

T.R.
GEBZE TECHNICAL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

**RESEARCHING THE SYNERGY BETWEEN LEAN
CONSTRUCTION, BUILDING INFORMATION MODELING (BIM),
AND PROJECT SUCCESS**

FURKAN POLAT
A THESIS SUBMITTED FOR THE DEGREE OF
MASTER OF SCIENCE
DEPARTMENT OF CIVIL ENGINEERING

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THESIS SUPERVISOR
ASSOC. PROF. DR. SEVİLAY DEMİRKESEN ÇAKIR

GEBZE
2023

T.C.
GEBZE TEKNİK ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ

YALIN İNŞAAT, YAPI BİLGİ
MODELLEMESİ (YBM) VE PROJE
BAŞARISI ARASINDAKİ SİNERJİNİN
ARAŞTIRILMASI

FURKAN POLAT
YÜKSEK LİSANS TEZİ
İNŞAAT MÜHENDİSLİĞİ ANABİLİM DALI

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GEBZE
2023

GTÜ Fen Enstitüsü Yönetim Kurulu'nun 02.02.2023 tarih ve 2023/09 sayılı kararıyla oluşturulan jüri tarafından 20/02/2023 tarihinde tez savunma sınavı yapılan Furkan Polat'ın tez çalışması İnşaat Mühendisliği Anabilim Dalı İnşaat Mühendisliği Programında YÜKSEK LİSANS tezi olarak kabul edilmiştir.

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SUMMARY

The construction industry is a complex and multidisciplinary industry. The construction process itself involves many different stages, from planning and design to maintenance and operation. This complexity can lead to a number of problems. The use of new project management practices can be an effective way to solve problems that arise in the construction industry. Lean Construction and Building Information Modeling (BIM) are two important applications that have been increasing in popularity recently. The main purpose of this study is to investigate the synergy between Lean Construction and BIM and to determine at what level both contribute to the success of the project. Firstly, Lean and BIM were examined through a literature review. With the literature study, implementations that are considered to have high potential compatibility between BIM and Lean Construction have been identified. A model was established after the implementations were determined. Then, the method to test the model was determined as Structural Equation Modeling (SEM) and a questionnaire survey was conducted in Turkey via an online platform in order to obtain the required data for the model. According to the analysis results, it has been determined that Lean Construction practices have a significant positive effect on BIM Processes and project success. However, BIM's contribution to project success has lagged behind Lean Construction's contribution to project success. In the final part of the study, according to the information obtained as a result of the analysis, various comments and suggestions were made.

Key Words: Lean Construction, Building Information Modeling (BIM), Project Success, Structural Equation Modeling (SEM).

ÖZET

İnşaat sektörü karmaşık ve çok disiplinli bir sektördür. İnşaat sürecinin kendisi, planlama ve tasarımdan bakım ve işletmeye kadar pek çok farklı aşamayı içerir. Bu karmaşıklık bir dizi soruna yol açabilir. Yeni proje yönetimi uygulamalarının kullanılması, inşaat sektöründe ortaya çıkan sorunları çözmek için etkili bir yol olabilmektedir. Yalın İnşaat ve Yapı Bilgi Modellemesi (YBM), son zamanlarda popüleritesi artan iki önemli uygulamadır. Bu çalışmanın temel amacı, Yalın İnşaat ve YBM arasındaki sinerjiyi araştırmak ve her ikisinin de projenin başarısına ne düzeyde katkıda bulunduğunu belirlemektir. İlk olarak Yalın ve YBM literatür taraması yapılarak incelenmiştir. Literatür çalışması ile, YBM ve Yalın İnşaat arasında uyum potansiyeli yüksek olduğu düşünülen uygulamalar tespit edilmiştir. Uygulamalar belirlendikten sonra model oluşturulmuştur. Daha sonra modelin test edilmesinde kullanılacak yöntem Yapısal Eşitlik Modellemesi (YEM) olarak belirlenmiş ve model için gerekli verilerin elde edilmesi amacıyla Türkiye'de online bir platform üzerinden anket çalışması yapılmıştır. Analiz sonuçlarına göre Yalın İnşaat uygulamalarının YBM süreçlerine ve proje başarısına önemli ölçüde olumlu etkisi olduğu tespit edilmiştir. Ancak YBM'nin proje başarısına katkısı, Yalın İnşaatın proje başarısına katkısının gerisinde kalmıştır. Çalışmanın son bölümünde ise yapılan analizler sonucunda elde edilen bilgilere göre çeşitli yorum ve önerilerde bulunulmuştur.

Anahtar Kelimeler: Yalın İnşaat, Yapı Bilgi Modellemesi (YBM), Proje Başarısı, Yapısal Eşitlik Modellemesi (YEM).

ACKNOWLEDGEMENTS

First of all, I am extremely grateful to my thesis advisor, Assoc. Prof. Dr. Sevilay DEMİRKESEN ÇAKIR, for her guidance, patience, encouragement, and support. Thanks to her vision, I had the opportunity to learn new and valuable ideas and to improve myself on these issues.

I would like to thank to my family who have always supported and encouraged me in my education and career. And of course, I could not have undertaken this journey without Ayşe ERUSTA. Her endless love, patience, and support have always given me strength.

I would like to thank my other committee members Assoc. Prof. Dr. Atilla DAMCI and Assoc. Prof. Dr. Onur ŞEKER for their time and constructive comments.

Finally, I would like to thank the volunteer survey participants who provided valuable data for this thesis.

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LIST OF ABBREVIATIONS AND ACRONYMS

<u>Abbreviations and Acronyms</u>	<u>Explanations</u>
2D	: 2 Dimensional
3D	: 3 Dimensional
4D	: 4 Dimensional
5D	: 5 Dimensional
6D	: 6 Dimensional
7D	: 7 Dimensional
8D	: 8 Dimensional
9D	: 9 Dimensional
10D	: 10 Dimensional
AEC	: Architecture, Engineering and Construction
AMOS	: Analysis of Moment Structures
BIM	: Building Information Modeling
CAD	: Computer Aided Design
CAFM	: Computer Aided Facility Management
CALIS	: Covariance Analysis and Linear Structural Equations
CFI	: Comparative Fit Index
CMIN	: Minimum Value of the Discrepancy
CMMS	: Computerized Maintenance and Management Systems
COBIE	: Construction-Operations Building Information Exchange
ENR	: Engineering News Record
EQS	: Equations
FPS	: Ford Production System
GLS	: Generalized Least Squares
HVAC	: Heating, Ventilation, and Air Conditioning
IFI	: Incremental Fit Index
IGLC	: The International Group for Lean Construction
IOT	: Internet of Things
JIT	: Just-in-Time
LEED	: Leadership in Energy and Environmental Design

LPS	:	Last Planner System
MEP	:	Mechanical, Electrical, and Plumbing
ML	:	Maximum Likelihood
NFI	:	Normed Fit Index
PDCA	:	Plan-Do-Check-Act
PPC	:	Percentage Planned Completed
RAMONA	:	Reticular Action Model or Near Approximation
RFI	:	Relative Fit Index
RMSEA	:	Root Mean Square Error of Approximation
SEM	:	Structural Equation Modeling
SPSS	:	Statistical Package for the Social Sciences
TLI	:	Tucker-Lewis Index
TPS	:	Toyota Production System
UK	:	United Kingdom
US	:	United States
VSM	:	Value Stream Mapping
WBS	:	Work Breakdown Structure
WLS	:	Weighted Least Squares
WO	:	Work Order
WWP	:	Weekly Work Plan

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1. INTRODUCTION

The construction industry had fallen behind from past to present according to labor productivity stats compared to all other industries. According to the McKinsey Global Institute Report [2017], construction workers work more inefficiently than other industry workers. Construction and manufacturing industries are compared in terms of labor productivity in Figure 1.1. The report shows that the majority of construction workers do not add value to their work. The report stated that if the labor productivity in the construction industry reaches the labor productivity of the total economy, the construction industry's added value will increase by approximately \$1.6 trillion. This means construction industry's value added would increase by using the same resources. As a result, many problems such as budget & time overruns, and poor-quality reveal in the construction industry due to low productivity.

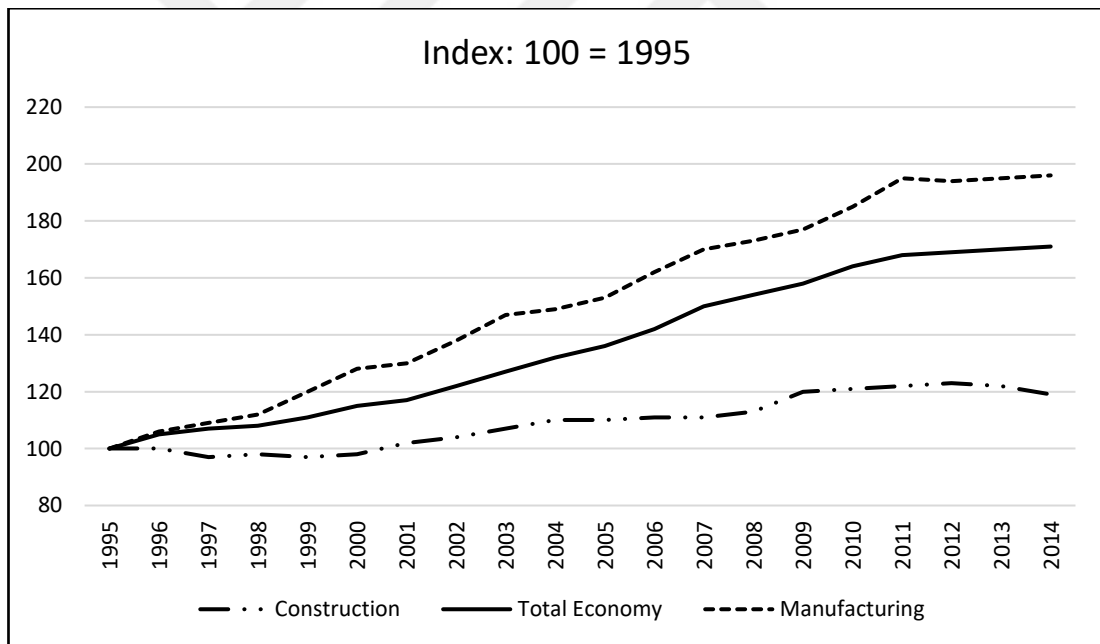


Figure 1.1: Real gross value added per hour worked, 2005 \$.

Today, different methods and implementations are developed to improve labor productivity in the construction industry. With the spread of methods such as Lean construction & Agile project management, implementations of technologies such as the Internet of Things (IoT) and Building Information Modeling (BIM), more efficient

workflows are targeted in construction projects. Eldeep et al. [2022] reported that significant increase in project efficiency by using of BIM and Lean in the design phase. They stated that BIM and Lean tools such as just in time reduced waiting time waste by almost 50% in the design process. In the case study, they showed that using BIM makes a significant contribution to Lean principles by adding more value to the customer and reducing waste. It showed that an increase of approximately 11% in the contract price and 25% in the contract time could be avoided by implementing BIM and Lean tools. These technologies are even more efficient when they are implemented together [Sepasgozar et al., 2021], [Sacks et al., 2010].

Considering the synergy of recently developing technologies in construction, the aim of the study is to analyze the synergy between Lean construction, BIM implementations, and project success. When BIM and Lean implementations are examined individually, it is known that there are positive effects on construction processes [Aziz and Hafez, 2013], [Eastman et al., 2011]. However, it is not known exactly how efficient when both are applied together. Therefore, this study targets to reveal which Lean and BIM implementations have positive effects on each other.

Within the scope of this thesis, first, literature review about Lean construction and BIM implementation was made. As a result of the literature review, components of Lean construction, BIM implementations, and project success were determined to examine the synergetic relations in between. In this context, a structural equation model was created to quantify the impacts. A questionnaire was administered to the construction professionals. Then, the model was analyzed using AMOS tool of SPSS software. The results are presented and discussed accordingly.

1.1. Problem Statement

Building defects are usually caused by reasons such as poor communication, lack of planning, inadequate supervision, poor quality materials, skill shortage, poor site layout, and designing problems during the design and construction phase. In addition, these causes significantly reduce efficiency in the construction industry [Aljassmi and Han, 2013], [Hasan et al., 2018]. According to Andújar-Montoya et al. [2017], the main cause of building defects is due to inadequate control of construction works which is represent nearly 75% of these anomalies. This high percentage can be reduced

by using information and communication technology such as intelligent sensors networks, and using different management methods such as Last Planner System (LPS).

According to the Egan [1998], studies in the United States (US), Scandinavia, and the United Kingdom (UK) have found that 30% of constructions are reworked. In addition, mistakes account for 3-6% of the total cost, and at least 10% of the materials were wasted. Love and Edwards [2003] stated that the cost of rework in Australian construction projects reaches up to 35% of the total cost. It has been concluded that it contributes up to 50% of the total overrun costs of projects. As a result, one of the most important reasons for inefficiency and poor quality in the construction industry is reworking.

According to John and Itodo [2013], poor supervision, use of poor-quality materials, and rework are the most critical factors causing waste on site. It shows that these wastes contribute 21-30% on average to the project cost overrun. In the study, it is mentioned that one of the biggest causes of waste is the lack of coordination during the construction process. Khanh and Kim [2014] stated that the most important wasting factors were time of inspection of construction works, waiting for someone else's work to be done before continuing, accidents on the construction site, and time of transporting materials, equipment, and workers. In addition, it is mentioned that 9.36% of the total project cost consists of total waste cost. Mossman [2009] refer that the waste in the construction processes is approximately 55-65%. This is a very high ratio of waste/value. Lean construction tools are a significant opportunity to reduce waste in construction processes.

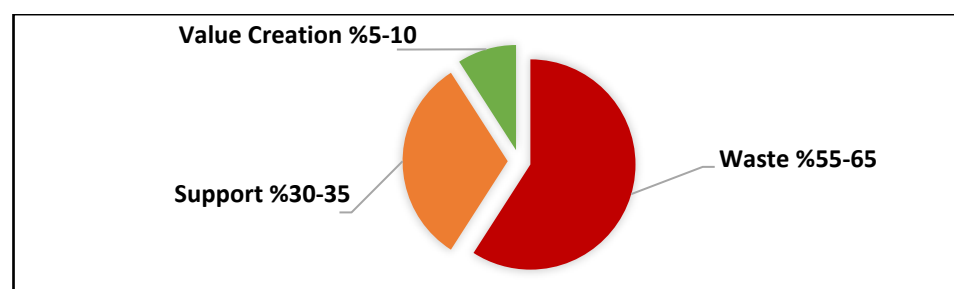


Figure 1.2: Waste & value in construction process.

According to Thomas et al. [2018] in PlanGrid and FMI's report, it is estimated that non-productive labor activities in the US caused a loss of \$177.5 billion in 2018

alone. In addition, the report mentions that 48% of reworks in the US are due to insufficient data and poor communication. This high percentage is on average up to 52% globally and costs \$280 billion worldwide. Also, the reasons such as the frequent change of workers, the low level of education of the workers, and the non-suitability to the environment of the construction site for technological innovation restrict the development in the construction industry. Loosemore and Lee [2002] stated that employing too many foreign workers in the construction projects can also cause many problems like miscommunication. Multicultural working environments and workers who are speaking different languages can lead to the lack of communication.

According to the McKinsey Global Institute Report [2015], the digitalization and use of technology in the construction industry have lagged behind compared to other industries. This report has been evaluated over 3 main headings: digital assets, digital usage, and digital workers. Compared to other industries in Figure 1.3, the construction industry has lagged behind in terms of digitalization. All problems in the construction industry are actually an opportunity. Because there are many areas to develop the construction industry.

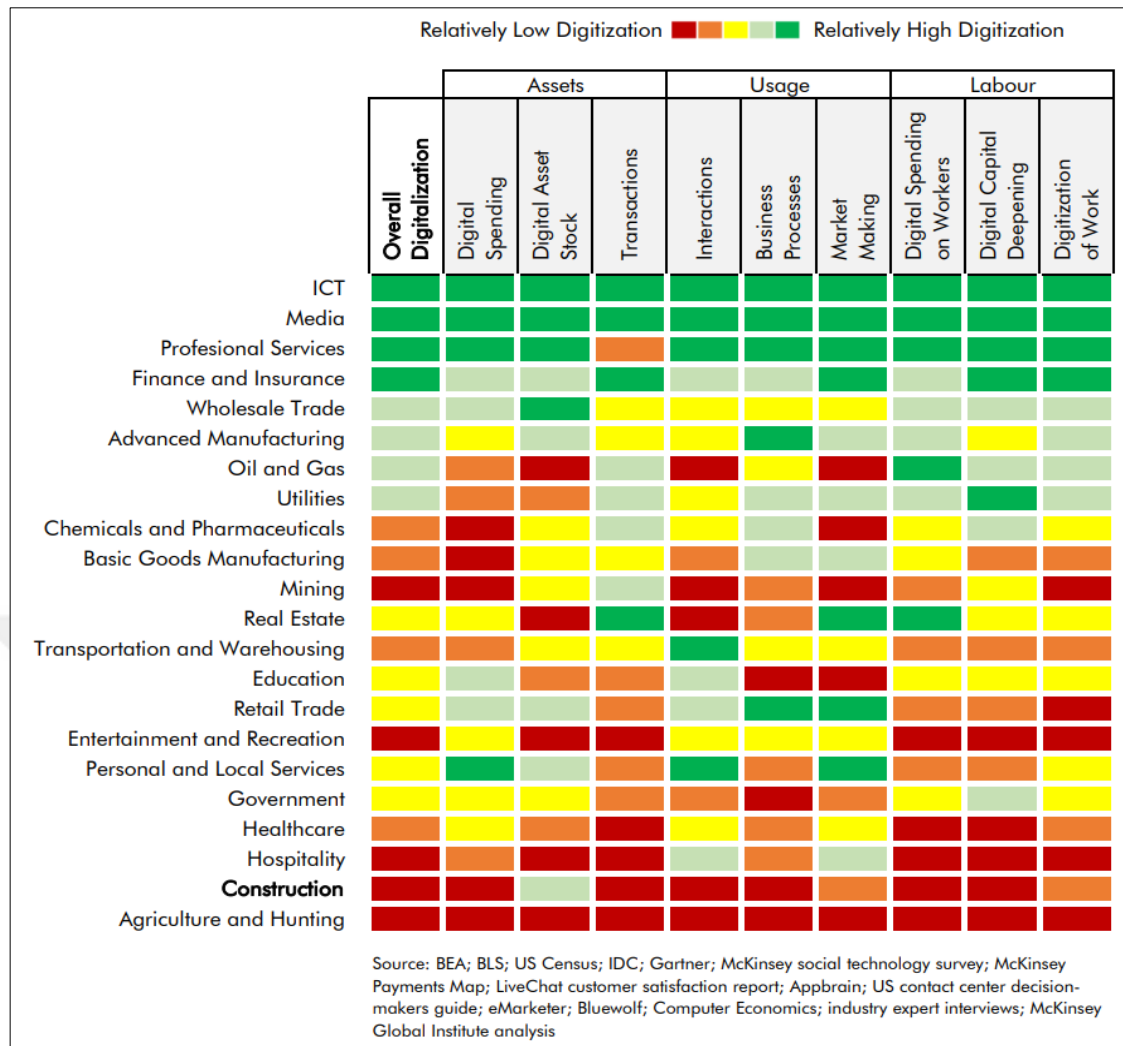


Figure 1.3: McKinsey Global Institute industry digitization index.

1.2. Aims and Objectives of the Research

There are many studies that analyze the interaction between BIM and Lean in the literature [Saieg et al., 2018]. Both concepts have their own processes and methods. Lean construction and BIM have been developed to increase productivity and, improve quality and processes in the construction industry. With this aspect, they have many common points. It is seen that especially companies that implement Lean construction in the construction industry use BIM making it a Lean construction tool. Although there is a lot of common points between Lean and BIM, there are still challenges when it comes to integrate these two concepts. There are many academic studies in the literature about the contribution of BIM to Lean processes, but the contribution of Lean tools to BIM processes has not been studied much [Pedo et al., 2021].

In this thesis, the contribution of Lean tools to BIM processes and the synergy between them is investigated. Also, the compatibility of Lean construction tools and BIM implementations with project success such as time, cost, quality, safety, and customer satisfaction are further assessed. The main aim contribution of this study is that it reveals the level of synergy between Lean construction, BIM, and project success, and highlights which functions are common. This study is expected to help construction practitioners to review their strategies toward Lean and BIM implementation based on the research outputs.

1.3. Research Method

Firstly, a literature review about Lean construction tools and BIM was conducted through online science databases, paper congresses, and conferences of the International Group for Lean Construction (IGLC). While the literature is being searched, the articles in which especially Lean and BIM together were reviewed. Thus, subjects more related to each other were determined and comprehensive reviews were conducted for the thesis. After the literature review, the hypotheses are created to research the links between Lean, BIM, and Project success.

This study adopted a quantitative research method. Data were collected with a questionnaire using Google Forms. Data from practitioners were analyzed by the SPSS AMOS program. This study is based on Structural Equation Modeling (SEM). The positive effects of Lean construction tools, BIM, and project success on each other were analyzed by using SEM.

1.4. Scope and Limitations

The implementation of Lean construction and BIM in construction management is gradually increasing across the world. Within the scope of this thesis, Lean construction tools, BIM processes, and project success criteria were examined. However, the study does not consider every Lean tool instead it considers the most widely applied ones and the ones that have been proven to have a significant impact and interaction with BIM practices based on the in-depth literature review. In addition, the five

most important headings like cost, time, quality, safety, and client satisfaction in project success criteria were determined to research the synergy between them. Moreover, quantitative methods were used in the research. The survey developed in this study targeted construction professionals operating in the Turkish construction industry. Survey data was collected only from practitioners who implement BIM and Lean construction implementations in their projects.

1.5. Organization of Thesis

This research consists of 6 main stages. In the first stage, it was introduced why this study was carried out and what are the problems in the construction industry. In the second stage, Lean and BIM concepts are presented. The origins and implementations of Lean and BIM are mentioned by conducting a literature review. In the third stage, survey questions which are the method of the research and data collection methods are presented. The questionnaire answers were examined and made ready for analysis. In the fourth step, the collected data were analyzed by the SPSS AMOS program. In the fifth stage, the results of the analysis are discussed. In addition, a summary of the study is presented. In the last stage, the results of the study are mentioned. Suggestions for future work are presented. The stages of the study are shown step-by-step in Figure 1.4.

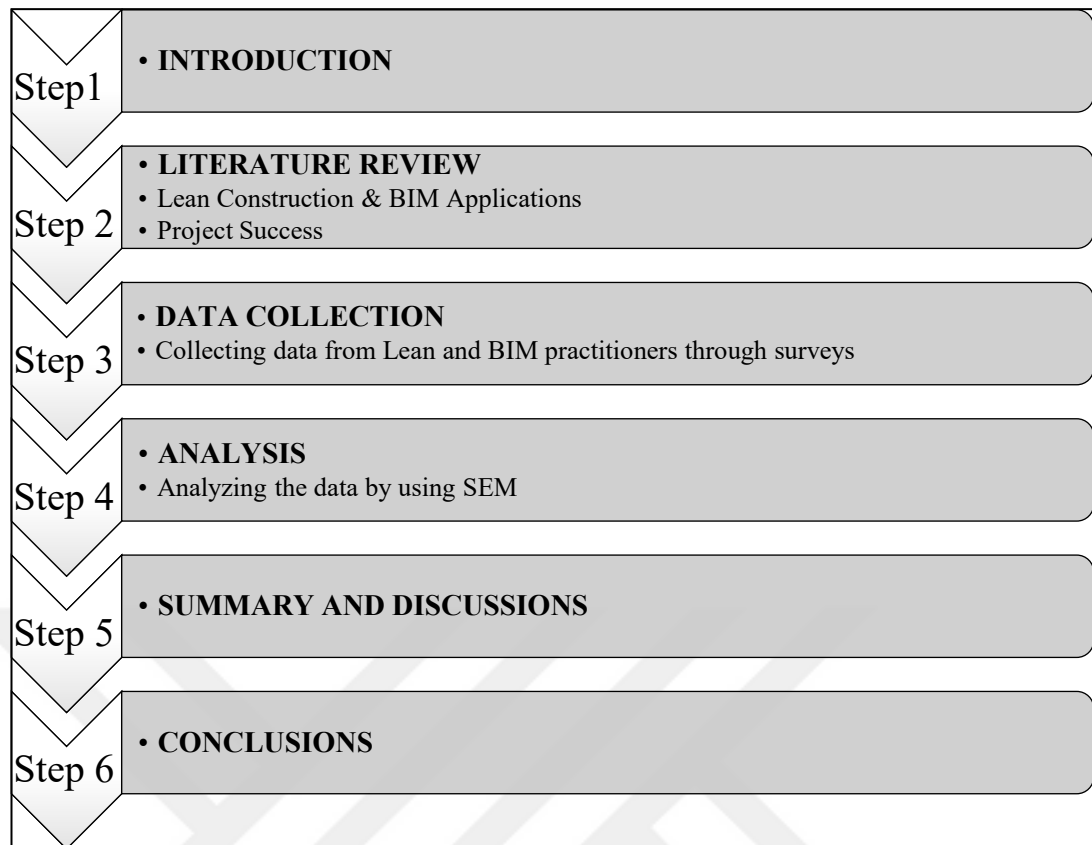


Figure 1.4: Organization of study.

2. LEAN IMPLEMENTATIONS IN CONSTRUCTION INDUSTRY

2.1. Background of Lean

From the industrial revolution to today, production approaches have constantly changed and new production philosophies have emerged. Many different production methods have been developed with new approaches to increase productivity. One of these methods is Lean production. Lean production has emerged as a result of many different processes over time. This method dates back to the 1950s which is the end of World War II. In that time, Kiichiro Toyoda, who is the president of Toyota Motor Company, realized that the company had to compete against US in three years or else Japan's automotive industry would not be able to survive. Because the difference between the production of an US worker and the production of a Japanese worker was considerable. An US worker produced about nine times more than a Japanese worker. Therefore, Japanese workers wanted to learn why this difference exists and what is US mass production method [Amaro et al., 2021], [Green, 1999].

Kiichiro Toyoda, Eiji Toyoda, and Taiichi Ohno visited US companies to learn about Ford Production System (FPS) known as mass production. However, during this visit, they noticed that the FPS was not suitable for Japan industry because both countries' market was not similar to each other. Hence, they began to develop the Toyota Production System (TPS). With this production method, they wanted to develop a production method more suitable for the Japanese industry [Amaro et al., 2021].

TPS was dramatically heard by the Western industry after the 1973 oil crisis. After the success of TPS in the crisis environment, the interest of the Western industry gradually increased in Japanese manufacturing [Pathak, 2012]. As a result of this intense interest, numerous academic studies and books have been published by researchers [Amaro et al., 2021].

This approach has been developed by industrial engineers in the automotive industry by trial and error for many years [Koskela, 1992]. The main idea of the TPS is to eliminate the processes that are determined as waste and to remove inventories by

using a small lot production approach [Shingo and Dillon, 1989]. Taiichi Ohno described the principles and techniques of the TPS method in his book *Toyota Production System: Beyond Large-Scale Production*, which was published in Japanese in 1978 and translated into English edition in 1988 [Chiarini et al., 2018]. The tools and ideas behind TPS are represented as a house. The TPS house is a cultural icon in the manufacturing industry. TPS house is shown in Table 2.1. The reason why TPS is likened to a house is that only strong pillars are not enough for a house to remain strong. So, all elements of the house should remain strong [Liker and Morgan, 2006].

