

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

**A SYSTEM DYNAMICS MODEL OF LEAN AND BIM
INTERACTION**

EMRAH ALTUĞ
**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

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2023

T.C.
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SİSTEM DİNAMİĞİ MODELİ

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SUMMARY

The construction industry, which has many complex relations in its nature, may bring many problems, especially exceeding the project budget and causing time delays. In addition, the construction sector may generate inefficient working conditions and waste due to the low adoption of technological developments and performance disclosures compared to other sectors. Lean applications aim to maximize added value while reducing waste. The most important contribution of Lean implementation is to increase customer satisfaction through performance improvements and revisions in production and workplace organization. Lean tools and techniques, being already implemented in various sectors, have recently gained considerable attention in the construction industry. For example, the principle of continuous improvement (KAIZEN), error-proofing applications (poka-yoke), and visual display tools (Kanban cards, Andon applications, etc.) help to demonstrate performance characteristics in construction projects. Besides the proven benefits of Lean practices, the construction industry further needs other techniques to improve productivity. The main purpose of this study is to show the synergy and integration between Lean applications and Building Information Modeling (BIM) tools to guide construction companies to experience higher performance in their projects. In the study, based on an in-depth literature study, common components in Lean applications and BIM processes were determined and analyzed in detail. To better reflect the relationship between Lean and BIM, a questionnaire was designed and administered to construction professionals. Based on the questionnaire results, a conceptual system dynamics modeling (SDM) of Lean and BIM interaction was revealed. The relations were further discussed over the model accordingly.

Key Words: Lean Construction, Building Information Modeling (BIM), System Dynamics, Construction Management, Construction Project Management.

ÖZET

Doğasında birçok açıdan karmaşık ilişkiler bulunan inşaat sektörü, bu ilişkilerin sonucunda proje bütçesinin aşılması ve zaman gecikmeleri başta olmak üzere birçok sorunu da beraberinde getirebilmektedir. Ayrıca diğer sektörlerle göre teknolojik gelişmelerin ve performans iyileştirmelerinin daha yavaş geliştiği inşaat sektörü verimsiz çalışma koşullarının ve israfın yaygın olarak ortaya çıktığı bir sektördür. Yalın uygulamalar, israfı azaltırken katma değeri en üst düzeye çıkarmayı amaçlar. Yalın uygulamaların en önemli katkısı organizasyon ve üretim hattında yapılacak revizyon ve iyileştirmelerle müşteri memnuniyetini arttırmayı hedeflemesidir. Yalın uygulamalar yıllardır farklı sektörlerde uygulanmakta ve son zamanlarda inşaat sektöründe ilgi görmektedir. Örneğin, sürekli iyileştirme ilkesi (KAIZEN), hata engelleme uygulamaları (Japonca'da poka-yoke) ve görsel öğeler (Kanban kartları, Andon uygulamaları vb.) inşaat projelerinde kullanılan performans iyileştirme yöntemleri arasındadır. Yalın uygulamalar, süreç iyileştirme ve işyeri organizasyonu açısından son derece önemli olsa da inşaat sektöründe verimliliği artırmak için başka iyileştirme tekniklerine de ihtiyaç vardır. Bu çalışmanın temel amacı, Yalın uygulamaları ve Yapı Bilgi Modellemesi (YBM) araçlarını entegre ederek inşaat projelerinin daha yüksek verimlilikle yürütülmesini sağlamaktır. Derinlemesine bir literatür çalışmasına dayalı olarak yapılan çalışmada, Yalın uygulamalar ve BIM süreçlerindeki ortak bileşenler belirlenerek detaylı bir şekilde analiz edilmiştir. Ayrıca Yalın uygulamalar ve BIM araçlarının entegrasyonunu araştırmak için uzmanlarla görüşmeler yapılmış ve bu görüşmelerin sonuçlarına göre kavramsal bir sistem dinamiği modeli (SDM) oluşturulmuştur. Sistem dinamiği modeli ile bu sinerji arasındaki etkileşim kavramsal bir model üzerinden açıklanmıştır.

Anahtar Kelimeler: Yalın İnşaat, Yapı Bilgi Modellemesi (YBM), Sistem Dinamiği, Yapım Yönetimi, İnşaat Proje Yönetimi.

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I hope that it will contribute to future academic studies and industry stakeholders in the construction industry, where Lean Construction and Building Information Modeling are increasingly adopted.

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LIST OF ABBREVIATIONS

<u>Abbreviations</u>	<u>Explanations</u>
2D	: 2 Dimensional
3D	: 3 Dimensional
4D	: 4 Dimensional
5D	: 5 Dimensional
6D	: 6 Dimensional
7D	: 7 Dimensional
AEC	: Architecture, Engineering and Construction
BIM	: Building Information Modeling
IFC	: Industry Foundation Classes
IGLC	: International Group of Lean Construction
JIT	: Just-In-Time
KPI	: Key Performance Indicator
LPS	: Last Planner System
LC	: Lean Construction
LCI	: Lean Construction Institute
LOD	: Level of Development
NIBS	: National Institute of Building Science
PCDA	: Plan-Do-Check-Act
PMBOK	: Project Management Body of Knowledge
PMI	: Project Management Institute
SDM	: System Dynamics Modeling
SDS	: System Dynamics Society
TPS	: Toyota Production System
TVD	: Target Value Design
TQM	: Total Quality Management
VE	: Value Engineering
VSM	: Value Stream Mapping

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1. INTRODUCTION

The construction industry inherently contains dynamic and complex relationships. Therefore, it is extremely important to follow the latest developments for innovations and project management processes in the sector. Among them, adopting approaches such as digitalization and adapting to new technologies are becoming important for maintaining competitiveness and improving performance. However, all stakeholders in the construction sector are struggling with inefficiency and cost increases due to many reasons, especially the lack of investment in new technologies, the desire to innovate, resistance to change, changes in working culture, and compliance problems.

The aim of this study is to express that lean principles and BIM applications in the construction industry contribute positively to the success of the project in many respects. A management approach has been tried to be put forward by making suggestions and evaluations for the realization of more efficient and successful projects within the framework of the dynamic model created by considering the common variables determined for lean construction principles and BIM processes in construction projects.

Within the scope of this study, the innovations brought by lean construction tools and BIM processes to the construction industry have been comprehensively examined. Accordingly, the difficulties and obstacles to the implementation of these innovative disciplines in the construction industry are discussed in detail. Afterwards, the interaction of lean and BIM and the system dynamics approach in which this interaction will be discussed are examined in detail in the literature study. Following the literature review, common components for lean principles and BIM processes in the construction industry are discussed with a system model approach. The data for the newly created system model was provided through a survey study, and after the necessary equations and expressions were defined, the model was tested and verified. Depending on the results of the model, evaluations were made of the implementation of lean construction tools and BIM processes in the construction industry.

1.1. Problem Statement

Lean and BIM, which offer new approaches to construction project management, are two very useful project management approaches. In the literature, the effects of these two approaches on the construction sector can be explained by the few studies conducted. In addition, it has not been sufficiently stated that lean construction thinking, and tools are beneficial to BIM processes, and BIM processes to lean thinking. Within the literature, it is thought that lean and BIM have positive benefits in construction projects and the interaction between these two disciplines should be increased both through academic studies and practices.

Within the study, some common parameters have been determined depending on the obstacles and limits in front of lean and BIM implementation. Considering these parameters with the system model approach, evaluations and results for increasing lean construction and BIM integration are included. A general simulation model of lean-BIM relationships has been formulated using system dynamics modeling. The model has been qualitatively validated by studies in the literature and expert opinions. Various individual policies and their different combinations have been explored through extensive simulation to analyze their impact on the dynamics of lean-BIM relationships.

1.2. Aims and Objectives of the Research

This study develops a system dynamics model to understand the insufficient causes of poor adoption of lean construction and BIM processes and to measure their impact on project performance. To observe this effect, the study presents a system dynamics model that includes the interactions of lean-BIM components as well as showing the dynamic relationships between them.

1.3. Research Method

Within the scope of the thesis, firstly, Lean thinking and the emergence of Lean thinking, secondly, BIM subjects and tools, and thirdly, Lean construction and BIM interaction are discussed through a literature review. In the next step, the system dynamics approach and its characteristics, which constitute the method of the research, are included. In the last step, an extensive literature study on the system dynamics modeling of lean construction and BIM interaction was examined.

Based on the comprehensive literature study, the most basic variables required for lean construction and BIM interaction were determined, and a system model was created using the system dynamics approach. The basic parameters determined for the Lean-BIM interaction system model are defined as causal loop diagrams, stocks, and flows in the system model.

A survey study was prepared to determine the effects of variables on each other in the system model created using system dynamics modeling tools. The prepared questionnaire was answered by Lean-BIM experts operating in the construction industry.

Lean-BIM impact factor coefficients were calculated along with the statistical collection and evaluation of the responses. These coefficients are necessary for the interaction of the variables with each other and are added to the system model through equations. The necessary mathematical equations and data are defined in the model.

Within the scope of the study, an evaluation was made of the Lean-BIM interaction, and the system model created was analyzed for the definition of ten years. Through the analyses carried out, the time-dependent effects of the variables in the system model were observed, and the Lean-BIM interaction and the effect of this interaction on the project's success were tried to be measured.

With the created system dynamics model, the Lean-BIM interaction was discussed, and the results of the analysis and behavior diagrams and the results of this interaction were examined. Some evaluations were made within the framework of the obtained results and literature review. As a result of these evaluations, the validity and reliability of the system model were examined. Some evaluations were made about the difficulties in implementing lean construction and BIM interaction and the contributions of these two project management ideas to project success.

1.4. Scope and Limitations

Efficiency, continuous improvement, and waste reduction are some of the goals set in the project success of a construction process. In addition, the parameters affecting the project management and success were determined within the scope of the study. Variables that affect lean construction, BIM performance, or both are constrained by their impact. In addition, within the scope of this study, variables affecting project management and project management processes were gathered under the roof of lean-BIM, and evaluations were made for all construction processes in order to determine their benefits. For example, poor human resource management affects lean and BIM performance, and as a result, performances that are negatively affected due to cause-and-effect relationships cause the system to exhibit a lean and BIM interaction preventive feature. As a result, the entire system is affected. In the following stages, the limits of the model of system variables are included.

1.5. Organization of Thesis

The research prepared within the scope of the thesis consists of six chapters. In the first step, the importance of lean construction and building information modeling approaches, which make many contributions to project management in the construction industry, is summarized.

In the second step, previous studies on lean construction and building information modeling were examined, and their interactions were investigated. Again, in this section, the system dynamics approach, which determines the method of Lean-BIM interaction, is examined within the scope of the thesis. At the end of this section, previous studies in which lean-BIM interaction was handled with system modeling were examined.

In the third step, a survey study on the Lean-BIM interaction is presented. Lean-BIM interaction factors were determined through a survey conducted by Lean-BIM experts.

In the fourth step, the Lean-BIM interaction model was created using the system modeling approach, and analyses were carried out.

In the fifth step, the effects of Lean-BIM interaction on covariates and project success are summarized, and the findings are discussed depending on the analysis results.

In the sixth and final step, conclusions and recommendations for future work and increasing Lean and BIM interaction are presented. Figure 1.1 shows the organization of the study.

