigma uses statistical analysis most in order to reinvent the business to achieve a higher level of customer satisfaction. Many people prefer to use lean rather than six sigma because they are afraid of numerical analysis and dominantly they use visual tools.

In general, the two methodologies are compatible in many aspects and that is easy to get them merged together.

2.16 Kanban

Kanban is a lean workflow approach developed by the Japanese automotive industry in order to visualize work and enhance efficiency and agility. in Japanese language Kanban means a signal card or billboard. It is like scheduling system to implement just-in-time manufacturing.

Kanban is considered as a lean technique that try to avoid labor and inventory waste, and handle replenishment of specific kinds of material.

supporting principles of Kanban

Kanban applies four principles of lean manufacturing: just-in-time, continuous flow, the pull production system and continuous improvement.

Kanban methodology aims to achieve the following goals:

- Provide customers what they really needs based on pulling system
- Manage to diminish of materials
- Eliminate unnecessary paperwork during ordering new material or increasing them
- Simplify site management
- A mechanism for eliminating waste
- Increasing transparency and teamwork ability
- Continuous improvement

Kumar (2010) believed that for having a successful kanban strategy some factors should be engaged, which include: inventory management, vendor and supplier participation, quality improvements and quality control and employee and top management commitment.

2.17 Takt time planning(Takt planning)

Takt is originally German words that it means “keep in time” and hint to “rhythm”. Technically, takt time refers to the required time for completion of a product (supply rate) in which it matches with customer demand rate. In the construction industry, takt time has been described as the allotted maximum number of days for accomplishing a task on the workstation (Frandson et al. 2013). Implementing a successfully lean principle in the construction industry requires a smooth flow as a first step. Establishing smooth flow obliges the implementation of numerous lean construction tools such as visualization and continuous improvement strategies, of which the main prerequisite is takt time (Liker, 2004).

If the project progress is further than takt schedule, job buffers increase that it leads to an excess of inventories and finally producing more waste. However, if the project progress is behind the takt schedule, task takes a longer time to finish and the successor task faces with delay, therefore, customer’s satisfaction declines. (Kenley et al., 2010). Implementing takt time in construction projects results in advantages such as: decreasing variability, declining the overall project lifecycle and help to finish the project under the budget. (Kenley et al., 2010).

2.18 Digitalization and lean management

2.18.1 Digitalization

Digitalization is the procedure of transforming of information in a digital format. Information should be digitized if they need to be protected better, shared and conveyed easier. Accessing in internet connections in the world has caused to spread digitalization concept through all the countries. In this competitive and volatile market, using information and communication technology (ICT) brings a lot of advantage for organizations, companies, institution, etc.

The advent of ICT made a great improvement to easily access data regardless of time and distance. Established companies understands the importance of applying digital technology on their business in term of increasing speed and reducing cost, besides in many occasion it could get involved customer in early phase of production and services (Sambamurthy et al. 2003). Digital technology makes it possible to compress, save and transmit a huge amount of information smoothly (Christensen, 1997).

Therefore, digitalization could be explained as "process of leveraging digital technology to promote a business model result in increasing productivity and benefit and value-adding opportunities, it is procedure of transferring to digital industry".

2.18.2 Collaboration between lean tools and digitalization

In the early 1990s, the first wave of lean production emerged and was implemented by many manufacturing companies. This implementation just included a set of rules for labor issues and reducing waste in an isolated part of companies that restrict the domain of influence. However, in the second wave of applying lean thinking started from the 2000s, companies looked at it as a more holistic approach and pay attention to the synergic impact of elements on each other. As a consequence of this holistic approach, companies managed to achieve a higher level of performance in accordance with cost-effective and added-value activities (Hoellthaler, et al., 2019).

Undoubtedly, one of the most important competitive advantages of digitalization is transferring data faster than before. Digital technology is able to digitize the information that makes it easy to compress, save and finally transmit them rapidly.

Fortunately, using digitalization could bring about other special opportunities for the company in comparison to other competitors, for example: decrease final cost, heighten safety, access to foreign market, etc.

The domain of change due to digitalization is completely different from that it depends on the type of application. It could result in just small improvement in services and processes or acts as disruptive in an organization and leads to reorganization or change the structure.

Therefore, ongoing utilizing of digitalization should be considered as a mean to address waste and eliminate it fruitfully. Flexibility and fast speed in information transmission are the things that connect digitalization to lean management. Hoellthaler, et al. (2019) concluded that contributing to digitalization in the third wave of lean production is indispensable and digitalization technology plays a fundamental role in augmenting the efficiency of LPS. Figure 12 illuminates the impacts of digitalization on the performance of LPS.

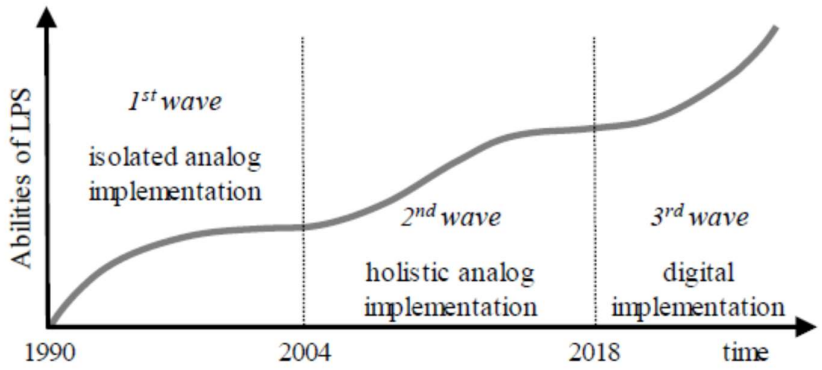

Figure 13: Comparing different waves of lean production

The lean production system, as well as other systems, will be undergone wonderful change due to digitalization. A combination of digitalization and lean management probably generates more opportunities and challenges simultaneously. Vast numbers of risk will be created because of digitalization, they include: no transparency, work from remote, alienation from the system or the inability to use specific software, etc. (Meissner et al., 2018)

2.19 Barriers to implementing lean techniques in construction

Need for improving productivity and minimizing waste persuades construction managers to adopt a new management strategy. Koskela was one of the pioneers to take advantage of lean thinking in the construction industry. Accordance with the lean principles, waste should be considered any inefficiency that does not result in an activity in which customer pay for it. However, waste management in the traditional construction approach is counted as a weakness due to not able to cover all kinds of waste. In traditional waste management tried to protect the environment from construction pollution especially during the demolition phase (Shen et al., 2002).

Therefore, architecture, engineering and construction (AEC) industry has attempted to select new philosophy to increase gross profit margin and optimize construction processes. Recent research and studies has shown that successfully implemented lean construction method led to reduce waste in term of material, time, cost, etc. and simultaneously maximize value, performance and efficiency (Salem et al., 2005, Nahmens, 2011). There will be found some specific features that differentiate construction industry from manufacturing and result in challenges during implementing lean construction. Koskela (2002) believed Onsite production, one-of-a-kind projects, and complexity are characters that distinguish construction from manufacturing. Those characters contribute to make construction processes being unique and complex. On-site production refers to the specific physical location, in contrast to manufacturing that has fix-position. One-of-a-kind project shows we face variety in construction as opposed to manufacturing that normally everything is standardized.

Small et al. (2017) illustrates a variety of factors that impact on implementing lean construction in their research. Table 2 summarized the most important factors which act as barriers to lean implementation.