Ohno [1998] describes that TPS consists of two main pillars which are autonomation and Just-in-Time (JIT) in his book. Autonomation or Jidoka which is one of the pillars emerged as a result of Toyoda Sakichi's ideas and practices. This method which he invented, was basically based on the automatic stopping of the machine in case of any defect. This autonomation idea has been extended to processes where machine operators stop the process via a button or cord when they see any problems. So, possible errors are minimized with Autonomation/Jidoka [Liker and Morgan, 2006]. The second pillar of the TPS is JIT. The JIT principle comes from the ideas of Toyoda Kiichiro. JIT is based on the principle of purchasing or obtaining the needed products at the right time, in the right place, and in the right quantity. All needs are determined by the market demands. This approach is seen as the opposite of the mass production system and is called the pull production system. In 1953, Ohno invented the implementation known as Kanban to be able to create and maintain the pull system. This implementation began to be used to provide continuous flow from customers to suppliers and to level accurately processes. However, Ohno thought that it is necessary to focus on eliminating waste to have continuous flow and level the production processes correctly. That's why Ohno divided waste into 7 main headings: overproduction, waiting, transporting, inventories, overproduction, overprocessing, and moving [Chiarini et al., 2018].

The foundation of the TPS house is as important as its pillars. Heijunka is called leveling production. The aim of Heijunka is to create a leveled order flow and workload. Balancing the workload brings with it many opportunities to standardize processes. So, the foundation of TPS should be given importance [Liker and Morgan, 2006].

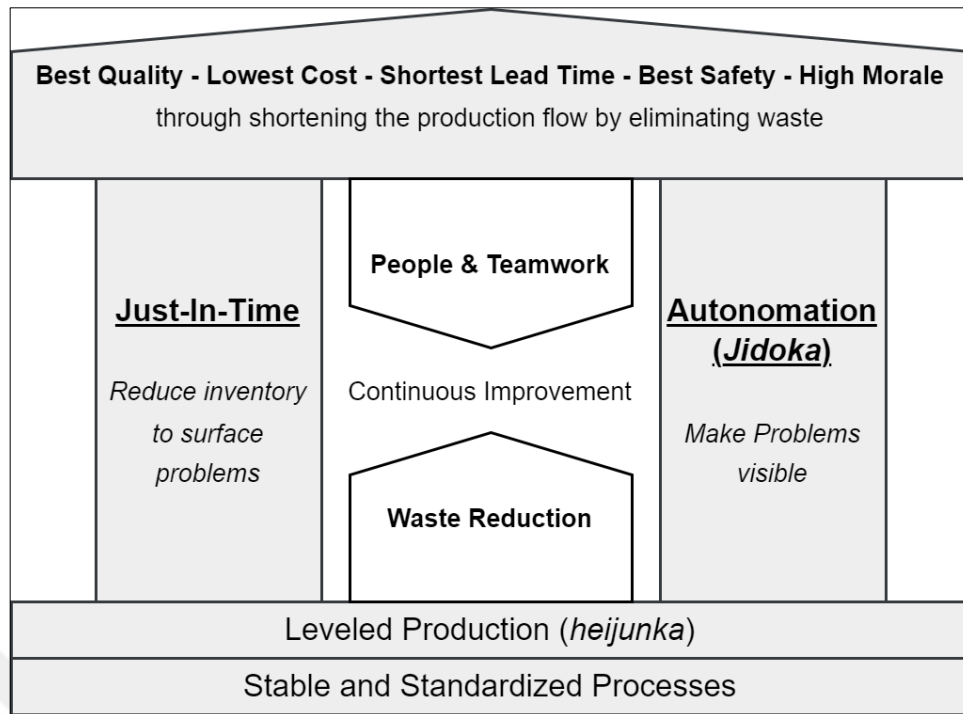


Figure 2.1: The Toyota Production System (TPS) house.

TPS, Toyota Way, and Lean are often confused with each other because the differences between them are not well known. This causes many negative effects on companies. The Toyota Way is different from the TPS and is not described as a system or program. Fujii Cho, who is a former Toyota president, released the Toyota Way model in 2001 after he noticed contradictions about what they should focus on among Toyota employees. Basically, the Toyota Way relies on the organizational culture. Cho wants to emphasize that people are the most important part of the organization. Therefore, continuous improvement and respect for people form the two pillars of the Toyota Way [Coetzee et al., 2016].

2.2. Lean Production

The concept of Lean Production was first coined by a member of the research team studying the international automobile industry in his book which is *The Machine That Changed the World*. “Lean” refers to a production system created to produce better products in less time and place by using fewer labor hours in contrast to the mass production system [Ballard and Howell, 2003].

Lean focuses on value above all else. However, value creation is equated with cost reduction in some companies. This shows that the concept of Lean is not fully understood. Therefore, Womack and Jones [1996] explained what Lean thinking focuses on and what the principles are. Lean is not just eliminating waste and reducing costs, it is preparing the product or service according to the customer's requirements. By doing this, it is aimed to provide more value to the customer [Hines et al., 2004].

Womack and Jones [1996] described the summary of Lean in the *Lean Thinking* book as follows:

“In short, lean thinking is lean because it provides a way to do more and more with less and less – less human effort, less equipment, less time and less space – while coming closer and closer to providing customers with exactly what they want.”

In Lean philosophy, if there is no problem in the process, there is a problem in fact. The main work of the employees and management in the production phase or whatsoever process is to identify obstacles experienced while reaching the optimum quality level in the processes and solve it. Lean assumes that there is no process without problems and everything needs to be constantly improved. Lean tools attempt to identify the underlying causes of problems. In Lean thinking, these problems can be defined as waste. Waste is the opposite of the concept of value. From customer's perspective, value is something he or she is willing to pay for. In other words, a product or process that doesn't create value for the customer is a waste [LeMahieu et al., 2017].

Waste in Lean thinking is considered under 8 main headings [Hartanti et al., 2022], [Melton, 2005]:

- The *Motion/Moving* is defined as the spending of time and energy by employees to do a job. For example, if the distance between the office and the production area is too long, it will be an unnecessary waste of time and energy for the workers.
- *Waiting* is another waste in processes. It is the most important type of waste that causes delay in plans. For example, when an architect is designing a construction project when she/he needs to get ideas from engineers, she/he gets the answer after a long time due to insufficient communication between them.

- *Overproduction* is a waste type referring to a product or process that is not needed or produced earlier than planned. For example, preparing more rebar than necessary at the construction site.
- *Excess stock* represents the holding of goods or products that are not required for current needs. Stocking materials to be used months later in the construction site is defined as a type of waste.
- *Defects* are errors that can be seen in processes. Usually, this type of waste is easily distinguishable. For example, wrong manufacturing according to the project during the construction phase is defined as waste
- *Extra transportation* is defined as waste according to Lean thinking. Shorter routes should always be preferred for transport processes.
- *Overprocessing* is doing more work than necessary. Processes such as holding more meetings than required and excessive reporting are a waste. Increasing productivity by doing more work is a misconception.
- *Non-utilized talent* is also a waste. Every employee's skills need to be used. In order to ensure continuous improvement, this type of waste must be eliminated.

Since the 1980s, many companies have started to follow up on the Toyota model for production because of its performance in times of crisis. In today's conditions, it is certain that manufacturing companies need a Lean model to compete with other manufacturing companies. Because now the Lean production model has been preferred instead of the mass production model. For example, it is difficult to find a hospital in the US that is not aware of Lean principles or does not take into consideration a Lean program. However, it is not easy to apply Lean concepts in such environments where the work is not in the workshop. It is better for companies to focus on Lean principles instead of focusing on production processes. Because Lean is a philosophy rather than a production model and it varies from company to company [Liker and Morgan, 2006].

Lean has five important principles. Lean tools are all created around these five principles [Fowler et al., 2022], [Womack and Jones, 1996]:

- *Value* is the most critical starting point of Lean. The customer defines the concept of the value and the producer created this value. It is necessary to provide the

right product or service to the customer at the right time and cost. Otherwise, waste will be created according to Lean thinking.

- *Value Stream* is the entire process from the producer to the customer of the service or product. With the mapping of the whole process, it is easily determined where the wastes occur. The value should be well defined. Thus, it is possible to determine which stages it goes through while creating value and wastes can be eliminated.
- *Flow* is the provision of an uninterrupted process by producing the value defined by the customer at the requested quality, quantity, and time. Processes that limit continuous flow should be eliminated.
- *Pull* is based on the idea of not making the product or service without customer request. In this way, wastes such as overstock and overproduction are prevented.
- *Perfection* is an endless journey. Aiming for perfection provides unlimited improvement opportunities for processes. Continuous improvement is made by using the other four principles.

In many different industries such as manufacturing, service, construction, etc. the concept of value can represent different meanings and visions. The concept of value in the construction industry is generally associated with parameters such as quality, cost, and time. However, even though all these definitions are associated with the concept of value, a universal value theory has not yet been developed in the construction industry [Salvatierra-Garrido and Pasquire, 2011].

2.3. Lean Construction

Technology and management techniques are two very important factors for efficiency. Although many new technological applications and construction management techniques have been developed in construction projects in the last 40 years, productivity has lagged far behind. One of the reasons for this is that new technologies do not reduce costs in the design and construction phase and cannot sufficiently improve the project processes [Aziz and Hafez, 2013].

The idea of implementing the Lean philosophy refer as a new production philosophy in the construction industry is based on a study by Koskela [1992]. The term

"Lean Construction" was coined at the IGLC's first meeting in 1993 [Tezel et al., 2020]. IGLC has led many studies on the implementation of the Lean philosophy in the construction industry. Developing tools such as planning, control, visualization, and continuous improvement, it has changed the way of management in the construction industry [Salem et al., 2006]. Egan [1998] mentioned that Lean construction is a way to improve performance in the construction industry and some construction companies have achieved significant success in quality and efficiency by applying Lean techniques. In the early stages of Lean construction, Lean tools such as 5S, Visualization, JIT and Value Stream Mapping (VSM) were introduced by researchers to improve productivity and quality in the construction industry [Jiang et al., 2022]. Since the construction and the manufacturing industry's work environment and way of doing work are not similar, tools had to be developed according to the construction projects. Aziz and Hafez [2013] mentions that managing construction processes according to Lean philosophy is different from ordinary practices. Because in the construction industry (1) net objectives are set for delivery processes (2) It is aimed at maximizing performance for the client at the project level (3) products and processes are designed simultaneously (4) production supervision is ensured throughout all projects. Planning and control stages are also very important in Lean construction, as is practiced in the manufacturing industry.

2.3.1. Gemba Walks

Gemba term is the "real place", where the action is produced and is seen as the center of value. To ensure the effective use of Gemba, it is important to go where the actual action is done and see the action being done. Being and spending time in Gemba helps to see and fix problems. Because it fosters people who do the actual work to produce value for customers in Gemba and it's important to contact them directly [Tyagi et al., 2015].

The "go and see" principle is referred to in the Lean manufacturing literature as Genchi Genbutsu. It is necessary to make direct observations and verify data on the site, rather than relying solely on computer data or information from someone else. We can also commonly see it as a glass icon in VSM [Lean Enterprise Institute et al., 2003].

Gemba Walk aims to identify non-value-added activities, which mean waste in processes such as reworks in the construction site. This tool is regularly used by senior managers to identify and eliminate waste. Observing and controlling how the process is ongoing during the work and talking to the workers doing the job are quite important for a full understanding of a process. The flow of material and information should be examined to identify waste at different workstations during the Gemba walk [Barth and Formoso, 2021].

Samudio et al. [2011] mentioned examples from a project in which the Gemba Walk in a study was used to continuously improve production on the construction site and increase the accuracy of weekly work plans. The team managed production by collecting feedback directly from site observers and workers. In addition, adjustments were made in weekly planning with the information obtained. Data collected by the project team showed that the team's efforts improved their performance and assisted in the use of LPS. In addition, Kerem et al. [2013] explained the importance of the Gemba Walk in the construction site with case studies. It mentioned that the managers who walking in the Gemba came to the work area and communicated with the workers, making the workers feel that the work is really important.

2.3.2. Takt Time Planning

"Takt" word, a German term, means "rhythm" or "beat". It refers to the regularity of a work. Takt time used as a design parameter in a production site (such as manufacturing, construction, etc.). That is, the works are tuned according to the customer's demand rate [Hopp and Spearman, 2011].

$$Takt\ time = \frac{Net\ time\ available\ during\ the\ period}{Customer\ demand} \quad (2.1)$$

In Lean context, takt is associated with Lean concepts such as continuous flow, standardization, and production line leveling. Takt represents the heartbeat of assembly lines in the TPS. Today, this approach is used in industries, and the use of takt varies appear difference. While the assembly line for the product keeps moving around

workers in the manufacturing industry and move of workers is too low, in the construction industry the (facility) product built is stationary and move of workers is too much [Tommelein, 2017].

In order for each worker to complete the work assigned to them, the speed of the production line and the working speed of the workers should be adjusted according to takt time. The speed should be designed in such a way that a little more time remains in the takt time. Under normal conditions, all of the given task will be done within the specified takt time. However, you can never be sure that all the work will be done. Because there can always be deviations from the works. Therefore the "time left" calculated serves as a buffer for work completion [Tommelein, 2017].

Takt time planning in the construction industry has recently emerged in the literature. In the literature, we can see takt time planning implementation in highway construction [Fiallo and Howell, 2012], hospital projects [Linnik et al., 2013], and housing projects [Binninger et al., 2018], [Nunes Mariz et al., 2013].

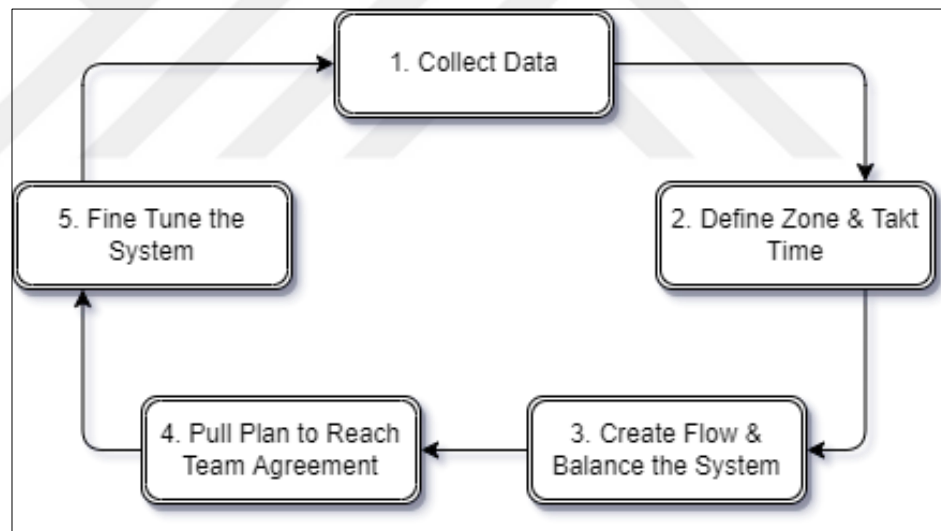


Figure 2.2: Steps for takt time planning.

Step 1. Collect Data: In the first phase, planners collect data a few weeks before the construction phase begins. The data collection process begins with a team meeting of the trades and contractor involved. Each work is determined how and when it will be done. At this stage, important issues such as the progress of the project, the working methods, the constraints that hinder the work, and the sequencing of the works are discussed [Tommelein, 2017]. One of the examples is the creation of colorful floor plans by people who know the details of the work such as a foreman, to show the work

to be done in a day. Examples are shown in Figure 2.3. This process helps to set durations and production plans. Work sequences are defined by coloring. Coloring is important for "take time planning" but it is not necessarily [Frandsen et al., 2013].

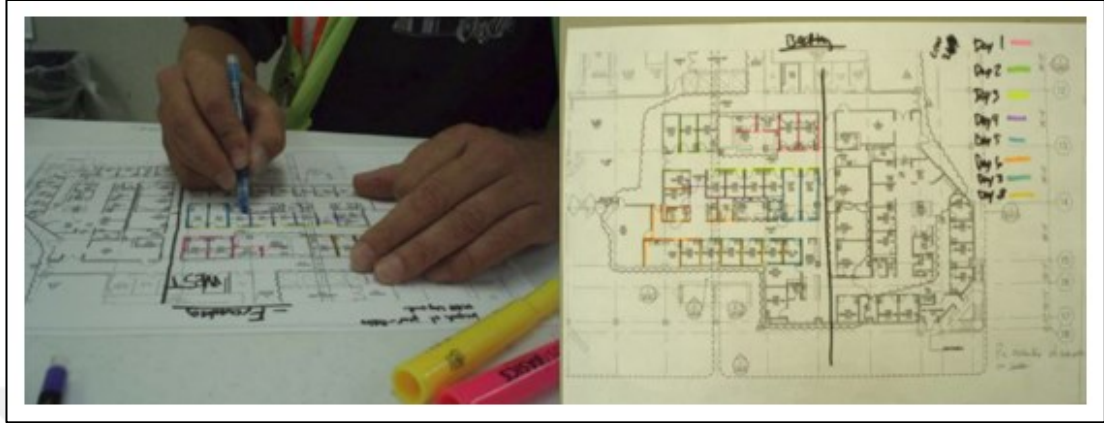


Figure 2.3: Developing color-up.

Step 2. Define Zone & Takt Time: Takt time is defined as the time it takes for trade to complete works in a zone. Zones are defined as areas that trade will control. Zones are created with the information obtained from the data collection stage. Takt time is still undefined when determining areas. Because there is still not enough information. Coordination meetings should be held to determine the trade sequence. It is vitally important who will work first and who will work after in a zone. The sequence of trades is derived from the pull planning. Bottlenecks in each group are identified and production rates in the areas are roughly estimated. In addition, more detailed knowledge of the sequence is required to develop a reliable takt time.

Step 3. Create Flow & Balance the System: At this stage, workflows are created and balanced. Zones are adjusted if necessary. The takt time is set to maintain the weekly cycle. It is improved by adjusting crew sizes or trades capacities according to takt time.

Step 4. Pull Plan to Reach Team Agreement: The processes that limit the milestone planning are discussed with the team. Information and analysis learned from processes are shared with other team members.

Step 5. Fine Tune the System: Finally, it is determined that the plan is reliable and the work sequences are feasible. Arrangements are made for better performance.

2.3.3. 5 Whys Analysis

5 Whys Analysis is an iterative technique used to identify the root causes of a particular problem. This technique was developed by Sakichi Toyoda and has been a significant problem-solving method in TPS. Taiichi Ohno, the architect of TPS, defined the 5 Whys Analysis as the foundation of Toyota's scientific approach, a method that makes the root causes and solutions of problems clearer by asking 5 why questions [Gangidi, 2019]. There are three important factors for the effective use of the five-cause analysis: (i) Expressing the problems accurately and completely, (ii) Giving honest answers to the question of why, (iii) Determinating to get to the root of the problems and solve the problems [Web 3, 2009]. The approach used in the 5 Whys Analysis is shown in Figure 2.4 [Ohno, 1988]. In the example, to determine why a machine stopped working, the question "why" was repeated 5 times and the root cause was investigated. Using this method can help uncover and correct underlying problems. If this method is not used, the fuse or pump shaft will be replaced. So, the problem will appear to be solved. However, since the source of the problem has not been identified, the same problem will most likely recur within a few months. The main problem that causes the machine to work is that the strainer is not attached in the lubrication pump. Since the strainer was not installed, the shaft was worn and rattling due to metal scrap entering the pump and therefore the machine malfunctioned. By attaching a strainer, the reoccurrence of similar errors can be largely prevented [Ohno, 1988].

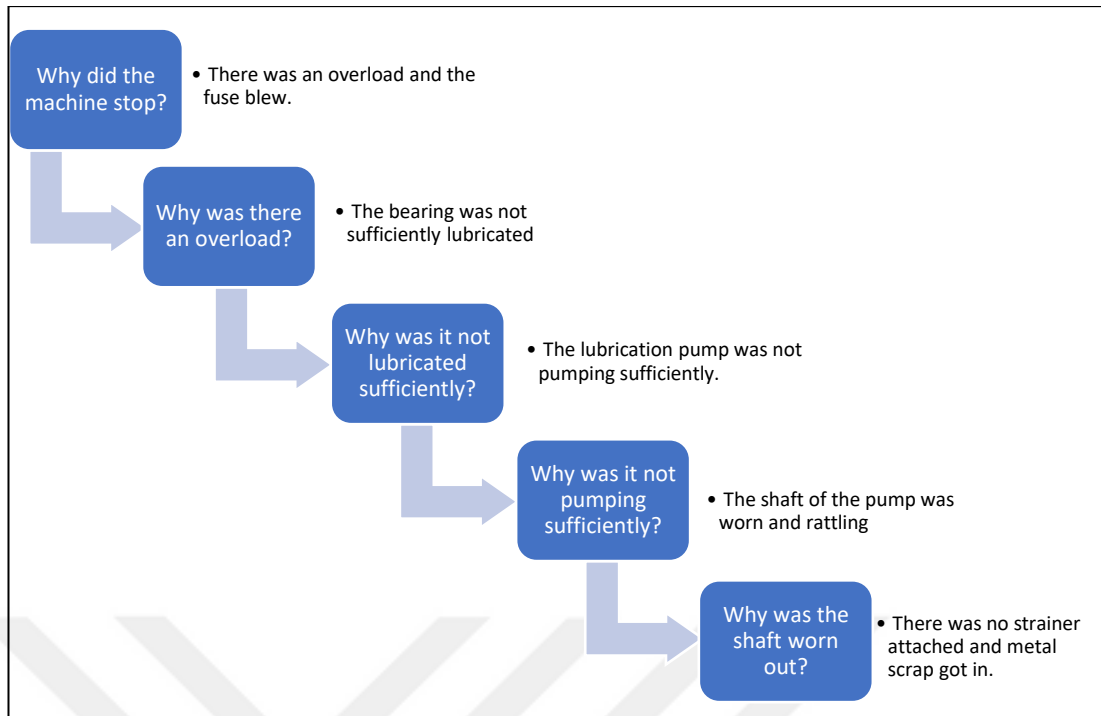


Figure 2.4: Example of 5 whys analysis.

When 5 Whys Analysis is implemented by a team, processes are greatly improved. This method basically consists of five steps. First, a team gathers and agrees on the problem. It is decided whether additional people are needed to solve the problem. The team's first why the question is asked. Three or four sensible answers are recorded on a place such as a whiteboard or a flipchart. For each answer given, four more "why" questions are asked in a row. All reasonable answers are followed up and reviewed. The root cause is determined when the "cause" issue does not provide any more useful information. If needed, questions are continued to go beyond the 5 questions. Among the dozens of answered, systematic causes of the problem are sought. These are discussed and decided on the most likely cause with the team. The most likely root cause of the problem is determined and team approval is obtained. Thus, appropriate corrective actions are developed [Web 3, 2009]. Unlike other sophisticated problem-solving methods, 5 Whys Analysis does not include advanced statistical tools. Therefore, it is easier and more suitable for integrating into operational tools [Murugaiah et al., 2010].

5 Whys Analysis has been successfully applied in many industries such as healthcare, manufacturing, and construction, to investigate, categorize and solve issues

[Braglia et al., 2017], [Card, 2017]. 5 Whys Analysis is one of the most preferred approaches in order to prevent productivity and quality losses in the manufacturing industry [Murugaiah et al., 2010]. In their study, Benjamin et al., [2015] has proven to be an effective approach in eliminating overall equipment effectiveness speed loss. In addition, studies related to the use of the 5 Whys Analysis in the construction industry have also been carried out in the literature. Jaber and Burhan [2020] used the 5 Whys Analysis in his study to identify obstacles to investments in the construction industry and argued this method very useful in identifying root causes.

2.3.4. 5S

The 5S practice is a method developed to form and maintain a quality and orderly environment in an organization [Ho and Cicmil, 1996]. Towards the 1960s, Japan was the first country to start implementing 5S approaches in their manufacturing industry organizations [Gupta and Jain, 2015]. But in retrospect, the philosophy of the 5S has been seen in Japanese culture for many years. Shintoism, which emphasizes "cleanliness", Confucianism, which emphasizes "orderliness," and Buddhism, which emphasizes "self-discipline", have an important place in the development of 5S practices in Japanese society [Randhawa and Ahuja, 2017].

Takashi Osada was the first person to create and develop the 5S practice by shortening *Seiri*, *Seiton*, *Seiso*, *Seiketsu*, and *Shitsuke* which are Japanese words. Osada, introduced the the 5S practice to create a quality environment in organizations [Randhawa and Ahuja, 2017]. The 5S practice has been used in Japan for many years. Most Japanese 5S practitioners think that this method not only improves the physical environment but is also useful for improving thinking processes [Ho et al., 1995]. The 5S practice is a quite popular housekeeping tool within Lean. It is the simplest method to implement processes of organizing, standardizing, and sustaining the workplace [Kilpatrick, 2003].

Each step in the 5S practice consists of different meanings. The steps of 5S and its equivalent in English language are shown in the Table 2.1. [Ahuja and Khamba, 2008].

Table 2.1: Elements of 5S.

Japanese	English	Meaning
Seiri	Sorting	Organization
Seiton	Set in order	Neatness
Seiso	Shine	Cleaning
Seiketsu	Standardize	Standardization
Shitsuke	Sustain	Discipline

Sorting is the first step of the 5S practice. The main idea of this stage is to determine the frequency of use of the products or equipment used, to identify unnecessary items, and to eliminate unwanted items that cause clutter. Unnecessary products are marked with a red tag. Rarely used items are moved out of the work area to a more organized storage area. Fully unnecessary materials are disposed of out of the work area [Peterson and Smith, 1998]. Sorting makes it easy to avoid batches of unnecessary material or equipment in the workspace, removing barriers to the workflow [Chapman, 2005]. After all unnecessary items are removed, the set-in order stage which represents the second S in the 5S practice is started. This stage helps organize the workspace. A place is determined for each item and it is ensured that each item is kept ready for use [Peterson and Smith, 1998]. At this stage, it enables the effective use of equipment or materials by using methods such as labeling within each item, coloring for quick distinguishing, keeping similar materials together. By using these methods, materials become more detectable [Gupta and Jain, 2015]. The third stage, Shine, represents cleaning. This step includes activities such as keeping clean the work area and maintaining the clean appearance. A maintenance program must be developed to clean dirt, dust etc. from equipment or the work environment [Randhawa and Ahuja, 2017]. In addition, a clean and tidy workspace provides motivation for employees. Employees enjoy their work in a clean and healthy environment. As a result, the quality of the work increases [Gupta and Jain, 2015]. The standardization stage helps improve the procedures made during the 5S practice. It actually is a review process. It enables everyone to maintain the 5S process in the most accurate way and to see the differences in the processes easily [Peterson and Smith, 1998]. A procedure needs to be established in order to maintain the Sorting, Set in Order, and Shine stages which are first 3S on a regular basis. An effective procedure can be created using a variety of checklists

[Randhawa and Ahuja, 2017]. The final step, Sustain, means sustaining all S stages. Implementing the last step is vital because it requires some changes in the behavior of employees within the organization. At this stage, employees within organization should make all the 5S practice a habit. In order to gain benefits such as increasing labor productivity, producing quality products, and preventing work accidents in workplace, it is necessary to sustain the 5S practice and make it a corporate culture [Randhawa and Ahuja, 2017].

Recently, it is also used as a "6S System" because most manufacturers see Safety as a priority. The 5S practice is primarily aimed at improving the quality of the workplace. With the addition of "Safety", which is the sixth step, to the 5S system, it is aimed to realize the importance of occupational safety. The 6S is a more comprehensive approach but can be successfully applied in many industries, including the construction industry [Misiurek and Misiurek, 2020].

Rowlinson [2004] highlights the importance of 5S by describing it as the "the mother of safety". He argued that the achievements of the 5S practice are extremely substantial in terms of preventing work accidents, tidying the working environment or site, discovering problems more quickly, increasing productivity, and creating a brighter, healthier, and more spacious environment. In addition, He states that it is one of the most effective ways to ensure safety at construction sites.