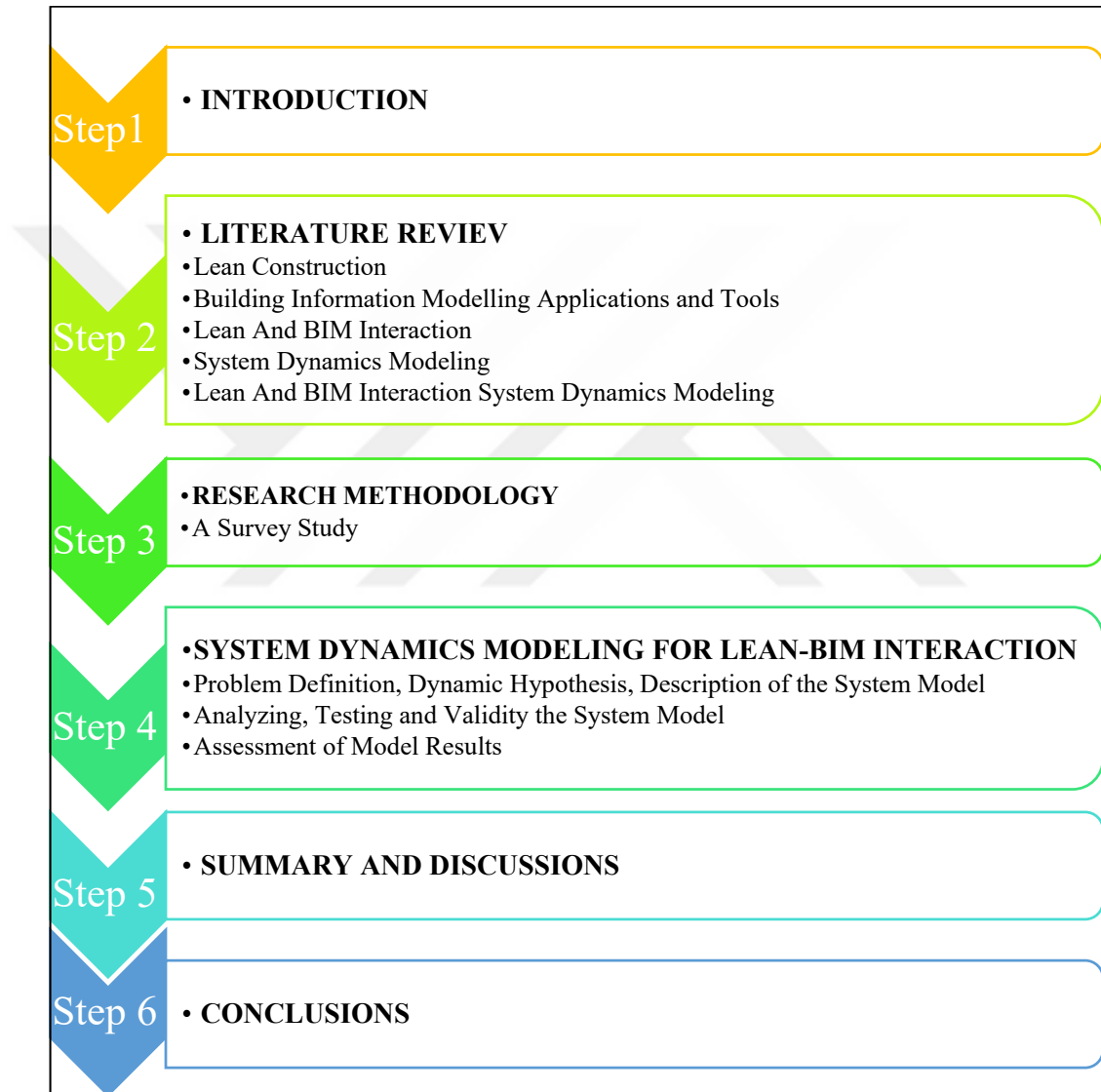


Figure 1.1: Organization of the study.

2. THEORETICAL BACKGROUND

2.1. Lean Construction

2.1.1. Lean Thinking and Lean Principles

Lean thinking is a business methodology that has received a lot of attention due to its emphasis on efficiency, waste reduction, and continuous improvement. First developed within the Toyota Production System (TPS) in the 1950s, lean thinking has been adapted and developed by numerous organizations in various sectors such as industry, healthcare, and education.

Lean thinking is shaped around the concept of creating value for the customer while minimizing waste in the process. It generally involves identifying and eliminating non-value-added steps in a process, focusing on value-adding steps, and optimizing the process flow. This methodology is applied through a set of principles such as value stream identification, flow generation, pull, and continuous improvement.

2.1.2. Definition of Lean Construction

Toyota, which made great progress with the laying of the foundations and development of lean manufacturing practices with the Toyota production system, first inspired other automotive companies and then companies in other sectors. In this direction, construction companies within the construction industry integrate the benefits of lean practices into their structures. 10% value-adding activity; 33% supporting activity 57% Waste (62% Non-Value Adding Activity) Value-Adding Activity: 12%; Supporting Activity: 26%; Waste: 6% (Non-Value-Adding Activity) Production (retail) and Construction Process. Used and are using lean manufacturing principles and practices in various academic and practical studies [LCI, 2012].

The implementation of lean manufacturing in construction companies took much more time compared to companies in other sectors. The Lean Construction Institute in the USA has defined lean construction as "a production management-oriented project delivery system implemented to ensure reliable and rapid delivery of value [LCI, 2012]. The term lean construction is another definition of the 1950s Toyota production

system that gives a new meaning to construction projects. Lean construction practices are implemented to manage and improve construction processes by generating minimum cost and maximum value in order to meet customer needs [Koskela et al., 2002]. Lean construction is defined as adapting the techniques of the construction process according to the characteristics of the construction process and applying these adaptations during the construction process to increase efficiency. If Lean Production principles and practices are applied in any field of construction activities, Lean Construction is used by adding 'Lean' to the beginning of its name, as in other sectors. It is a window of production philosophy and has an ever-increasing application area. Depending on the lean production methodology, it is looking for ways to reduce waste and create continuous value in the construction industry with each passing day. Lean construction is a system that is constantly evolving. The concept of lean construction was first used at the 1993 International Group of Lean Construction (IGLC) meeting. It was mentioned that the target audience is a system that includes architects, civil engineers, electrical and mechanical engineers, suppliers, contractors, and owners [Gleeson and Townend, 2007]. The necessity of adopting the principles and practices of lean production in order to do better work in the triangle of time, cost, and quality was also put forward at this meeting. The goal is to increase value while reducing cost, based on seven main waste classifications. These are: errors, delays, overprocessing, overproduction, unnecessary storage, unnecessary transportation, and procurement of materials and equipment, as well as unnecessary displacement of the workforce [Ohno, 1988]. This classification is valid in the construction sector as well as in all sectors where lean manufacturing is applied. According to the results obtained from the implemented applications, lean construction applications reduce costs by 30% [Lostuvali, 2012]. In other words, 30% wastage is experienced throughout the world in the construction processes. According to a study conducted in 2010, it was stated that the profit margin increase in a specific construction process in which Lean Construction principles and practices were implemented increased between 31% and 148% [Alarcon, 2010]. The 20% decrease in the productivity of the US construction industry in the last few years is also an important reason for the implementation of lean construction [Balci, 2011]. Although, for concrete reasons, lean production has focused on waste the most, this is not the only issue that lean construction focuses on in order to achieve its goals. Although the resolution of the waste issue is at the forefront of lean

applications, the processes are trying to be improved in terms of quality, cost, and time by focusing on the following three issues in lean construction applications:

- Reducing and eliminating waste,
- Arrangement of management systems according to lean production,
- Implementation of lean planning and construction systems [Al-Aomar, 2012].

The adoption and application of lean thinking in the construction process has been adopted and implemented by many companies in the construction industry [Koskela, 1992], [Ballard, 2000]. In the industry, it is important to use "lean" processes wherever possible because lean manufacturing aims to minimize non-value-creating activities and use resources in the most efficient way. It aims to optimize time, cost, and resource use in construction processes with lean construction practices [Formoso et al., 2002], [Alarcon, 2003]. In this way, it allows the work to be completed faster, at a lower cost, and with less waste. In addition, the application of lean manufacturing principles to construction processes provides benefits such as preventing waste, increasing efficiency, and increasing quality [Sacks et al., 2010]. For example, it aims to optimize all workflows within a business, including resource use, workforce management, and even workplace layout. However, due to the simple behavior of the processes in the construction process, it brings improvements in many areas, such as supply chain management, material and equipment management, workforce management, project management, risk management, quality control, and safety. For example, lean supply chain management ensures that materials are procured just in time and to meet exact needs, thus reducing the cost of excess inventory and warehousing. In addition, lean workforce management includes training and developing workers, thereby increasing workforce productivity and reducing waste. Project management, when managed in a simple way, allows for a fast and smooth project completion process. In addition, lean practices in other areas, such as quality control and safety, can help detect and prevent potential workplace problems early. Finally, for the full adoption and implementation of lean practices in the construction industry, stakeholders in the industry should come together and set a common vision and goals [Koskela, 1992], [Sacks et al., 2010]. This is important for better adaptation and integration of lean principles in construction applications.

As stated above, although the types of waste are divided into seven different classifications, each construction site may have different types of waste depending on its location, the size of the construction activity, and the type of building being built. The following are examples of waste types in the construction process [Al-Aomar, 2012]:

Table 2.1: Waste types in the construction process.

Late delivery	Retesting the work,
Long approval process	Extreme security measures
Activity start delay	Unproductive work
Business repair	Excessive training times
Equipment breakdown	Excessive management
Waiting periods	Unfinished business
Long transport times	Increased material
Damaged material	Excessive use of equipment
Business errors	Theft, lost
Business interruptions	Extremely large area
Doing the same work again	Overqualified resources
Clarification needs (legislation)	Design errors
Extreme labor movement	Application errors
Excessive material handling	

The types of waste on construction sites can be very diverse and classified. The causes of these wastes are included in six different classes [Gavilan et al., 2008]:

- Design: Waste from poor project management, design errors, project changes, and lack of coordination.
- Supply: Waste caused by supply chain processes such as incorrect delivery of materials, delays, inadequate quality control, transportation damage, or incorrect orders.
- Material handling and use: Wastes resulting from improper storage, misuse, overstocking, or loss of materials.

- Operation/application: Waste is generated by operational processes such as a lack of worker training, faulty assembly, a lack of quality control, or misapplication.
- Waste: waste material and packaging, non-recyclable materials, hazardous waste, and other types of garbage.
- Other (theft, waste management plan, etc.): Waste from other factors such as theft, materials confiscated for security reasons, an incomplete waste management plan, or a lack of regulatory compliance.

2.1.3. Lean Construction Concepts and Tools

Lean manufacturing principles according to Toyota production system; value, value stream, continuous flow, pull and excellence.

Identify Value: It is the definition of what is valuable to the customer and customer expectations, and it is important to define waste from the customer's perspective. Anything that does not add value to the customer is defined as waste [Womack et al., 1996]. Value is the provision of customer expectations and demands within a certain time and within a certain budget [Yükselen, 2011]. Value and flow are complementary ways for production [Bertelsen et al., 2002]. Product value is related to the product such as material composition, price of construction, and flexibility. Process value is related to the construction process and relationships between the producers such as time and communication. Value theory in construction has been shaped by defining value-adding and no value-adding activities. [Bertelsen et al., 2002].

Create Flow: In the lean production process, after eliminating the activities that do not create value, the source and information flow is ensured, and the aim is to ensure the systematic continuity of this flow. In case of continuous flow, precaution will be taken against any obstacles, delays and congestion that may occur in the next work items. It is accepted that the faster the raw material and resource turn into the final product, the higher the flow rate of the production system. This principle aims to eliminate waiting, downtime, and scrap between the steps and create continuous flow from beginning to the end. This understanding increases productivity and reduces batch size.

Pull Production: The process of transforming the source into the final product is also shortened considerably by ensuring a continuous flow and preventing waste. Thus, when the product is requested by the customer, 'just-in-time production' becomes

possible. The pull system starts with the customer requesting the product and follows a backward flow as each process requests the product from the previous process. With the pull system's production, the additional costs of stocking and stocking are prevented, and the waste caused by overproduction is reduced. Thanks to the pull system, instead of many and one type of product whose customers are unknown, it is possible to produce different types of products with different configurations, responding to customer expectations. This system also offers the flexibility to realize the differentiated demand in a short time in case the customer demand changes. The production depends on customer demand.

Perfection: When the other 4 principles of lean production are applied, improvements in quality and efficiency will be achieved in the production process, and customer satisfaction will be increased by making the improvement continuous. According to the lean production approach, the reason for faulty production should not be investigated through individuals but rather the main reasons that caused faulty production. This ensures that the main causes of errors are determined and necessary measures are taken to prevent the same errors from recurring. Thus, the 'learning' mechanism in the production process will also become functional. The full implementation of the lean philosophy in the production process is only possible with the participation of all individuals in the process, from management to production. According to this notion, process standardization includes ongoing learning and development. [Womack, 1996].