Factors considered as barriers to lean implementation in survey			
1	Incomplete and complicated designs	18	Lack of agreed implementation
2	Cyclic nature of the construction industry	19	Deficiency in technical skills and
3	Less involvement of contractors and	20	Lack of strategic and long-term supplier
4	Lack of lean understanding	21	Extensive use of subcontractors
5	Poor communication among stakeholders	22	Long implementation periods for new
6	Low tender prices	23	Weak integration of supply chain
7	Slow decision making process	24	Poor professional wages

8	Inadequate pre-planning	25	Lack of standardization
9	Lack of individual performance	26	Fragmented nature of construction
10	Lack of long-term commitment to change	27	Shortage in manpower
11	Inadequate organizational culture and	28	Lack of customer satisfaction
12	Regulatory authority intervention and	29	All kinds of waste considered
13	Lack of process-based performance	30	Deficiency in realizing customer needs
14	Delays in materials delivery	31	Short supply of materials
15	Lack of clear definitions of individual	32	Unclear project definition and outcomes
16	Lack of training	33	Lack of client and suppliers involvement
17	Lack of management support and	34	Lack of financial resources

Table 2: Factors chosen for surveying of barriers to lean implementation

The first barrier to implementing lean construction is resistant to change the traditional model and believe that LC concept does not result in better result. According to Salem et al. (2005), top management plays a key role in this transformation and help other stakeholders to get engaged. Mossman A. (2009) argued about the disadvantages of fragmentation in the construction industry. Fragmentation leads to decrease incentive and motivation to learn together and cooperation, in other words, having different subcontractors probably could reduce final cost in the short term but impact negatively on the workflow long-term. Since implementing of LC requires adequate knowledge and skills, furthermore Mossman A. (2009) indicated follow factors as barriers: lack of understanding of the concept; lack of technical skill among staff or professionals; non-engagement of new knowledgeable staff; high-level illiteracy among construction operatives; lack of training; and consistency in operatives' training, which will not enhance lean.

Every method that wants to run correctly needs initial financial support and subsidize and lean construction is not exempt. This fund could include: team training program, money for technological mean and software, equipment and tools.

3 Research methodology

This chapter deals with the methodology for information collection and analysing procedures to address the master's research questions.

3.1 Introduction

This chapter is like a foundation to show the policy for obtaining tailored literature and analyzing them in order to answer research problems. It is substantial for readers to keep in mind that there is an obvious difference between research methods and research methodology.

The research could be enunciated as a systematic and concrete search for proper information on a particular topic. It consists of defining the problem, develop a hypothesis or research questions, collect data and analyze them, evaluate the hypothesis, interpret results and drawing a conclusion based on the facts. All of the techniques, schemes, algorithms and analyzing used in the course of carrying out research are designated research methods.

Research methodology, as its name hint, refers to the science behind using the methods to solve the problem. Hence, a research methodology prepares an all-encompassing philosophical and structural framework that is utilized for initiating a project to clarify the reasoning behind the adopted research methods.

It is vital to understand the nature of the study and the necessity of doing this master thesis. Murphy's Law indicates that if something goes wrong, it will continue going wrong and it is undoubtedly as part of the research. Therefore, before trying to find a proper methodological approach that provides background and rationale for the research, it is highly recommended to define the narrowly detailed topic.

Generally, researches could be conducted based on two different methods: qualitative and quantitative methods.

The quantitative approach is particularly associated with numbers, the relationship between variables, statistical procedures and transforming data to a usable numerical form that provides the base for quantifying, dimensioning, comparing, sorting and discovering the pattern and concluding.

The qualitative approach often emphasizes understanding rather than relying on the numbers. It is used to understanding motivation, reasons, opinions and discovering trends behind the phenomena. By utilizing this approach, we attempt to describe, interpret, conceptualize an idea and gather in-depth insights regard to the topic.

In the following, some example of qualitative and quantitative methods will be shown:

Qualitative data collection methods:

- literature review
- interview (face to face-telephone-skype,etc)
- focus groups
- case studies

Quantitative data collection methods:

- content analysis
- survey (online – paper)
- experiments
- observation

I decide to employ two qualitative methods simultaneously to collect and organize data in order to get reasonable answers for problem statements. For achieving the purpose of this study, the following research method will be adopted in order to achieve the goals of the study:

3.2 Literature review

Providing literature review for Lean principle, production and construction for the purpose of access all the available knowledge about lean construction. This literature review consists of different information, which provides a theoretical framework for the research that helps to a qualitative approach. The literature review describes fundamental theories – for this research includes Toyota production system, lean thinking …and finally various lean construction tools – and explanation such as value and waste. This information is mainly taken from peer-review journals and other reliable resources.

Collected data will be analysed and prioritized and finally leads to comparative study.

Conducting a comprehensive literature review helps to situate better this study among all available knowledge and probably result in identifying the hidden gap between literature which research attempts to address.

As discussed above, writing a comprehensive literature review is one of the pillars for this study since it prepares background, relevance and support for the explored idea. Thus, before starting for finding books or papers, scope and area will be delimited in order to avoid lengthy and time-consuming literature searches.

“Investigating about lean construction tools”

From the topic, some of the key words helped me to find the area of scholarship. First of all, the research should give a broad insight into the lean. I can assume that the content should be also intriguing and brief. What is lean? What is the root of lean? What things can be counted as waste?

Secondly, how we could take advantage of lean in the construction industry? What are the main waste in the construction industry?

Thirdly, what are the lean construction tools for improving efficiency in the construction industry? What are the challenges and barriers when we are applying LCT?

After restricting the scope of the study, I could start to find reliable and valid literature. However, we should keep in mind that there have been four main objectives for the literature review:

1- To present a professional grasp of the area and show understanding of main theories
2- To justify the gap in current knowledge and describe boundaries
3- Discuss the previous study and situate a new approach
4- To synthesize gathered information in a well-organized structure and meticulously referenced.

3.2.1 Collecting, evaluating and prioritizing articles

Since I defined my topic with my supervisor for a master thesis, I began to gather any relevant information about lean construction. Although, a turning point for more detailed and complex research returned to earlier of September, when Jardar held a class to create a systematic selection of papers. In brief, he demonstrated how to make the best of keywords and how to assess the value of articles, for example how to evaluate papers based on the impact factor. In further, collecting information will be discussed and then evaluate sources to being aligned with the aims of the study. In the following, some practical database, which I used to access substantial sources, are categorized and researchers based on their needs could use them.

- Google scholar
- NTNU Library
- IGLC database
- Scopus
- Elsevier

- ASCE library

3.2.2 Criteria for evaluating sources

Source evaluation is one of the critical processes that aids researchers to sort their resources based on creditability and reliability. Identifying appropriate sources could provide a solid theoretical foundation for the study. There are five suggested criteria that should be applied in order to make a distinction between sources.

1. **Currency**: when did the sources publish? It should be noticed some of the sources are ageless and hardly outdated because they are the basis for ongoing research
2. **Relevancy**: to what extent does the source cover the research area?
3. **Authority**: who is the publisher or author?
4. **Accuracy**: to what extent we could trust them? Does it include bias or error?
5. **Purpose**: recognizing the kind of information and reason for the author for publishing. Deciding that sources contain any evidence of bias is helpful to evaluate the quality of sources.

On the other hand, there are two criteria that they could show the importance of sources and are applied for articles often, impact factor and number of citations.