There are many examples of successful implementation of 5S in industries such as service, and construction, apart from the production industry [Ho, 1999]. Leino et al. [2014] determined that the number of accidents decreased and the weekly safety inspection indices increased by 3.4 percent after the implementation of the 5S practice on the construction site. Tezel and Aziz [2016] found that item transaction times were saved by 50% and the usable area increased by 30% in a 5S practice pilot application in a storehouse in the construction industry. It also improved cleanliness, health, and safety. This method provides the opportunity to follow the maintenance of equipment and materials.

2.3.5. Standardization

Lean principles do not perform well when everyone is allowed to implement their own way of working. The reason for this can be shown as the results are unpredictable and complicate the workflow. Standardization is crucial for the implementing of more successful and reliable processes [Chan and Tay, 2018]. Standardization is key to continuous improvement. It is not a set of pre-prepared and controlled documents. Rather, it is a way to create the most efficient performance possible. It is the steady continuation of processes [Liker and Meier, 2006]. The definition of Standardized Work according to Lean Enterprise Institute [2003] is as follows:

“Establishing precise procedures for each operator’s work in a production process, based on three elements:

- *Takt time, which is the rate at which products must be made in a process to meet customer demand.*
- *The precise work sequence in which an operator performs tasks within takt time.*
- *The standard inventory, including units in machines, required to keep the process operating smoothly.”*

In standardization, there are some additional applications besides the three elements mentioned above. Works can be standardized by using job instructions, visual controls, charts, and process spreadsheets [Nunes Mariz et al., 2012]. Standardized work is defined as specific instructions that help make a process run most efficiently. These instructions are one of the ways developed to achieve the goal. It helps to identify areas that need improvement by focusing on eliminating waste in processes [Mor et al., 2019]. According to Gibb [2001], standardization of processes creates more efficient processes by organizing the resources and time of project teams. He also mentions that standardization reduce costs and increases quality.

2.3.6. Continuous Improvement

Kaizen is a Japanese word that describes activities undertaken to improve processes or the environment in workplaces. It represents continuous improvement [Brunet and New, 2003]. The person who first used the term "Kaizen" and often cited

it was Imai Masaaki, who wrote *Kaizen: The Key to Japan's Competitive Success* [1986]. In this book, he summarized the Kaizen concept, principles, and implementations used in the continuous improvement process. "Kaizen" term is derived from two Japanese words Kai (change) and Zen (good). According to Chiarini et al. [2018], Kaizen is a way of thinking that encourages everyone to improve processes by making changes to benefit the work and the team.

Any task in a business process into three categories which are incidental work, value-added work, and muda. Accordingly, each task is considered one of these three categories [Koskela, 1992] [Monden, 2011]. Incidental works are processes that do not add value to the product but are mandatory works. This type of work does not create full value from the perspective of the customer. Value-added works consist of works that add value to the product or service. Processes that do not add value or muda (which means waste in Japanese), are works that are not necessary in the process and are defined as worthless in the perspective of the customer. Some companies simply increase working hours to increase value-added work. However, instead of increasing this value-added works, it increases muda and incidental works. Instead, a better way is to identify waste and continually improve it to reduce it. Value-added work should be increased by continuous improvement as shown in Figure 2.5. [Chen et al., 2010].

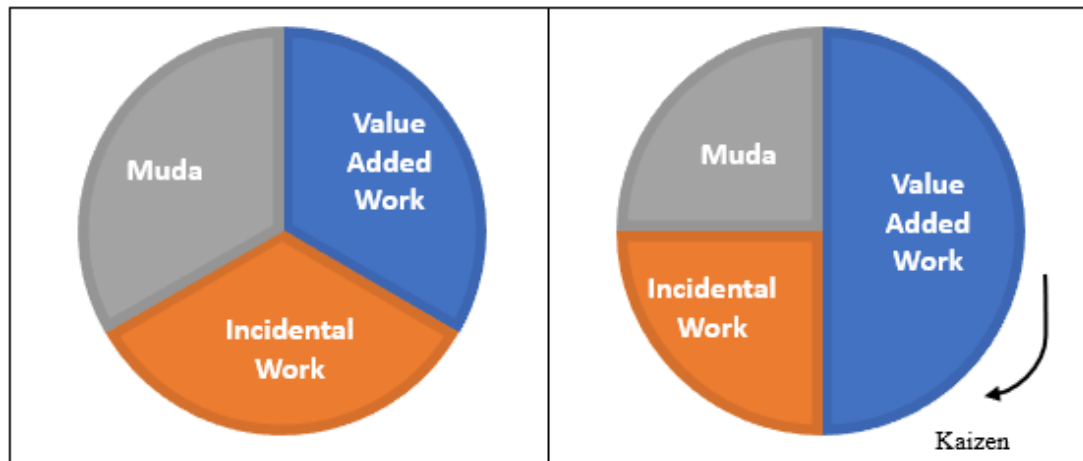


Figure 2.5: Effect of Kaizen.

Kaizen concept is based fundamentally on human effort. Various approaches can be used to achieve continuous improvement. The Plan-Do-Check-Act (PDCA) Cycle is described as the most obvious kaizen implementation. Certain progress is made at each

stage. The plan is the stage of setting goals for improvement. Do is the stage in which the plan is implemented. Check is the stage where the plan and implementations are used effectively or not. The act is the stage where processes are standardized and new targets are set in order to improve the process [Al Smadi, 2009].

2.3.7. Mistake Proofing

Poka-Yoke is a Japanese term meaning mistake proofing. *Poka* means inadvertent mistakes, while *Yokeru* means avoidance. Mistake-proofing is the method of preventing errors by setting limits for the correct execution of work. The original term is Baka-yoke but since it means fool-proofing (or idiot-proofing) it has been replaced with a more appropriate term poka-yoke [de Bucourt et al., 2011].

Mistake Proofing is a quality improvement approach that often uses simple devices to develop improvements. It is aimed to prevent errors by using environmental cues, simple devices, switches, and indicators. In order to develop techniques for mistake-proofing, it is first necessary to determine why errors occur and what factors help in minimizing errors [Stewart and Grout, 2001].

Although Mistake Proofing is seen as a Lean manufacturing technique, there are various literature studies showing that it is a Six Sigma technique [Vinod et al., 2015]. In addition, this technique is not only used in the manufacturing industry. For example, the Mistake Proofing technique can be applied in the health industry. According to Kumar and Steinebach [2008], the use of Mistake Proofing technique in hospitals helps to achieve success in patient operations. It helps to prevent the staff from making medical mistakes and ensures that the surgeries are correct, painless and prevents complications that may arise from medical mistakes. Also, Kumar and Steinebach, [2008] mentions that it saves a lot of costs because it reduces the error rate.

According to Santos and Powell [1999] case studies, it has been determined that the Mistake-Proofing approach is very beneficial in construction practice. There is a wide range of applications for this approach, especially in construction machinery.

2.3.8. Last Planner System

Greg Howell and Glenn Ballard, who know the dynamics and problems of the construction industry closely, suggested that it was a way to standardize their workflow. These two researchers and other Lean construction thinkers developed the Last Planner System in a series of experiments in the early 1990s [Porwal et al., 2010]. With the publication of the Shielding Production G. Ballard et al. [1998] article, LPS implementations have increased and examples of implementations have been seen in countries such as the US, UK, Denmark, Finland, Indonesia, Australia, Venezuela, Brazil, Chile, Ecuador and Peru [Ballard and Howell, 2003].

LPS is basically a Lean construction tool that focuses on planning, monitoring, and controlling [Gjerde et al., 2019]. LPS is seen as a management system that focuses on optimizing workflow and learning rapidly. The last planner represents the last person in the decision chain in the organization, usually a foreman [Fernandez-Solis et al., 2013]. As seen in the Figure 2.6, the Last Planner focuses only on workable tasks, unlike traditional planning. In addition, processes are structured to encourage learning. This prevents the same mistakes from being repeated over and over [Kim and Ballard, 2010].

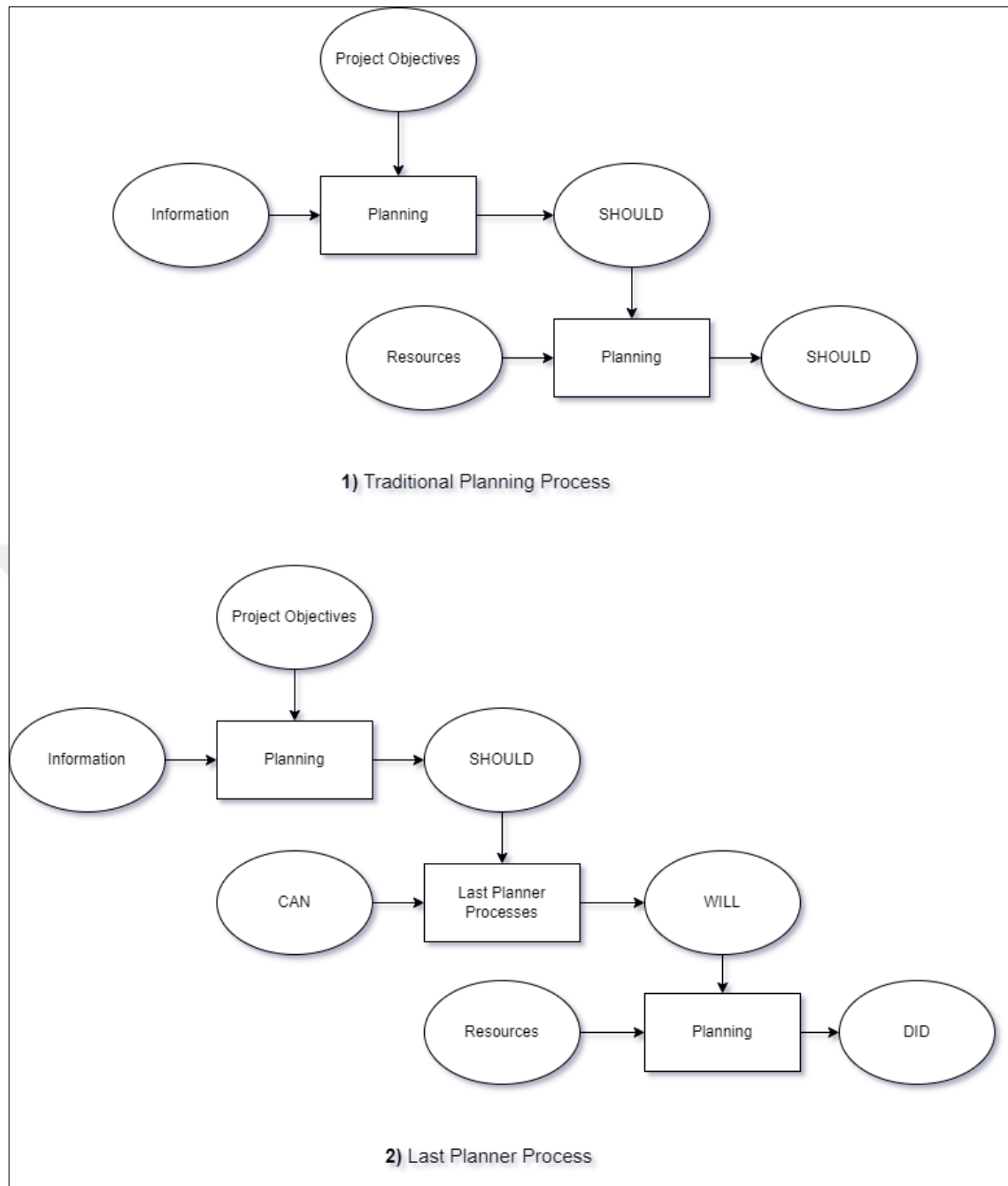


Figure 2.6: Traditional planning process and last planner process.

According to Ballard [2000], there are four main categories for any project task. These are Should, Can, Will, and Did.

SHOULD: It consists of tasks that should be performed in the near future according to the project plan. It is the first stage for the work to reach the determined milestones. In this process, various information is obtained from project objectives, past experiences of planners, customer demands, etc. Then, tasks are created based on the information obtained.

CAN: This process consists of adjustments that need to be made in the Should phase. All prerequisites must be done and the necessary labor and materials must be ready. In addition, project constraints are determined at this stage.

WILL: These tasks are the process that works assured to be completed after all constraints are assessed.

DID: These tasks are completed works.

In addition, there is a planning hierarchy used in these stages. These are respectively the master plan, pull plan, look-ahead plan, and weekly work plan (WWP). Finally, it consists of learning processes in Did stage [Gao and Low, 2014]. Figure 2.7 shows the main steps of LPS. [Ballard and Tommelein, 2016], [Heigermoser et al., 2019].

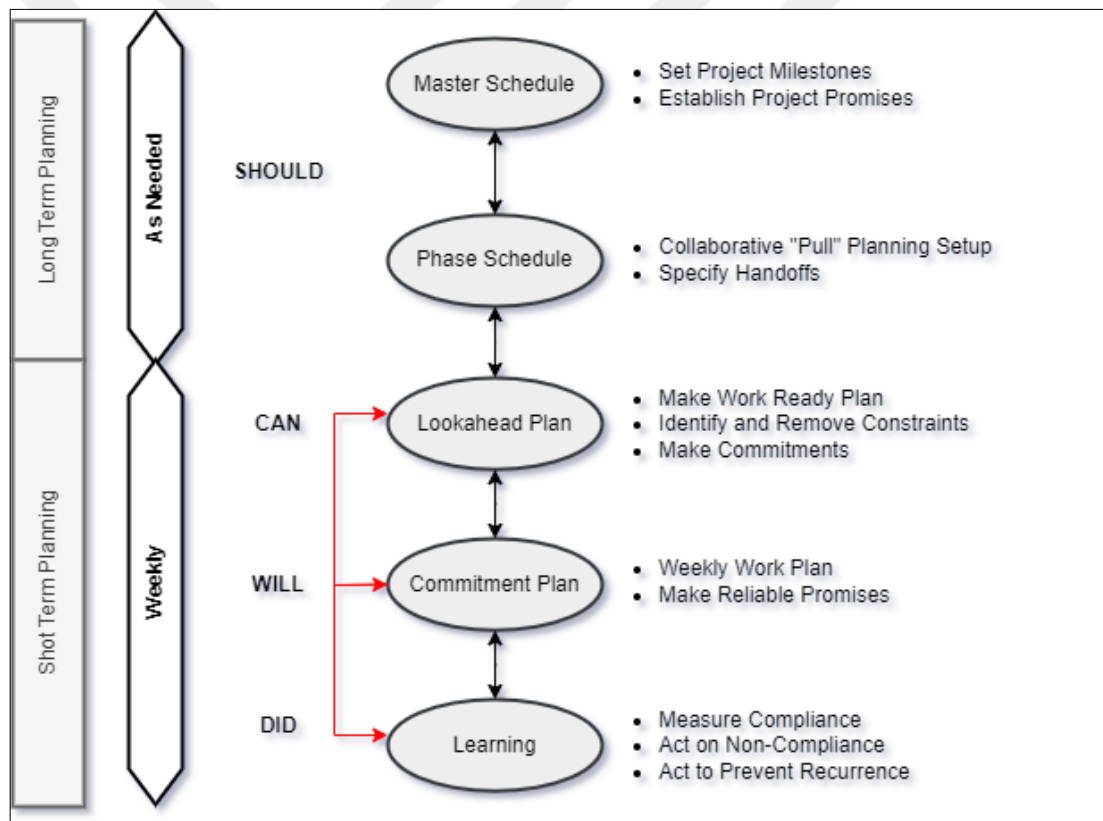


Figure 2.7: Stages of the Last Planner System.

Firstly, main program (master schedule) of the project is created by team of project. The main purpose here is to set up important dates, milestones in the project,

provide general information and visualize them. Master schedule can be a graph similar to the Gantt chart, and generally, not much detail is given here. This part must show the work to be completed for the project [Maimon, 2015].

Phase schedule is derived from the first program and is more detailed than the master schedule. Milestones are determined on a board in the (technical) big room. Also, in this stage shows that specifies handoffs between subcontractors and contractors. Phase schedule develops with entire stakeholders of the project [Maimon, 2015]. Pull planning, also called reverse phase scheduling, is used as planning backwards from the completion date of the work. Using this technique reduces waste caused by over production [Ballard et al., 2007].

The Look-ahead plan is a more advanced planning level than previous planning levels. This creates a schedule of the tasks to be carried out for the next 6 weeks. In this process, materials, workforce, equipment the reliability of the planning, in short, project features are determined [Ballard et al., 2007] At this stage, a progress meeting is held at least once a week. The Look-ahead plan is the most important stage as it forms the basis of the control mechanism [Maimon, 2015]

The next stage after look-ahead planning is weekly work plan. Weekly work plan, which is a more detailed program, is a stage at the assignment-level. Thanks to WWP, the completed part is evaluated by measuring with the percentage plans completed every week. In this way, by means of received feedback, it provides continuous learning opportunities. Weekly assignment schedule is constantly updated [Kalsaas et al., 2009].

LPS aims to continuously improve planning processes. For this, some reports are needed. Planning failures are monitored and a report on the percentage planned completed (PPC) is prepared. Thus, the development of continuous improvement works is followed by project teams [Kalsaas, 2012]. Did, Can and Will processes are evaluated and the reliability of commitments and productivity are monitored. Thus, it provides an opportunity for continuous improvement, which is one of the foundations of lean philosophy.

2.3.9. Visual Management

One of the most important tools of Lean production is Visual Management. Using Visual Management effectively will help to develop standardization [Liker and Meier, 2006]. Visual management tools are an underestimated but essential tool to control processes. Its tools are used to accurately guide operations and processes [Parry and Turner, 2006].

The purpose of Visual Management is to make information visible to every stakeholder. It shows information with visual signs instead of long text, making it easier for each stakeholder to understand. Every piece of information needs to be grasped quickly to increase efficiency and value [Singh and Kumar, 2021].

According to Galsworth [2017], Visual Management tools are divided into 4 headings: visual indicator, visual signal, visual control and visual guarantee.

- *Visual Indicator*: It does not have any power to be implement something. After transmitting the information, the application is entirely at the people's discretion. For example, speed limit signs in traffic.
- *Visual Signal*: Visual management tools in this class give a striking sign at first and then convey the message to people. Andon lights in production lines are one of the most substantial examples.
- *Visual Control*: It provides control by size, quantity, direction, and time. Kanban cards are an example of this class.
- *Visual Guarantee*: It consists only of signs that give precise information. It gives a clear message to people on important events or cases. It prevents possible errors. In this respect, it is often compared to Poka-Yoke.

Using visual management tools on construction sites increases the transparency of the process and provides an opportunity for continuous improvement [Brandalise et al., 2018]. In addition, in workplaces where workers from many different nationalities work, such as on construction projects, the number of workers who are familiar with English or the local language may be few. For this reason, employees receive the message directly through visuals instead of reading texts, allowing information to be accessed more effectively [Singh and Kumar, 2021].

2.3.10. Just-in-Time

Just-in-Time (JIT) is an inventory management tool that aims to produce a product in the required quantity and time and delivery it to the right location [Monden, 2011]. JIT is based on the premise that inventories cause waste and reduce value in the process. Therefore, units or products should only be available when needed [Salem et al., 2006].

The reason why JIT first appeared was actually that Japan had a relatively small geography. For this reason in Japan, the most effective ways to use limited resources were sought. The Japanese managed to turn this disadvantage into an advantage by implementing the JIT [Canel et al., 2000].

Project materials make up a large part of the costs in a construction project. For this reason, many contractors order materials before they are needed and stock them in warehouses or construction sites and they consider this a more economical model. However, excessive inventory is not an economic approach. This adds to the construction costs. JIT benefits stakeholders in construction processes. Although its implementation requires cost in the first stage, it provides savings in the long run. It also creates an environment of trust between the contractor and the suppliers [Akintoye, 1995]

According to the study of Bamana et al. [2019], the use of JIT technique in the construction industry brings many advantages. The results of the study showed that a well-organized construction site and easily accessible materials had a significant impact on reducing the project duration. In addition, it is mentioned in the study that the use of prefabrication increases productivity in the construction industry.

Jeong et al. [2016] conducted a BIM-integrated simulation study, taking into account the operational tasks and the relationships between various activities, activities, and resources, and calculated the production rate per hour of the project. Using such approaches provides more reliable construction planning. Thus, the use of JIT implementations in processes yielded more successful results.

3. BUILDING INFORMATION MODELING (BIM)

3.1. Fundamentals of BIM

BIM is one of the most important developments in the architectural engineering and construction industry (AEC). The National Institute of Building Sciences [2007] has defined BIM as follows:

"A digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward."

This technology contains solutions that can be a solution to many problems in the AEC industry. BIM creates one or more virtual models of a structure in its digital form. It provides better analysis and control by improving the design phases. Computer-generated models generate a lot of data, supporting activities such as construction, manufacturing, and procurement. In addition, BIM contains many functions for modeling the lifecycle of a structure. A well-designed BIM Model makes it easy to build a higher quality building with lower cost and reduced project time [Eastman et al., 2011].

According to Lee, Sacks, and Eastman [2006], BIM is the process of creating and managing building information in an interoperable and reusable way. One of the points to be considered here is that the entire lifecycle of the building should be considered and included in the processes. In addition, Lee et al., [2006] stated that a building consists of geometric components and geometric information is included in BIM design. BIM provides methods to facilitate the creation of building information and geometric shapes in a building model. It also preserves the validity of the information. Building designs can be maintained when an overhaul is required.

According to Smith [2014], BIM includes much more dimensions than 3D Modeling. The level of knowledge in the building model increases with each new dimension added. Each dimension has a purpose and consists of various information. Although there are various discussions between 6D and 7D, Smith [2014] has listed the

BIM Dimensions as follows: 3D (shape), 4D (time), 5D (cost), 6D (facility management applications), and 7D (sustainability). In their study, Ershadi et al. [2021] revealed that the 10 dimensions of the BIM system characterize its full functionality. BIM dimensions are shown in Figure 3.1. Dimensions up to the 7th dimension have been used since the early 2000s through various software packages. However, 8D, 9D, and 10D still need improvement. While the simplest BIM provides technical documentation of a facility/building, an advanced BIM system includes aspects such as safety, Lean construction, and full industrialization.

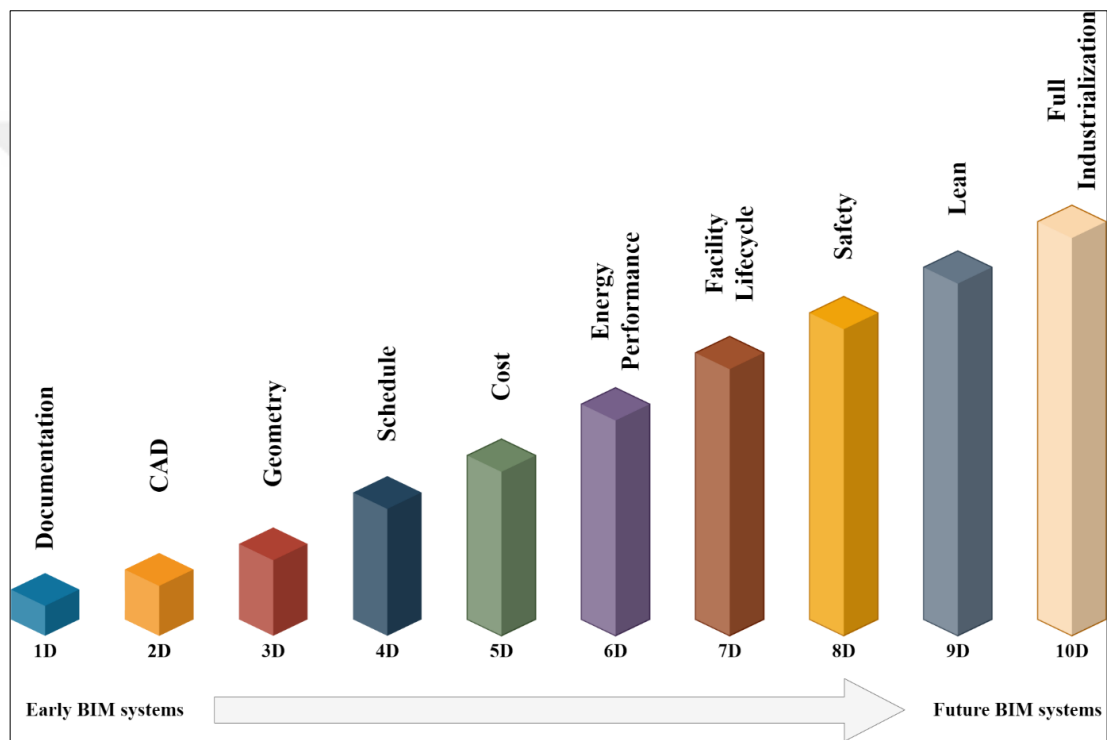


Figure 3.1: Dimension of building information modeling.

Recent studies have shown that BIM provides significant benefits in planning, conflict detection, design consistency, visualization, data management, cost estimation, Lean construction practices, and team collaboration in the AEC industry. [Martínez-Aires et al., 2018].

BIM platforms can be used in different areas of building construction. For example, an architect might use it for design modeling, while an engineer might use BIM platforms for structural or energy analysis [Eastman et al., 2011]. Implementing BIM requires using many different types of software such as Revit or Navisworks [Ahn et al., 2016]. However, many BIM software has been developed today. BIM software

map is shown in Figure 3.2. [Web 1, 2022]. Each software focuses on different processes. This results in a large variety of software.

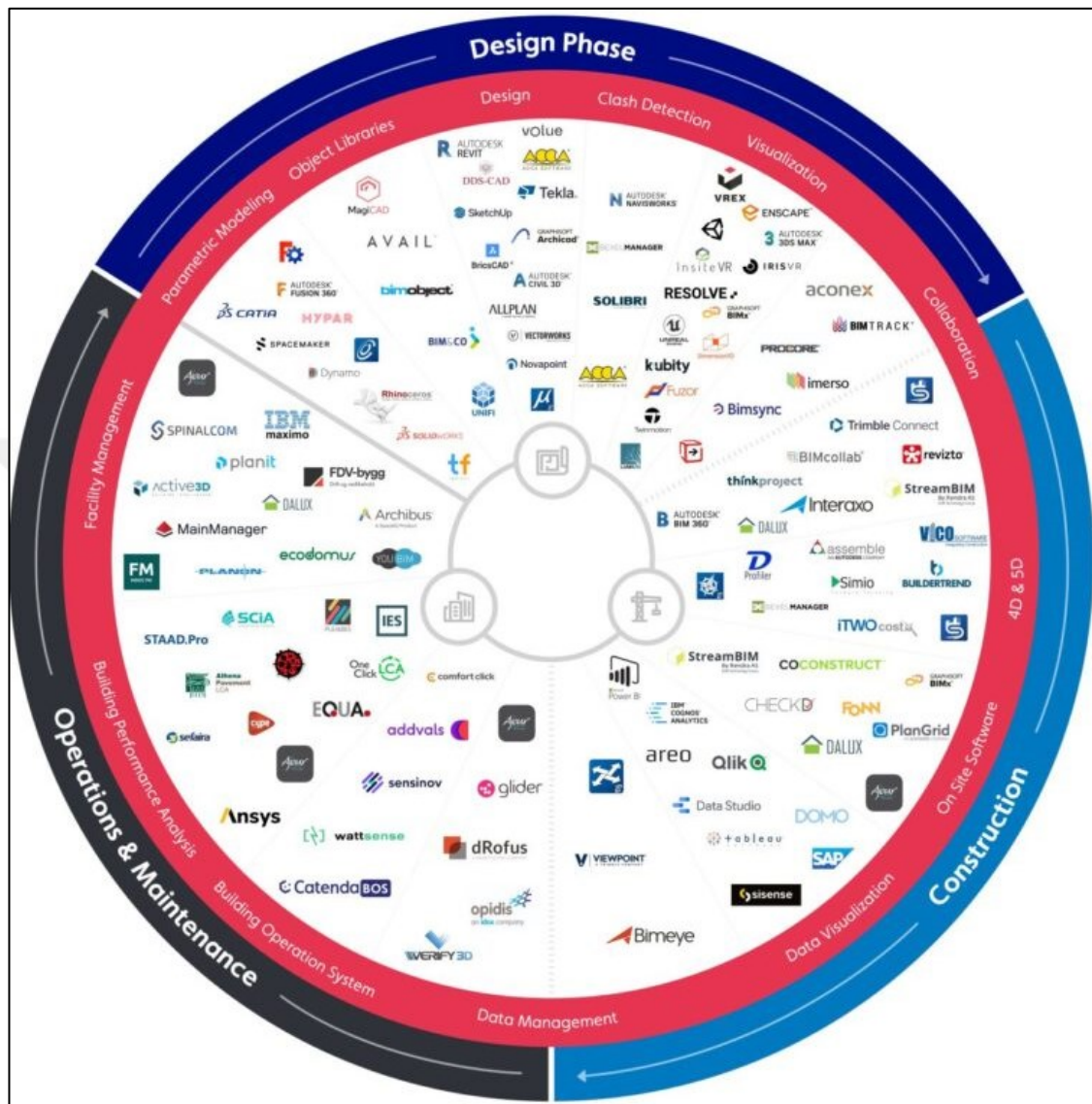


Figure 3.2: BIM platforms map.