Lean construction uses a variety of tools and techniques that can be applied throughout the life cycle of construction, from design and planning to project delivery and even post-construction, to achieve many goals, notably the "value" mentioned in the previous section and above.

Value Stream Mapping (VSM): This tool is a lean management tool used to analyze and improve the flow of materials and information in a production process. It provides a visual representation of the entire process, from the start to the finish, including all the steps and activities involved. The purpose of VSM is to identify non-value-added activities or wastes and opportunities for improvement. By mapping out the value stream, stakeholders can better understand how to optimize the flow of materials and information, eliminate waste, and increase efficiency. VSM is commonly used in the manufacturing, healthcare, and service industries, and it helps organizations reduce lead times, increase quality, and enhance customer satisfaction.

In the context of value stream, activities in the production process are classified under three headings:

- Value-creating activities: Activities that provide transformation in line with customer requests,
- Activities that do not create value but are necessary for the completion of production: waiting, transportation,
- Activities that do not create value and are avoidable: waiting, counting, sorting, error, repair, etc. The most wasteful activities in the value stream are activities that do not create value for the customer.

The purpose of the value stream is to reduce the activities that do not create value for the customer but cause waste in the production process [Yükselen, 2011]. In this way, time and cost losses will be prevented, delays and negative variations will be reduced, and an increase in production efficiency will be achieved.

Target Value Design(TVD): A project delivery system that focuses on maximizing value and reducing costs in the design and construction process. The TVD process involves a collaborative effort between the owner, designer, and contractor to establish a target budget and identify the most important elements of the project.

During the TVD process, the team sets a target budget and identifies key performance indicators (KPIs) that will be used to measure the project's success. The KPIs can include items such as energy efficiency, sustainability, safety, and functionality. The team then works to develop a design that meets these KPIs while staying within the target budget. The TVD process is different from traditional project delivery methods in that it places a strong emphasis on collaboration and transparency between all stakeholders.

Just-in-Time (JIT) Delivery: In line with the lean manufacturing philosophy of just-in-time production, which is one of the basic applications of the lean production system, the activities, production, and supplies required within the system are aimed at ensuring that the desired time, quantity and quality are realized. The JIT approach, which aims at continuous improvement by preventing and eliminating waste of time, resources, and materials in the enterprise, by increasing efficiency and effective operation of processes, is a method that takes place with the participation of all units. As lean construction practices, JIT delivery involves delivering materials and supplies to

a work site only when needed. This reduces the need for storage space, minimizes waste, and increases productivity.

Kanban: It is a production method and a visual workflow control system consisting of the Japanese words "kan" meaning "card" or "visual sign" and "ban" meaning "plate" or "wood". A method of controlling a workflow through cards, labels, or other visual cues used during the processing or movement of materials, products, or services in the manufacturing process. It is often used in conjunction with the JIT method and provides efficient communication and coordination between all components in the supply chain. This method allows us to determine exactly how much material or resource each step in the production process needs, manage production in these quantities, and keep stock levels as low as possible.

Pull Planning: This technique involves scheduling tasks according to deadlines. It is based on the philosophy of "pulling" the business from the next stage of the process rather than "pushing it forward". The creation, follow-up, and management of the work schedule, which is used for the planning and management of construction projects, are carried out in cooperation with all teams. It requires all project teams to come together and follow all the steps of the construction process backward. Thus, it is determined how much time is needed to complete the work, and it is planned what kind of materials, resources, and equipment will be used in this process. This method increases efficiency and time management in construction projects.

Last Planner System (LPS): LPS is a collaborative planning and scheduling system used to improve workflow on construction projects. It involves breaking the project into smaller, manageable tasks, assigning responsibilities for each task, and setting deadlines and goals for completion. LPS includes collaborative planning and control tools that engage all stakeholders to identify potential problems early by involving all project stakeholders in the planning and scheduling process. In doing so, it uses visual management tools such as the Final Planner Dashboard to monitor project progress and ensure it is completed on time and within budget. The system emphasizes the involvement of all stakeholders in the planning process, with the aim of creating a more collaborative environment and identifying potential issues early on.

The LPS system includes a set of tools, such as the Pull Planning tool, which is used to create a project schedule that reflects the input and expertise of all stakeholders. The system also includes the use of the lean work structuring tool, which involves

breaking down the project into manageable work packages and identifying the necessary resources and constraints for each package.

One of the key features of the LPS system is the use of the Last Planner Board, which is a visual management tool that helps the team monitor the progress of the project and identify any issues that need to be addressed. The board is updated regularly and provides a visual representation of the status of the project, helping to keep everyone on track and ensuring that the project is completed on time and within budget.

Total Quality Management (TQM): While meeting customer needs is the most important factor for companies today, it has become imperative to reach high quality standards in order to meet customer needs and ensure customer satisfaction. In this way, it offers some developments to set quality standards, measure performance, and continuously improve processes to meet these standards, with an approach that emphasizes the participation of all employees in the quality process.

Achieving a quality level that exceeds expectations in the products produced brings the following benefits for companies [Omachonu et al., 2004]:

- High customer loyalty
- Increase in market share
- Increase in company value
- Reduction in after-sales service costs
- High product price
- High productivity

This method accepted that with the total quality management approach, which aims for continuous improvement with the participation of all system components, by putting customer needs at the center, not only by measuring the output quality but also by internalizing the quality phenomenon and importance of all processes and employees, the system as a whole will create quality. Key components are employee involvement/training, problem-solving teams, statistical methods, long-term goals, and the identification of system-generated deficiencies.

Visual Management: Visual management involves using visual tools such as charts, graphs, and diagrams to communicate information about the project to all stakeholders. Visual management helps improve communication, collaboration, and decision-making throughout the construction process by providing a clear and concise view of project status, progress, and goals.

5S: The 5S technique used for the organization of the workplace takes its name from the first letters of the words used for each stage. The aim is to organize the work area systematically, cleanly, and with safety as a priority. Thanks to this structure, the productivity of the employees increases, while the work standardization efforts become more effective while facilitating visual management. These steps include elements such as arranging materials at the construction site, systematizing the workflow, maintaining cleanliness and order, ensuring compliance with procedures, and continuing the implementation of lean construction practices.

The techniques used in the 5S are, in order: seiri (sort), seiton (order), seiso (clean), seiketsu (standardization), and shitsuke (continue).

- Seiri (sequencing): Keeping the equipment and tools required for the current operation and activities in the work area and removing the unnecessary ones from the work area.
- Seiton (Order): Arrangements are required to create a suitable place for all equipment and tools and to label the places appropriately so that the people who will work can easily find the necessary materials and that the materials are easily put in their places as a result of the work.
- Seiso (clean): Keeping the work area and equipment clean ensures that the equipment is always in the most suitable condition for use, while clean equipment, materials, and working environments help detect situations that may lead to erroneous or poor quality results in production much earlier and easier.
- Seiketsu (Standardization): The system developed for maintaining, monitoring, and maintaining the created structure is called standardization. In this way, the expected normal state of the system can be visually controlled more easily, and non-standard situations that arise can be quickly detected and intervened in.
- Shitsuke (continue): It refers to the maintenance of the standardized work area and the dynamic operation of this structure in line with continuous improvement.

Kaizen (Continuous Improvement): It is a combination of the Japanese words "KAI" meaning continuous and "ZEN" meaning good. Kaizen is the improvement of the system as a result of eliminating all waste sources that do not add value but create costs, regardless of how small the target is [Liker, 2007]. The basic method to achieve this goal is that all employees adopt this approach and make small but continuous improvement activities and suggestions. In addition, this tool is a core principle of lean construction and includes the continuous detection and elimination of waste and inefficiencies in the construction process. It is based on the philosophy that small improvements made consistently over time in construction processes will result in significant improvements in overall performance.

The Kazien Institute defines Kaizen as a method of continuous improvement that adheres to the following principles:

- Good procedures lead to good outcomes.
- One should go and observe the situation directly in order to understand it.
- It is necessary to talk with data and manage with facts.
- Problems must be addressed to their roots.
- Should collaborate.
- Kaizen is everyone's works.

Lean Supply Chain Management: This method requires applying lean principles to supply chain management. It aims to increase efficiency and reduce waste by eliminating non-value-added activities and improving communication and coordination between supply chain partners.

Prefabrication: Prefabrication involves constructing a building's components off-site and then assembling them on-site. This technique reduces waste, shortens construction time and improves quality.

Poka-Yoke: Poka-Yoke is a Japanese term that means "mistake-proofing" or "error-proofing". It is a quality management technique that aims to prevent mistakes from occurring in the production process by designing products and processes in a way that makes it impossible or very difficult for errors to occur. Poka-Yoke is based on the idea that human error is inevitable and that mistakes will occur even with the most

skilled and experienced workers. By implementing Poka-Yoke techniques, the goal is to minimize the impact of these errors and reduce the likelihood of them happening in the first place. The technique involves using devices, tools, or procedures that prevent mistakes from happening or detect them as soon as they occur. This can be achieved through simple mechanisms such as using color-coding, shapes, or markings to indicate which parts go where, or more complex mechanisms such as sensors or alarms that detect errors and alert the operator.

These tools and many others, as examples, are essential components of a successful lean construction program. By adopting a collaborative and continuous improvement mindset and using these tools and techniques to optimize value and minimize waste, construction companies can increase the efficiency and effectiveness of their operations, increase customer satisfaction, and achieve greater profitability.

2.1.4. Advantages and Benefits of Lean Construction

Manufacturing in the construction industry can remove non-value-added procedures like waiting and inspecting components by implementing a process flow perspective. Lean manufacturing is achieved by reorganizing the workforce to streamline new work methods and bring about cultural changes inside the organization. To make lean theory work for their business, organizations must select the right organizational framework. They may also need to adjust employee lifestyles or employ other management strategies and tactics. There are numerous techniques and resources available to assist with these factors. Lean procedures have a number of advantages, such as lower total costs, enhanced productivity, improved worker safety, and more customer satisfaction.

Basically, construction is a production process and categorizes lean production periods as follows [Koskela, 1992]:

- An efficient production mechanism that reduces material waste,
- A philosophy of general management,
- A set of systems for continuous quality improvement.

Construction manufacturing should be a process flow rather than a transformation of process. Elimination of non-value-added processes such as waiting, and examining the elements is one of the benefits of implementing a steps flow perspective. The concept of the lean industry is determined as the rearrangement of the workforce to boost and streamline new work practices and main cultural changes that are produced within the company and single to achieve lean manufacturing. So, a company needs to choose the Lean theory to examine how it can reach the most appropriate organizational framework on which this device can work. Likewise, it seems necessary for a company to modify lifestyles to meet its unique circumstances or to use other techniques and methods to maintain its new structures' management. It has to be noted that methods and tools have been solved to help the two remaining factors discussed earlier. Some of the benefits of lean techniques are listed below.

- Construction supply chain
- Conducting on-site subcontractor evaluations
- Completing transactions in buildings
- Labor and building subsets
- Improving labor workflow in construction
- Template engineering:
- (Structure and Finishes) construction projects
- Making prefabricated concrete
- Infrastructure projects

The principles of lean construction aim to reduce waste and improve efficiency, resulting in a higher bottom line and improved project outcomes [Ahmed et al., 2021]. By adopting these principles, construction companies can decrease the materials and resources required, leading to lower costs and less waste [Martinez et al., 2020]. Additionally, lean construction promotes increased planning and strategic vision, which can result in shorter construction times and improved worker focus and safety [Koskela, 1992]. Collaboration and communication between all stakeholders, including owners, designers, and contractors, is emphasized in lean construction to achieve the best possible project outcomes and reduce stress levels [Womack et al., 1990], [Arditi

et al., 2018]. Lean construction prioritizes productivity and customer satisfaction, leading to increased profits and work satisfaction for workers [Martinez et al., 2020]. By focusing on the elimination of non-value-added activities and the optimization of the construction process, lean construction increases productivity and efficiency, thereby minimizing waste and reducing project completion times [Ballard, 2000], [Alarcón and Sánchez, 2018]. Moreover, lean construction emphasizes the use of technology and data to improve decision-making and the construction process [Koskela, 2000].