The impact factor is not the best means of evaluating a source's quality but there is nothing better than this. The impact factor is a statistical measurement of citation to all items published in the journal in the last two years. This method devised by Eugene Garfield, founder of ISI.

$$IF_{2019} = \frac{Citation_{2017} + Citation_{2018}}{Publication_{2017} + Publication_{2018}}$$

In addition, author scholarly background could give us envision about the credibility of his or her publication. Are the writer specialist in this area? How many times the author was cited in other publications.

Meanwhile, it should be noticed above tools are just fast gauge to reliability and validity but nothing could be guaranteed by them. Judging the source's quality also is so effortless based on the mentioned tools rather than scrutinizing all the information.

Title	Year	Author	Journal	Keyword	Impact factor	Currency	Relevancy	Authority	Accuracy	Purpose	Number of citation
Das Toyota-Produktionssystem	2013 (1978)	Ohno	Book	TPS	-	x	✓	✓	✓	✓	464
Der Toyota Weg	2014	Liker	Book	TPS	-	x	✓	✓	✓	✓	202
The machine that changed the world	1990	Womack	Book	TPS, Lean thinking	-	x	✓	✓	✓	✓	248
Application of the new production philosophy to construction	1992	Koskela	Book	Lean production	-	x	✓	✓	✓	✓	2403
Applying lean thinking in construction and performance	2013	Aiziz et al.	Alexandria Engineering journal	Lean production	3.696	✓	✓	✓	x	✓	292
Lean Construction: From Theory to Implementation	2006	Salem et al.	Journal of Management in Engineering	Lean Consstruction	2.282	✓	✓	x	✓	✓	339
What is Lean Construction	1999	Howell	-	Lean construction	-	x	✓	✓	✓	✓	694
Identification of Root Causes of Construction and Demolition (C&D) Waste: The Case of Turkey	2017	Polata et al.	Identification of Root Causes of Construction and Demolition (C&D) Waste: The Case of Turkey	Waste, construction	1.04	✓	✓	x	✓	✓	10
Lean Construction Techniques and Individual Performance	2019	LI et al.	IGLC	Lean construction Tools	-	✓	✓	x	✓	✓	-
Identifying barriers in lean implementation in the construction industry	2019	Demirkesen et al.	IGLC	Barriers, obstacle, lean implementation	-	✓	✓	x	✓	✓	-

Table 3: Preliminary evaluation of sources

3.3 Interview

The interview is one of the useful research instruments to collect data from respondents and finally yields reliable results from them. Interview is basically more formal than a questionnaire, which pursues a greater detail and in-depth than a standard questionnaire. The interviews are specifically practical for exploring the story behind a respondent's experiences. A qualitative research interview tries to highlight both a factual and a meaning level; however, it is usually more challenging to interview on a meaning level. (Kvale, 1996)

The underlying benefits of conducting the interview are explained in the following:

- Being practical due to targeting a specific group of respondents
- It is almost inexpensive. A large amount of data is obtained in a relatively short period of time.
- They are easy for analyzing and comparing. After designing questions and collecting information, analyzing and comparing could be done easily and scientifically.
- The interview often does not have an intensive time restriction for respondents
- Being anonymous is the advantage point for respondents to answer correctly without any ongoing consequence.

On the other side, disadvantages should not be neglected while considering the interview as an obtaining data tool.

- Reliability and validity
- Misinterpretation of questions
- Restricted answers

3.4 Interview approach

At this study, five interviews have been performed with a duration of approximately one hour each through Skype meeting. In addition, for achieving goals of this study, a semi-structured type of interview was chosen. It should be noted that my supervisor and I emphasized on the diversity of participants because of cognitive mapping. All the interviewees have been selected from Skanska, Statsbygg, veidekke and Backe based on their qualification and experience in lean construction. The interview were conducted in English language to decrease the misinterpretations. In order to get the most reliable and valid result, author preferred to anonymize participants. However, numbers is used to show different participant's quotations. In order to protect participant's privacy, all the data have been saved in author's laptop.

3.5 Interviewee's background

Interviewees have been chosen from the top and middle management of large and well-known contractors. participants for interviews gained significant experience in different positions for many years. In order to get better vision of participants, the table shows the personal information of interviewees briefly. The interviewees got involved many different and complex projects. Based on the interviews with respondents, they participated in the large and small projects from concept phase to delivering phase.

Title	*Age*	*Education*	*Respondent profession*	*Experience in construction industry*	*Average cost for last projects (Mil NOK)*
Participant 1	40-50	Master degree Project management	Vice president	5 years	150 – 200
Participant 2	50-60	Master degree Civil engineering	Head of Project planning	13 years	various
Participant 3	30-40	Master degree Project management	Head of BIM & VDC	6 years	500-2000
Participant 4	20-30	Master degree Civil engineering	Assistant project manager	3 years	200
Participant 5	40-50	PHD Design management	Head of design management and BIM development	25 years	70-100

Table 4: Personal information of participants in the interview

4 Interviews

In this chapter, a set of interviews was held to elicit the attitude of contractors toward lean construction philosophy. It will also answer two research questions. The purpose of this study is to evaluate the maturity of Norwegian construction organizations regards to recognition of lean construction philosophy. In addition, the focus of qualitative interviews is to know to what extent the lean construction tools have been implemented in the last projects. Contractors were identified based on their experience in implementing lean; I would like to say that all of them are among the best construction companies in Norway. It is noteworthy to explain that all of the participants confirmed that they are familiar with lean philosophy before conducting the interviews.

4.1 Lean construction maturity

Totally, maturity is the sign of being complete, developed and perfect. On the other hand, immaturity is the expression of incomplete, imperfect and unripe (Oxford English dictionary). However, when we use mature for a human being, it probably describes the state of being developed physically, mentally and having balance in personality.

Organizational maturity could be similarly conceptualized, the state of perfection and showing high performance. Therefore, the maturity of a company is possibly described the effectiveness of a company or its ability to manage the processes, projects and portfolio efficiently. However, how we can understand the maturity level in the construction companies?

For the starting point, the elements, which will be affected by implementing lean construction tools, should be defined. I would like to mention Lead-time, budget, environment, safety, etc. that they will attribute to the company's success in the future. As it is obviously clear, there are many parameters that we could use them as an indicator to measure the performance of lean construction techniques. Furthermore, any of the key performance indicators (KPI) triggers one of the values that should be improved by implementing lean theory.

Since there is no one-best-way recipe for applying lean construction tools (Netland, 2013), this study did not try to find an elaborated prescription for assessing the maturity of lean construction in construction companies. In this research, the author proposed a list of questions for the interviewees, and then they had an opportunity to answer based on their desire and experience.

In this study, the specific KPIs have not been chosen and actually, the interviewees are free to assess techniques based on their experiences and cover all the aspects of outputs.

In the next chapter, the discussion with respect to collected data has been done. Finally, in the last chapter, the conclusion has been drawn while all the importances have been considered.

4.2 Construction productivity

All the interviewees agreed that non-value added activities like rework, deficiency, overproduction and transportation are still seen in construction projects. Regarding the waste in construction, participant 1 tried to address this issue with this sentence “no one is perfect”. He intended to connect productivity to human performance. Besides, he defined the best way to measure productivity is to consider it in terms of cost, in another word he illustrated just cost as the indicator of performance.

According to participant 2, “we have low consciousness and knowledge about process planning. Unfortunately, we are not good at reverse planning as well as breaking down the structure. All of them are connected together and caused to have low productivity in the construction industry. For example, if you assume a complex project you can see that extremely coordination should be done in order to get the desired output.” he also described the following reason as the most challenge for decreasing productivity, “ everyone needs to have awareness of how the system works, and we are all part of the system. So we cannot attribute the deviation to just one person, For instance, in corona times (COVID- 19) we need to be aware of what not to do, and it is parallel in construction productivity.