3.1.1. Documentation

Until recently, project data and project documents in the construction site were kept with paper-based documents. This is one of the main reasons for high project costs and project delays [Ian Davidson and Skibniewski, 1995]. As-built documentation contains very significant information needed about the project during and after the construction of a project. The documentation is an information source to quickly learn

the details of the project and any modifications to the project. Considering the document processes, BIM has been found to be a very powerful tool for conflict detection and change orders [Abd and Khamees, 2017].

According to Chen and Kamara [2011], the flow of information in the construction industry suffers many interruptions while being transmitted to the construction site. Project workers at the construction site must always carry paper-based documents with important information such as drawings, specifications, and design clarifications to get information about the project. There are difficulties in construction information management due to the inadequacy of the control system to manage the document flow and the weak document management. In addition, the disappearance of paper-based information documents on construction sites with the completion of the project damages the process accumulation of construction companies [Lee and Cha, 2015].

BIM, which allows information assets to be easily standardized and managed, also allows construction information to be accumulated. It also creates an automated environment for information management drawings preparation, quantity calculations, and other construction management resources [Lee et al., 2018]. One of the main innovations of BIM is the use of a detailed 3D view instead of traditional document management. It makes the information much more understandable thanks to the definition of the properties of each material and their visualization. You can see the comparison in Figure 3.3. [Leicht and Messner, 2007].

Krygiel and Nies [2008] mention that document coordination comes automatically when all drawings in the BIM model are placed in a single integrated database. Considering that buildings are becoming increasingly complex today, BIM provides users with an advantage. While editing pages of documents 50 years ago took a lot of time, now this is automated thanks to BIM.

distribution and consumption, water supply, and waste disposal. These simulations are performed by experts in the design team using detailed analysis models [Eastman et al., 2011]. In order to evaluate the building's performance at the early design stage, a lot of information is needed, such as the form of the building, material information, and technical systems. However, document-based CAD design does not allow this approach. BIM enables multidisciplinary information to be stored in a single virtual twin building. A building information model is capable of storing different types of information. This capability makes BIM a rich source of information to be able to perform different analyses [Schlueter and Thesseling, 2009].

BIM simplifies the simulation steps as it can obtain a lot of information about the building's geometry information and material parameters from the digital model. It can be used in a wide variety of simulations such as structural analysis, energy analysis, and evacuation simulations during the design phase [Borrmann et al., 2018].

According to Azhar et al. [2011], the importance of sustainable buildings is increasing due to rising energy costs and environmental concerns. The increasing popularity of Leadership in Energy and Environmental Design (LEED), which is accepted as a green building certification program, especially for sustainable buildings, has increased the importance of energy analysis in building design. Energy analysis is done by considering many different aspects such as structural integrity, lighting, temperature control, ventilation, energy distribution, and consumption. Therefore, integrating performance analysis into the BIM model is an opportunity. BIM Models not only provide data on building geometry but also enable energy calculation [Jalaei and Jade, 2014].

According to a survey of 145 design and construction companies in the US, it was concluded that practitioners who implement BIM-based sustainable analysis save time and cost compared to traditional methods [Azhar, 2010]. BIM makes several contributions to sustainable design. For example, building orientation for minimum energy costs, building massing to analyze building form, daylight analysis, energy modeling to reduce energy needs and identify renewable energy alternatives, water harvesting to reduce water needs, materials management to reduce material needs and use sustainable materials, activities such as logistics and site management to reduce waste and carbon footprint can be carried out through BIM [Azhar et al., 2010], [Krygiel and Nies, 2008].

BIM models also provide the potential for engineers by adding time (4D) and cost (5D) data to 3D geometric design. This type of data provides geometry, material property, and loading conditions for structural analysis. A structural engineer can physically process objects into the model with Autodesk Revit, create structural connections of objects with Tekla Structures, and add to structural loads on model [Vilutiene et al., 2019]. When using almost all building structural analysis software programs, extensive tasks such as model geometry, defining material properties, and applying loads to the model need to be handled. In cases where BIM tools combine these three works, all works can be automatically assigned to a single model and a structural analysis can be applied [Eastman et al., 2011).

One of the biggest concerns in construction projects is clashes. Manually detecting clashes is a time-consuming process and requires an extraordinary synthesis of design and experience. Using BIM tools helps to detect clashes before construction begins for design professionals and contractors [Akhmetzhanova et al., 2022]. Clash analysis using BIM software enables early detection of problems that may occur. A steel beam and a wall or heating, ventilation, and air conditioning (HVAC) unit clash can be easily recognized as shown in Figure 3.4. [Azhar et al., 2008].

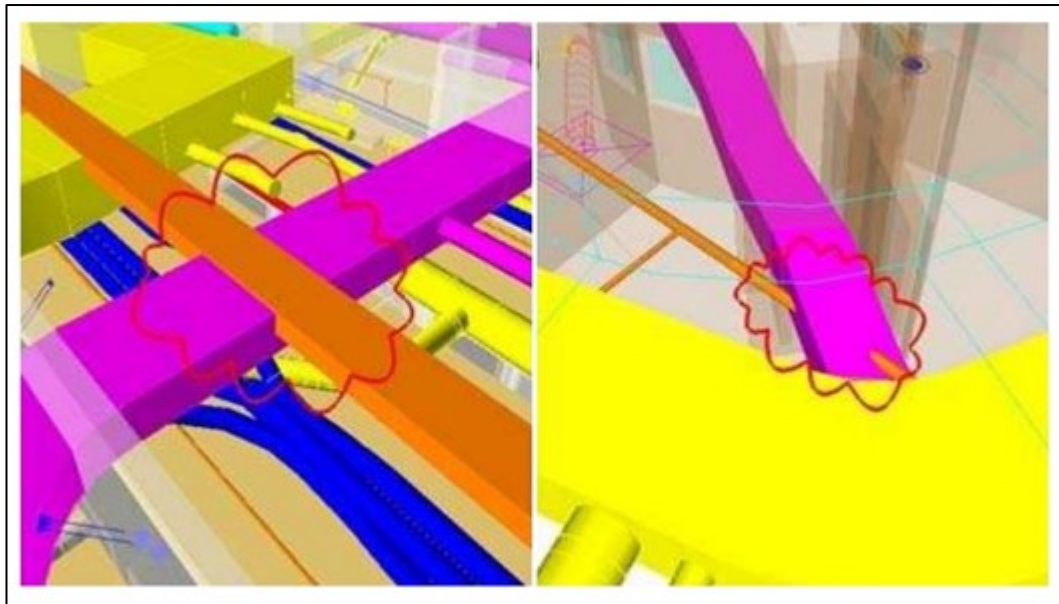


Figure 3.4: Clash detection example.

3.1.3. Coordination & Collaboration

In recent years, building design and construction processes have become increasingly complex. It has become impossible for designers to carry out a design project without consultants, contractors, or other experts [Krygiel and Nies, 2008]. One of the key benefits of BIM is that it increases communication among teams. Sacks et al., [2009] mentions that BIM can allow to show animated construction sequences and its implementation is very successful for designers and planners. With the digitization of processes, communication and coordination between teams increases. It can also improve processes by providing even unskilled workers with the opportunity to demonstrate how, when and where a building should be built.

Large project groups are very difficult to manage and control. Today, project groups are often managed with complex hierarchical relationships. This causes other workgroups to work independently of each other. The independent operation of disciplines can bring many problems. Thanks to its digital background, BIM enables disciplines to work together, as shown in Figure 3.5. [Huang, 2014]. BIM provides a significant gain in terms of time, as it enables a quick interdisciplinary information exchange during the design phase [Popov et al., 2006].

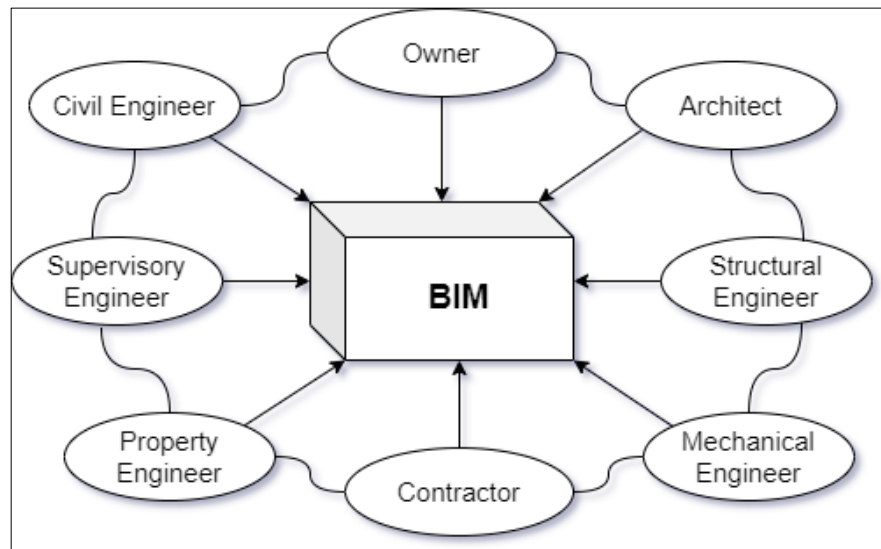


Figure 3.5: Cooperation in BIM.

According to the Kymmell [2008], the coordination of project teams is one of the important aspects that BIM has developed. 3D view of a project can provide significant benefits in terms of speed and time instead of an ordinary 2D drawing. Such models create a suitable environment for resolving conflicts and increasing interaction between responsible workers. In addition, the use of BIM optimizes productivity by making the outputs transparent to all team members.

3.1.4. Visualization

BIM allows us a huge of 3D models for the design, construction, and operation of large-scale construction projects. These models contain a lot of information from the design stage to the real situation. BIM is also used for various analyses and simulations throughout a facility's life cycle. Visualization techniques are also used to analyze this data [Ivson et al., 2019]. The realistic 3D model of the building is one of the key advantages of visualization in BIM. This makes it easier for stakeholders like architects, engineers, and contractors to comprehend the design and spot possible problems or conflicts. In addition, The BIM model can be used to make animations and walkthroughs. A 3D model created by BIM is designed directly instead of creating many different 2D views. Thus, each section is not created separately. Desired sections can be created automatically on the 3D model. This can be seen as a more accurate and faster method for the design phase [Eastman et al., 2011].

Visualization can be used to share information across disciplines because all data is already available in 3D in the BIM Model [Johansson et al., 2015]. For example, a BIM Model can provide a separate visualization for each discipline as a result of containing a series of smart objects. As seen in Figure 3.6, an architect, a civil engineer, and a mechanical engineer want to display may be different visuals of a model. This also provides an easier working environment for each discipline [Azhar et al., 2008].

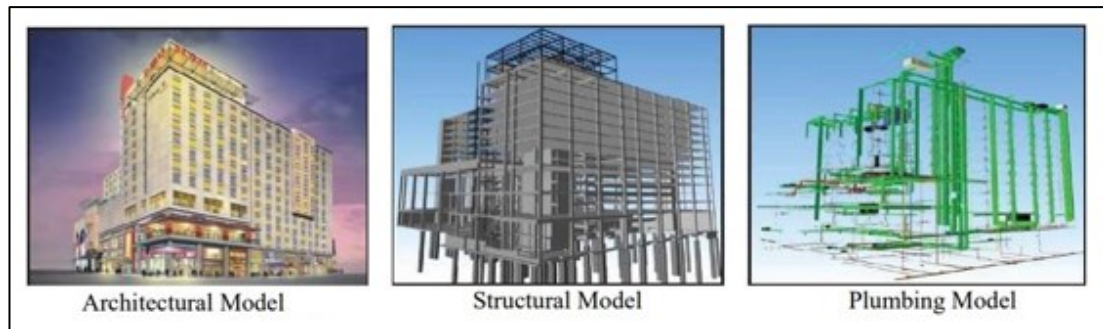


Figure 3.6: Different visual type of BIM model.

According to Chegu Badrinath et al. [2016], the most common use of BIM is visualization, and the most important part of visualization in engineering is communication. Visualization can improve communication between stakeholders in the AEC industry and provide a better understanding of what the customer wants.

Visualization is also used to show analysis results. For example, thermal performance results can be visualized in detail by BIM platforms. Thermal energy results allow not only architects or engineers to understand, but also ordinary people to examine the results, with the coloring of building elements in the BIM model [Jeong et al., 2020]. Visualization can be used to create 4D and 5D models, which include information about time and cost. It allows us to simulate the construction process and evaluate the impact of different options on schedule and budget.

Visualization also contributes to managing facilities and maintaining operations. All information about operations must be collectible and accessible. BIM is one of the technologies capable of providing this information. A work order (WO) is used to store information about maintenance and repair work in a facility. With visualization, this information can be made more accessible. An example of a visualization of the WO is shown in Figure 3.7. [Akcamete et al., 2011].

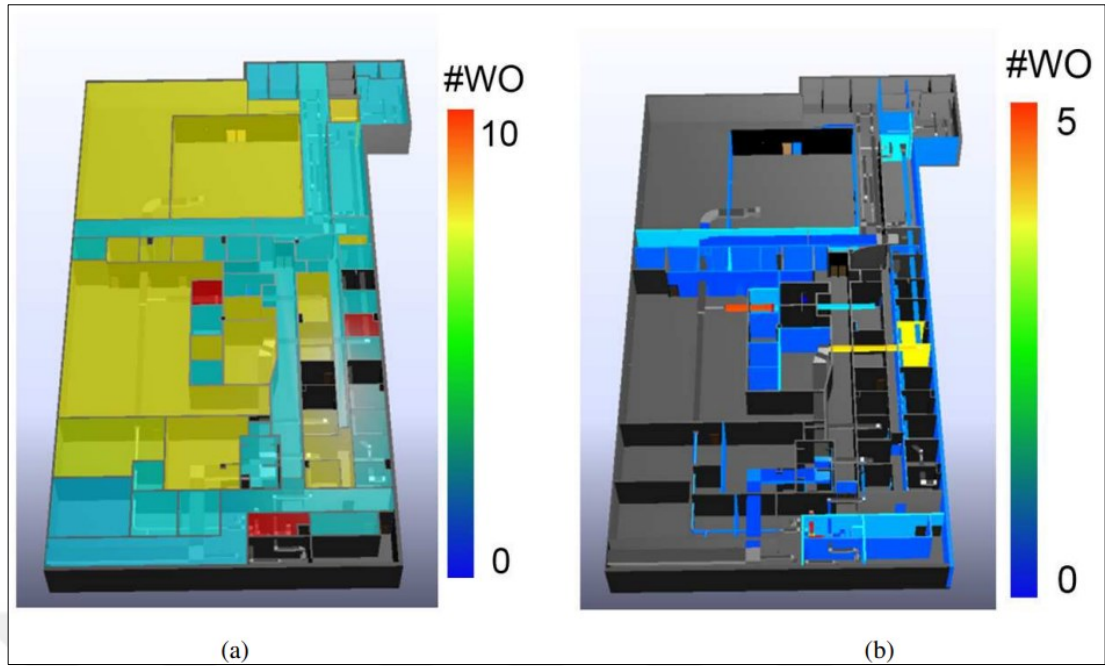


Figure 3.7: Visualization for WO associated with (a) spaces and (b) components.

BIM can also be used in construction task planning. By means of animations showing the sequence of activities in the field, disruptions in planning for engineers can be prevented. It also facilitates the understanding of the business plan for all stakeholders. One of the most popular applications is Visibility Animation. Facility components that have not yet been built remain invisible in simulation. As the simulation time progresses, the constructed components become visible [Ivson et al., 2020]. Figure 3.8 shows an example of visibility animation pictures [Zhang and Hu, 2011].

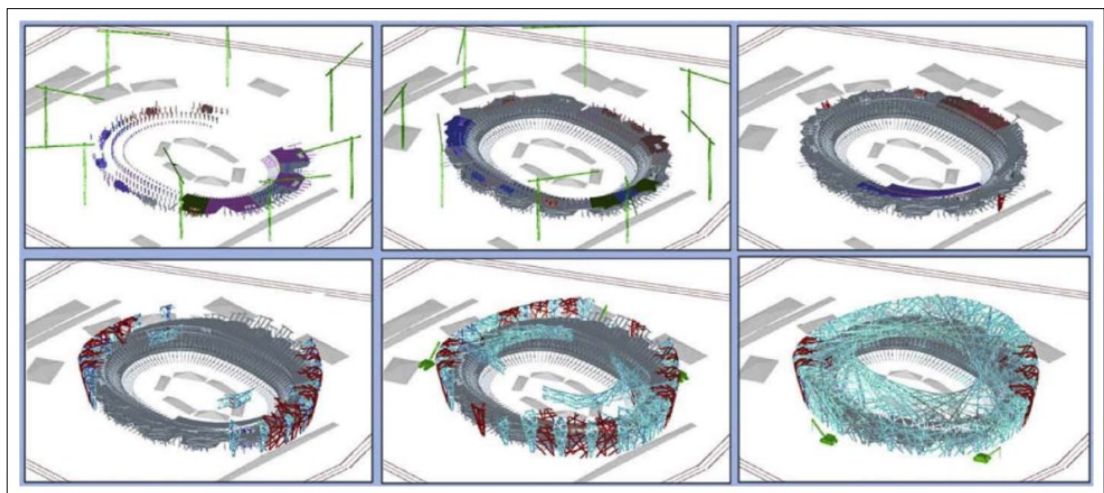


Figure 3.8: Example of visibility animation.

3.1.5. Planning

Planning a construction project consists of many sequential activities. A planning is made by considering topics such as procurement, use of resources, and project constraints, etc. However, only people who are experienced in the project and how the project will be built can determine whether the construction planning is viable. For this reason, with the development of technology, this deficiency has been tried to be eliminated [Eastman et al., 2011]. Most BIM-based planning management tools focus on basic simulation and visualization functions. However, in a planning it is necessary to create a tool with decision-making functions. Various methodologies and functions are required for this [Moon et al., 2015].

A 4D planning model with a construction schedule, a schematic construction sequence simulation can be created. With the help of visualization, planning simulation can be performed for works such as mobilization, crane placement. The BIM Model can include production rate information for a lines of balance schedule analysis. This allows fine-tuning for various jobs based on project locations and production rates [Kymmell, 2008]. An example of visualization for planning is shown in Figure 3.9 [Web 5, 2023].

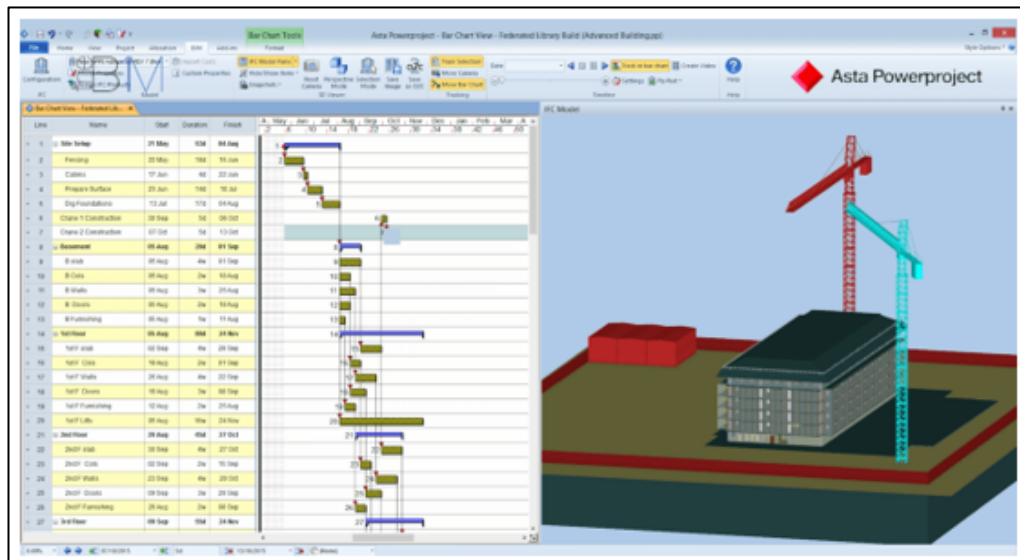


Figure 3.9: Example of visualization for scheduling.

Schedule planning in BIM can be done through the use of a 4D model. The 4D model allows users to simulate the construction process and to evaluate the impact of

different options on the schedule. This can help to identify potential issues or delays and to make adjustments to the schedule as needed. Also, users with BIM can access real time information about the availability of different resources, which can be used to plan the construction process more efficiently.

BIM can also be used to communicate with other stakeholders including architects, engineers, and contractors as well as to create detailed schedules, cost estimates, and resource lists. BIM allows for better coordination and management of the entire planning process, which can enhance project results. Therefore, the use of BIM in construction planning processes shows significant potential.

3.1.6. Operation & Maintenance

Over the years, the importance of maintenance processes has increased. Today, as a result of increasing automation and mechanization, the rate of maintenance spending has increased within the total operating costs [Garg and Deshmukh, 2006].

Operations simulation tools are another properties of BIM that draw various conclusions and analyze using data from a model [Eastman et al., 2011]. BIM allows capturing and transferring information from the design and construction phases to the operational and maintenance phases. Today, there are commercial systems that provide information transfer from BIM to Computerized Maintenance and Management Systems (CMMS) and/or Computer Aided Facility Management (CAFM) Systems. Similarly, with its Construction-Operations Building Information Exchange (COBie), it allows capturing the information in the first stage of the building model, in a certain format, and there is no need to re-create the facility information later. COBie is simply the creation of all necessary basic information in a specific format and sharing it among the project team at any stage of the project [Akcemet et al., 2010].

BIM describes the process of creating a digital building model, as well as the process of maintaining, and modifying the built building throughout its entire life. Figure 3.10 shows the cycle of BIM processes in a simple way [Borrmann et al., 2018].

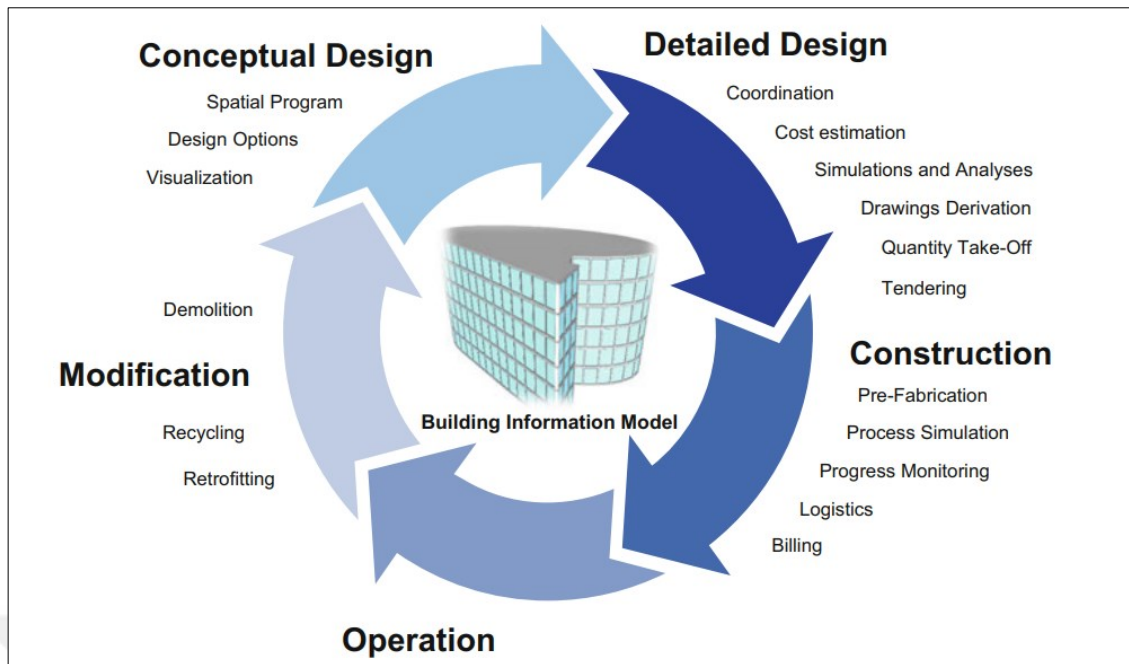


Figure 3.10: Cycle of BIM processes.

BIM can be applied to monitor, maintain, and operate a building after it has been built. This process is called Facility Management. Facility managers may more efficiently manage and maintain the building over its lifetime with the use of BIM, which gives them access to comprehensive information on the building and its systems. According to the data obtained from the BIM Model, maintenance activities can be tracked as shown in Figure 3.11.

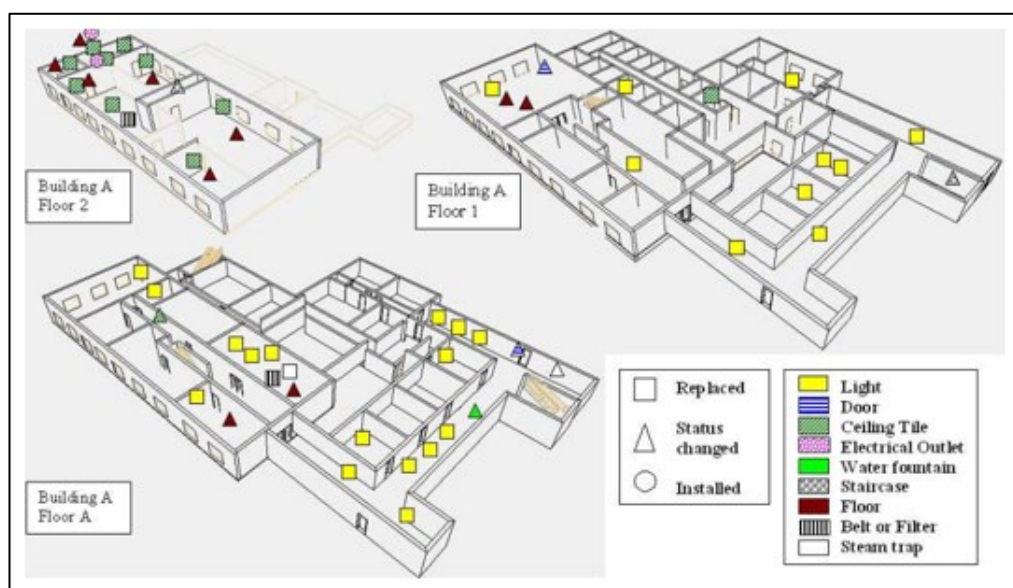


Figure 3.11: Maintenance of a building model.