According to the study by Demirkesen and Bayhan [2020], a lean success factor and the recommended criteria in the context of the construction industry were merged, and a model to quantify the success of the lean implementation was developed in order to measure and evaluate the effectiveness of lean practices in the industry. Leadership, process management, education and training, cooperation, and innovation make up the five primary components of the developed paradigm. The leadership component is cited as being the most significant and the innovation element as the least significant of the five factors for the success of lean implementation.

2.1.5. Barriers and Challenges in Implementing Lean Construction

The implementation of lean methodology in any organization requires the collective effort and cooperation of all members, including management officials and employees [Koskela, 1992]. Even a single space in the chain can disrupt the effectiveness of this methodology [Sacks and Koskela, 2004]. While the new rules of production may not be easily accepted by some workers, managing officials must lead their employees efficiently and directly for successful implementation [Ballard and Howell, 2003]. The success of the lean operation method relies heavily on how well a management leader can work with their employees to establish standard procedures [AbouRizk, 2010]. However, clashes of personality and other issues may arise during this process [Koskela and Howell, 2002]. Furthermore, the training and education of employees in the rules of lean take dedication and time [Womack et al., 1990].

The difficulties and obstacles to the successful implementation of lean construction methods are explored in order to pinpoint the elements that prevent their adoption in the construction sector. With the literature review and field study, they determined the factors that prevent the successful implementation of Lean Construction practices

in the construction industry. These barriers are grouped under seven main categories and stated below [Demirkesen et al., 2019].

- Political Barriers
- Economical Barriers
- Workforce Barriers
- Cultural Barriers
- Managerial Barriers
- Communication Barriers
- Technical Barriers

Since the position of lean applications in the construction industry is still new, it argues that the obstacles in front of it will be eliminated thanks to the studies and applications to be made. The study also showed that the most important obstacles to lean construction can be found in the socio-cultural background. In addition, the first three obstacles are: lack of top-level management support, misperception of lean practices, lack of information sharing, and integrated change control.

Some managers may find it challenging and become frustrated in their efforts to stay on course with a new operating system in lean construction [Howell, 1999]. To achieve cohesive teamwork, every member must excel in their position but also rely on one another to address any gaps in the system in lean construction [Sacks et al., 2010]. While training workers with updated systems may take time and affect project or design timelines, management must control all production issues to minimize any disruptions in lean construction [Ballard and Howell, 1998]. Communication is key in notifying suppliers and distributors of changes in production in lean construction, but this may also cause problems [Koskela, 2000]. Ultimately, the change in policy may temporarily decrease employee morale in lean construction, but with consistent effort and dedication, the implementation of lean methodology can lead to long-term success and higher performance [Womack and Jones, 2003].

2.2. Building Information Modelling (BIM)

2.2.1. Definition of BIM

Building Information Modeling (BIM) is a concept created with the initials of the words "building," "information, and "modeling" in general. The first word, "building," constitutes the construction stages and project types determined for all kinds of construction activities. As the second word, the word "information" describes the data that constitutes all the information about the building in general, from planning to quantity, from cost to demolition. The third and final word, "modeling," represents models for business, demolition, energy, statics, architecture, and many more. In short, BIM represents an approach that can be applied throughout the entire life cycle of the project, from feasibility studies to facility management, from energy analysis to demolition.

According to Eastman [2011], BIM is a set of approaches, technologies, and methods that enable the management of different and complex processes throughout the building life cycle. The National Institute of Building Sciences defines BIM as "a digital representation of the physical and functional characteristics of a facility" [NIMBS, 2007].

Azhar et al. [2008], define BIM as "a process that focuses on the development and use of a computer output model to simulate the plan, design, construction, and operation of a structure."

According to the statement of Eastman et al. [2008], "With BIM technology, an accurate virtual model of a building can be created digitally, and a computer-generated design model can present some features of the building when fully completed. Along with these features, it offers geometry as well as accurate information to support design, prefabrication, and purchasing activities. It is an approach that has the potential to offer alternative uses of BIM at different stages consisting of conceptual, design, construction, and post-production [BCA, 2013].

Although it is accepted that the foundations of the emergence of BIM technology at the conceptual level were laid before the 1980s, it can be stated that the transformation began in the 1990s [BIMgenius, 2018].

The initial BIM concepts appeared in the 1970s, and after Autodesk Corporation first proposed BIM in 2002, the trend of building technology advancement spread internationally [Xu, 2017].

The emerging method and technology known as BIM, which has recently gained popularity and is being used globally [Cheung et al., 2012], [Connaughton et al., 2011], proposes a new method of integrating information. Digital representations of a building or facility's geometric and non-geometric data are used in BIM [NIBS, 2007].

BIM is a cutting-edge method of communicating project information. The Architecture, Engineering, and Construction industry has shown a lot of interest in the ability to add incredibly detailed property information to 3D building models [Eastman et al., 2011].

BIM is believed to provide several advantages for the AEC industry, including increasing production efficiency in the design and construction processes through shared information and cooperative collaboration among project participants [Eastman et al., 2011]. Additionally, it offers structures that are more efficient in terms of costs, prices, and environmental considerations.

The US National Institute of Building Science (NIBS) developed the most widely used and recognized definition of building information modeling. The NIBS's [2007] definition of BIM is as follows.

“BIM is a digital representation of physical and functional characteristics of a facility...and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition.”.

Building information modeling is defined by Autodesk in terms of its benefits [Web 1, 2020]. The Autodesk BIM definition is as follows.

“BIM is an intelligent 3D model-based process that provides insight for creating and managing building and infrastructure projects faster, more economically, and with less environmental impact promises to eliminate the problem associated with the traditional approach to project coordination and management.”.

The most popular value for the most recent method of building design, construction, and maintenance is undoubtedly BIM. It is described as an interactive collection of guidelines, procedures, and tools that produces a technique for managing building design and project data digitally over the course of a building's existence [Sugar, 2009].

BIM helps planners make important decisions by allowing the virtual simulation of the building's construction process, making it possible to see the details of the upcoming work at any time [Chau et al., 2004].

BIM enables the creative creation of a viable building model by combining data from various disciplines for use by the entire project team [Sugar, 2009].

Offering a single digital resource for all participants in the lifecycle management of a building, from design to facility management, BIM demonstrates its potential to be a transformative technology [Sabol, 2008].

According to Khemlani [2009], BIM is a cutting-edge technology that goes beyond the 3D design stage and manages processes throughout the project lifecycle. BIM can be used to integrate structural components and systems that makeup components and to estimate costs and quantities before construction [Shen et al., 2013]. For cost consultants, BIM's capacity to combine graphical and non-graphical data models provides more accurate cost information [McKenna, 2008].

BIM is the structure that facilitates the simultaneous and collaborative work of many design disciplines in the project delivery process. It can also be characterized as a parametric digital model containing all the data regarding the structural and functional characteristics of a project [Aibinu et al., 2014].

According to Masood et al., BIM is a 3D digital representation of a facility with key features and components made up of smart building components. It is a virtual design tool and application that acts as a forum for information and data sharing among stakeholders throughout the entire lifecycle [Eadie et al., 2015].

BIM offers important solutions for the needs of all industry stakeholders, especially employers, designers, main contractors, and consultants, with the features it contains and possesses. Accordingly, project stakeholders can greatly benefit from BIM to develop higher-quality and better-performing structures. In addition, it offers important potential solutions for increasing sustainable building performance, reducing financial risks, accelerating the construction process, making accurate budget estimates, and building management [BIM Handbook, 2008].

BIM adoption and maturation processes need to be completed efficiently in order for industry stakeholders to benefit from all the opportunities and solutions brought by BIM [McGraw-Hill Construction, 2014]. The efficiency to be obtained from the adoption and maturation process of BIM in companies depends primarily on a good definition of the needs in the design, construction, delivery, and subsequent asset management stages [Cavka et al., 2017].

A lot of criteria and guidelines have been produced by official administrations and even made necessary in the majority of the nations that have finished the BIM adoption process [McGraw-Hill Construction, 2014].

As stated in RICS [2014], BIM in construction projects is basically carried out within the scope of four stakeholders and three basic models. These are employers, designers, main contractors, and consultant companies that carry out architectural, static, and electrical/mechanical installation models. The design models that progress with the joint coordination and updates of these companies are the basic disciplines that makeup BIM. According to the scope of the project, apart from the basic three disciplines, there are also disciplines such as landscape and elevator.

BIM is a collaborative digital representation built on open standards for interoperability [Lkhagva-Erdene, 2018]. It allows different parts of the design team to better coordinate the fabrication of different building systems [Nawari, 2012]. BIM does not just mean the visualization of the project (3D). It also covers different dimensions such as work programming (4D), real-time cost estimation (5D), life cycle management (6D), and facility management (7D) [Sahil, 2016], [Kim et al., 2016].

Especially in recent years, the concept of BIM, led by developed countries, has become a concept that architecture and engineering offices quickly transition to and actively use. However, academically, especially in the field of civil engineering, there are gaps in the content, direction and method of this transition [Pekeriçli et al., 2017]. The concept of BIM has presented new methods and concepts to all stakeholders in the industry, and it enables industry stakeholders to remain competitive with the advantage of using various software it contains [Lkhagva-Erdene, 2018].

2.2.2. BIM and Related Concepts

BIM is project management thinking that brings a new way of thinking to the construction industry that differs from the traditional workflow. Thanks to BIM, all stakeholders in the construction industry (architects, engineers, contractors, etc.) work on a common database and act as a bridge between industries. BIM supports more efficient coordination of project teams and increases productivity. In addition, it represents a discipline in which the visualization of the project and the solutions for all the problems that may occur during the construction phase are made before starting the construction phase of the projects. the resolution of problems.

According to the Penn State BIM Guide, there are essentially six BIM planning components [Computer Integrated Construction Research Program, 2013],[. The components of BIM planning are shown in Figure 2.1.

Strategy	The Purpose of BIM Implementation
	Mission – Vision – Goals - Objectives
Uses	The Specific Method of Implementing BIM
	Generating – Processing – Communicating – Executing – Managing
Process	The Means of BIM Implementation
	Current – Target – Transition
Information	The Information Needed About the Facility
	Model Element Breakdown – Level of Development – Facility Data
Infrastructure	The Infrastructure Needs to Implement BIM
	Software – Hardware – Workspace
Personnel	The Effects of BIM on Personnel
	Roles & Responsibilities – Hierarchy – Education – Training – Change Readiness

Figure 2.1: The BIM Planning Elements.

BIM planning elements consist of strategy, infrastructure, personnel, information, usage, and processes. For example, while the strategy section contains information such as the definition of BIM targets and the support of the management, in the infrastructure part there are infrastructure requirements that will support the use of BIM, such as software and hardware [Messner, 2019].

BIM is a new approach to construction project management and is very important for the construction industry and other industries that the industry interacts

with. Since its inception, BIM has been thought of in relation to many other concepts since its inception. BIM and related concepts are included in many sources [RICS, 2014]. BIM-related concepts are shown in Figure 2.2. In addition to these, Geographical information systems and Innovation can be added.

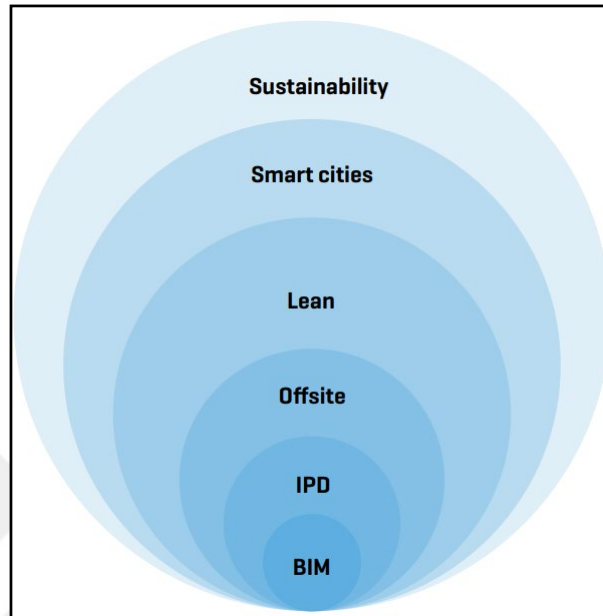


Figure 1.2: BIM and related concepts.