It is true that many studies have been carried out to identify and then eliminate all kinds of waste but is this potentially feasible to happen? According to participant 4, we are still on the early stage to reach a consensus on construction productivity and how to measure performance.

According to participant 3, the different parameters should choose for each project during productivity measurement. He explained that construction disciplines are different and we can not use one parameter for all projects. Moreover, he also indicated that in megaprojects, many companies collaborate with each other, furthermore obtaining information and data analyzing are perhaps more complicated due to large samples. The aforementioned challenges could lead to inconsistencies in productivity measurements.

Not all respondents could assert to what extent it is possible to improve productivity by eliminating waste. Probably the reason why the positive effects of lean has not been measured is the complexity of calculating the financial benefits in each phase. By the way, participant 3

explained that he did a study before in order to estimate saved money, and it was almost 20 percent. However, he mentioned that it was a special case and we could not attribute it to all projects. I suppose that it comes back to the nature of civil projects. Civil projects are unique and various. In addition, many factors could affect the workflow, for instance, lack of appropriate material, equipment, site condition, change, weather and labor market condition.

According to participant 4, despite all the benefits that have been seen by using lean principles, there is one thing that could negatively affect the performance noticeably. In this respect, the client's involvement should be supported and applied through the construction phase in order to reduce non-added value activities. These late changes will cause extra cost and interruption in the project schedule.

Participant 5 confirmed productivity in the construction industry is still affected by many intractable problems such as delay in one process possibly it transfers to other activities and finally causes to persistently poor performance in the whole project. Beside, participant 5 mentioned examples to explain where these deviations originated from. For instance, if the plan is not designed based on the customer's goal or somebody makes a mistake in his or her task it might change the condition.

4.3 Construction techniques

Different kinds of improvement techniques have been implemented in order to meet the goals in the construction industry such as accomplishing projecst faster and cheaper with higher quality. Among all the powerful approaches, Building Information Technology, Lean Construction and critical path could gain the most attention. However, there could be found different techniques in which they associated to improve project performance.

Participant 1 stated that they normally use Involverende planlegging (IP) that is too similar to one of the lean construction techniques named LPS. IP is a methodology for driving progress in project based on the specified principles. The main objective of IP is to reach a smooth workflow in production. In addition, they have ICE MEETING that basically consists of engineers with various backgrounds such as architects, top managers, MEP consultants, etc. This meeting run by the project leader and highlights the subjects that should be executed in the near future. In this meeting, everybody can discuss and propose new idea for better performance. Undoubtedly, some conflicts will arise during the meeting. However, it results to the best outcomes at the end.

According to participant 4, Lean construction, BIM and PDCA are the most famous tools that employees are working with them in the company. PDCA (figure 13) is a continuous loop of planning, doing, checking and acting. The cycle includes four steps that it allows us to provide an iterative test for improving and managing changes. Besides, nowadays every company consciously or unconsciously is applying BIM, although maturity levels in utilizing these tools are variant among construction companies.

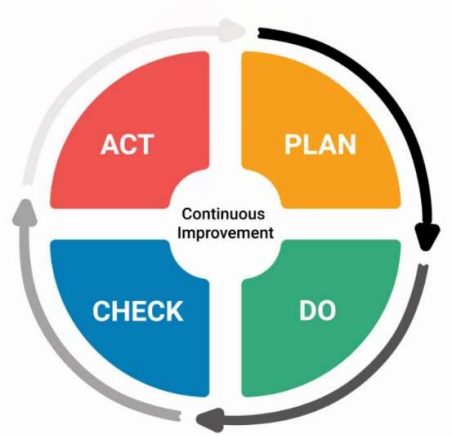

Figure 14: PDCA cycle

Participant 2 claimed that they combined four strategies to increase the effectiveness in implementation, and finally it leads to a successful project. As shown in figure 14, the key strategies include: lean, systematic completion, digitalization and logistics.

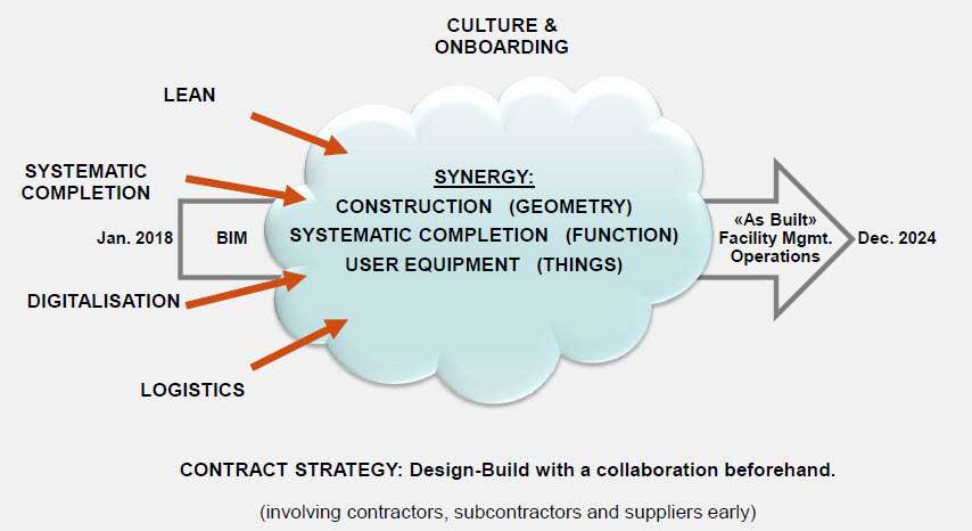

Figure 15: strategies and totality introduced by participant 2

Participant 5 indicated they used collaborative planning as a lean technique in their company. In this technique, different participants get involved in the discussion in order to use their knowledge in planning and executing.

4.4 Lean construction

Lean methodology, with its origin in Toyota Production System, is one of the approaches was invented to increase efficiency in the production. Lean construction includes many tools in which they have been developed over time, afterward they implemented in construction projects based on lean principles. With considering this truth that there is no agreed definition of lean construction, respondents had different perceptions, understanding and knowledge.

According to participant 1, “lean is a philosophy and specific way of thinking that helps us to avoid unnecessary works and eliminate the works that do not create value for the project”.

Participant 2 claim that lean as a methodology that it works everywhere, because it is considered as a mean to create the best possible flow and also to reduce the most possible waste.

According to participant 3, “it becomes quite difficult to explain lean, the more you work with it, and the harder is it to describe it in one sentence”. He continued that it is like a philosophy

that deals with different strong principles in which they focus simultaneously on the waste, customers and flow.

From the viewpoint of participant 4 “lean is like equipment to find out how we lose money, time, etc.” participant 4 concluded briefly lean is an opportunity to diagnose construction values. The problem with lean philosophy is that, it is kind of young, and if the project managers want to set the standard from the beginning, employees do not understand the mechanism and system. The only thing they care about is planning and they do not see the whole procedure, in another word, they know just takt planning.

Participant 5 highlighted “lean construction is not only a concept to eliminate unnecessary waste and improve efficiency but also it aims to add value for the owner, customer and all the participants in the project”. Participant 5 continued that keep the company updated in terms of the latest lean knowledge is very significant. Hence, the company sends normally relevant staff to the lean conferences and has a close collaboration with many high reputed universities like Berkeley, Bergen, etc.