3.1.7. Design

Design processes have gradually changed and become advanced as a result of technological developments. All developments have also changed the relationship between structural engineers and architectural designers who are working together in building design processes. In addition, it is seen that the use of simulation in the projects has increased with BIM development beyond visualizing building designs [Yan and Damian, 2008].

In earlier design modeling technologies, it allows to a single user working on the data file. This imposes restrictions on other users' access to file data. Whereas, component modeling technology focuses on working in parallel with all design data, covering the entire design cycle. These models include object geometry, properties, connections, etc. In addition, all elements have a specific 3D shape. A user can define parameter properties to these elements like a real material and have them link with other elements [Popov et al., 2006].

Traditional building design and the creation of project documentation are complicated tasks. Misunderstandings between project participants during the design phase can complicate the project in terms of time and cost. By presenting an accurate and sufficiently detailed design model, BIM ensures quality and effective information sharing, enabling finding the optimum workflow. In addition, it helps to reduce the demands and work pressure on the designer [Pruskova and Kaiser, 2019].

According to Borrmann et al. [2018], BIM provides a significant benefit for engineering and design processes. Unlike traditional 2D drawings, in BIM applications, horizontal and vertical sections are derived directly from the building model. The fact that models and sections are interconnected and created automatically contributes to consistency in the design phase. BIM provides benefits not only in the static design of buildings but also in various stages such as green building certification. According to Jalaei and Jrade [2015], BIM helps designers choose the right type of material at the early design stage and ensure a sustainable building lifecycle. In this way, it helps designers easily visualize sustainable buildings at the conceptual stage.

Architectural design, structural design, and mechanical, electrical, and plumbing (MEP) design generally generate mass data and information in a building design process. Structural design and MEP design are closely related to the information obtained

from architectural design. Calculating the behavior of the building under the influence of different loads in structural design is a very complex and dynamic process. A structural model is an essential component of the BIM model. For this reason, studies on BIM-based structural design have been increasing in recent years [Hamdi and Leite, 2014], [Liu et al., 2016].

3.1.8. Monitoring, Controlling and Reporting

Controlling and monitoring project progress on a construction project is one of the most important tasks for project success. It is necessary to constantly monitor many information such as the work of each team member, how the project is progressing, where they are now according to the target plans, and cost control [Memon et al., 2005].

Construction projects can be easily affected by environmental factors due to the dynamic nature of the projects. Therefore, works such as comprehensive feasibility studies and pre-project cost calculations may lose their function over time. Therefore, it is necessary to constantly monitor environmental effects, calculate cost overruns and take various measures in order to finish a project with successful conclusion. [Eadie et al., 2013]. One of the benefits of monitoring, controlling, and reporting is managing the construction process more efficiently. Users can access real time information about the availability of different resources, such as materials, equipment, and labor in the BIM Model.

BIM has become increasingly popular today to provide accurate, consistent, and up-to-date building facility management. BIM can be used in facility management in many different ways. Applications such as visualization, ease of maintenance, and energy monitoring can be easily implemented with BIM. Although facility management is getting more and more complex in today's conditions, BIM has the potential to eliminate this complexity [Suprabhas and Dib, 2017].

Various tools are used in construction processes to control, manage and report project status. BIM has detailed quantification and component knowledge that can be associated with other different applications. This information provides an important resource in control processes. It helps to visually analyze and control project progress for contractors and project stakeholders. For example, the variances between budget

and actual costs can be tracked using the Vico Cost Explorer. Where these differences are greater can be visually displayed. Thus, it is easier to understand where the key problems are. In addition, control management can be created through colors for each component of the facility. So, the team can take a quick decision on the status of the facility [Eastman et al., 2011].



4. PROJECT MANAGEMENT PERFORMANCE

In the construction industry, one of the most essential industries in the economy, human endeavors interact with almost all areas of projects. However, the complexity and dynamic nature of most construction projects is challenging for many project managers. Therefore, some milestones are used in project management to predict results. In addition, various criteria are taken into account in order to measure the success of the project. While the problems that may be experienced in the project can be reduced by risk management, failures such as cost overruns and project delays may still occur in the projects [Meyer et al., 2002], [Nguyen et al., 2004] For this reason, the success of the projects should be kept under constant control with the help of various measures.

Success in project management has been widely discussed in the literature. These usually include studies of how project success is measured, and what factors influence success [Wang et al., 2006]. The criteria for the performance of project success vary in the literature. These performance criteria vary according to the perspective of the project participants [Wu et al., 2017].

In many articles in the literature, success in project management traditionally consists of three main criteria: cost, time, and quality [A. P. C. Chan and Chan, 2004], [Hatash and Skitmore, 1997], [Walker, 1995]. Atkinson [1999] defined these three criteria as the "iron triangle". He also argued that while other definitions of project management change and develop, the criteria in this iron triangle have always been at the center of the project success criteria. These three criteria are still relevant today and are central to evaluating project success. However, over time, these three criteria have been criticized for being insufficient to measure project success [Papke-Shields et al., 2010]. In order to overcome this deficiency, studies such as discovering the parameters that affect success and adding more dimensions have been carried out [Berssaneti and Carvalho, 2015].

In addition to the iron triangle criteria, there are also studies in which various criteria are added to measure the success of the project. For example, Wuellner [1990] determined that the project success criteria were professional image, quality of design, profitability, risk management, adherence to schedule and budget, and customer satisfaction.

According to Wit [1988], the most commonly used criteria to measure the success of a construction project are budget and schedule performance, client satisfaction, functionality, contractor satisfaction, and team satisfaction. A. P. C. Chan and Chan [2004] added criteria such as profitability, safety, environmental performance, functionality and satisfaction in addition to time, cost and quality, which are often used in project success criteria.

Lim and Zain [1999] claimed that project success in the construction industry is affected by factors such as cost performance, quality performance, time performance, safety performance, environmental performance, and relationship with stakeholders of project scope. On the other hand, Kumaraswamy and Thorpe [1996] has taken into account budget, cost, quality, customer and project manager satisfaction, technology transfer, environmental performance, and safety.

In this study, two more criteria were added in order to better measure the project's success besides the three important project success criteria. These are safety and customer satisfaction. The project success criteria used in the model are shown in Figure 4.1.



Figure 4.1: Criteria of project success.

4.1. Time

Time basically represents a process required to complete a project. This requires contractors to plan according to the target date set by the customer [Hatush and Skitmore, 1997]. For contractors and clients, on-time project completion is the primary measurement of project success. It takes a disciplined management effort to complete a construction project on time. Because while controlling the time, it is necessary to control the parameters such as cost and quality at the same time [Bowen et al., 2002].

Construction time performance is seen as one of the three important success factors in project management, along with cost and quality. According to Walker [1995], construction time performance is important to the customer. Problems with time performance are predictable. Thus, alternative plans can be implemented.

4.2. Cost

Cost is regarded as the extent to which a project is finished within its projected spending limit [Bubshait and Almohawis, 1994]. The cost does not only represent the tender amount. From the beginning to the end of a construction project, the costs arising from modifications, litigation, and arbitrations should also be considered in the total cost [A. P. C. Chan and Chan, 2004]. According to Molenaar and Songer [1998], the success criterion of a construction project is the completion of the project within the budget.

Products and services in the construction industry are quite expensive. Construction investment is risky for customers due to high cost. It's the same for the contractor because a large project can constrain a significant portion of the capital. Therefore, cash flow and cost have an important thing in projects. However, it should be noted that having a budget plan for good project performance is not sufficient for success [Chua et al., 1997]. According to A. P. C. Chan et al., [2002], costs must be closely monitored during the pre-construction and post-construction phases. Because small changes in the costs of projects can significantly change the success of the project.

4.3. Quality

Quality is another project success criterion frequently mentioned by researchers in the literature but it is actually quite subjective [A. P. C. Chan and Chan, 2004]. Quality is defined as the totality of the ability of a facility, product, service, or workmanship to meet a particular need. In other words, it can ultimately be evaluated as a measure of fitness for purpose [Parfitt and Sanvido, 1993].

Considering that a construction project goes through many different stages throughout the project life, quality is one of the most critical factors of project success [Ali and Wen, 2011]. Achieving acceptable quality levels in the construction industry has always been difficult. Time, money and resources are wasted every year due to inefficient quality management procedures in construction processes [Ashokkumar, 2007].

4.4. Safety

The construction industry involves many potential hazards and risks, such as falls, equipment accidents. As a result, in order to reduce the likelihood of accidents and safety employees and the environment, construction companies must emphasize safety in all aspects of their operations. Safety is defined as the degree to which a project is completed without a major accident or injury [Bubshait and Almohawis, 1994]. Safety can never be overlooked. Since most of the accidents in a project occur during the construction phase, this period is especially focused on [A. P. C. Chan and Chan, 2004]. According to the Hughes et al. [2004], in some projects industry professionals specifically recognized that safety success is more important than other classical metrics.

4.5. Client Satisfaction

Satisfaction basically refers to the level of happiness of people affected by a project [A. P. C. Chan et al., 2002]. According to Hassan et al. [2000], the importance of quality has now expanded to customer satisfaction. Both quality and customer satisfaction are not completely independent of each other. Because a poor-quality product will greatly reduce customer satisfaction.

According to Torbica and Stroh [2001], if the end user is happy and satisfied, the project is successful in the long run. In addition, providing superior quality and satisfying customers gives companies a competitive advantage over their competitors. In Collins and Baccarini [2004] study, it was determined that the most important success criterion is meeting customer needs. This proves that increasing customer satisfaction has a very important place in project management. With the scope and quality management done by the project management, the customer's requirements must be fully met.

5. RESEARCH METHODOLOGY

This thesis study was created by considering three main steps. First, a detailed literature study about BIM and Lean construction was made. Studies in which both subjects were evaluated together were analyzed and common aspects of both applications were determined. In the second step, a hypothesis was put forward by considering the common aspects and the factors affecting the success of the project. This hypothesis has two main purposes. The hypothesis model is shown in Figure 5.1. The purpose of this hypothesis is to determine the impact of Lean construction processes on BIM processes and the impact of both BIM and Lean on project success. A questionnaire was created in order to determine the results of the hypothesis created. It is aimed to obtain important data by addressing the survey questions to people who are experienced in BIM and Lean in the construction industry.

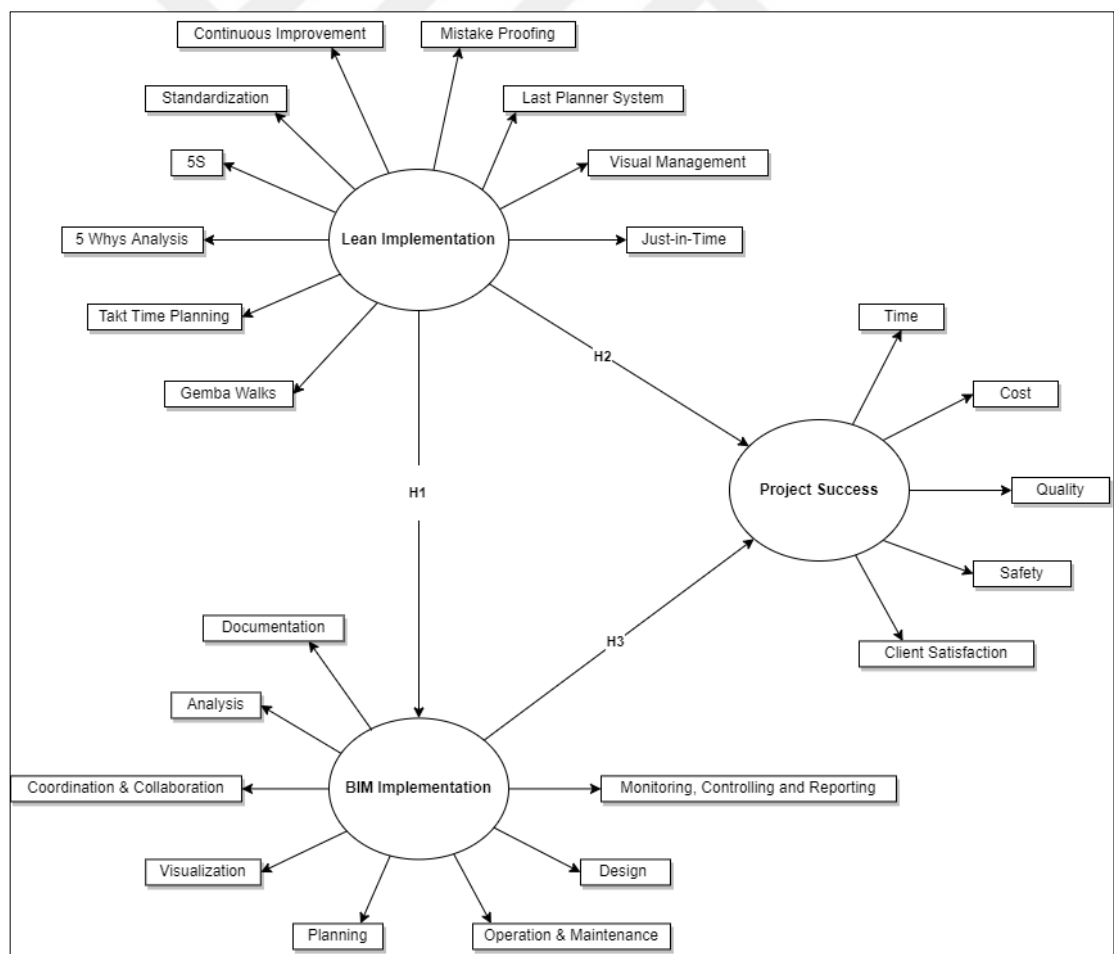


Figure 5.1: Hypothesis of thesis.

After the get survey data, the last stage which is the analysis stage created. In order to evaluate the survey data, Structural Equation Modeling (SEM) was used. The model was created in the SPSS AMOS program and all the results were obtained through SPSS AMOS. Finally, the findings from model are interpreted and discussed.

5.1. Survey

A survey was conducted in order to obtain the results of the research. The main points with the highest potential for interaction between Lean and BIM applications, which were determined as a result of the literature study, were asked to the construction industry employees through the survey. The questionnaire was created in Google Forms and shared only with people working in the Turkish construction industry via online platforms.

The survey consists of two main pages. On the first page of the questionnaire, a section including the research topic, the confidentiality of the participant data, and the contact information of the researchers was added. Then, various questions like experience, project type, project budget, and area of expertise of the company were asked in order to obtain general information about the participant and their company.

In the second stage, questions were asked about Lean, BIM, and project success. The questions were designed using the Likert scale. That is the questions were answered as 5 - very good, 1 - very poor. Responses were collected from the participants according to Lean, BIM, and project success criteria.

5.2. Structural Equation Modeling

Structural Equation Modeling (SEM) is one of the scientific research technics used to determine the relations of variable sets with each other in basically. This technique helps researchers test and validate a theoretical model [Loon, 2008]. Collier [2020] explains the SEM in its book as follows:

"SEM is a statistical method that examines the relationships among numerous variables in a simultaneous way. SEM is not considered a single procedure but rather a family of related statistical techniques. This family of analysis techniques examines

the measurement properties of a variable along with the interrelationships between variables and is often seen as a combination of regression and factor analysis. "

The multivariate analysis enables researchers to perform in-depth explanatory analysis with the needed statistical efficiency. SEM is considered a very useful technique to examine many different series at once by solving multiple equations. The general approach of an SEM analysis is shown in Figure 5.2. [Thakkar, 2020].

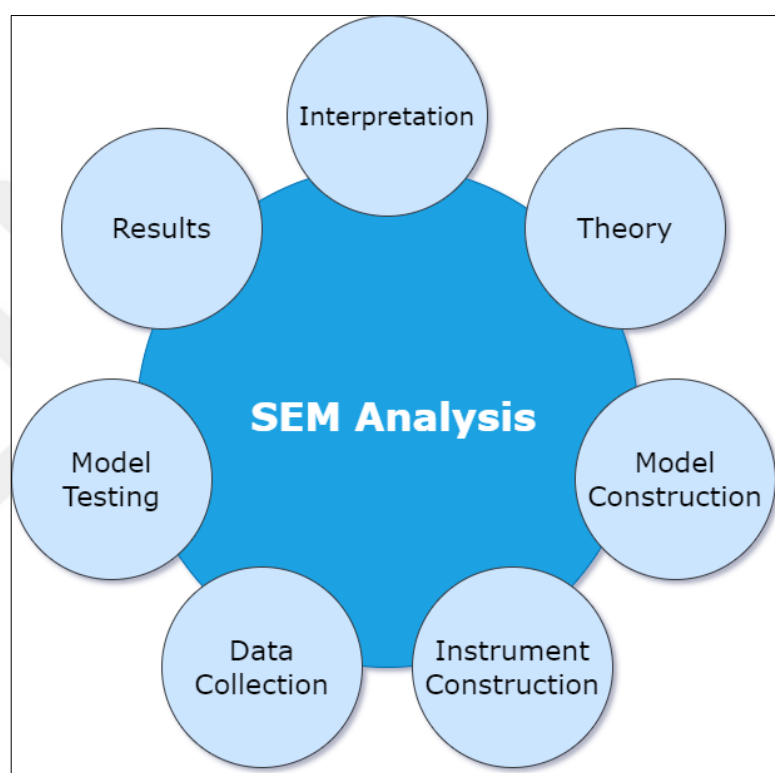


Figure 5.2: General approach of SEM analysis.

The SEM technique consists of 5 main steps in addition to the data collection. These steps consist of specification, identification, estimation, evaluation, and modification of models as shown in Figure 5.3. [Thakkar, 2020].

In the model specification stage, the researcher creates a theoretical model to determine the observed variables and the relationship between these variables. In particular, a measurement and a structural model should be determined. The variables in the theoretical model and the relationships between them can be visualized by creating a diagram [Crockett, 2012].

The model identification stage is often a complex phase to understand in SEM. Most researchers see this not as a step but as a condition to be considered before analyzing data. At this stage, it is examined whether the model is sufficient or not [Weston and Gore, 2006].

After identifying the model and collecting the necessary data from enough participants, the data is organized and then the estimation phase begins. There are many estimation methods in SEM, such as maximum likelihood (ML), generalized least squares (GLS), weighted least squares (WLS). Each researcher should determine the estimation methods researcher will use in his analysis before performing his analysis. Because each estimation method has its pros and cons [Weston and Gore, 2006]. ML estimation is an estimation method used by default in most SEM software often. Many SEM models in the literature are based on ML estimation method [Kline, 2015].

Model testing includes measurements and analysis to determine the fit of both the overall model and the individual model. Multiple fit indices should be analyzed to control the degree of fit of the theoretical model to the sample data [Crockett, 2012]. The aim here is to determine whether there are relations between the measured variables in the model. After testing the model, the significance of the predicted parameters should be evaluated in terms of the variances of the observed variables and how good and fit the overall model is [Weston and Gore, 2006].

Model modifications, the final stage of the analysis, includes work to improve the theoretical model. According to the SEM results, some parameters can be added or trimmed. The SEM model encourages the researcher to refine the established model quality by constantly experimenting [Crockett, 2012].

In SEM technique, many parameter values are checked for the accuracy of the model. One of them is CFI. CFI compares the improvement of a model's fit with an independent model for which there is no relationship between the variables. CFI Values range from 0 to 1.0. A result value closer to 1.0 indicates a more accurate result [Weston and Gore, 2006].

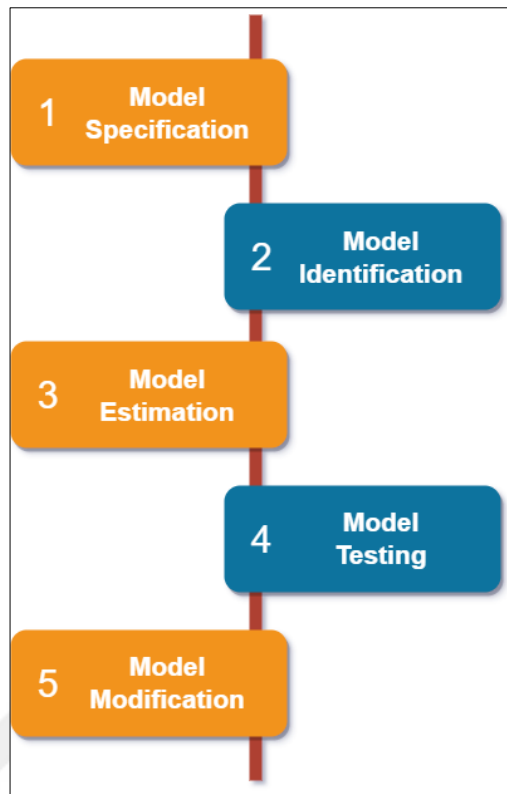


Figure 5.3: Model steps of SEM.

Computer software programs are a very important tool for performing and conducting SEM analysis. SEM can be performed by means of several software programs. Linear Structural Relationships (LISREL) was the first software program available for SEM. However, the situation is different today. Because there are alternative programs for the model-fitting program. Programs such as Analysis of Moment Structures (AMOS), Covariance Analysis and Linear Structural Equations (CALIS), Equations (EQS), Linear Structural Equations with a Comprehensive Measurement Model (LISCOMP), Reticular Action Model or Near Approximation (RAMONA) can be used for SEM Analysis [Kline and Rex, 1998]. In this thesis, SPSS AMOS program, which is a more user-friendly program, was preferred because of its ability to solve SEM analyzes.

There are many advantages to using the SEM method. According to Bagozzi and Yi [2012], it has an integral function. In other words, it is a method that covers many programs. It also enables researchers to reach more precise results in determining their hypotheses. SEM easily shows how well the theory fits with the data. It also allows comparison with different models. It provides some basis for predicting outcomes for researchers as conditions change [Bentler and Stein, 1992].

6. RESULTS

6.1. Survey Results

The questionnaire was sent to 223 people in total. The people to whom the survey was sent are especially experienced in BIM and Lean. A total of 73 people responded to the survey. 2 answers were not included in the survey results because 2 participants have insufficient answers to the questions. Thus, the total response rate of the survey is 31.83%.

Figure 6.1 shows the field of the operation of participants. According to the results of the questionnaire, 60.6% of all participants work in the construction field. After that, the engineering field comes out with a rate of 32.4%. Finally, it was concluded that 7% of the participants were from the field of architecture.

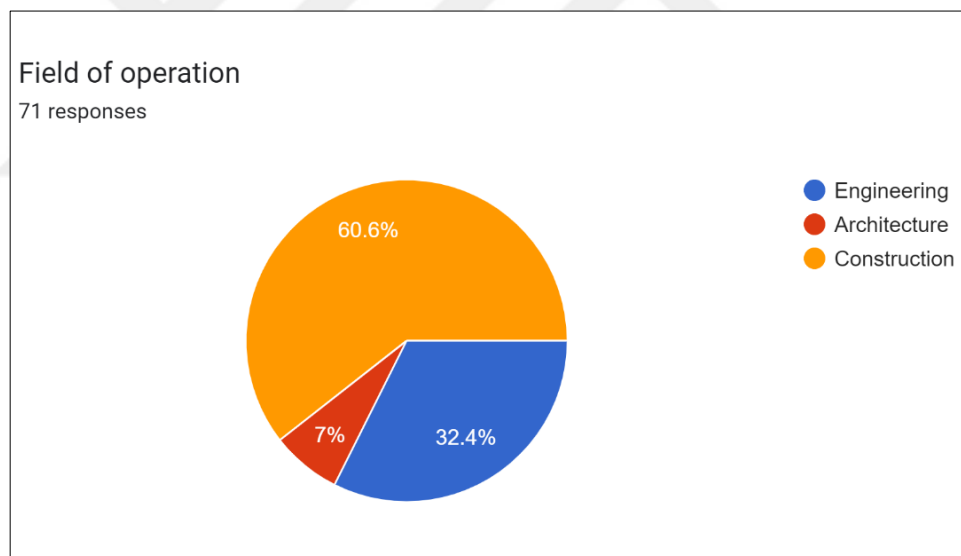


Figure 6.1: Field of operation.

Figure 6.2 shows the age distribution of companies. According to the Figure, it is concluded that the experience of the participants' companies is quite close to each other. According to the results, 26.8% of the participants work in a company with more than 50 years of experience. The rate of the participants working in the company with the experience range of 0-10 is 9.9%, which is the lowest rate according to survey results.

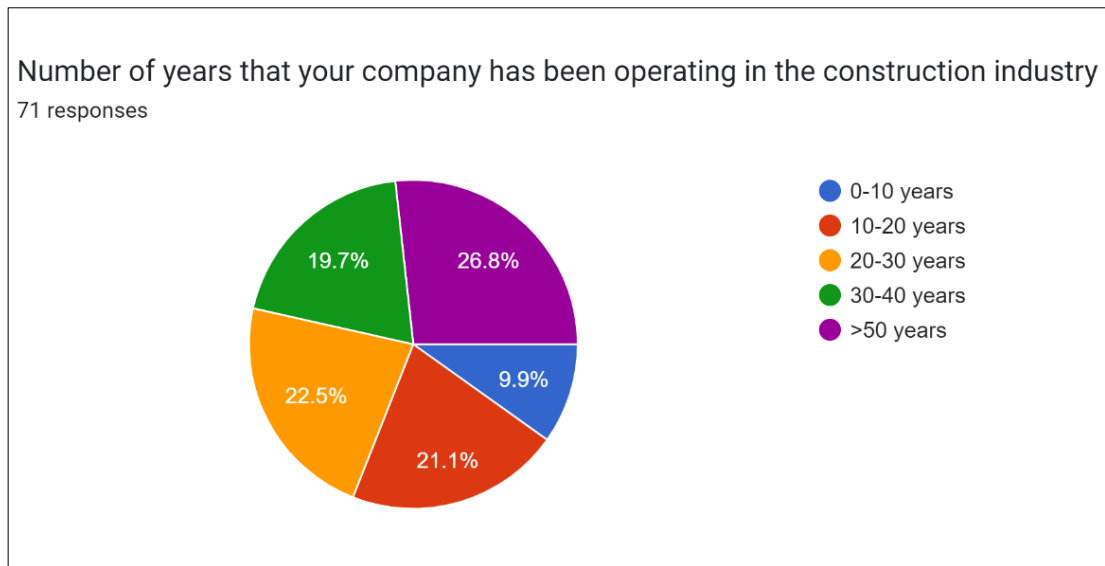


Figure 6.2: Age distribution of companies.

Figure 6.3 shows the areas of expertise of the companies in which the participants work. In this question, more than one answer could be accepted as a company may operate in more than one area. According to Figure 5.3, the majority of the companies that the participants work for operate in the field of building construction. The other answers are industry, transportation infrastructure, and water structures, respectively.