Innovation: BIM is one of the most important innovations in the construction industry in recent years. This innovation needs to be quickly adopted and implemented by industry stakeholders. The realization of innovation in the construction sector is expressed as the widespread adaptation of applications that occur as a result of advances in technology and business processes [Lansley, 1996]. Innovation and innovation management for construction is the whole of the collaborations that emerge depending on the result of the coordination of the interactions around the company [Mention, 2011].

Integrated Project Delivery (IPD): The BIM construction project facilitates participant cooperation and knowledge sharing, which is a key component of the IPD strategy. One of the most effective ways to help IPD is through BIM, which promotes coordinated and sustainable collaboration with IPD. According to common consensus, BIM makes the IPD method easier by improving teamwork, coordination, and com-

munication [Özorhon, 2018]. By creating a collaborative strategy that blends the aspirations and goals of the project team with the sharing of risk and reward, the IPD system seeks to improve project outcomes [Kent and Prensik-Gerber, 2010].

2.2.3. The Level of Development (LOD)

BIM is a process for creating and managing building data throughout a building's lifecycle and can be used at various levels of detail, from 3D models to more comprehensive, data-rich models. These levels of BIM are often referred to as "Levels of Development" (LOD).

Project stakeholders need to better understand BIM's processes to engage in more efficient and innovative work and overcome problems. At this point, thanks to the geometric and non-geometric features provided by BIM, maximum benefit is obtained from BIM. These features of BIM are shown in the Table 1.2 These features are necessary and important for BIM to provide good communication and coordination.

Table 2.2: Properties for BIM elements.

Geometric Features	Non-Geometric Features
Dimension	System data
Direction	Performance data
Shape	Legal compliance
Height	Specification
Volume	Cost

Working groups that design buildings, carry out construction tasks, offer consulting services for their construction, and operate and maintain them are all part of the BIM process area. Leadership, infrastructure, human resources, and goods and services are all entwined with the BIM process area. For instance, in order to enable model-based collaboration, collaborative methods and database-sharing abilities are needed [Succar, 2009].

The titles of the process area can be listed as follows [Kassem et al., 2022]:

- Model detail level,
- Model's workflow,
- Information sharing method,

- Coordination of teams,
- Delivery documents.

According to Özorhon [2018], although LOD is generally known as the development level, it is sometimes confused with the concept of detail level. The difference between these two levels is basically:

The detail level is the level that determines how much detail is in the model element. However, the development level refers to the geometry of the element as well as the extent to which the attached information is taken into account. At development levels, the goal is to determine to what extent project stakeholders and team members can rely on the model when using it. The detail level is regarded as an element's input. But development levels are not like that and essentially refer to the process of achieving reliable output.

LOD levels can be started from 100 and detailed up to 500. Detailed explanations of LOD levels are exemplified below:

- LOD 100: Concept Projects
- LOD 200: Implementation Projects
- LOD 300: Shop-Drawings (manufacturing drawing)
- LOD 400: As-Built Projects (drawings for the final project)
- LOD 500: Fully Integrated Projects for Building Management

The models include information such as geometric features of building components or non-geometric material parts, insulation characteristics, color, acoustic characteristics, and application workmanship details. To promote accurate communication between BIM users regarding the data quality of architectural elements, LOD has been developed [Web 2, 2020].

The level of development and their meanings are indicated in the Figure 2.3. Models at LOD 100 level refer to conceptual meaning only, while models at the LOD500 level correspond to implementation models.

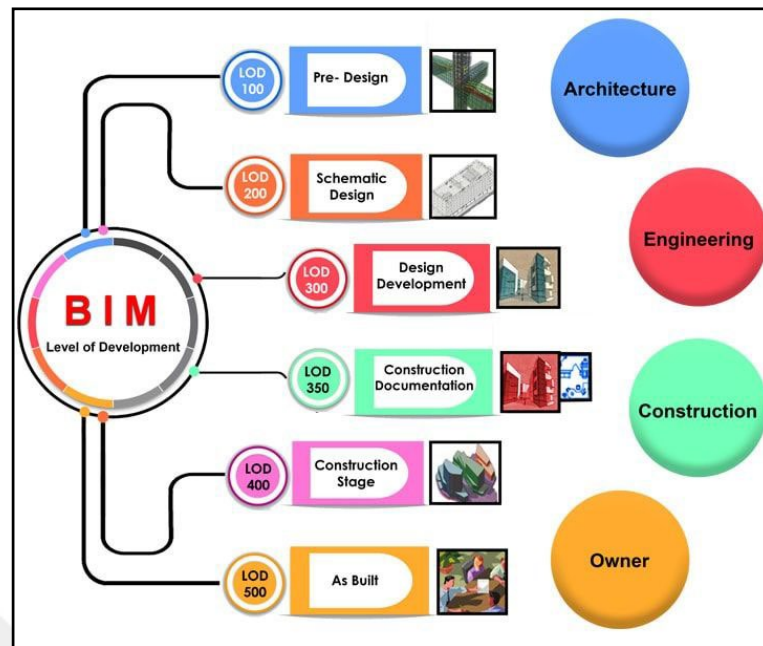


Figure 2.3: Levels of development for BIM.

The words LOD 100, 200, 300, 400, and 500 were defined by AIA in 2013; afterwards the BIM Forum developed the definition for LOD 350.

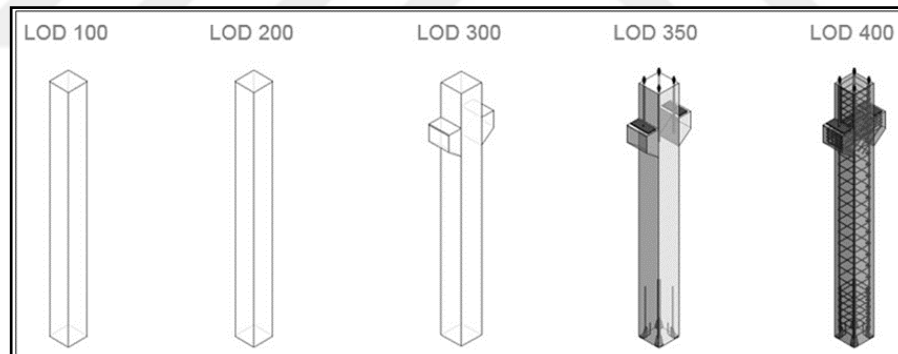


Figure 2.4: LOD levels of carrier column element.

Model detail levels are shaped according to the needs of the relevant disciplines.

LOD 100 represents the lowest level of detail, with a simple 3D model that includes basic geometry and minimal information about the building's components. It is a level that just relies on conceptual attributes for model components. Using 2D symbols, the model information that is summarized is expressed.

LOD 200 the model includes more detailed geometry and information about the building's components, such as dimensions and materials. It is the level at which the

quantities, positions, directions, and dimensions of the model elements can be determined approximately.

LOD 300: The model elements are described at this level in terms of particular systems, dimensions, numbers, positions, and directions. the model includes even more detailed geometry and information about the building's components, as well as information about their relationships and connections.

LOD 350 comprises interfaces and components required for the coordination of the element with the surrounding or attached elements in the model, in addition to the LOD 300 detail level.

LOD 400, represents the highest level of detail, with a fully coordinated and detailed model that includes all information about the building's components, including their properties, performance, and behavior. In addition, this level is depicted as adding enough information to allow fabrication and assembly above the LOD300 level.

LOD 500: With a model that contains details on the building's systems, maintenance, and operation, LOD 500 reflects the building's operating phase. For application scenarios and facilities management, model components are more than adequate.

2.2.4. BIM Maturity Level

BIM is constantly evolving technologically and systematically, but not all users can simultaneously adapt to this development of BIM [Porwal and Hewage, 2013]. However, the maturation stages of BIM cover all construction project stakeholders. The incentives of employer companies play the most important role in this maturation process [McGraw-Hill Construction, 2014]. For this reason, BIM maturity levels have been developed.

BIM maturity levels appear as pre-BIM status, object-based modeling, model-based collaboration, and network-based integration, and are defined at four levels. The Figure 2.5 shows the BIM maturity levels.

The definition of BIM maturity levels was accepted and published by the UK government in 2011 as Level 0, 1, 2, and 3 definitions in British Standards. A helpful illustration for comprehending the BIM development levels of the UK maturity model is provided [Bew et al., 2008]. This graph may be seen in the Figure 2.5.

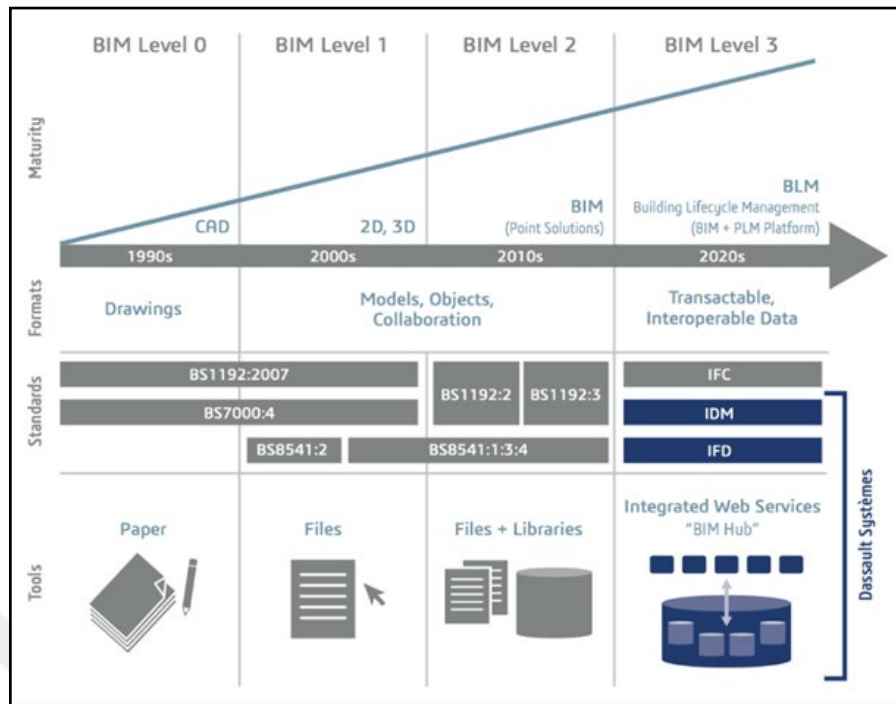


Figure 2.5: The BIM maturity model.

4 maturity levels for BIM given as follows. [Arayici, 2015], [Web 3, 2019];

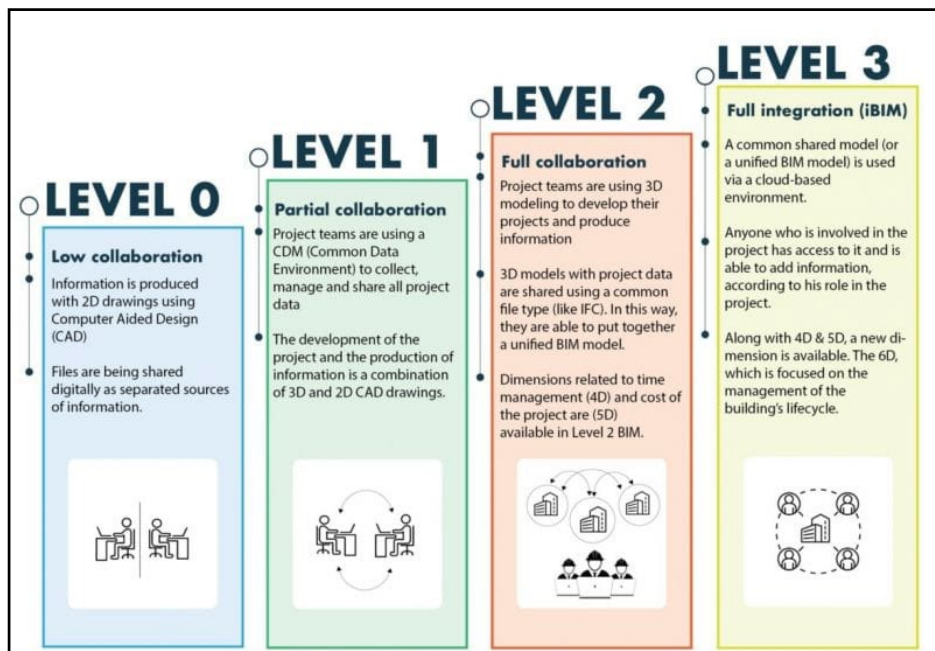


Figure 2.6: BIM maturity levels descriptions.