4.5 Lean implementation

The advantages of implementing lean construction tools are slowly spreading amongst the construction industry. In order to identify the positive and negative effects of lean thinking on construction projects, lean techniques should be applied in projects but the main question is how we could measure the effectiveness. According to all participants, there is no agreed-on a solution for the mentioned question and every person had different interpretations regard to successful implementation. However, all respondents explicitly asserted that monetary factors are the best indicator for prioritizing and comparing lean techniques.

Participant 1 said they have a special department that the people carry responsibilities for applying lean principles and formulate new rules with respect to lean methodology. It starts with the feasibility phase and supports other phases consequently. Besides, they always check the latest change in techniques and technology in which help to improve performance.

Participant 2 said that their company has not any specific standard or department for implementing lean philosophy; however, they used lean principles in the projects constantly. For instance, he recommends the customer to make the project structure repeatable as it is possible which it is a kind of lean mentality thinking.

According to participant 3, every person in the company has gone through a certain amount of lean training, but there are different levels of understanding of the lean application.

Concerning the importance of human force, participant 4 mentioned that they are always checking workflow on the construction site, for example, where did the people go every day to throw plastic or stuff like that. Hence, in a mature environment, managers should try to get involved with all the people in the project. Their involvement not only increases the level of accountability and responsibility but also encourages them to be more initiative and creative which more likely helps to better performance. Furthermore, participant 4 pointed out that their company hired a lean professional who has vast lean experience and tried to execute lean principles by explaining to the staff. In fact, it did not go well because all the persons just pretended to understand and approved that it is a great approach. While, when they came back to the work they did their work like the past.

Participant 5 argued that they use leaflet as standard in which it includes three parts related to design, construction of buildings and lastly for civil. This leaflet describes the company's approach that how to use lean tools in order to stimulate improvement to a certain extent. Participants 5 believed that the general population and most of the workers in the construction industry are ready to embrace lean thinking but we still have some persons that they do not follow the LC method and they are out of our guidance system. Moreover, participant 5 concluded that measuring the lean maturity in projects is completely difficult due to the different sizes and complexity of projects. Nevertheless, we could use general parameters such as time, cost, quality and customer satisfaction to monitor performance and get a better overview in order to find which part of the current system needs to be changed.

4.6 Lean construction tools

It is significant to know which lean construction tools have been used most by the companies in their projects and then analyze them. In this study, due to time restriction, I am not looking for measuring the impacts of tools on productivity individually or comparing them with each other. As described in chapter 1.3, this research presents the trend of using common lean tools among the construction companies. In this stage, I asked the interviewees if they are familiar with the theory and capability of each lean construction tools. The results of the interviews are given in Table 4. Needless to say, that it does not mean they have used these tools or masterfully have knowledge about them.

	Project Delivery System	*Last Planner*	*Concurrent Engineering*	*5S system*	*Value stream mapping*	*TVD*	*Lean six sigma*	*Takt planning*
Participant 1	✓	✓	✓	×	×	×	✓	×
Participant 2	×	✓	×	✓	✓	✓	✓	✓
Participant 3	✓	✓	✓	✓	✓	✓	✓	✓
Participant 4	×	✓	×	✓	×	×	✓	✓
Participant 5	✓	✓	✓	✓	✓	✓	✓	✓

Table 5: The well-known construction techniques in companies based on the respondent's answer

4.7 Adopting lean strategy on the projects

In the interviews, it has been acknowledged by the majority of interviewees that it is not easy to attribute overall project performance to the individual performance of each technique due to synergic effect of other techniques like BIM, agile, etc. However, this research eminently focuses to report the importance of each of lean construction techniques in projects and their effect to improve final performance. Besides, in this stage, the interviewees could express their opinion freely about the applied lean construction tools in projects. Participant 3 argued that lean mature company applies lean principles in the core management system and lean construction tools are been involved in their project obviously. In general, these companies are constantly looking for values and continuous improvement while removing waste.

Participant 2 stated that “they are fully exploiting the potential of takt planning in the projects while other companies pursue to utilize last planner techniques”. He argued that the last planner does not include too much information and advance detail in contrast to takt planning. He stated that takt planning is a logical way of detailing in the earlier phase. Therefore, we hope that when we are deploying takt planning we involve everything in the final process.

Participant 4 stated that the estimation of the cost of the implemented lean tools is very hard since it is very challenging to assess various management approaches on the same project. According to Participant 4 they struggled to prioritize the factors that they have great impacts on the final cost and schedule of the project. Furthermore, it is widely agreed that the takt

planning and 5S tool are the best low-cost techniques that could improve the project performance greatly.

Interviewee 2 indicated that the benefits of using lean construction should cover all the phases, it starts from concept phase to phase of use. Regarding this context, participant 2 underlined the high potential of lean thinking in the supply chain after the construction phase, for example, he expressed that the installation of equipment completely depends on lean design.

4.8 Lean construction barriers

Despite all the continuous efforts that have been initiated by organizations and contractors for successful implementing LC, there are still obstacles that hinder the deployment and developing lean construction. Many researches were conducted to find out the tangibles barriers. The finding of this research recognized some obstacles that the most significant of them which were indicated by respondents are targeted. Considering the construction as a unique production cause to resist for implementing this approach. It is true that each project has a specific condition and planning but it is a lame excuse to stop executing the lean construction approach. Moreover, design and planning are discovered as the main attributes of the procedure of lean construction.

Participant 2 argued that the current level of lean knowledge is not sufficient among the people, therefore, the main challenge refers to raise the competence and awareness level. It is not only the duty of organizations to teach their employees about lean thinking but also it is like a mutual responsibility that everyone needs to foster their knowledge. In addition, a change in habits is always difficult. People cannot easily ignore what they have been doing for five to ten years and probably they show resistance. Besides, the employees should take into consideration that every new technique needs time to show its benefit.

According to participant 1, change is always difficult and it depends on how large the changes are. People are always struggling to embrace new changes and they need to be motivated. It is the duty of organizations to teach employees, and then inspire them to follow up the changes. Therefore, change culture should be considered as a necessary prerequisite for applying lean philosophy.

Participant 3 said fragmentation and subcontracting in construction projects is one of the biggest challenges in implementing lean construction. It is essential that all the participants collaborate and cooperate effectively together in order to establish a smooth workflow. Participant 3 also

pointed out that one of the main barriers is related to technical issues. Many of the waste during the implementation phase originated from engineering design especially architectural design. Some of architectural design cannot be executed exactly and thoroughly due to a lack of comprehensive construction knowledge.

Participant 4 claimed that Applying lean techniques in construction projects need a long time to achieve goals. For example, daily huddle meeting demands employees involvement in which multidisciplinary teams communicate continuously to know what has been done and what might impede the project progress.

According to participant 5, it seems that poor transition due to the resistance of people against change is the major challenge for successful lean implementation. Basically, it is vital to balance adequate lean training with motivational measures.

5 Discussion

This chapter encapsulates all the main findings in regard to the literature review and conducted interviews. The construction industry is still criticized for deadline delays, cost overrun, quality problems and producing huge amounts of waste. Many executives in this industry believe traditional philosophy has profound implications for occurrences of those negative problems, especially when complexity and uncertainty are increased due to the changeable needs of the customer and dynamic environments. In recent years, there has been a growing focus on sustainable development in the construction industry with considering profit margin. In order to improve efficiency and effectiveness, many innovative techniques and management strategies have been introduced. Lean construction is one of the techniques that has been taken from lean manufacturing to better the situation.