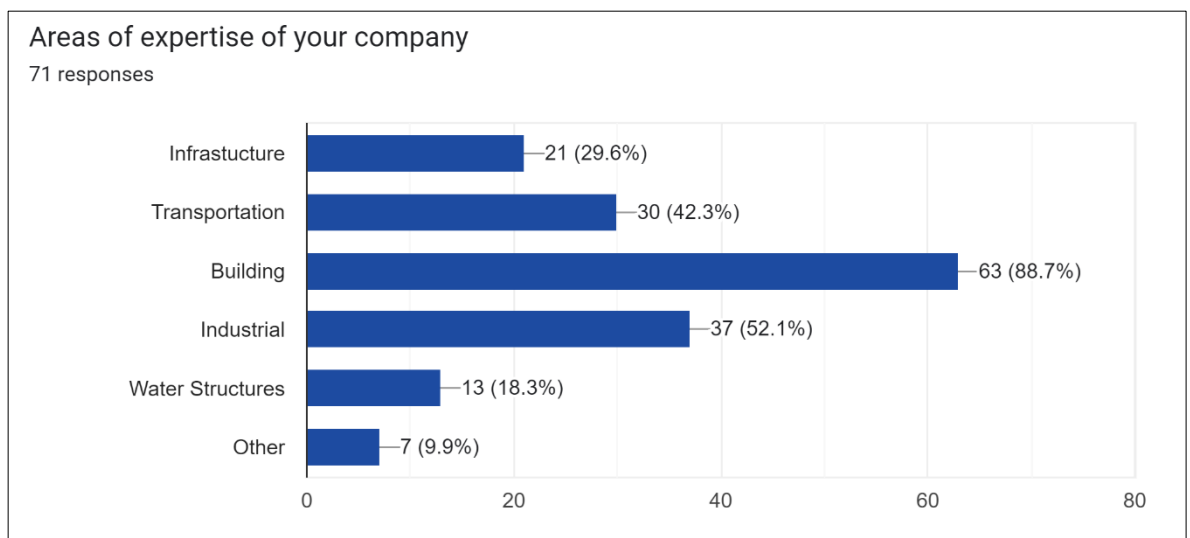


Figure 6.3: Areas of company of participant.

Figure 6.4. shows the experience of the participants. 40.8% of the participants have 15-20 years, 21.1% have 10-15 years, 19.7% have more than 20 years, 9.9% have 5-10 years, and finally, 8.5% have less than 5 years of experience.

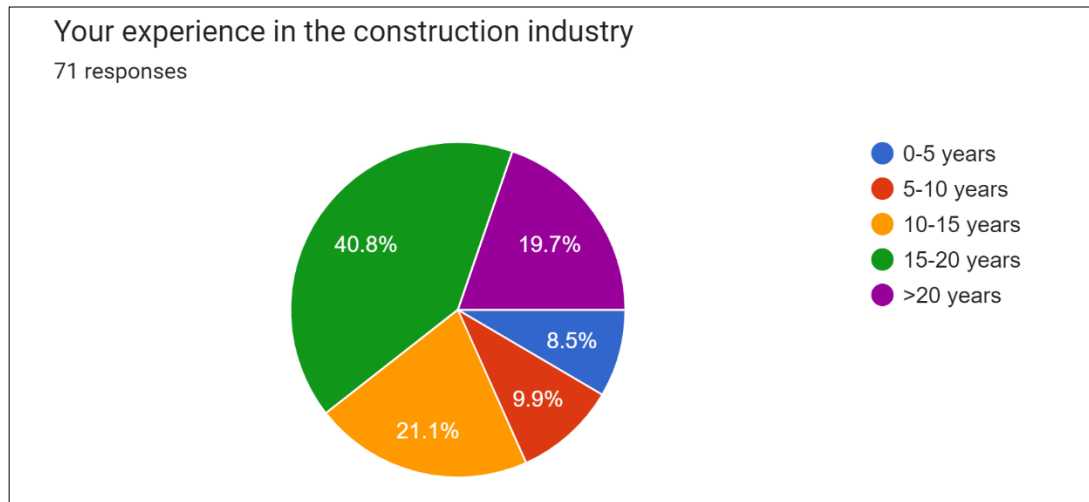


Figure 6.4: Experience of participants.

Figure 6.5 shows the positions of the participants in the company. The majority of the respondents are working in a manager position. Another majority with 31% is working in engineer position.

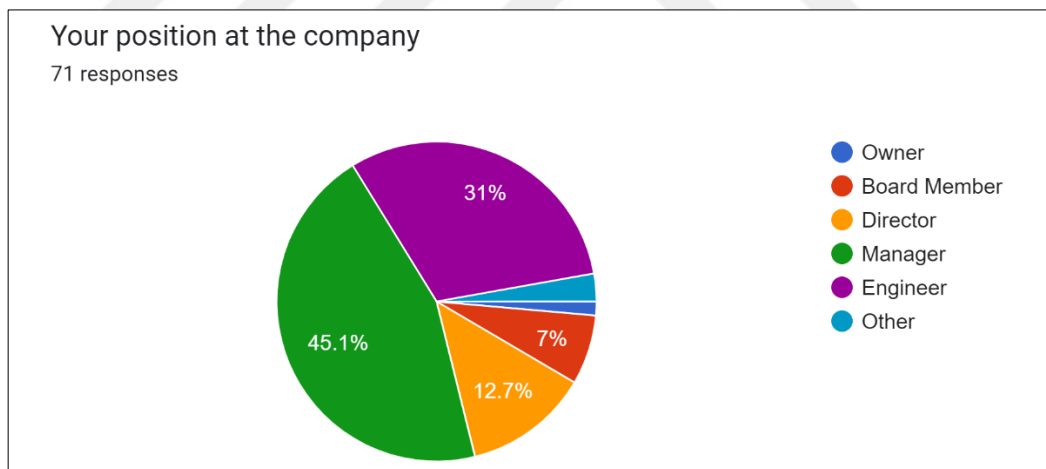


Figure 6.5: Position of participants.

Figure 6.6 shows the types of projects the participants are working on. 40.8% of the participants work on a building project, 21.1% on a transportation project, 19.7% on an infrastructure project, 15.5% on an industry project, and 2.8% on other types of projects.

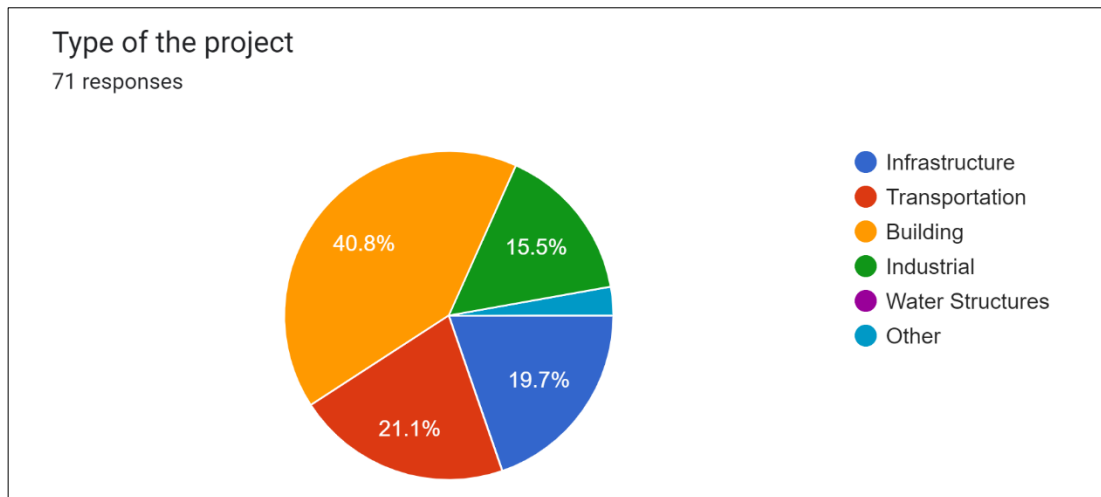


Figure 6.6: Type of project.

Figure 6.7 shows statistics on project ownership of the companies the participants work for. While 39.4% of the companies are sole, 28.2% is a joint venture, 9.9% is a consortium, and 22.5% is other type company.

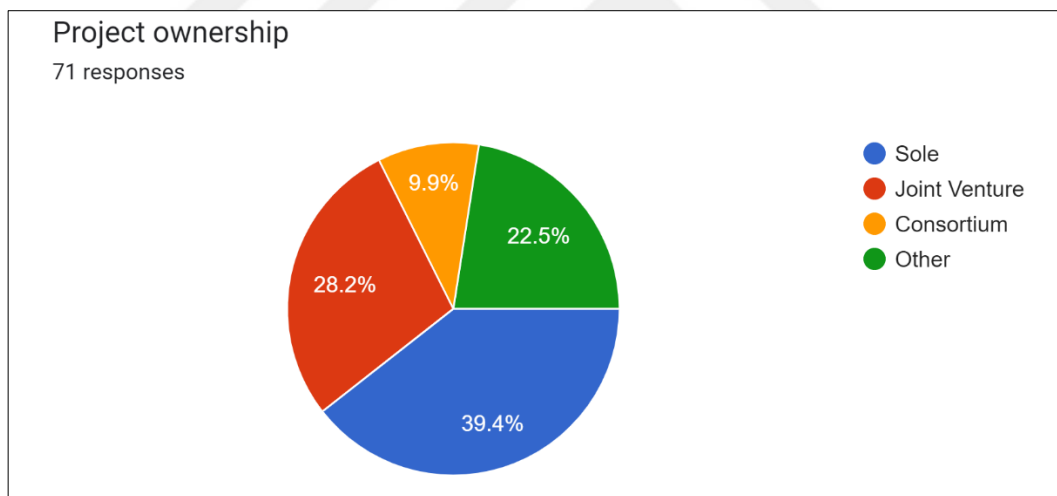


Figure 6.7: Project ownership.

Figure 6.8 shows the role of the companies in the projects. 40.8% of these companies are contractors, 25.4% are subcontractors, 4.2% are designers, 2.8% are clients, while 26.8% assume other roles.

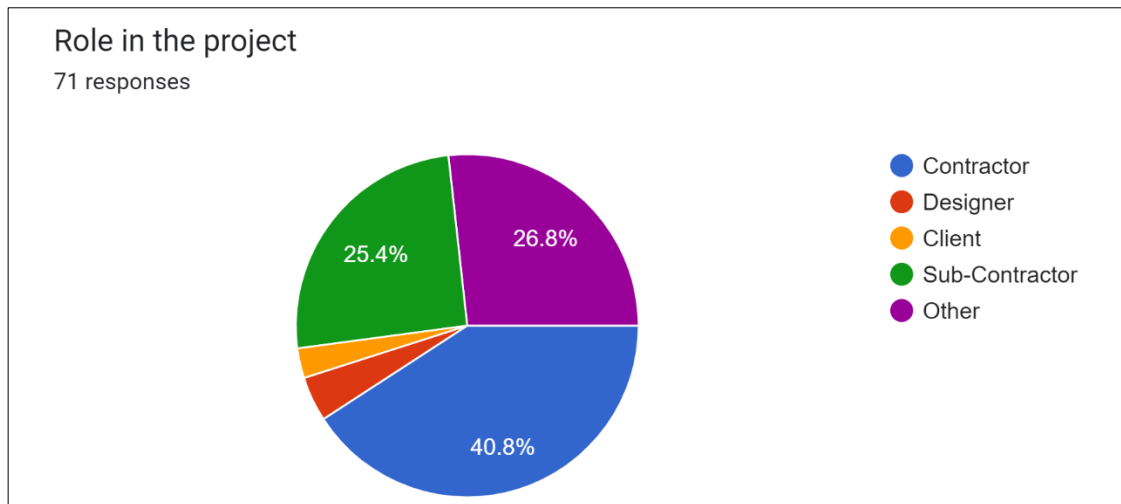


Figure 6.8: Role of participant companies in the project.

Figure 6.9 shows the contract types of the projects that the participants are working on. 39.4% of the answers are both unit price and lump sum contract type. 18.3% of answers are turnkey contracts type, while only 2.8% are cost plus fee.

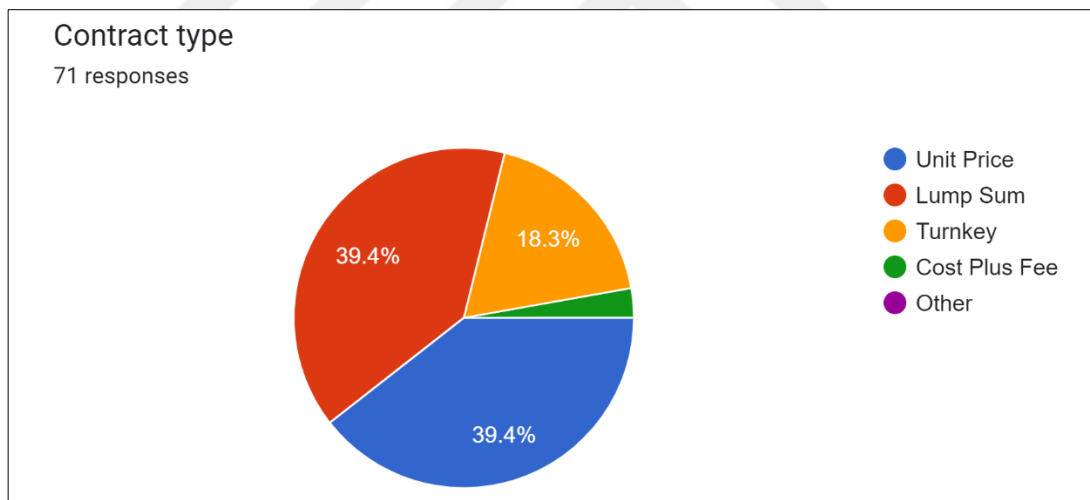


Figure 6.9: Contract type.

Figure 6.10 shows the performance statistics of Lean construction implementation according to survey participants. According to the results of the survey, the Lean construction implementations in which the participants showed the highest performance is Visual Management (3,62). Another high-performing practice is Standardization (3,60). The performance results of other Lean construction implementations according to survey participants are listed as follows: 5S (3,54), Continuous Improvement (3,54), Just-in-Time (3,44), 5 Whys Analysis (3,30), Mistake Proofing (3,22),

Last Planner Systems (3,01) Gemba Walks (2,87), Takt Time Planning (2,87). The average of all results was found to be 3,31. According to the results, it can be evaluated that the Lean construction performance of the survey participants is at a low-average level. Standardization and Visual Management gave higher performance results compared to other implementations. This can be interpreted as the implementation of standardization and visual management being easier than other implementations.

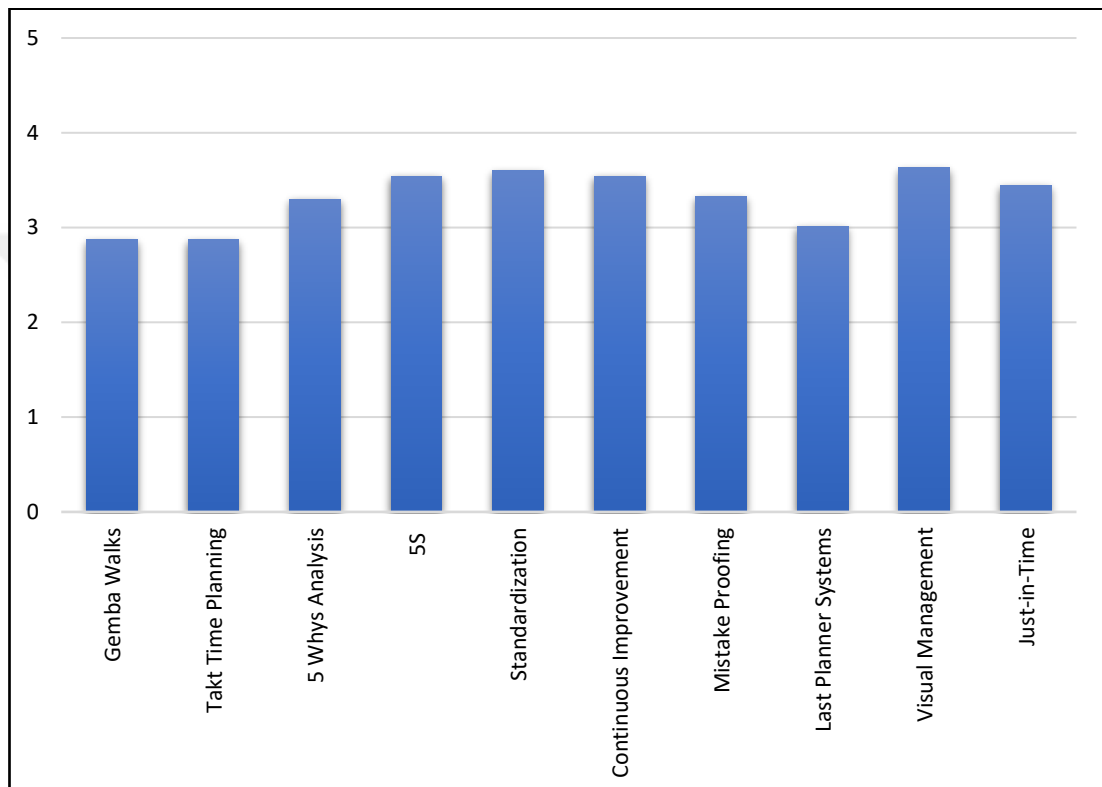


Figure 6.10: Lean construction implementation statistics.

Figure 6.11 shows the performance statistics of BIM implementation according to survey participants. According to the results of the survey, the BIM application in which the participants showed the highest performance is Visualization (3,7). Another high-performing practice is Monitoring, Controlling, and Reporting (3,67). The performance results of other BIM implementations according to survey participants are listed as follows: Coordination & Collaboration (3,61), Documentation (3,60), Analysis (3,52), Planning (3,41), Design (3,41), Operation & Maintenance (3,3) The average of all results was found to be 3,53. According to the results, it can be evaluated that the BIM performance of the survey participants is at a high above-average level. Vis-

ualization and Monitoring, Controlling, and Reporting gave higher performance results compared to other implementations. However, other survey results are also not low. In general, the above-average performance of all implementations indicates that the implementation of BIM is positive for companies.

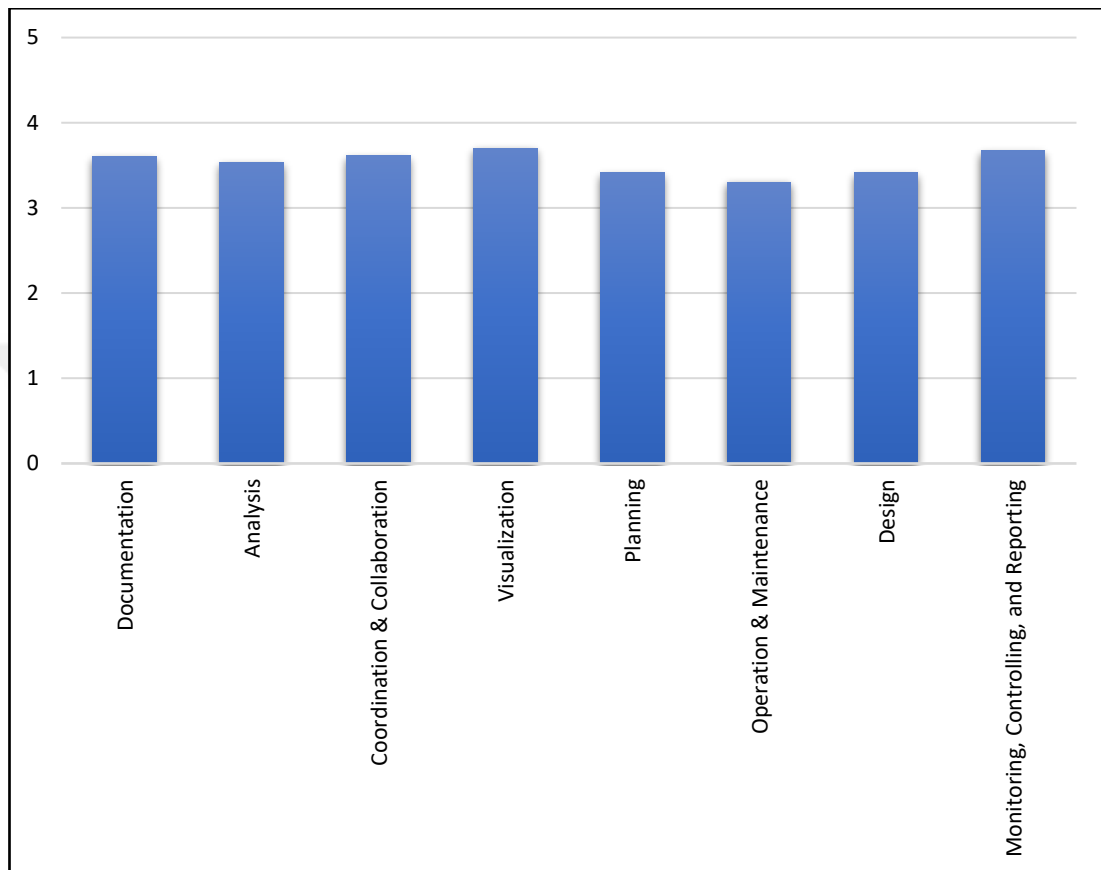


Figure 6.11: BIM statistics.

Figure 6.12 shows the performance statistics of project success according to survey participants. According to the results of the survey, the Project Success in which the participants showed the highest performances are Quality and Safety (3,62). The performance results of other project success according to survey participants are listed as follows: Client Satisfaction (3,45), Cost (3,32), Time (3,24). Quality and Safety gave higher performance results compared to other indicators. 3,45. According to the results, it can be evaluated that the project success performance of the survey participants is at a high above-average level. The lowest performance value is time and cost. The fact that there are time and cost overruns in many construction projects supports the results.

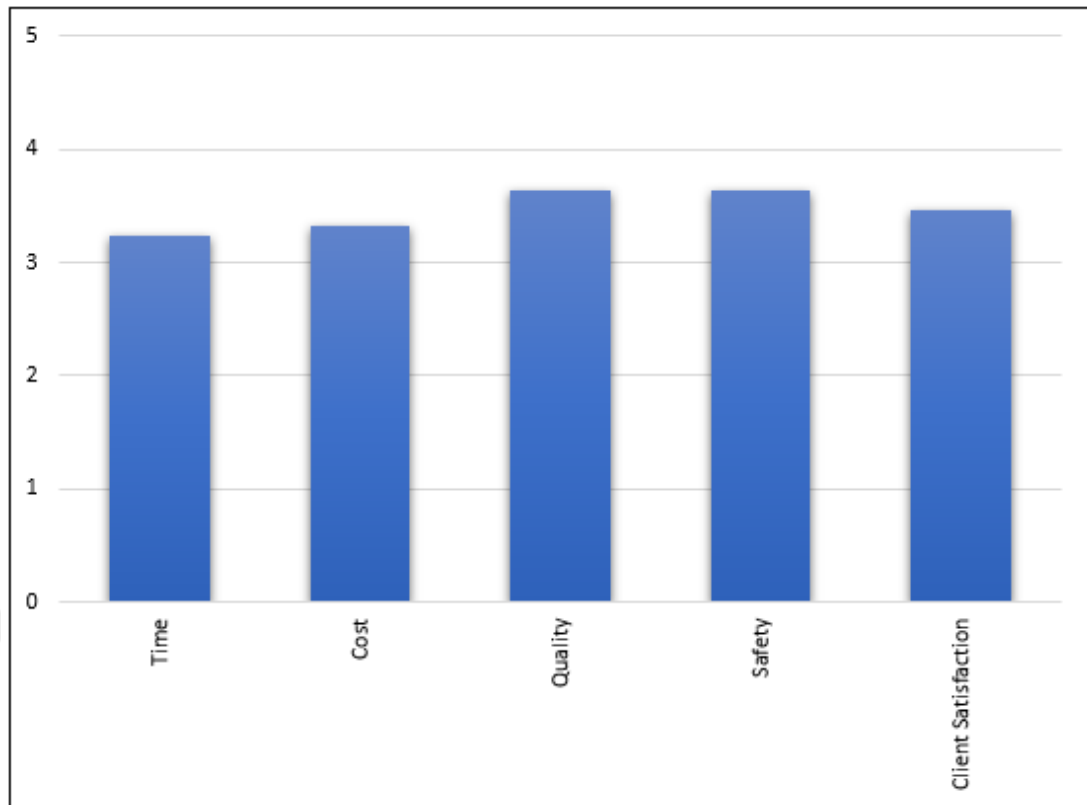


Figure 6.12: Project success statistics.

6.2. Analysis Results of the Structural Model

SPSS AMOS is a very powerful SEM software for researchers. It enables to conduct of a multivariate analysis including regression, factor analysis, correlation, and variance analysis [Web 2, 2013]. SPSS AMOS is a highly popular software with unique graphical interface for solving SEM problems [Thakkar, 2020].

According to Collier [2020], SPSS AMOS is user-friendly software for new users. There are some differences when compared to programs such as LISREL, EQS and MPLUS. The major difference is that SPSS AMOS models are conceptualized and analyzed in a graphical interface format, while other programs focus on entering code to analyze a model. When constructing the theoretical model in SPSS AMOS software, it is necessary to know what certain markings mean. These marks are shown in Table 6.1. [Collier, 2020].

Table 6.1: Diagram symbols in SPSS AMOS.

Latent/Unobservable variables are represented as circle.	
Observed variables are represented as squares or rectangles.	
The error terms are represented by an arrow and a circle.	
Direct effects are represented by an arrow.	
Covariance is represented by a curved line with arrowheads both ends.	

6.2.1. Specification of the Model

In this thesis study, SEM method was preferred in order to understand the relationship between dependent and independent variables. SPSS AMOS Version 22 was used in this study to analyze the hypotheses of the model. First of all, a model has been developed in order to determine the relationships between Lean Construction, BIM, and project management performance indicators, which are three independent subjects. The implementations that are likely to interact with each other in each variable have been determined with depth and comprehensive literature. The variables' names determined as a result of the literature research are shown in Table 6.2.

Table 6.2: Description of model name.

Model Name	Implementation Name
Lean Construction Implementation	
L1	Gemba Walks
L2	Takt Time Planning
L3	5 Whys Analysis
L4	5S
L5	Standardization
L6	Continuous Improvement
L7	Mistake Proofing
L8	Last Planner Systems
L9	Visual Management
L10	Just-in-Time
BIM Implementation	
B1	Documentation
B2	Analysis
B3	Coordination & Collaboration
B4	Visualization
B5	Planning
B6	Operation & Maintenance
B7	Design
B8	Monitoring, Controlling, and Reporting
Project Management Indicators	
P1	Time
P2	Cost
P3	Quality
P4	Safety
P5	Client Satisfaction

General SEM approaches were taken into account when analyzing the model.

The three main hypotheses to be investigated in the SEM model are as follows:

- *H1*: Lean Construction Implementation has a significant and positive impact on BIM.
- *H2*: Lean Construction Implementation has a significant and positive impact on project success.
- *H3*: BIM has a significant and positive impact on project success.

6.2.2. Estimation and Identification of the Model

After the variables were determined, model identification and estimation steps were started. Unobserved endogenous variables consist of three main subjects which are Lean Construction Implementation, BIM, and project success. Observed endogenous variables consist of 23 sub-subjects. The constructed SEM Model was created in SPSS AMOS software. Then, the survey data were processed one-to-one on the SEM model. The created SEM model is shown in Figure 6.13.