Level 0: There is no model yet, but the drawings that make up the model have been produced. It represents traditional construction practices facing problems with inefficiencies. Project information, drawings, and written documents are stored on paper and are difficult to use. Weak knowledge management processes cause misunderstanding of the planned structure, functional inadequacy, erroneous start-up, and conflict between components [Khosrowshahi and Arayici, 2012].

Level 1: The created lines and drawings are converted into 2D objects, and model production begins. The transition from two-dimensional to three-dimensional object-based modeling and documentation is prioritized. Elements in the BIM model are real architectural elements that are accurately represented from all angles and belong to the discipline. File transfers are documents that can be sent in CAD form [Khosrowshahi and Arayici, 2012]. Data is managed with incompatible finance and cost management packages [BIS, 2011].

Level 2: With the coordinated production of 3D models, the transition to BIM has been ensured, making cooperation and interoperability possible. The design and management of the building is a complex process that requires good communication and collaboration among project team members [Khosrowshahi and Arayici, 2012]. The data is kept in BIM tools in separate disciplines, and this level makes it possible to plan the 4D structure or use the 5D cost information [BIS, 2011]. Model-based outputs are taken for projects, and it represents the stage where the BIM adoption process for companies is completed.

Level 3: Upon reaching this process, a transition from cooperation to integration is achieved at all stages. According to BIM needs, companies can carry out 4D planning and building management through BIM models. This fully integrated process reflects the true philosophy of BIM. BIM has reached its final level of maturity. Project lifecycle phases are largely absent, and players interact in real time to gain real benefits from the ever-increasing virtual workflow [Khosrowshahi and Arayici, 2012]. This BIM level makes it possible to use construction planning, cost information, and project lifecycle management information [BIS, 2011].

2.3. Lean and BIM Interaction

Lean thinking, rooted in the Toyota Production System, is related to the basic principles of continuous improvement (kaizen) and respect for people. Any industry can systematically adapt its business processes by integrating lean tools and practices into its projects, by adopting the 'challenging everything' and 'capture the change' mindset [Özorhon, 2018].

Lean principles aim for a high level of efficiency by identifying wastes that create inefficiency and allowing these wastes to be reduced. The Table 2.3 shows some work items that cause waste for the construction industry.

Table 2.3: Some waste in the construction industry.

Waiting Time	The amount of time it takes to wait for the next step in completing a task.
Inventory	The number of products and materials that are not processed or pending
Overproduction	A situation that occurs when products are produced in excess of what is required.
Extra Action	Delivering work and quality above employer requirements.
Movement	Excessive or unnecessary movement
Unused Talents	Making use of the talents of the employees only partially
Flaws	Exerting too much effort due to duplication of work and information pollution
Transportation	Excessive transportation of products and materials

Although waste reduction and waste reduction techniques are sometimes considered to be a form of lean, lean principles are significantly more significant and provide more complex project solutions. Realizing the significance of these ideas, the building industry adopts "lean construction" as a new paradigm.

Lean construction is a new method of project delivery that entails "designing production systems in a way that saves material, time, and effort to achieve maximum value" [Koskela et al., 2002]. The objective is to maximize value while gaining from

each project participant to attain excellence. The entire project lifecycle must be enhanced if lean manufacturing principles are to be completely applied in a building project. This is possible with many methods to be applied in design, purchasing, construction, and operation.

By preventing conflicts that can happen if considerably more time and effort is needed in the design and planning stages, lean construction saves time and money [Özorhon, 2018].

Lean manufacturing was not the only application of lean building. Methods of project delivery are included in this strategy. Lean construction is based on concepts like early involvement in the process, integrating project design and process design, including project participants in decision-making, and integrating all participants [Özorhon, 2018].

For a project delivery system where waste is minimized and perfection is possible, realizing the following concepts should be the main objectives [Howell and Ballard, 1994]:

- Adding value for the client, removing practices that don't offer value,
- To set up the production so that there is a continuous influx,
- By considering customer wants, increasing diversity, and improving quality,
- Reducing stage, part, and link pages,
- Expanding the product's versatility,
- Increasing the process's transparency,
- Put your attention on process control,
- Enhancing the procedure continuously.

Lean construction considers BIM to be a lean tool and it is thought that there are four basic connections between lean and BIM [RICS, 2014]:

- BIM contributes directly to lean principles by reducing the amount of waste.
- Lean principles can be utilized in the development of BIM-based methodologies and tools.
- Lean principles and methods can be supported and facilitated through BIM,
- The adoption of BIM is facilitated by lean concepts.

Also, Both the public and private sectors play a significant part in the successful adoption of BIM applications [Wong et al., 2009]. Projects utilizing BIM might not be simple given the time and money savings, upfront fees, and learning curve [Zhou et al., 2019]. Long-term project efficiency will be ensured by the BIM methodology nonetheless. Institutions are required to invest time and money in this area, to teach their staff, and to be open to innovations [Daniotti et al., 2020].

2.3.1. Lean Construction and BIM Interaction for SD Modeling

The construction sector has a uniquely defined structure, and developments in the sector are not sufficiently followed by the sector's employees and stakeholders. In addition, the sector employees should deal with the problems in the sector together with new methods and developments. Innovative technologies, especially lean thinking and BIM, and the integration of many tools that will benefit the sector into the construction sector will be possible with the experience of the processes in which the stakeholders of the sector will be involved.

The construction industry has become a traditionalist and introverted sector that does not want to keep up with development. It also causes the neglect of technological benefits and slows down the transition process. The construction sector does not adapt to technological developments and innovations as much as the service, manufacturing, and industry sectors [BIMgenius, 2018].

The construction industry is resistant to change due to technical challenges such as having many stakeholders in its structure, site conditions, and non-standard workflows.

According to a study by McKinsey Global Institute [Web 4, 2016], the adaptation of the construction sector to digitization lags far behind when compared to sectors such as informatics, media, finance, and manufacturing. In other words, as seen in Figure 2.7 the sector is above only the agricultural sector in terms of the digitalization index and has a worse performance compared to other fields.

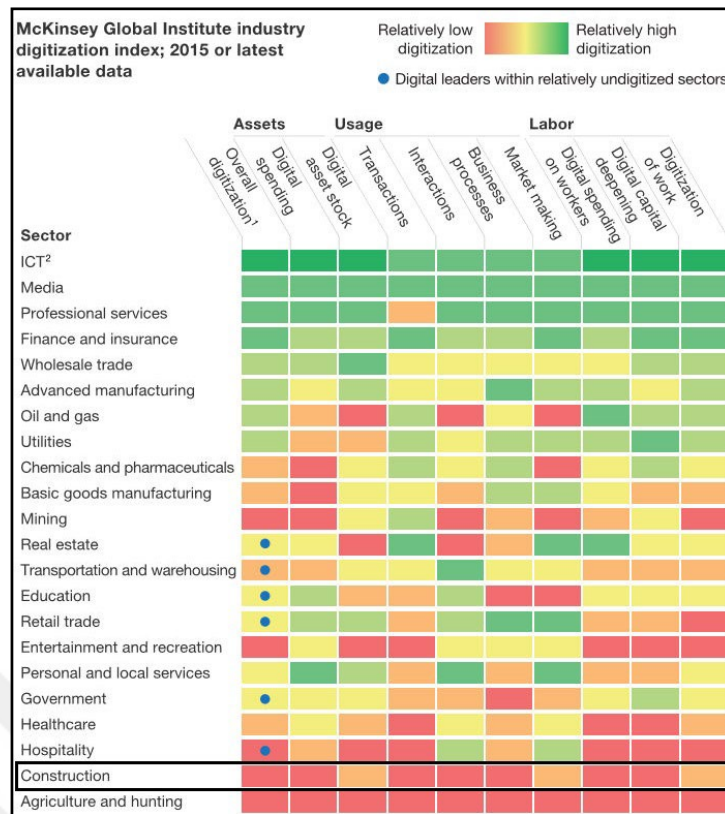


Figure 2.7: Digitization index for industries.

However, the stakeholders of the construction sector are considered sufficient in terms of displaying skills, having adequate equipment, and problem-solving. Due to the many sub-business groups and stakeholders that the construction industry contains, the system's behavior exhibits a very bad characteristic. Due to the systemic problem, the impact of the project stakeholders, investors, and hundreds of sub-sectors of the construction sector causes a bad system.

For example, it has become a sector with low profit margins worldwide; it has a low supply chain; and 95% of the companies in the sector included in this sector are low-scale companies. In addition, factors such as the establishment of short-term relationships by sector stakeholders and the fact that companies work on a project-based basis or are dependent on a few projects can be listed.

In the sector, many problems, such as low innovation capacity, problems in the transition to digitalization, competition, and trust problems, arise. Even when these effects, which are given as examples, are examined, dozens of problems may occur within the system. These effects generally lead to low digitization, inefficiency, and serious time losses. In addition, the fact that RandD studies are weak compared to other sectors causes these problems to remain unsolved. In this sense, the dynamics of this

system, which has many complexities, should be correctly determined and handled with a system dynamics approach that takes into account all factors. As a result, these negative effects in the construction sector and the development of many parameters will contribute to its development accordingly.

Finally, most of the stakeholders in the sector think that they are doing their works in the best way possible. This situation highlights the fact that stakeholders are resistant to change and cannot adapt to emerging technologies and innovations.

Some other obstacles can be listed as follows.

Not welcoming new ideas, tools, and working cultures,

- The change does not come from the customer,
- Existence of the idea "We are doing this".
- Being dependent on the current situation and conditions.
- Governments and representatives of the private sector, which are the biggest customers, do not have a change-oriented vision.

Lean thinking offers a new management approach for the construction industry. BIM, on the other hand, offers information management technology. In general, lean construction has principles and objectives. A few lean tools are used to achieve these goals.

BIM has a very clear contribution to lean construction in terms of principle and technique. BIM has revolutionized the construction industry by providing a visual representation of the entire construction project and enabling better collaboration among different stakeholders. This innovative approach to construction project management has a number of benefits that are helping to improve the overall quality and efficiency of construction projects. One of the key benefits of BIM is improved collaboration. BIM allows for better communication between project stakeholders, including architects, engineers, contractors, and owners. This results in a more coordinated approach to the construction project, reducing the risk of errors and rework.

Another benefit of BIM is enhanced planning and scheduling. By providing a visual representation of the construction project, BIM allows for better planning and scheduling, reducing rework and waste. This results in a more efficient construction process, reducing the overall project timeline and increasing productivity. In addition,

BIM provides a more comprehensive view of the construction site, allowing for better identification of potential hazards. This situation makes lean tools easier to use safely. This results in improved overall safety, reducing the risk of accidents and injuries on the construction site.

One of the most important benefits of BIM is its ability to enable better material management. By providing a detailed view of the construction process, BIM allows for a more informed approach to material selection, reducing waste and overproduction. This results in a more cost-effective construction project, with reduced waste and a more sustainable approach. Finally, BIM streamlines construction processes, reducing manual effort and increasing efficiency. This results in higher productivity, with a more streamlined and efficient construction process. Furthermore, BIM provides a centralized database of information, allowing for better quality control and reducing the risk of errors and omissions.

Lean construction management tools also add a lot to BIM. Lean construction practices emphasize streamlining BIM procedures and cutting waste to improve efficiency and project performance as a whole. While fostering a collaborative environment, enables improved teamwork and communication among many stakeholders. Reduces rework and wasteful effort by taking a value-focused approach, which improves project outcomes. Furthermore, a flexible and adaptive strategy enables projects to react swiftly to evolving conditions and requirements.