5.1 Lean strategy

In contrast to the conventional approach in the construction industry, which focuses on discrete activities, the lean philosophy aims to consider whole the processes for eliminating non-value added activities. Eventually effective applied lean philosophy cause to reduce variability, increase reliability, and facilitate workflow.

Most of the respondents agreed upon the importance of implementing lean thinking in the design phase. At this stage, the maximum benefit could be expected as the biggest change in procedures and innovative processes could happen. It is highly recommended to identify factors that affect construction productivity during the front-end and design phase because it is easier to find an appropriate construction strategy. At micro-level, skilled labour is a valuable source of information to concerning their performance.

The result from the interviews seems to have confirmed that the implementation of lean construction is largely dependent on organizational learning and policy. The author especially claims that most of the companies try to embed lean principles generally in their policy rather than applying each lean construction tools individually during the project lifecycle. Therefore, as utilizing of lean construction principle highly relies on appropriate standardization, construction organizations and companies should obtain key elements that could meet the future needs. For example, in this dynamic market we should not ignore the effect of high-tech tools.

For a successful transformation, it is dispensable to standardize processes with key and flexible principles. In this context, Womack and Jones (2003) concluded that the implementation of lean should consider the key and visible activities firstly. To achieve this goal, it is highly essential to

disseminate lean knowledge in different levels of the organization and finally, these ongoing changes should be tracked to ensure for executing the right strategy.

However, a common concern among the participants was that waste identification was encumbered heavily by old routines. Various studies have clearly reported that people are unwilling to newly released instruction and they do not believe they were producing waste with traditional methods. Therefore, they undermine achieving new milestones and challenges associated with subsequent stages will arise. A better solution in order to encourage employees to increase involvement is to assign them to write a report regarding continuous improvement or fill a checklist. This measure could provoke accountability and cause to decrease the propensity for producing waste by controlling tasks.

Taking the results presented in table 5 into consideration, it highlights that some of the lean techniques are the most popular and commonly utilized. The overall result indicated that the widespread use of the last planner has been proved. Meanwhile, the data were clustered by interviews indicated implicitly that takt planning has better performance technically than other techniques when it comes to arranging repetitive works. Achieving stability and continuous flow by overlapping activities through precise and exact planning is the main goal.

The majority of the reviewed publication demonstrated lean construction tools could identify specific obstacles related to off or on-site firstly, and then address them. Furthermore, in the following, the applicability of each lean construction tool, which has positive effects on the project, has been presented.

Chiarini (2014) emphasized that lean construction tools such as 5S are able to decrease injury rates and improve the poor condition of health and safety noticeably.

Bae and Kim (2008) outlined that initially 5S concentrates on organizing workplace and inventory management. Bae and Kim further argued this standardization ends up creating lower accident and immaculate workspace for employees.

Cherrafi et al. (2016) asserted that Just-in-time (JIT) approach, which is one of the lean tools that applies pull system directly, focus on interrelation between supplier and contractor at the right time and maintaining optimum inventory levels. In a review done by Koranda et al. (2012), JIT method can be defined as LC tool to decrease damages and material waste that potentially caused by excessive inventory level. On the contrary, Horman and Thomas (2005) argued that when inventory level and buffer time plunged to zero it could impact on the performance negatively. Therefore, Due to likelihood of occurring uncertainty and highly we should keep in

mind that volatile market that although it is true that the ultimate aim of JIT is to optimize inventory list, any mistake in utilizing JTI leads to deterioration in productivity.

According to Ballard and Howell (2003), the Last planner is a planning, monitoring and holistic system that provides a detailed plan depended upon size and complexity by those who perform tasks. Ideally, LPS contains all the restrictions and prerequisites to warranty all activities could be executed without any bottleneck and defection.

5.2 Constructive amalgamation of a different approach with lean

Although there are reticence and scepticism yet for supporting of implementation of lean techniques, this thesis seeks to point out the positive effects of lean on the project performance.

The study carried out by Torp et al. highlights the factors in which they could impact positively on utilizing lean in construction contractors holding companies and their underlying sister's companies.

- leadership and management support and commitment
- lean awareness through the sister's companies and break down tasks in a logical way
- supplying sufficient resource for utilizing lean techniques
- Motivating people by showing them successful results of early lean adopters
- Illustrating achieved goals and benchmarks during project life-cycle
- providing a forum to facilitate exchanging collected data and experiences through whole responsible

Despite the numerous studies revealed the positive role of lean construction techniques on successful performance, many researchers strived to reduce waste and improving productivity by the combination of lean and other construction techniques.

Sacks et al. (2010) addressed the issue of stable production flow for the whole project by proposing KanBIM concept and its defined requirements. They developed the BIM pull flow software based on the Last Planner System™. This concept was expected to impacts on the following issues: visualization of construction procedures; support for planning, communication and status feedback; evaluation of continuous improvement.

Olav et al. (2018) suggested both LPS system and uncertainty management (UM) have a commonality and the integration of both concepts will optimize performance by improving project planning and controlling. For instance, they proposed to add some risk-reducing activities into the master schedule level. Modifying the master schedule based on the risk

factors, such as a change in material price or bankruptcy of plumber, could be a reliable method to guarantee smooth workflow.

5.2.1 Lean and digital opportunity

The digital revolution played a substantial role in terms of developing, operating, and coordinating the activities of organizations (Setia et al. 2013). The changes in the procedures and processes are clearly visible amongst organizations. The potential forlean construction tools is still not completely exploited when their components are isolated. Although some studies have been conducted in order to show how the transition to the digital systems brings new opportunities for implementing lean productively, many firms struggle to find the right platform to grasp efficiently the benefits of this transformation.

Digitalization could serve as a catalyst for better transparency, easier coordination, faster communication, and finally increased productivity in engineering design. In order to bring a lean system to the next level of excellence and overcome the traditional barriers, companies should be assured that lean principles are integrated successfully into digital transformation Using the digital capabilities could mobilize the further progress in lean construction tools and applying lean principles.

Value stream mapping is one of the LC tools that its performance totally will be developed by digitalization. It is obviously clear that visual planning (VP) is one of the main parts of VSM. Visual planning helps the group in the implementing phase in which it shows the timeline for deliverables. Generally, the visualization is used in order to have a better overview of the situation. Therefore, Visual workflow management contributes to supporting sustainable improvement and comprehensive control over the project.

Historically, a post-it note, a colourful marker and a whiteboard have been used as a visual tool. However, traditional tools were practical but they had significant limitations like enough space to illustrate all the information for complex and mega projects. A digital project status display, by contrast, could be extensively used for sharing a huge amount of information. Plus it could be utilized as a means for a pull system.

Meanwhile, the negative effects of digitalization on lean should not be ignored. For instance, embedding digital technologies into lean construction requires structure, guidelines and practice time.

The benefits of each lean construction tool probably differ for various projects and different sizes of contractors. Cost is the dominant factor for selecting appropriate lean construction tool by most of the contractors.

Customer and staff satisfaction is another substantial criterion that could be considered as an assessment tool for lean implementation. It can be seen that suitable digital infrastructure increases transparency between managers and stakeholders, therefore this collaborative workspace could address related problems and opportunities.