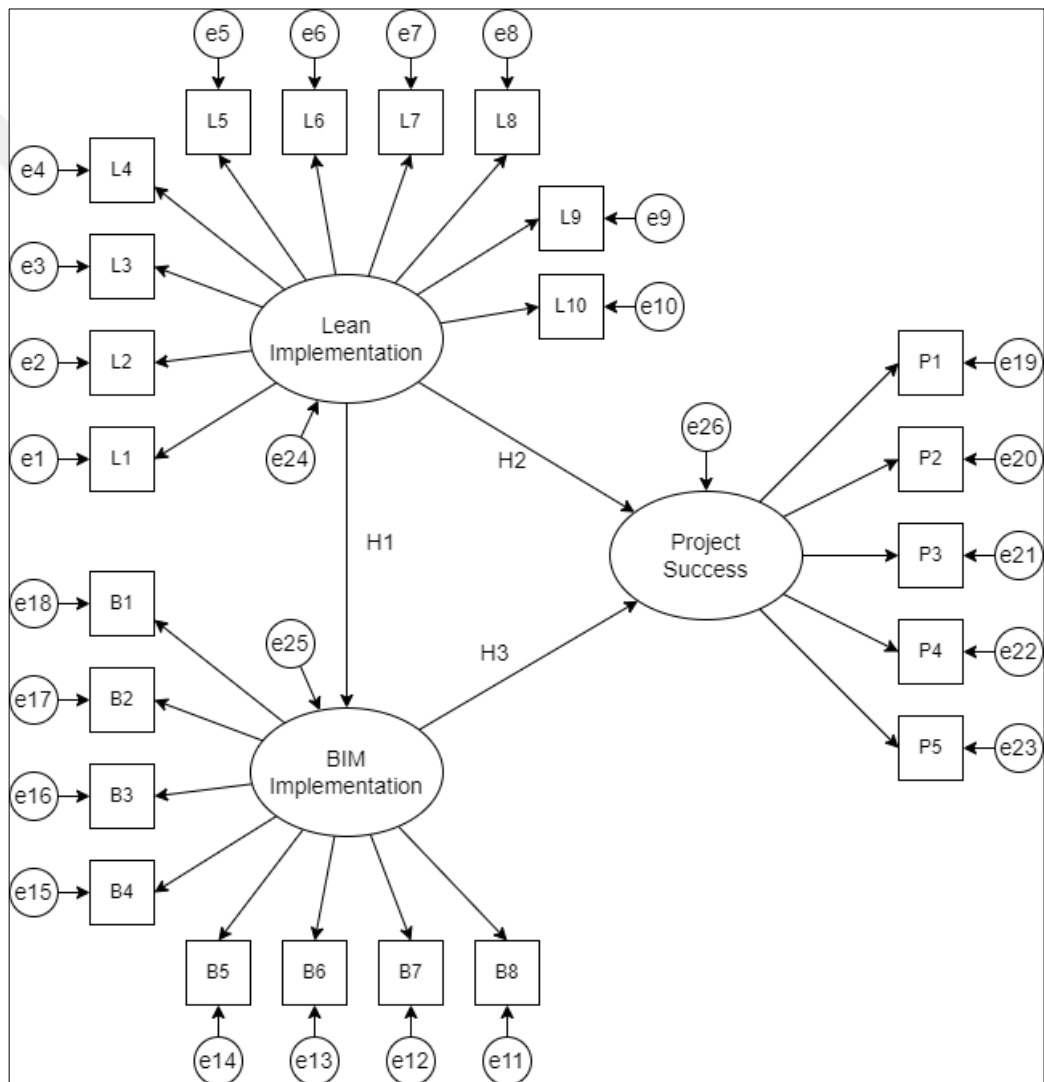


Figure 6.13: First SEM model.

The model creation was conducted in SPSS AMOS software. Then estimation calculations were started. There are several different estimation methods when applying SEM. However, maximum likelihood will be used as the estimation method for

this study. ML simply describes the statistical principle underlying the derivation of parameter estimates. It is a normal theory method because multivariate normality is assumed for the population distributions of the endogenous variables [Kline, 2015]. The initial estimation results are shown in Table 6.3.

Table 6.3: Standardized regression weights of first model.

			Estimate
BIM Implementation	←	Lean Implementation	,795
Project Success	←	Lean Implementation	,793
Project Success	←	BIM Implementation	,108
L1	←	Lean Implementation	,693
L2	←	Lean Implementation	,780
L3	←	Lean Implementation	,749
L4	←	Lean Implementation	,791
L5	←	Lean Implementation	,717
L6	←	Lean Implementation	,842
L7	←	Lean Implementation	,655
L8	←	Lean Implementation	,792
L9	←	Lean Implementation	,749
L10	←	Lean Implementation	,876
B1	←	BIM Implementation	,837
B2	←	BIM Implementation	,889
B3	←	BIM Implementation	,839
B4	←	BIM Implementation	,807
B5	←	BIM Implementation	,857
B6	←	BIM Implementation	,691
B7	←	BIM Implementation	,707
B8	←	BIM Implementation	,857
P1	←	Project Success	,678
P2	←	Project Success	,827
P3	←	Project Success	,830
P4	←	Project Success	,832
P5	←	Project Success	,859

According to the results of the first model, it was determined that Lean implementations contributed positively to BIM implementations and project success. However, the contribution of BIM implementations to the success of the project remained very low.

CMIN, Baseline Comparisons, and RMSEA results for the first model are shown in Table 6.4, Table 6.5, and Table 6.6, respectively.

Table 6.4: CMIN results of first model.

<i>Model</i>	NPAR	CMIN	DF	P	CMIN/DF
<i>Default Model</i>	72	378,286	227	,000	1,666
<i>Saturated Model</i>	299	,000	0		

Table 6.5: Baseline comparisons of first model.

<i>Model</i>	NFI Delta1	RFI rho1	IFI Delta2	TLI rho2	CFI
<i>Default Model</i>	,761	,733	,888	,873	,886

Table 6.6: RMSEA results of first model.

<i>Model</i>	RMSEA	LO 90	HI 90	PCLOSE
<i>Default Model</i>	,098	,081	,115	,000
<i>Independence Model</i>	,276	,263	,289	,000

6.2.3. Evaluation of the Model Fit

After the results of the first model were taken and evaluated, the improvements that could be made on the model were discussed. It was decided to continue on the same implementation variables, since there is no low values path emerged according to the model results. However, covariance relations were established between some implementation parameters in order to make the model results more compatible. After evaluating the results obtained from the initial model, implementations variables were selected to make covariances. In order to establish the covariance relationship, variables with high modification indices were determined. Accordingly, firstly, a covariance was established between the project success criteria, time and safety (MI: 13,10). Then, the covariance relationship was established among BIM implementations. These

were done between Documentation and Analysis (MI:11.89) and between Documentation and Monitoring, Controlling, and Reporting (MI:6.29). After establishing the covariance relations, the model was made ready for SEM analysis again. Figure 6.14 shows the Final Model.

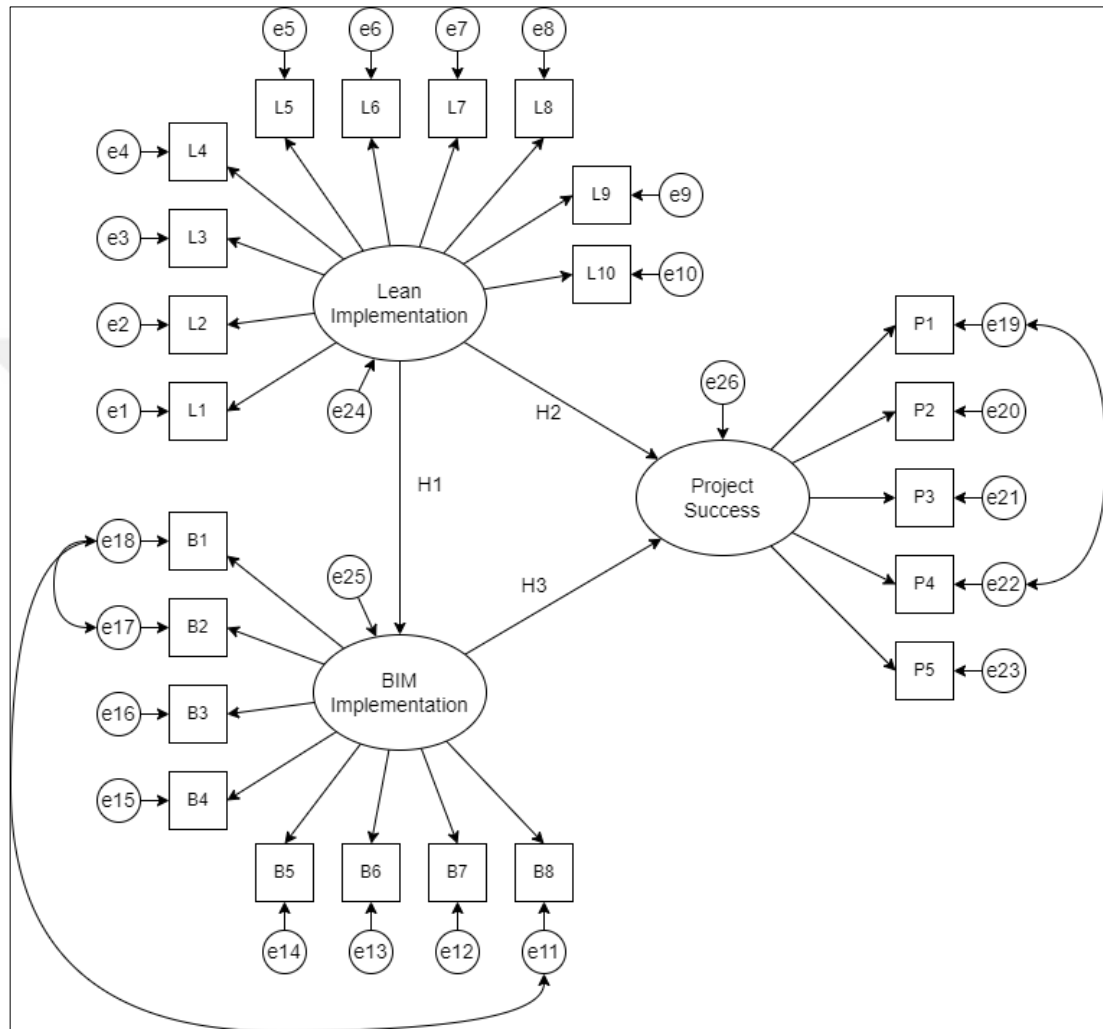


Figure 6.14: SEM model after model fit.

The analysis results of the final model are shown in Table 6.7. Studies for model fit have changed the results. However, this change did not occur in large values. For example, it has been determined that the effect of Lean Implementation on BIM Implementation and the effect of BIM Implementation on the Project Success have increased.

Table 6.7: Standardized regression weights of final model.

			Estimate
BIM Implementation	←	Lean Implementation	,795
Project Success	←	Lean Implementation	,775
Project Success	←	BIM Implementation	,123
L1	←	Lean Implementation	,691
L2	←	Lean Implementation	,782
L3	←	Lean Implementation	,747
L4	←	Lean Implementation	,788
L5	←	Lean Implementation	,720
L6	←	Lean Implementation	,841
L7	←	Lean Implementation	,651
L8	←	Lean Implementation	,794
L9	←	Lean Implementation	,750
L10	←	Lean Implementation	,876
B1	←	BIM Implementation	,778
B2	←	BIM Implementation	,860
B3	←	BIM Implementation	,838
B4	←	BIM Implementation	,816
B5	←	BIM Implementation	,881
B6	←	BIM Implementation	,719
B7	←	BIM Implementation	,724
B8	←	BIM Implementation	,839
P1	←	Project Success	,733
P2	←	Project Success	,836
P3	←	Project Success	,808
P4	←	Project Success	,856
P5	←	Project Success	,852

CMIN, Baseline Comparisons, and RMSEA results for the final model are shown in Table 6.8, Table 6.9, and Table 6.10, respectively.

Table 6.8: CMIN results of final model.

<i>Model</i>	NPAR	CMIN	DF	P	CMIN/DF
<i>Default Model</i>	75	334,816	224	,000	1,495
<i>Saturated Model</i>	299	,000	0		

Table 6.9: Baseline comparisons of final model.

<i>Model</i>	NFI Delta1	RFI rho1	IFI Delta2	TLI rho2	CFI
<i>Default Model</i>	,788	,761	,918	,906	,917

Table 6.10: RMSEA results of final model.

<i>Model</i>	RMSEA	LO 90	HI 90	PCLOSE
<i>Default Model</i>	,085	,065	,103	,003
<i>Independence Model</i>	,276	,263	,289	,000

X^2/df , TLI, IFI, CFI and RMSEA values were compared in order to determine that the model fit was applied successfully. This comparison is shown in Table 6.11. The results support the successful implementation of model fit.

Table 6.11: Reliability values and fit indices for two models.

Index	Recommended Value	Initial Model	Final Model
X^2 / df	< 5.0	1,666	1,495
TLI	0 (no fit) to 1 (perfect fit)	,873	,906
IFI	0 (no fit) to 1 (perfect fit)	,888	,918
CFI	0 (no fit) to 1 (perfect fit)	,886	,917
RMSEA	< 0.10	,098	,085

7. CONCLUSIONS

7.1. Discussions of Findings

The construction industry is a very valuable industry that directly contributes to the growth of the economy of a country but can be affected by crises very easily. According to Öcal et al. [2007], a crisis in the construction industry directly affects about 200 other industries. For this reason, it is vital to prevent crises that may occur in this industry in advance. For example, COVID-19 which caused one of the most important crises of recent years had a very negative impact on the construction industry. Many construction companies faced high costs and overtime with this crisis and even had to cancel some projects [Gamil and Alhagar, 2020]. This crisis, which affected the whole world, also seriously affected Turkey. The high inflation triggered by the crisis increased the construction cost index. The construction cost index in Turkey is shown in Figure 7.1. So, it is necessary to improve the construction activities and working methods in the construction industry and make them more efficient.

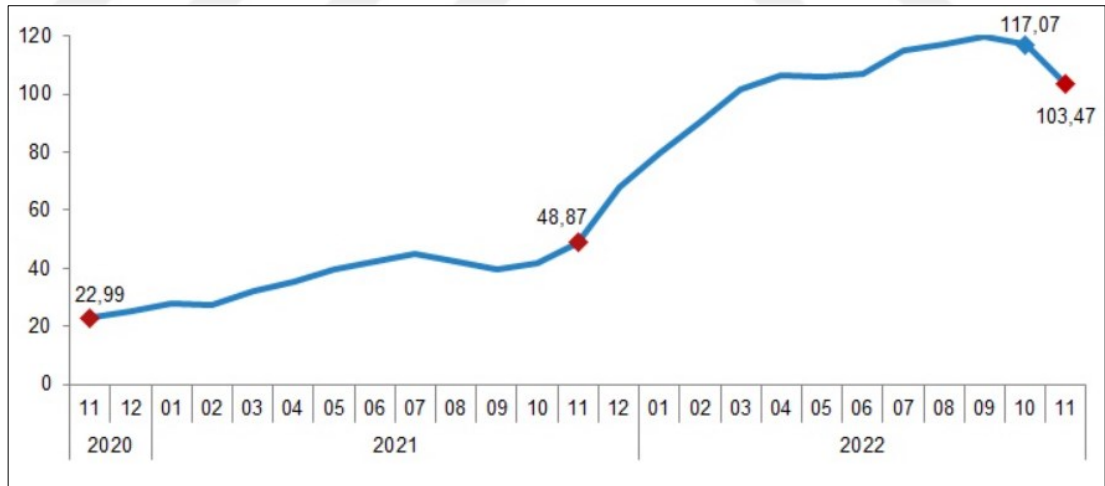


Figure 7.1: Construction cost index in Turkey.

According to Sambasivan and Soon [2007], the main causes of delays in the construction industry can be seen as inadequate contractor planning, poor site management, lack of communication, equipment availability and failure, and problems with subcontractors. According to Haaseb et al. [2011], the lack of adequate details of the

project, and the lack of equipment and materials on-site on time are essential factors in project delays.

According to Engineering News Record (ENR) reports in 2022, there are 42 Turkish companies in the Top 250 International Contractors List. In addition, there are 79 Chinese companies and 41 US companies in the same report [Web 4, 2022]. It is very important that many Turkish contractors are on this list and can compete with Chinese and US contractors. However, in order to compete well and successfully with others companies, it is necessary to eliminate the inefficiency in the construction industry. Lean construction and BIM can be an important key factor for increasing productivity.

Changes and improvements made in the understanding of project management when crises occur are not new. The basics of Lean production, which spread all over the world in the oil crisis that occurred in the 1970s, are still being used and developed today [Pathak, 2012]. BIM, on the other hand, is a development that is increasingly used in the construction industry. BIM is not only a technology but also a set of processes [Azhar et al., 2012]. Therefore, the positive potential of both developments for the construction industry was detected and the study was designed accordingly.

According to Sepasgozar et al. [2021], although the studies on Lean construction and BIM are increasing gradually, there is no study investigating these topics before 2009. In this study, Lean and BIM which are the rising trend globally were examined and various results were revealed regarding the relationship between them. There are studies in the literature to investigate the contribution of BIM to Lean Implementations. However, the contribution of Lean Implementations to BIM Implementations has not been adequately examined. The aim of this study is to reduce this gap in the literature. In addition, project management indicators were added to the study and the contribution of both subjects to the project success was investigated.

The summary information obtained from the analysis results is shown in Figure 7.2.

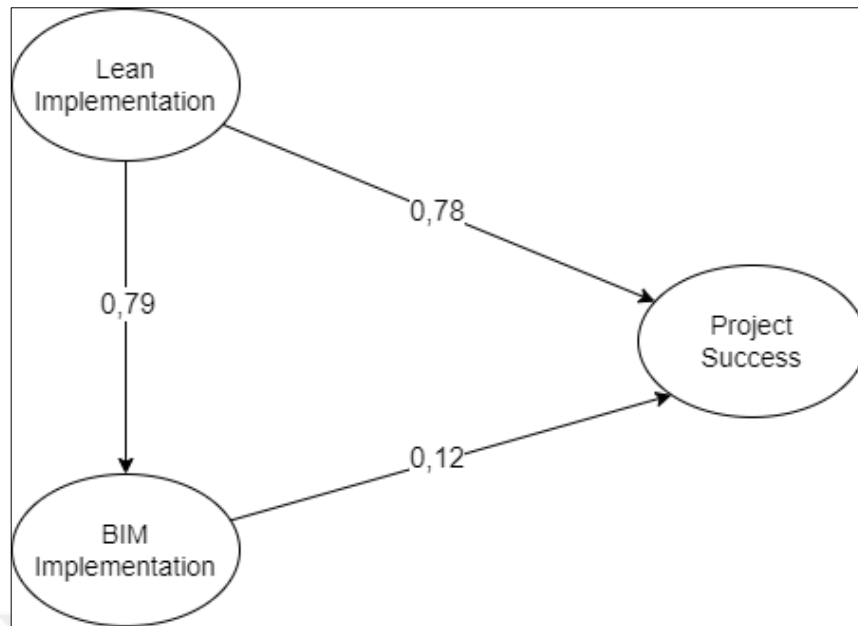


Figure 7.2: Summary of analysis result.

Based on these results, the following comments were made about Lean and BIM in the Turkish construction industry.

- Lean Implementations have a very significant and positive impact on BIM Implementations. The Lean Implementation aims to facilitate processes and improve communication within the team by eliminating waste in order to increase efficiency in project management. Lean's positive contribution to BIM implementation shows that Lean Implementation have achieved their purpose.
- While Lean Implementations contributed significantly to project success, BIM's contribution to project success was low. The reason for this may be that it takes time for people to adapt to technology, companies are not willing to switch to this technology yet, and there are not enough qualified personnel. In addition, since BIM may vary depending on the specific project and organization, its contribution to project success may be limited.
- BIM is widely used in many countries however adoption of BIM may vary in different regions. It is possible that BIM is not as commonly used in Turkey. Because the use of digital technology is limited especially in the construction industry in Turkey. But without more information, it is difficult to say for certain.

- The basis of Lean is to eliminate waste so it is an opportunity to identify and eliminate unnecessary steps in BIM processes. There are many practices that support this. For example, standardization prevents rework activities that can occur in BIM processes. Since rework activities are considered waste, Lean Implementation has a positive contribution to BIM processes. In addition, problems in BIM processes can be eliminated by using the 5 Whys Analysis Methods. 5 Whys Analysis not only eliminates problems but also encourages the "collaboration between disciplines" emphasized in BIM processes. There are also other implementations that increase collaboration. Daily stand-up meetings, one of the Lean implementations, can be used to increase communication and collaboration among team members. This ensures that everyone shares the same goal.

As a result, according to the survey results, Lean implementations came to the fore much more than BIM implementations. The fact that lean implementations are much more accessible than BIM may have improved the results positively. However, according to the results obtained, BIM should not be interpreted as having little effect on project success. Because this study was done to interpret the relationship between the two subjects.

7.2. Conclusions

Lean construction is seen as a management philosophy that aims to minimize waste and increase efficiency in construction projects. This approach helps make construction projects more efficient. BIM is a technological development that increases efficiency by using digital data in construction projects. BIM offers an interdisciplinary approach to the design, construction and operation of construction projects. Both Lean construction and BIM are two approaches that aim to increase efficiency and minimize waste in projects. Especially today, increasing competition has forced companies to increase project efficiency by using different project management approaches.

The aim of this thesis study was to determine the impact of Lean construction implementations on BIM implementations and the impact of both Lean and BIM im-

plementations on project success. Accordingly, an in-depth literature search was conducted, especially on Lean Construction and BIM implementations. Then, the implementations with the highest potential for the intersection of BIM and Lean implementations were determined and included in the model.

In order to analyze the model, data were collected from 71 people through a questionnaire. The survey was conducted in Turkey and was limited to the Turkish Construction Industry. The people who participated in the survey consisted of people who are familiar with and apply Lean Construction and BIM implementations. The obtained data were evaluated in order to validate the model and test the hypotheses. For this, the SEM method was used. The proposed model was analyzed in detail and the model was revised according to the results obtained in SEM. The reliability values of the final model and the high model fit index support the accuracy of the model. Finally, the information obtained as a result of the analysis was evaluated and interpreted.

Productivity in the Turkish construction industry lags behind when compared to other industries. One of the most important reasons is the slow adoption of new technologies and new project management approaches in the construction industry. But, Lean and BIM can be an opportunity to eliminate inefficiency.

It should not be forgotten that the construction industry is complex. In addition, there are many factors that affect efficiency and project success such as the complexity of the project, the experience of the team, conditions in global, the availability of resources, etc. So, the implementation of digitalization and new project management approaches should be carefully planned and executed, with the goal of improving efficiency and productivity.

According to the results of the survey, it was seen that both implementations contributed to the success of the project. Therefore, Lean and BIM are applications that can help overcome many crises. Another aim of this study is to introduce BIM and Lean to the construction companies in the Turkish construction industry and to provide data supporting success. However, there are some limitations in the study. First of all, the number of employees who have applied both Lean and BIM in Turkey is quite low. Therefore, participation in the survey was relatively low. This hypothesis can be re-tested with a larger number of data to reach more accurate results. As companies' interest in both issues increases, we can see more implementation examples. In this way, the number of experienced professionals in these subjects can increase and much more

accurate results can be obtained. In addition, the variables in the hypothesis can be increased. Thus, many more applications can be examined in terms of relation to each other.



REFERENCES

- Abd A. M., Khamees A. S., (2017), "As built case studies for BIM as conflicts detection and documentation tool", *Cogent Engineering*, 4(1), 1-11.
- Ahn Y. H., Kwak Y. H., Suk S. J., (2016), "Contractors' transformation strategies for adopting building information modeling", *Journal of Management in Engineering*, 32(1), 1-13.
- Ahuja I. P. S., Khamba J. S., (2008), "Total productive maintenance: Literature review and directions", *International Journal of Quality and Reliability Management*, 25(7), 709-756.
- Akcamete A., Akinci B., Garrett J. H., (2010), "Potential utilization of building information models for planning maintenance activities", *The International Conference on Computing in Civil and Building Engineering*, 151-57, Nottingham, UK, 30 June-2 July.
- Akinci B., Garrett Jr J. H., (2011), "Integrating and visualizing maintenance and repair work orders in BIM: lessons learned from a prototype", *The International Conference on Construction Applications of Virtual Reality*, 3-4, Weimar, Thuringia, Germany, 16-19 November.
- Akhmetzhanova B., Nadeem A., Hossain M. A., Kim J. R., (2022), "Clash detection using building information modeling (BIM) technology in the Republic of Kazakhstan", *Buildings*, 12(2), 102-122.
- Akintoye A., (1995), "Just-in-time application and implementation for building material management", *Construction Management and Economics*, 13(2), 105-113.
- Ali A. S., Wen K. H., (2011), "Building defects: Possible solution for poor construction workmanship", *Journal of Building Performance*, 2(1), 59-69.
- Aljassmi H., Han S., (2013), "Analysis of causes of construction defects using fault trees and risk importance measures" *Journal of Construction Engineering and Management*, 139(7), 870-880.
- Amaro P., Alves A. C., Sousa R., (2021), "Lean thinking as an organizational culture: A systematic literature review" *Organizational Cultures*, 21(2), 63-102.
- Andújar-Montoya M. D., Marcos-Jorquera D., García-Botella F. M., Gilart-Iglesias V., (2017), "A context-driven model for the flat roofs construction process through sensing systems, internet-of-things and last planner system", *Sensors*, 17(7), 1691-1721.
- Ashokkumar D., (2014), "Study of quality management in construction industry", *International Journal of Innovative Research in Science, Engineering and Technology*, 3(1), 36-43.

Atkinson R., (1999), "Project management: cost, time and quality, two best guesses and a phenomenon, its time to accept other success criteria", *International Journal of Project Management*, 17(6), 337-342.

Azhar S., (2010), "BIM for sustainable design: results of an industry survey", *Journal of Building Information Modeling*, 4(1), 27-28.

Azhar S., Brown J. W., Sattineni A., (2014), "A case study of building performance analyses using building information modeling", 27th International Symposium on Automation and Robotics in Construction, 213-222, Bratislava, Slovakia, 25-27 June.

Azhar S., Carlton W. A., Olsen D., Ahmad I., (2011), "Building information modeling for sustainable design and LEED® rating analysis", *Automation in Construction*, 20(2), 217-224.

Azhar S., Khalfan M., Maqsood T., (2012), "Building information modeling (BIM): now and beyond", *Australasian Journal of Construction Economics and Building*, 12(4), 15-28.

Azhar N., Farouqi R. U., Ahmed S. M., (2008), "Cost overrun factors in construction industry of Pakistan", *First International Conference on Construction in Developing Countries*, 499-508, Karachi, Pakistan, 4-5 August.

Aziz R. F., Hafez S. M., (2013), "Applying lean thinking in construction and performance improvement", *Alexandria Engineering Journal*, 52(4), 679-695.

Bagozzi R. P., Yi Y., (2012), "Specification, evaluation, and interpretation of structural equation models", *Journal of the Academy of Marketing Science*, 40, 8-34.

Ballard G., Hamzeh F. R., Tommelein I. D., (2007), "The last planner production workbook - Improving reliability in planning and workflow", *Lean Construction Institute*.

Ballard G., Howell G. A., (2003a), "An update on last planner", 11th Annual Conference of the International Group for Lean Construction, Virginia, USA.

Ballard G., Howell G. A. (2003b), "Lean project management", *Building Research and Information*, 31(2), 119-133.

Ballard G., Howell G., (1997), "Shielding production: An essential step in production control", Department of Civil and Environmental Engineering, University of California. Construction Engineering and Management Program, Berkeley, USA.

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

Ballard G., (2000), "The last planner system of production control", Doctoral dissertation, University of Birmingham.

Bamana F., Lehoux N., Cloutier C., (2019), "Simulation of a construction project: assessing impact of just-in-time and lean principles", *Journal of Construction Engineering and Management*, 145(5), 05019005.

Barbosa F., Woetzel J., Mischke J., (2017), "Reinventing construction: A route of higher productivity", McKinsey Global Institute.

Barth K. B., Formoso C. T., (2021), "Requirements in performance measurement systems of construction projects from the lean production perspective", *Frontiers of Engineering Management*, 8, 442-455.

Benjamin S. J., Marathamuthu M. S., Murugaiah U., (2015), "The use of 5-WHYs technique to eliminate OEE's speed loss in a manufacturing firm", *Journal of Quality in Maintenance Engineering*, 21(4), 419-435.

Bentler P. M., Stein J. A., (1992), "Structural equation models in medical research", *Statistical Methods in Medical Research*, 1(2), 159-181.

Berssaneti F. T., Carvalho M. M., (2015), "Identification of variables that impact project success in Brazilian companies", *International Journal of Project Management*, 33(3), 638-649.