Lean construction assists in the early identification of potential risks, enabling proactive risk management and lowering the likelihood of adverse effects. This makes it possible to better monitor and manage the construction process thanks to enhanced openness and real-time project data.

Lean environments and relational contracts support BIM and ensure its full implementation. It provides full support, from the design to the construction process to facility management.

Thanks to lean thinking, waste reduction and value stream analysis are constantly monitored in BIM processes. For example, thanks to the overlap analyses made during the design stages, mistakes that will occur during the application are prevented. Thanks to this situation, activities that do not benefit the employees and cause time loss are prevented by predetermining, and material losses are prevented.

In BIM processes, for example, last planner, visual management, A3 reporting, continuous improvement cells, etc. in determining development levels (LOD). The use

of tools allows the use of lean tools and methods on BIM. In addition, the interaction of lean and BIM is very important for the project stakeholders.

In this part of the thesis, positive and negative variables for lean and BIM interaction, which were determined by the literature study in the previous sections, are included. In the determination of these variables, the effects of the variables on Lean and BIM were evaluated depending on the extensive literature study.

2.3.2. Lean and BIM Interaction Variables for SD Modeling

This chapter includes the variables that affect lean construction and BIM performance. These variables were used in the establishment of the system model, and the evaluations within the scope of the thesis were made depending on the effects of these variables on each other.

2.3.2.1. Adoption of Value Engineering

Value engineering is a systematic process that helps identify and eliminate unnecessary costs and improve the overall value of a project. The adoption of value engineering in the design phase of the project offices and throughout the construction processes causes the projects to be completed much more efficiently. As a result, project performance increases after the adoption and implementation of value engineering.

The adoption of value engineering in construction projects can lead to improved performance in terms of cost, schedule, and quality [Elsonoki et al., 2021]. Similarly, adoption of value engineering principles can result in a reduction of waste and an increase in overall construction performance [Huang et al., 2018], [Lu et al., 2019]. Koskela [2000] also expressed that value engineering can help identify and eliminate waste, improve the quality of the project, and increase customer satisfaction.

The adoption of value engineering can have a significant positive impact on the performance of lean construction projects. By identifying and eliminating unnecessary costs and improving overall value, value engineering leads to more efficient and effective project completion, resulting in improved performance in terms of cost, schedule, quality, waste reduction, and customer satisfaction. Therefore, organizations and

individuals involved in lean construction should consider incorporating value engineering as a key practice in their approach to project management.

2.3.2.2. Avoiding Customer Satisfaction

Lean construction is a methodology that aims to improve the performance of construction projects by reducing waste and increasing efficiency. However, it is important to remember that customer satisfaction should not be neglected when implementing lean construction practices. By involving the customer in the design and construction process and ensuring that their needs and wants are met, projects are completed more efficiently and effectively, resulting in improved performance.

According to studies has found that neglecting customer satisfaction leads to a lack of trust and cooperation between stakeholders, ultimately impacting the performance of construction projects [Liang et al., 2015], [Luo et al., 2020]. Similarly, a study by Masrom et al. [2010] has expressed that avoiding customer dissatisfaction can lead to increased productivity and improved construction performance. According to Koskela [2000] projects that prioritize customer satisfaction have higher performance levels than those that do not. This is because when the customer is involved in the design and construction process, they have a better understanding of the project and are more likely to be satisfied with the end result. Additionally, involving the customer also leads to more effective communication between stakeholders, which can help to prevent delays and mistakes. Neglecting customer satisfaction leads to a lack of trust and cooperation between stakeholders and reduced productivity while prioritizing customer satisfaction leads to improved performance. Therefore, organizations and individuals involved in lean construction should make sure to put the customer at the center of their approach to project management to ensure success.

2.3.2.3. Avoiding Excess Inventory

Inventory management seeks to avoid excess inventory and allocate resources more effectively, which greatly increases the performance of lean construction projects. Excess inventory can lead to a number of problems in construction projects, including increased costs, wasted resources, and delays. By avoiding excess inventory through just-in-time inventory management, construction teams can improve performance by reducing waste, increasing efficiency, and lowering costs.

Avoiding excess inventory can result in a reduction of waste and an increase in overall construction performance [Xie et al., 2018]. Projects that avoid excessive inventory have higher performance levels than those that do not, and their just-in-time inventory management teams avoid excess inventory, leading to reduced waste, increased productivity, and a positive direct increase in project success [Koskela, 2000].

2.3.2.4. Development of Lean Thinking

One key element in achieving success with lean construction is the development of lean thinking. Consequently, the application of lean thinking has had a significant impact in academic and industrial circles. There has been an important development and “localization” in the lean concept, which is supported by its rapid spread to the automotive industry and then to many other industry sectors. However, despite successful "lean" implementations, the lean approach offers many benefits due to a lack of human integration or high-volume repetitive production environments. Lean refers to providing a framework and pointing out areas for understanding not only as a concept but also its application within an organization [Hines et al., 2004]. However, a number of studies have been developed on Lean thinking in the manufacturing or service sector and many positive results have been observed [Sfakianaki et al., 2019]. The development of lean thinking can lead to improved project performance in terms of cost, schedule, and quality. Also among construction teams can result in increased efficiency and improved construction performance. These studies highlight the importance of developing lean thinking in order to achieve success with lean construction. The implementation of lean thinking can lead to improved performance by re-

ducing waste, increasing efficiency, and improving the quality of the project. This emphasizes the importance of not only implementing lean construction practices but also fostering a lean-thinking mindset among the construction team [Koskela, 2000].

2.3.2.5. Good Communication

Good communication is essential for the success of lean construction and BIM performance. This includes clear and effective communication between all parties involved in the project, including management, employees, and stakeholders. It allows team members to share information, collaborate effectively, and make informed decisions. Clear and consistent communication between all project stakeholders, including architects, engineers, contractors, and owners, is crucial for ensuring that the project runs smoothly and that all team members are on the same page. Good communication prevents misunderstandings and mistakes, leading to a more efficient and successful project. When communication is clear and efficient, projects are completed on time and within budget. Effective communication is critical for successful BIM implementation [Zhang and Gao, 2013]. Effective communication leads to improved collaboration and decision-making, ultimately resulting in better project performance [Kim et al., 2016]. Team members lead to improved coordination and a positive impact on construction performance [Elhag et al., 2018].

2.3.2.6. High Experience

High levels of experience among employees is crucial for the success of lean construction and BIM performance. Experienced employees have the skills and knowledge necessary to effectively implement and maintain lean processes. This can result in improved performance by increasing efficiency and reducing errors.

A high level of experience with BIM technology among project team members is positively associated with better BIM performance. This is because experience improves team members' ability to use the technology effectively, resulting in improved project outcomes. [Zhao et al., 2018]. Experienced team members are more likely to be proficient in BIM software, understand the project requirements, and be able to identify and resolve issues. Experienced professionals are better equipped to handle

the complexities of BIM projects, leading to improved performance [Elhag et al., 2018].

2.3.2.7. Management Support

Management support is one of the most important expressions for lean construction and BIM interaction and implementation. Because these two disciplines bring new approaches to new and existing cultures, change is difficult. This change should be provided and adopted by the management in the first place. For this reason, it is very important to provide management support and to show awareness to the management. Without the support of management, employees may not have the resources or authority to make necessary changes, and projects may not receive the necessary funding or attention. When management is supportive, they allocate the necessary resources and provide the necessary training, tools, and support to make the implementation a success.

Management support for BIM is crucial for the successful implementation of the technology and when management is fully committed to BIM and provides the necessary resources, the technology is more likely to be adopted and used effectively [Doğan, et al., 2016]. Managers play a key role in providing direction, allocating resources, and fostering a culture of innovation. Management support is an important factor in the successful implementation of BIM [Azhar, et al., 2017].

2.3.2.8. Sufficient Resources

Sufficient resources are necessary for the successful implementation of lean construction and BIM. This includes funding for training, equipment, and software, as well as the necessary personnel to implement and maintain the new processes. Without sufficient resources, projects may be delayed or not completed to the desired standard. This includes things like software, hardware, and data storage, as well as staff time and expertise. Without sufficient resources, BIM projects can struggle to keep up with the demands of the project, leading to delays and inefficiencies.

While adequate resources are resources such as finance, hardware and software, and personnel, insufficient resources bring along delays, increased costs, and low-

quality work [Li et al., 2017]. Having sufficient resources for lean construction leads to improved construction performance and increased project success, along with the successful implementation of lean construction techniques [Zhau and Wang, 2014]. Adequate resources, including financial, technical, and human resources, are essential for the successful implementation of BIM and sufficient resources were more likely to achieve better project outcomes [Lines and Smithwick, 2019].

2.3.2.9. Team Collaboration

The integration of BIM and lean construction practices leads to improved performance in construction projects. Team collaboration is a key aspect of this integration, as it allows for better communication and coordination among team members. Team collaboration leads to increased trust and cooperation among stakeholders, ultimately impacting the performance of construction projects [Tauriainen, 2016], [Bhatla and Leite, 2012]. Effective team collaboration leads to improved productivity and construction performance [Li et al., 2017]. By working together, team members can share ideas and knowledge, and find solutions to problems more quickly and effectively. This can lead to a more efficient project and a better final product.

Team collaboration is essential for the success of lean construction. By working together, all parties involved in the project share ideas, knowledge, and skills, resulting in improved performance. This includes improved communication, increased efficiency, and reduced errors.

2.3.2.10. Waste Reduction

Waste reduction is a key principle of lean construction, which aims to eliminate non-value-adding activities and improve overall efficiency and performance. This is achieved by implementing practices such as just-in-time inventory management, value engineering, and involving customers in the design and construction process. These practices bring about reductions in waste, improved project performance, reduced excess inventory, streamlined processes, eliminated unnecessary steps, and increased customer satisfaction. Additionally, the development of lean thinking among construction teams also contributes to waste reduction by promoting a mindset of continuous

improvement and the elimination of waste. By identifying and eliminating waste, resources are allocated more effectively, resulting in improved performance. Waste reduction can lead to improved efficiency and cost savings, ultimately resulting in better project performance [Li et al., 2017].

2.3.2.11. Challenges of Regulations

Regulatory challenges can greatly hinder the performance of lean construction. This can include dealing with building codes, permits, and inspections that can slow down the construction process. By addressing these challenges, projects can be completed more efficiently and effectively, resulting in improved performance. Regulations and bureaucratic procedures can slow down the construction process and lead to increased costs and delays [Koskela, 2000]. Challenges related to regulations impact project performance by increasing costs and delaying schedules [Vass and Gustavsson, 2017]. Compliance with regulations is a challenge for the implementation of lean construction techniques, leading to a negative impact on construction performance [Umar, 2022].

2.3.2.12. Lack of Coherent Vision

A lack of a coherent vision can greatly hinder the performance of lean construction. This can include a lack of clear goals and objectives, which can lead to confusion and poor coordination among all parties involved in the project. By developing a clear vision, projects can be completed more efficiently and effectively, resulting in improved performance.

A lack of a coherent vision among stakeholders can lead to poor project performance [Zhau and Wang, 2014]. Without a clear vision and understanding of the goals and objectives of the project, it can be difficult to effectively implement lean construction principles. A lack of coherent vision leads to confusion and a lack of direction for the project team and the implementation of lean construction resulted in confusion and decreased construction performance [Koskela, 2000], [Ayman et al., 2020].

2.3.2.13. Lack of Coordination

When there is a lack of coordination among different teams and departments, it can lead to delays, increased costs, and decreased quality in the construction process. This can hinder the implementation of lean construction principles, as effective coordination is a key component of achieving efficiency and minimizing waste. For example, when different teams are not communicating effectively, it can lead to delays in the construction schedule as teams wait for information or approvals from other teams. Additionally, without effective coordination, there may be duplication of work or conflicting instructions, which can lead to errors and wasted time and resources. To overcome this, it is important to establish clear lines of communication, develop a detailed project plan, and ensure that all team members are aware of their roles and responsibilities.

A lack of coordination among stakeholders can lead to poor project performance [Kim et al., 2016]. A lack of coordination among team members can lead to a negative impact on construction performance [Elhag et al., 2018]. A lack of coordination can lead to delays, increased costs, and a lack of communication among team members [Koskela, 2000].