5.3 Relation of lean construction and sustainability

Song and Liang (2011) stated that if lean philosophy just focuses to maximize the economic benefits eventually it probably results in harmful impacts on the environment. Following the essence of lean production, which is traditionally represented as 'doing more with less', some of the researchers explained that both concepts of lean construction and sustainability have been evolved individually and attempt to address specific problems. Implementing sustainability approach in conjunction with lean principles, not only could lead to a synergetic effect but also decrease their weaknesses. The lean approach is associated with reducing variabilities, minimizing waste, improving workflow, enhancing customer satisfaction and heightening quality. While sustainability is oriented toward decreasing the harmful impacts on the environment, social and economy due to construction activities (Francis & Thomas, 20191).

In 2016, Marjaba et al. reported that the extreme effects related to the construction industry happen in the use phase. On the other hand, Torres (2014) argued that in order to get the most effective results, a sustainable strategy should be implemented in the earlier stages of conceptualization and design.

In a review done by Carvajal et al. (2019), the substantial benefits of cooperation of both philosophies are postulated: productivity increase, waste reduction, construction cost decrease and construction time decrease. Nonetheless, it is noticed that the environmental aspects have been improved most among the three fundamental aspects of sustainability; whereas it is evident that the financial aspect is the main convincing reason to implement lean techniques.

Longoni and Cagliano (2015) believe that cross-functional coordination between operations executives and sustainability managers should be applied to get the highest vertical and horizontal alignment between lean practices, social and environmental goals. Whereas, in well organizational structure, both operational and sustainability managers should be involved in making decision related to operation, lean practice and sustainability.

From the social aspect, according to Bae and Kim (2007), utilizing lean construction techniques such as Kaizan, value stream mapping, and 5S attempt to improve the human welfare, increase workplace safety and occupant health.

Hence, this study briefly represents that the potential synergies, derived by merging of lean and sustainability approaches, could greatly augment productivity and efficiency. It can be observed that environmental effective measures such as reducing material wastage, air pollution, and minimizing the resource depletion could result in economic impacts like reduction in project life cycle and cost. The same scenario can be attributed to social positive effects such as improved safety and health condition (Carvajal et al., 2019).

6 Conclusion

This chapter summarizes all the importance of this study as well as answering the problem statement briefly and finally suggests a subject for further research. Since many years ago, the AEC industry, in an effort to solve the chronic problems of the construction industry, tries to utilize different methodologies such as lean management. Although lean construction technics were introduced many years ago, we are still in the embryonic level of implementing lean thinking. It could be caused by different underlying reasons but probably lack of adequate information and organizational barriers play key roles in this situation. The lean principle has been involved in different construction levels. When the lean construction method is going to apply, we expect that it produce values. These values probably will be considered in different significance due to various viewpoints of stakeholders. For example, contractors are looking for eliminating waste that affects the time and cost. On the other hand, authorities are seeking sustainability in which applying lean leads to minimize the negative effects on the environment, economic and social.

The result form this study revealed that despite the awareness level of lean concepts are incrementally increasing in the construction industry, we are still lack of concrete practical framework in order to successfully implement lean policy.

In chapter one, this research reflects the necessity and motivation for upgrading traditional approaches in the construction industry and discusses the challenges of conventional methods. Next, the study's goals and chapters are outlined elaborately to get an in-depth overview of the master thesis. The concept of lean management originated from Toyota Company which clearly showed the differences between added-value or non-added value activities. In chapter two, literature review starts with a history of lean and then focus other aspects of this approach such as lean tools, identification of waste, etc.

Generally, Lean means producing with minimizing various kinds of waste as much as possible. Lean principles contribute to making a balance for using material, labor, and resources that result in reducing waste, cost and delivering the project on due time (Banawi , Bilec, 2014). Lean construction is an innovative approach, which derived from lean philosophy. With applying lean construction principles, we suppose to achieve the following goals: continuous improvement, decreasing non-added value activities, increasing quality, enhancing communication and smoothing workflow.

In chapter three, the Policy for achieving the goals of this study is described. Moreover, factors that impact on the spectrum, validity and reliability of articles were defined. In chapter four, the interviews are presented in which my supervisor and I tried to select interviewees with different backgrounds amongst different companies. In chapter five, the study discusses the implication of lean construction tools on construction performance. The requirement and barrier for successful implementing construction tools are proposed. In chapter 6, the conclusion is drawn from research findings and lastly highlights recommendations for future work.

6.1 Research question answers

RQ1- What is meant by lean construction and can LC concept be utilized as a solution to minimize waste?

Lean thinking is a management strategy to create the most values for end-users by minimizing all the waste. Lean thinking focuses on incremental improvement, productive maintenance and participating customers.The rapid diffusion of lean philosophy, enhancing productivity through reducing waste, grabbed the attention of Koskela. Furthermore, Koskela managed to adapt manufacturing principles and took advantage of them for construction industry. Lean construction is looking forward to a new foundation for project management in construction.

Lean construction is a kind of innovation in the construction industry as its approach is different from a typical conventional one. Whenever there is a change in a certain arrangement, there is always a back out from its usage like innovation (Singh, Kumar, 2019). It should be noticed there is not any unanimous and explicit definition for lean construction.

RQ2- What are the most common used lean construction tools, and how they affects the project performance?

In this study, different lean construction techniques, as well as the prerequisite for implementing them, have been shown in the literature review. It should be noticed that each of lean techniques and tools has its own applicability and constructability.

In this context, the majority of interviewees particularly confirm that the last planner system, 5S, takt time planning, BIM (lean design) and TVD are the most used lean tools. In this step, research concentrates upon results that came from articles, which showed role of lean construction techniques in fostering productivity and assessed implementing lean construction.

Hamed (2013) confirmed that implementing lean construction techniques has a positive effect on reducing lead-time. In addition, the occurrence of most of the risk factors were minimized and Hamed recommended that lean tools should be implemented in a developed country because of simplicity and high efficiency.

RQ3- Which types of waste we have in the construction industry and how they are produced?

Generally, when people hear waste they just think about the physical waste that is dumped in landfills. While there could be identified numerous waste during the construction process. During the last decades, many techniques have been conducted to decrease waste as well as lean management. Waste in construction could be categorized in different groups such as physical waste, delay time, non-value adding activity, rework, defects, deterioration in piled material, etc.

Polat et al. (2017) demonstrated a framework to introduce the roots of material waste in construction. There are 34 factors that led to waste; needless to mention that all factors could be considered as causes for generating waste in lean management's perspective.

RQ4-What are the challenges for implementing lean construction tools?

Although the positive effects of lean construction techniques have been seen, there is a long way to embrace lean thinking by the construction industry. Small et all. (2017) argued about how lean construction affects positively on projects. They indicated that the most significant factor to secure the success of LC is cultural change. Everybody, from the highest level to the lowest level, should get involved in this new method as well as governmental agencies. The following culture must be considered for adapting:

- Buy-in form senior management
- Concentration on customers and end-user as well as process delivery
- Adequate and efficient daily conversation

Training and education should not be undermined for implementing effective LC.

Hoellthaler et al. (2019) talked about three distinct waves of implementing lean production. In the first wave, the regulations were restricted to organizing labor and reducing waste that resulted in an isolating production system. In the second wave, lean production applied in a holistic manner through the whole system, which augmented synergistic effects between different elements of system. Although the second wave showed higher maturity than the first

one, inefficiency due to utilizing the analog system was obviously clear. Digitalization plays a key role in transforming the second wave to the third wave since it facilitates optimization of information flow along with added-value activities.

RQ5-Have the construction companies adopted lean construction techniques in their routines?