Binninger M., Dlouhy J., Müller M., Schattmann M., Haghsheno S., (2018), "Short takt time in construction—a practical study", 26th Annual Conference of the International Group for Lean Construction, 16-22, Chennai, India, 18-22 July.

Borrmann A., König M., Koch C., Beetz J., (2018), "Building information modeling: Why? what? how?", Springer International Publishing.

Bowen P. A., Cattel K. S., Hall K. A., Edwards P. J., Pearl R. G., (2002), "Perceptions of time, cost and quality management on building projects", *Construction Economics and Building*, 2(2), 48-56.

Braglia M., Frosolini M., Gallo M., (2017), "SMED enhanced with 5-Whys Analysis to improve set-upreduction programs: the SWAN approach", *The International Journal of Advanced Manufacturing Technology*, 90, 1845-1855.

Brandalise F. M., Valente C. P., Viana D. D., Formoso C. T., (2018), "Understanding the effectiveness of visual management best practices in construction sites", 26th Annual Conference of the International. Group for Lean Construction, 754-763, Chennai, India, 18-22 July.

Brunet A. P., New S., (2003), "Kaizen in Japan: an empirical study", *International Journal of Operations & Production Management*, 23(11-12), 1426-1446.

Bubshait A. A., Almohawis S. A., (1994), "Evaluating the general conditions of a construction contract", *International Journal of Project Management*, 12(3), 133-136.

Canel C., Rosen D., Anderson E. A., (2000), "Just-in-time is not just for manufacturing: a service perspective", *Industrial Management & Data Systems*, 100(2), 51-60.

Card A. J., (2017), "The problem with '5 whys'", *BMJ Quality & Safety*, 26(8), 671-677.

Chan A. P., Chan A. P., (2004), "Key performance indicators for measuring construction success" *Benchmarking: An International Journal*, 11(2), 203-221.

Chan A. P., Scott D., Lam E. W., (2002), "Framework of success criteria for design/build projects", *Journal of Management in Engineering*, 18(3), 120-128.

Chan C. O., Tay H. L., (2018), "Combining lean tools application in kaizen: a field study on the printing industry", *International Journal of Productivity and Performance Management*, 67(1), 45-65.

Chapman C. D., (2005), "Clean house with lean 5S", *Quality Progress*, 38(6), 27-32.

Badrinath A. C., Chang Y. T., Hsie, S. H., (2016), "A review of tertiary BIM education for advanced engineering communication with visualization", *Visualization in Engineering*, 4(1), 1-17.

Chen J. C., Li Y., Shady B. D., (2010), "From value stream mapping toward a lean/sigma continuous improvement process: an industrial case study", *International Journal of Production Research*, 48(4), 1069-1086.

Chen Y., Kamara J. M., (2011), "A framework for using mobile computing for information management on construction sites", *Automation in Construction*, 20(7), 776-788.

Chiarini A., Baccarani C., Mascherpa V., (2018), "Lean production, Toyota Production System and Kaizen philosophy: A conceptual analysis from the perspective of Zen Buddhism", *The TQM Journal*, 30(4), 425-438.

Chua D. K. H., Loh P. K., Kog Y. C., Jaselskis E. J., (1997), "Neural networks for construction project success", *Expert Systems with Applications*, 13(4), 317-328.

Coetzee R., Van Dyk L., Van der Merwe K., (2016), "Lean implementation strategies: how are the Toyota Way principles addressed?", *South African Journal of Industrial Engineering*, 27(3), 79-91.

Collier J. E., (2020), "Applied structural equation modeling using AMOS: Basic to advanced techniques", Routledge.

Collins A., Baccarini D., (2004), "Project success—a survey", *Journal of Construction Research*, 5(02), 211-231.

Crockett S. A., (2012), "A five-step guide to conducting SEM analysis in counseling research", *Counseling Outcome Research and Evaluation*, 3(1), 30-47.

de Bucourt M., Busse R., Güttler F., Wintzer C., Collettini F., Kloeters C., ... Teichgräber U. K., (2011), "Lean manufacturing and Toyota Production System ter-

minology applied to the procurement of vascular stents in interventional radiology”, *Insights into Imaging*, 2, 415-423.

Eadie R., Odeyinka H., Browne M., McKeown C., Yohanis M. (2013), “An analysis of the drivers for adopting building information modelling”, *Journal of Information Technology in Construction*, 18(17), 338-352.

Eastman C. M., Teicholz P., Sacks R., Liston K., (2011), “BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors”, John Wiley & Sons.

Egan J., (1998), “Rethinking Construction”.

Eldeep A. M., Farag M. A., Abd El-hafez L. M., (2022), “Using BIM as a lean management tool in construction processes—A case study”, *Ain Shams Engineering Journal*, 13(2), 101556.

Öca M. E., Oral, E. L., Erdis E., Vural G., (2007), “Industry financial ratios—application of factor analysis in Turkish construction industry”, *Building and Environment*, 42(1), 385-392.

Ershadi M., Jefferies M., Davis P., Mojtahedi M., (2021), “Implementation of Building Information Modelling in infrastructure construction projects: A study of dimensions and strategies”, *International Journal of Information Systems and Project Management*, 9(4), 43-59.

Fernandez-Solis J. L., Porwal V., Lavy S., Shafaat A., Rybkowski Z. K., Son K., Lagoo N., (2013), “Survey of motivations, benefits, and implementation challenges of last planner system users”, *Journal of Construction Engineering and Management*, 139(4), 354-360.

Fiallo M., Howell G., (2012), “Using production system design and takt time to improve project performance”, 20th Annual Conference of the International Group for Lean Construction, San Diego, CA, USA, 18-20 July.

Fowler C., Steffen E., Mentz C., (2022), “Using lean principles as an implementation strategy within the EBP process”, *Journal of PeriAnesthesia Nursing*, 37(1), 137-142.

Frandsen A., Berghede K., Tommelein I. D., (2013), “Takt time planning for construction of exterior cladding”, 21st Annual Conference of the International Group for Lean Construction, Fortaleza, Brazil, 29 July-2 August.

Galsworth G. D., (2017), “Visual workplace visual thinking: Creating enterprise excellence through the technologies of the visual workplace”, Taylor & Francis.

Gamil Y., Alhagar A., (2020), “The impact of pandemic crisis on the survival of construction industry: a case of COVID-19”, *Mediterranean Journal of Social Sciences*, 11(4), 122-122.

Gangidi P., (2018), "A systematic approach to root cause analysis using 3×5 why's technique", *International Journal of Lean Six Sigma*, 10(1), 295-310.

Gao S., Low S. P., (2014), "The last planner system in China's construction industry—A SWOT analysis on implementation", *International Journal of Project Management*, 32(7), 1260-1272.

Garg A., Deshmukh S. G., (2006), "Maintenance management: literature review and directions", *Journal of Quality in Maintenance Engineering*, 12(3), 205-238.

Gibb A. G., (2001), "Standardization and pre-assembly-distinguishing myth from reality using case study research", *Construction Management & Economics*, 19(3), 307-315.

Gjerde M. R. D., Ratnayake R. C., Samarakoon S. K., (2019), "Effective implementation of last planner system® in construction projects: a case study", 2019 IEEE International Conference on Industrial Engineering and Engineering Management, 1139-1144, Macao, China, 15-18 December.

Green S. D., (1999), "The missing arguments of lean construction", *Construction Management & Economics*, 17(2), 133-137.

Gupta S., Jain S. K., (2015), "An application of 5S concept to organize the work-place at a scientific instruments manufacturing company", *International Journal of Lean Six Sigma*, 6(1), 73-88.

Hamdi O., Leite F., (2014), "Conflicting side of building information modeling implementation in the construction industry", *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, 6(3), 03013004.

Hartanti L. P. S., Gunawan I., Mulyana I. J., Herwinarso H., (2022), "Identification of waste based on lean principles as the way towards sustainability of a higher education institution: A case study from Indonesia", *Sustainability*, 14(7), 4348.

Hasan A., Baroudi B., Elmualim A., Rameezdeen R., (2018), "Factors affecting construction productivity: a 30 year systematic review", *Engineering, Construction and Architectural Management*, 25(7), 916-937.

Haseeb M., Bibi A., Rabbani W., (2011), "Problems of projects and effects of delays in the construction industry of Pakistan", *Australian Journal of Business and Management Research*, 1(5), 41-50.

Hassan A., Shariff Nabi Baksh M., Shaharoun A. M., (2000), "Issues in quality engineering research", *International Journal of Quality & Reliability Management*, 17(8), 858-875.

Hatush Z., Skitmore M., (1997), "Evaluating contractor prequalification data: selection criteria and project success factors", *Construction Management and Economics*, 15(2), 129-147.

Heigermoser D., de Soto B. G., Abbott E. L. S., Chua D. K. H., (2019), "BIM-based Last Planner System tool for improving construction project management", *Automation in Construction*, 104, 246-254.

Hines P., Holweg M., Rich N., (2004), "Learning to evolve: a review of contemporary lean thinking", *International Journal of Operations & Production Management*, 24(10), 994-1011.

Ho S. K., (1999), "5-S practice: the first step towards total quality management", *Total Quality Management*, 10(3), 345-356.

Ho S. K., Cicmil S., (1996), "Japanese 5-S practice", *The TQM Magazine*, 8(1), 45-53.

Ho S. K., Cicmil S., Fung C. K., (1995), "The Japanese 5-S practice and TQM training", *Training for Quality*, 3(4), 19-24.

Hopp W. J., Spearman M. L., (2011), "Factory physics", Waveland Press.

Huang K. W., (2014), "Application of BIM in project management", *Applied Mechanics and Materials*, 496, 2836-2839.

Hughes S. W., Tippet D. D., Thomas W. K., (2004), "Measuring project success in the construction industry", *Engineering Management Journal*, 16(3), 31-37.

Davidson I. N., Skibniewski M. J., (1995), "Simulation of automated data collection in buildings", *Journal of Computing in Civil Engineering*, 9(1), 9-20.

Imai M., (1986), "Kaizen: The key to Japan's competitive success", McGraw-Hill.

Ivson P., Moreira A., Queiroz F., Santos W., Celes W., (2019), "A systematic review of visualization in building information modeling", *IEEE Transactions on Visualization and Computer Graphics*, 26(10), 3109-3127.

Jaber A. M., Burhan A. M., (2020), "Analyzing the obstacles of investment process in Iraq using (5 whys) and Focus Group Discussion (FQD) Techniques", *IOP Conference Series: Materials Science and Engineering*, 012030, September.

Jalaei F., Jrade A., (2014), "Integrating building information modeling (BIM) and energy analysis tools with green building certification system to conceptually design sustainable buildings", *Journal of Information Technology in Construction*, 19, 494-519.

Jeong W., Yan W., Lee C. J., (2020), "Thermal performance visualization using object-Oriented physical and building information modeling", *Applied Sciences*, 10(17), 5888.

Jeong W., Chang S., Son J., Yi, J. S., (2016), "BIM-integrated construction operation simulation for just-in-time production management", *Sustainability*, 8(11), 1106.

Jiang L., Zhong H., Chen J., Cheng J., Chen S., Gong Z., ..., Su Z., (2022), "Study on the construction workforce management based on lean construction in the context of COVID-19", *Engineering, Construction and Architectural Management*, (ahead-of-print).

Johansson M., Roupé M., Bosch-Sijtsema P., (2015), "Real-time visualization of building information models (BIM)", *Automation in Construction*, 54, 69-82.

John A. O., Itodo D. E., (2013), "Professionals' views of material wastage on construction sites and cost overruns", *Organization, Technology & Management in Construction*, 5(1), 747-757.

Kalsaas B. T., Skaar J., Thorstensen R. T., (2009), "Implementation of last planner in a medium-sized construction site", 17th Annual Conference of the International Group for Lean Construction, 15-30, Taipei, Taiwan, 15-17 July.

Kalsaas B. T., (2012), "The last planner system style of planning: Its basis in learning theory", *Journal of Engineering, Project & Production Management*, 2(2), 88-100.

Kerem C., Barak R., Sacks R., Priven V., (2013), "Learning to see—managers working in the gemba as part of the Tidhar Way Training Program", 21th Annual Conference of the International Group for Lean Construction, 957-966, Fortaleza, Brazil, 31-2 August.

Khanh H. D., Kim S. Y., (2014), "Evaluating impact of waste factors on project performance cost in Vietnam", *KSCE Journal of Civil Engineering*, 18, 1923-1933.

Kilpatrick J., (2003), "Lean principles", Utah Manufacturing Extension Partnership, 68(1), 1-5.

Kim Y. W., Ballard G., (2010), "Management thinking in the earned value method system and the last planner system", *Journal of Management in Engineering*, 26(4), 223-228.

Kline R. B., (2015), "Principles and practice of structural equation modeling", Guilford Publications.

Kline R. B., (1998), "Software review: Software programs for structural equation modeling: Amos, EQS, and LISREL", *Journal of Psychoeducational Assessment*, 16(4), 343-364.

Koskela L., (1992), "Application of the new production philosophy to construction", 72, Center for Integrated Facility Engineering, Stanford University, USA.

Krygiel E., Nies, B., (2008), "Green BIM: successful sustainable design with building information modeling", John Wiley & Sons.

Kumar S., Steinebach M., (2008), "Eliminating US hospital medical errors", *International Journal of Health Care Quality Assurance*, 21(5), 444-471.

Kumaraswamy M. M., Thorpe A., (1996), "Systematizing construction project evaluations", *Journal of Management in Engineering*, 12(1), 34-39.

Kymmell W., (2008), "Building information modeling: Planning and managing construction projects with 4D CAD and simulations (McGraw-Hill construction series)", McGraw-Hill Education.

Marchwinski C., Shook J. (Eds.), (2008), "Lean lexicon: a graphical glossary for lean thinkers", Lean Enterprise Institute.

Moon, H., Kim, H., Kamat, V. R., Kang, L., (2015), "BIM-based construction scheduling method using optimization theory for reducing activity overlaps", *Journal of Computing in Civil Engineering*, 29(3), 04014048.

Lee D. G., Cha H. S., (2015), "Exploratory study on BIM-based information breakdown structure for construction document management", *Journal of Construction Engineering and Project Management*, 5(1), 32-39.

Lee D. G., Park J. Y., Song S. H., (2018), "BIM-based construction information management framework for site information management", *Advances in Civil Engineering*, 2018, 1-14.

Lee G., Sacks R., Eastman C. M., (2006), "Specifying parametric building object behavior (BOB) for a building information modeling system", *Automation in Construction*, 15(6), 758-776.

Leicht R. M., Messner J. I., (2007), "Comparing traditional schematic design documentation to a schematic building information model", 29th Bringing ITC Knowledge to Work: Proceedings of the 24th W78 Conference, 39-46, Maribor, Slovenia, 26-29 June.

Leino A., Heinonen R., Kiurula M., (2014), "Improving safety performance through 5S program", 22nd Annual Conference of the International Group for Lean Construction, 1401-1412, Oslo, Norway, 25-27 June.

LeMahieu P. G., Nordstrum L. E., Greco P., (2017), "Lean for education", *Quality Assurance in Education: An International Perspective*, 25(1), 74-90.

Liker J. K., Meier D., (2006), "Toyota way fieldbook", McGraw-Hill Education.

Liker J. K., Morgan J. M., (2006), "The Toyota way in services: the case of lean product development", *Academy of Management Perspectives*, 20(2), 5-20.

Lim C. S., Zain Mohamed M., (1999), "Criteria of project success: an exploratory re-examination", *International Journal of Project Management*, 17(4), 243-248.

Linnik M., Berghede K., Ballard G., (2013), "An experiment in takt time planning applied to non-repetitive work", 21th Annual Conference of the International Group for Lean Construction, 31-2, Fortaleza, Brazil, 29 July-2 August.

Liu Z. Q., Zhang F., Zhang J., (2016), "The building information modeling and its use for data transformation in the structural design stage", *Journal of Applied Science and Engineering*, 19(3), 273–284.

Loon S., (2008), "Issues and procedures in adopting structural equation modelling technique", *Journal of Quantitative Methods*, 3(1), 76–83.

Loosemore M., Lee P., (2002), "Communication problems with ethnic minorities in the construction industry", *International Journal of Project Management*, 20(7), 517–524.

Love P. E., Irani Z., Edwards D. J., (2003), "Learning to reduce rework in projects: Analysis of firm's organizational learning and quality practices", *Project Management Journal*, 34(3), 13–25.

Maimon A. D., (2015), "Applications of the last planner system", *Annals of "Dunarea de Jos" University of Galati. Fascicle XI Shipbuilding*, 38, 131–134.

Manyika J., Ramaswamy S., Khanna S., Sarrazin H., Pinkus G., Sethupathy G., Yaffe A., (2015), "Digital America: A tale of the haves and have-mores", McKinsey Global Institute.

Martínez-Aires M. D., López-Alonso M., Martínez-Rojas M., (2018), "Building information modeling and safety management: A systematic review", *Safety science*, 101, 11–18.

Melton T., (2005), "The benefits of lean manufacturing: what lean thinking has to offer the process industries", *Chemical Engineering Research and Design*, 83(6), 662–673.

Memon Z. A., Majid M. Z. A., Mustaffar M., (2005), "An automatic project progress monitoring model by integrating auto CAD and digital photos", *International Conference on Computing in Civil Engineering*, 1–13, Cancun, Mexico, July 12–15.

De Meyer A., Loch C. H., Pich M. T., (2002), "Managing project uncertainty: from variation to chaos", *MIT Sloan Management Review*, 43(2), 60–67.

Misiurek K., Misiurek B., (2020), "Improvement of the safety and quality of a workplace in the area of the construction industry with use of the 6S system", *International Journal of Occupational Safety and Ergonomics*, 26(3), 514–520.

Molenaar K. R., Songer A. D., (1998), "Model for public sector design-build project selection", *Journal of Construction Engineering and Management*, 124(6), 467–479.

Monden Y., (2011), "Toyota Production System: An Integrated Approach to Just-In-Time", Productivity Press.

Mor R. S., Bhardwaj A., Singh S., Sachdeva A., (2019), "Productivity gains through standardization-of-work in a manufacturing company", *Journal of Manufacturing Technology Management*, 30(6), 899–919.

Mossman A., (2009), "Creating value: a sufficient way to eliminate waste in lean design and lean production", *Lean Construction Journal*, 2009, 13-23.

Murugaiah U., Benjamin S. J., Marathamuthu M. S., Muthaiyah S., (2010), "Scrap loss reduction using the 5-whys analysis", *International Journal of Quality & Reliability Management*, 27(5), 527-540.

National BIM Standard Project Committee, (2007), "National building information modeling standard, version 1, Part 1: Overview, principles, and methodologies", National Institute of Building Sciences.

Nguyen L. D., Ogunlana S. O., (2004), "A study on project success factors in large construction projects in Vietnam", *Engineering, Construction and Architectural Management*, 11(6), 404-413.

Mariz R. N., Picchi F. A., Granja A., (2013), "Application of standardized work in Franki Piles concrete work", 21st Annual Conference of the International Group for Lean Construction, 461-470, Fortaleza, Brazil, 29 July -2 August.

Nunes Mariz R., Picchi F. A., Granja A. D., Savio R., de Melo S., (2012), "A review of the standardized work application in construction", 20th Conference of the International Group for Lean Construction, San Diego, CA, USA, 18-20 July.

Ohno T., (1988), "Toyota production system: beyond large-scale production", CRC Press.

Papke-Shields K. E., Beise C., Quan J., (2010), "Do project managers practice what they preach, and does it matter to project success?", *International Journal of Project Management*, 28(7), 650-662.

Parfitt M. K., Sanvido V. E., (1993), "Checklist of critical success factors for building projects", *Journal of Management in Engineering*, 9(3), 243-249.

Parry G. C., Turner C. E., (2006), "Application of lean visual process management tools", *Production Planning & Control*, 17(1), 77-86.

Pathak A. K., (2012), "Some aspects of lean manufacturing", *Advanced Materials Research*, 488-489, 1142-1146

Pedo B., Tezel A., Koskela L., Whitelock-Wainwright A., Lenagan D., Nguyen Q. A., (2021), "Lean contributions to BIM processes: the case of clash management in highways design", 29th Conference of the International Group for Lean Construction, 116-125, Lima, Peru, 12-18 July.

Peterson J., Smith R., (1998), "The 5S pocket guide", CRC Press.

Popov V., Mikalauskas S., Migilinskas D., Vainiūnas P., (2006), "Complex usage of 4D information modelling concept for building design, estimation, scheduling and determination of effective variant", *Technological and Economic Development of Economy*, 12(2), 91-98.

Porwal V., Fernández-Solís J., Lavy S., Rybkowski Z. K. (2010), "Last planner system implementation challenges", 18th Annual Conference International Group for Lean Construction, 548-554, Haifa, Israel, 14-16 July.

Pruskova K., Kaiser J., (2019), "Implementation of BIM Technology into the Design Process Using the Scheme of BIM Execution Plan", IOP Conference Series: Materials Science and Engineering, 022019.

Randhawa J. S., Ahuja I. S., (2017), "5S—a quality improvement tool for sustainable performance: literature review and directions", International Journal of Quality & Reliability Management, 34(3), 334-361.

Rowlinson S., (2004), "Construction safety management systems", Spon Press.

Sacks R., Treckmann M., Rozenfeld O., (2009), "Visualization of work flow to support lean construction", Journal of Construction Engineering and Management, 135(12), 1307-1315.

Saieg P., Sotelino E. D., Nascimento D., Caiado R. G. G., (2018), "Interactions of Building Information Modeling, Lean and Sustainability on the Architectural, Engineering and Construction industry: A systematic review", Journal of Cleaner Production, 174, 788–806.

Salem O., Solomon J., Genaidy A., Minkarah I., (2006), "Lean construction: From theory to implementation", Journal of Management in Engineering, 22(4), 168-175.

Salvatierra-Garrido J., Pasquire C., (2011), "Value theory in lean construction", Journal of Financial Management of Property and Construction, 16(1), 8-18.

Sambasivan M., Soon Y. W., (2007), "Causes and effects of delays in Malaysian construction industry", International Journal of Project Management, 25(5), 517-526.

Samudio M., da CL Alves T., Chambers D., (2011), "Employing the principle of" going and seeing" to construction", Lean Construction Journal, 2011, 41-53.

Sanguinetti P., Abdelmohsen S., Lee J., Lee J., Sheward H., Eastman C., (2012), "General system architecture for BIM: An integrated approach for design and analysis", Advanced Engineering Informatics, 26(2), 317–333.

Santos A. dos Powell J., (1999), "Potential of Poka-Yoke Devices to Reduce Variability in Construction", 7th Conference of the International Group for Lean Construction, 51-62, Berkeley, California, USA, 26-28 July.

Schlueter A., Thesseling F., (2009), "Building information model based energy/exergy performance assessment in early design stages", Automation in Construction, 18(2), 153–163.

Sepasgozar S. M., Hui F. K. P., Shirowzhan S., Foroozanfar M., Yang L., Aye L., (2020), "Lean practices using building information modeling (BIM) and digital twinning for sustainable construction", Sustainability, 13(1), 161.

Shingo S., Dillon A. P., (1989), "A study of the Toyota production system: From an Industrial Engineering Viewpoint", CRC Press.

Singh S., Kumar K., (2021), "A study of lean construction and visual management tools through cluster analysis", *Ain Shams Engineering Journal*, 12(1), 1153–1162.

Smadi S. al., (2009), "Kaizen strategy and the drive for competitiveness: Challenges and opportunities", *Competitiveness Review*, 19(3), 203–211.

Smith P., (2014), "BIM & the 5D project cost manager", *Procedia - Social and Behavioral Sciences*, 119, 475–484.

Suprabhas K., Dib H. N., (2017), "Integration of BIM and utility sensor data for facilities management", *International Workshop on Computing in Civil Engineering 2017*, 26-33, Seattle, Washington, US, 25-27 June.

Stewart D. M., Grout J. R., (2001), "The human side of mistake-proofing", *Production and Operations Management*, 10(4), 440-459.

Tezel A., Aziz Z., (2016), "Visual management/visual controls implementation pilot: 5S in highways construction and maintenance", *School of the Built Environment, University of Salford*,

Tezel A., Taggart M., Koskela L., Tzortzopoulos P., Hanahoe J., Kelly M., (2020), "Lean construction and BIM in small and medium-sized enterprises (SMEs) in construction: A systematic literature review", *Canadian Journal of Civil Engineering*, 47(2), 186–201.

Thakkar J. J., (2020), "Structural equation modelling application for research and practice (with AMOS and R)", *Springer Nature*.

Thomas E., Schott P., Bowman J., Snyder J., Spare N., (2018), "Construction disconnected", *Industry Report*.

Tommelein I. D., (2017), "Collaborative takt time planning of non-repetitive work", *25th Conference of the International Group for Lean Construction*, 745-752, Heraklion, Greece, 9-18 July.

Torbica Ž. M., Stroh R. C., (2001), "Customer satisfaction in home building", *Journal of Construction Engineering and Management*, 127(1), 82-86.

Tyagi S., Choudhary A., Cai X., Yang K., (2015), "Value stream mapping to reduce the lead-time of a product development process", *International Journal of Production Economics*, 160, 202–212.

Vilutienė T., Kalibatienė D., Hosseini M. R., Pellicer E., Zavadskas E. K., (2019), "Building information modeling (BIM) for structural engineering: a bibliometric analysis of the literature", *Advances in Civil Engineering*, 2019, 1-19.

Vinod M., Devadasan S. R., Sunil D. T., Thilak V. M. M., (2015), “Six sigma through Poka-Yoke: A navigation through literature arena”, *International Journal of Advanced Manufacturing Technology*, 81(1–4), 315–327.

Walker D. H. T., (1995), “An investigation into construction time performance”, *Construction Management and Economics*, 13(3), 263–274.

Wang A., Guess M., Connell K., Powers K., Lazarou G., Mikhail M., (2006), “Fecal incontinence: A review of prevalence and obstetric risk factors”, *International Urogynecology Journal*, 17(3), 253–260.

Weston R., Gore P. A., (2006), “A brief guide to structural equation modeling”, *The Counseling Psychologist*, 34(5), 719–751.

Web 1, (2022), <https://catenda.com/bim-building-information-modeling-software/> (Erişim Tarihi: 21/01/2023).

Web 2, (2013), <https://www.ibm.com/downloads/cas/K8V9RWB2> (Erişim Tarihi: 15/01/2023).

Web 3, (2009), <http://www.adb.org/documents/information/knowledge-solutions/assessing-effectiveness-assistance-ca-> (Erişim Tarihi: 20/09/2022).

Web 4, (2022), <https://www.hurriyetdailynews.com/42-turkish-contractors-in-top-250-list-176437> (Erişim Tarihi: 21/01/2022).

Web 5, (2023), <https://www.theblm.com/video/what-is-4d-bim> (Erişim Tarihi: 15/01/2022).

Wuellner W. W., (1990), “Project performance evaluation checklist for consulting engineers”, *Journal of Management in Engineering*, 6(3), 270-281.

De Wit A., (1988), “Measurement of project success”, *International Journal of Project Management*, 6(3), 164-170.

Womack J. P., Jones D. T., (1996), “Lean thinking—banish waste and create wealth in your corporation”, *Journal of the Operational Research Society*, 48(11), 1148-1148.

Wu G., Liu C., Zhao X., Zuo J., (2017), “Investigating the relationship between communication-conflict interaction and project success among construction project teams”, *International Journal of Project Management*, 35(8), 1466–1482.

Yan H., Damian P., (2008), “Benefits and barriers of building information modeling”, 12th International Conference on Computing in Civil and Building Engineering, Beijing, China, 16-18 October.

Zhang J. P., Hu Z. Z., (2011), “BIM- and 4D-based integrated solution of analysis and management for conflicts and structural safety problems during construction: 1. Principles and methodologies”, *Automation in Construction*, 20(2), 167–180.

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