As explicitly explained before, construction industry endeavour to apply different techniques in order to achieve a feasible solution for enhancing construction productivity. One of the biggest challenges for contractors is still to perceive and apply lean concepts on the projects since there are no obvious pathways to deploy LC successfully. Many underlying actions should be done together simultaneously in order to get the most benefit from applying lean production in the construction industry. An in-depth understanding of the current situation is highly decisive to provide valuable insight into what are waste and what things customers look at them as values. Secondly, it is commonly seen that lack of appropriate level of awareness of lean construction tools does not let to achieve lean goals easily. Apart from these, the author suggests that specific following measures will be conducted:

- Providing a lean training course and disseminating lean knowledge
- Establishing a research group for lean implementation (Also it is beneficial to use the experiences of external lean consultants)
- Developing new parameters for measuring lean performance
- The necessity of releasing the result of successful implemented lean projects
- Being updated always about the IT tools and ERP systems
- Integration of other techniques with appropriate lean tools to get synergic benefits
- Participation of all stakeholders in implementing lean principles should be active, specifically top managers support lean implementation by incentives

The goal of Lean construction is to minimize waste (non-value activities) in order to increase efficiency that is desirable for the customer. It is highly recommended to apply lean thinking from the earlier phase of the project (design) to get the best result.

6.2 Limitation and future work

This study contains numerous limitations that should not be ignored, in the following, four of them are mentioned:

- Time restriction for master thesis did not allow the author to conduct more interviews, also it affected the size of the questionnaire.
- Abnormal situation due to the spread of COVID-19 (pandemic) and travel restriction should be taken into consideration, the author was not able to conduct the interview either on-site or personally.
- It included a limited number of reliable resources.
- The author chose a set of selected lean tools for investigating; there are still other techniques that were not explained.

Lastly, this study decides to propose some topics for further researches that are beneficial for all the stakeholder in construction industry.

The first research recommendation is to develop a framework for measuring the efficiency of lean construction tools in fast and accurate implementation. It could be done by an easy-to-understand questionnaire and targeted interviews that all professionals participate.

It will also be interesting that investigate about the role of lean construction tools in reducing uncertainty. The third recommendation could be a comprehensive and sophisticated comparison between the productivity of lean construction management and other approaches.

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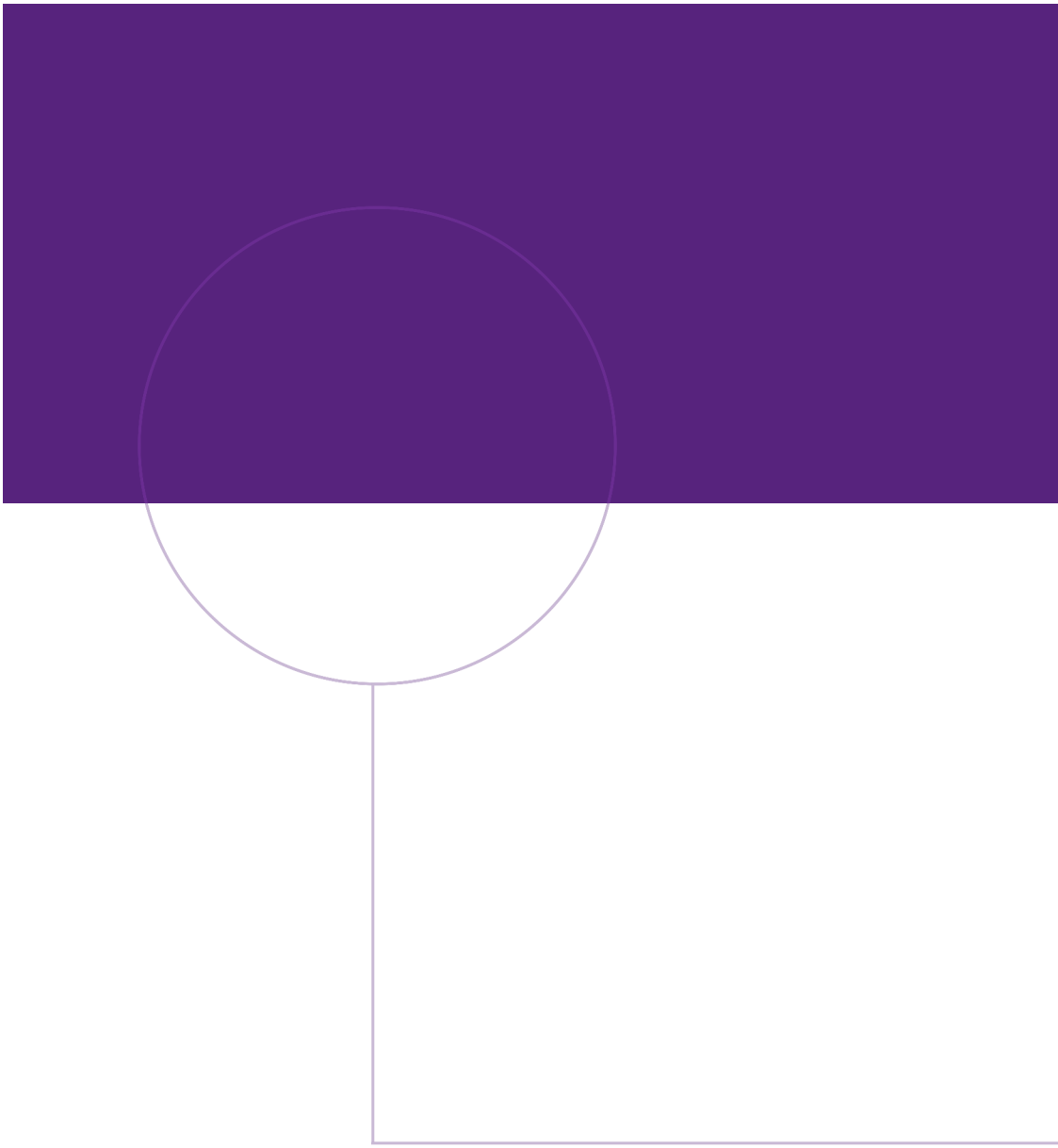
Appendix

Interview questions

Background questions	
1	What is your education level? What did you study in the university?
2	How old are you? (For example between 20-30 or 30-40).
3	What is your position now in the company?
4	How many years do you have experience in the construction industry?
5	What is the average budget for the last projects you have done?
Knowledge about lean philosophy	
6	What is your viewpoint regard to non-value added activities like rework, deficiency, over production, inventories and transportation? Do you think we still have waste more than is expected?
7	What is your opinion regarding continuous improvement and productivity in civil industry? Do you think is it possible to optimize more than now?
8	What kind of techniques you know in order to improve performance in projects?
9	To what extend do you know about lean construction approach? Could you please describe lean?
10	Could you please name some lean construction tools that you know about them?
Applying lean techniques in the company	
11	Does your company have any standard or instruction for executing lean approach in construction projects?

12	Are all the staff (could be anybody, for example workers or subcontractors) ready to embrace and apply lean construction tools? To what extent?
13	How does your company keep itself updated with the latest knowledge of lean construction?
14	Which is the best phase to utilize lean construction tools?
15	To what extent your company participate to produce new knowledge regarding lean construction tools?
	Lean construction Tools
16	What are the most productive lean techniques for implementing on the project?
17	What are the most challenges to implement lean construction tools?
18	Does any of lean construction tools have reverse result when it comes to implementation? if yes please explain more? Is there any lean tools that your company intentionally does not utilize?
19	How do you measure maturity in term of applying lean construction techniques on your company/organization?
20	Does the implementing lean construction tools have tangible effect to prioritize processes and procedures on the projects?



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