2.3.2.14. Lack of Funding

A lack of funding can make it difficult to acquire the necessary resources and equipment needed to implement lean construction methods. Without sufficient funding, companies may be unable to invest in new technologies, such as building information modeling (BIM) software, which can be essential for achieving efficiency and minimizing waste. Additionally, without funding, companies may be unable to provide the necessary training for personnel to implement lean construction methods, which can lead to a lack of understanding and resistance to change. To overcome this, it is important to develop a detailed budget and funding plan and to seek out grants, loans, or other forms of funding to support the implementation of lean construction methods.

Without adequate funding, BIM projects may struggle to secure the necessary resources and staff, leading to delays and inefficiencies. This can also affect the quality of the final product, as corners may be cut in order to stay within budget.

A lack of funding can be a major obstacle to successful BIM implementation and limited funding was less likely to achieve their goals and had lower levels of BIM adoption [Doğan, et al., 2016]. Lack of funding is one of the main barriers to the successful implementation of BIM and BIM performance [Li et al., 2017].

A lack of funding impact project performance by limiting resources and delaying schedules [Li et al., 2017]. A lack of funding is a barrier to the successful implementation of lean construction techniques, leading to decreased construction performance. Also, a lack of funding can lead to delays, increased costs, and a lack of resources to implement lean strategies [Chen et al., 2019], [Koskela, 2000].

2.3.2.15. Lack of Sources

A lack of access to necessary materials and equipment is a barrier to the successful implementation of lean construction techniques and BIM performance, resulting in decreased construction performance [Ayman et al., 2020]. A lack of sources, including data and information, negatively impacts BIM performance, and projects with limited access to sources are more likely to experience delays and errors.

Insufficient sources lead to delays, increased costs, and poor quality [Li et al., 2017].

For example, when a company is unable to acquire the necessary materials, it can lead to delays in the construction schedule as the company waits for the materials to arrive. Additionally, without sufficient resources, it may be difficult to implement new technologies or methods, which can limit the ability of a company to achieve efficiency and minimize waste. To overcome this, it is important to establish a strong supply chain and to develop relationships with suppliers and vendors to ensure a reliable source of materials, equipment, and other necessary resources.

Without adequate sources, BIM projects may struggle to make informed decisions and to effectively plan and design the project. Access to the right materials and equipment is essential for the success of lean construction, but a lack of sources can lead to delays, increased costs, and a lack of resources to implement lean strategies [Koskela, 2000].

2.3.2.16. Lack of Standards

The performance of BIM and lean construction are both seriously hampered by inadequate standards. Standards give all stakeholders a single language and set of rules to adhere to, which promotes better coordination, communication, and collaboration. A lack of standards increases the possibility of misinterpretation and misunderstanding, which can cause delays, mistakes, and inefficiencies. In Lean and BIM, the adoption of standardized procedures and data formats helps to maintain consistency, cut down on waste, and raise the caliber of the finished product.

2.3.2.17. Lack of Infrastructure

The lack of adequate infrastructure negatively affects the performance of BIM. Infrastructure refers to the physical and technological resources necessary for the effective use of BIM, such as computer hardware, software, internet connectivity, and power supply. If these resources are not available or are insufficient, the use of BIM becomes difficult, leading to decreased productivity and increased costs. Outdated or insufficient computer hardware can result in slow processing times, while poor internet connectivity hinders access to BIM data and collaboration with remote team members, causing delays. A lack of infrastructure, including technology and equipment, can negatively impact BIM performance. The study found that projects with inadequate infrastructure were more likely to experience delays and inefficiencies [Ayman et al., 2020].

2.3.2.18. Market Uncertainty

Economic uncertainty and market fluctuations can make it difficult for companies to plan and budget for lean construction projects. This can lead to a lack of funding and resources and make it difficult to implement new technologies and methods. To overcome this, it is important to stay informed about market trends and to be prepared to adjust plans and budgets as necessary in response to changing economic conditions. Market uncertainty leads to poor project performance by creating a lack of predicta-

bility and stability [Kim et al., 2016]. This uncertainty creates challenges for the implementation of lean construction techniques and negatively impacts construction performance.

Poor HR Management: Poor HR management can lead to high turnover rates, difficulty in recruiting and retaining skilled personnel, and lack of employee engagement. This can hinder the implementation of lean construction principles, as a skilled and engaged workforce is necessary for success.

2.3.2.19. Poor HR Management

Poor HR management leads to high turnover rates, difficulty in recruiting and retaining skilled personnel, and a lack of employee engagement. This hinders the implementation of lean construction principles, as a skilled and engaged workforce is necessary for success. To overcome this, it is important to establish clear HR policies and procedures, provide training and development opportunities for personnel, and create a positive work environment that encourages employee engagement and commitment. In addition, a major obstacle to BIM performance. This includes things like a lack of staff or a lack of expertise among staff members. Without adequate HR management, BIM projects may struggle to secure the necessary resources and staff, leading to delays and inefficiencies [Madanayake, 2015].

Poor human resource management negatively impacts BIM performance and inadequate, team members are less likely to be properly trained and motivated, leading to lower levels of BIM adoption and use [Khodeir and Nabawy, 2021]. Poor HR management negatively impacts BIM performance. Inefficient HR practices can lead to poor recruitment, retention, and training of staff, leading to delays and inefficiencies [Doğan, et al., 2016], [Koskela et al., 2002], [Ballard and Howell, 2003].

2.3.2.20. Resistance to Change

Resistance to change is a natural phenomenon that occurs when people are asked to change the way they do things. It manifests in various forms such as fear of the unknown, lack of trust in leadership, lack of understanding of the benefits of the change, and lack of ownership of the change process. Caused by factors such as a lack of trust in the proposed changes, a lack of understanding of the benefits of the changes, and fear of the unknown [Koskela, 2000]. Change is difficult, and some employees may resist new methods and technologies. This can make it difficult to implement lean construction principles and BIM performance, as buy-in and support from all members of the team are necessary for success. It is an obstacle to BIM performance [Ayman et al., 2020]. Team members may be hesitant to adopt new technologies and processes, leading to delays and inefficiencies. To overcome resistance to change, it is important to provide clear communication and training on the proposed changes, as well as involve stakeholders in the decision-making process [Koskela, 2000]. To overcome this, it is important to provide training and education on the benefits of lean construction and to involve employees in the process of change to ensure their buy-in and support. Without buy-in from all team members, BIM projects may struggle to implement new technologies and processes, leading to delays and inefficiencies. This also affects the quality of the final product, as team members may be reluctant to embrace new ideas and ways of working.

2.3.2.21. Resistance to Technology

The use of technology is an essential aspect of lean and BIM performance and hinders the implementation of lean practices and BIM. This barrier to the successful implementation of lean construction techniques results in decreased construction performance [Ayman et al., 2020]. Resistance to technology as a barrier to the successful implementation of lean construction methods stems from a lack of understanding or knowledge about the technology, as well as a lack of trust in the technology being proposed. To overcome resistance to technology, it is important to provide clear communication and training on the technology, as well as involve stakeholders in the decision-making process. Team members' reluctance to embrace new technologies has a

detrimental impact on BIM performance and leads to delays and inefficiency [Koskela, 2000].

2.3.2.22. Staff Resistance

Resistance from the staff makes it difficult to implement lean construction principles and BIM. A resistance-based behavior hinders the overall performance of the construction process. This is caused by a lack of trust in management, a fear of change, a lack of understanding of the change or initiative, or a perception that the change or initiative will not bring any benefits to the staff. Staff resistance to new construction methods and technologies can negatively impact construction performance [Zhau and Wang, 2014]. Staff resistance is an obstacle to BIM performance. Without buy-in from all team members, BIM projects struggle to implement new technologies and processes, leading to delays and inefficiencies. In order to overcome staff resistance, it is important to provide clear communication and training on the proposed changes, as well as involve staff in the decision-making process [Koskela, 2000]. Support and training are needed to help staff adapt to new technology and overcome problems encountered.

2.3.2.23. Cultural Factors

The success of Building Information Modeling (BIM) implementation is heavily influenced by cultural factors such as attitudes, values, beliefs, and organizational norms. Cultural elements such as a strong project-oriented culture, effective collaboration, supportive leadership, a skilled workforce, efficient processes, an innovative organizational culture, open communication, a positive attitude towards technology, and high-risk tolerance can positively impact BIM adoption and usage [Kamat, 2017].

Lack of Infrastructure: Lack of infrastructure can be a major obstacle to BIM performance. This includes things like internet connectivity, data storage, and hardware. Without adequate infrastructure, BIM projects may struggle to keep up with the demands of the project, leading to delays and inefficiencies.

The elements identified in the literature for lean construction and building information modeling are categorized in the table below. Because the variables identified

by this categorization have an impact on both the performance of lean construction and BIM separately and jointly, interactions have been built in the system model.

These variables are necessary in the Lean-BIM interaction system model to produce causal loop diagrams, stock-flows, and then extra (intermediate) variables.

Table 2.4: Classification of lean and BIM components for system model.

Components	Lean, BIM, Lean and BIM?
Adoption of Value Engineering	Lean Performance
Avoiding Customer Satisfaction	Lean Performance
Avoiding Excess Inventory	Lean Performance
Development of Lean Thinking	Lean Performance
Good Communication	Lean and BIM Performance
High Experience	Lean and BIM Performance
Management Support	Lean and BIM Performance
Sufficient Resources	Lean and BIM Performance
Team Collaboration	Lean and BIM Performance
Waste Reduction	Lean Performance
Challenges of Regulations	Lean Performance
Lack of Coherent Vision	Lean Performance
Lack of Coordination	Lean Performance
Lack of Funding	Lean Performance
Lack of Sources	Lean Performance
Lack of Standards	Lean Performance
Lack of Infrastructure	BIM Performance
Market Uncertainty	Lean Performance
Poor HR Management	Lean and BIM Performance
Resistance to Change	BIM Performance
Resistance to Technology	Lean and BIM Performance
Staff Resistance	Lean and BIM Performance
Cultural Factors	BIM Performance

2.4. System Dynamics

2.4.1. Development of Systems Thinking and System Dynamics

Systems are models that help people to know their environment better and to solve existing dynamic problems. These models provide convenience for people to

better understand their environment. Like everything else, people are part of the system. While it is exposed to the influence of other systems, it also affects the system. While traveling in a ship, passengers not only travel but also constantly redesign the travel process [Sterman, 2000]. The most important feature of the systems created for human beings to better understand their environment is that their boundaries are arbitrarily determined. In this case, the problem owner can shape the boundaries of the problem according to her own understanding and purpose of solving the problem. In any system, it is seen that the problems that can be solved cannot be solved if you focus on instant situations instead of focusing on the whole system. Thanks to the system philosophy, the whole system is handled easily and solutions are offered to the problems [Senge, 2016].

System Dynamics is a powerful simulation modeling technique created to model complex systems and problems, as well as to determine the relationships between system elements and to understand the long-term behavior of the entire system [Forrester, 1961]. Professor Jay W. Forrester developed it at the Massachusetts Institute of Technology in the 1950s. By its definition, system dynamics is concerned with how systems change over time. It uses computer simulation to obtain already known information about the details in the world that exist in the environment, to illustrate the behavior of social and physical systems. It shows that the source of problems that others are often blamed for is one's decision-making policy and how policies can be developed to correct the problem. Thanks to the system dynamics approach, systems in which a large number of variables and parameters coexist become more understandable, and the analysis and evaluation of problems and their relations with each other are revealed more easily. In order for a system to be evaluated well, the relationships between the parameters that make up the system should be revealed. The system dynamics approach is a set of conceptual tools and modeling methods that enables us to understand the structure of such complex systems and their interactions with each [Sterman, 2000]. With this approach, the system is considered as a whole, and the changes in its components and different scenarios that will occur are analyzed in terms of the whole system [Sayyadi and Awasthi, 2017]. Evaluation of the results obtained by running different scenarios can guide the activities to be implemented in the future and thus creates a feedback loop that can affect the starting point [Web 5, 2017].

The concept of a system refers to a whole formed by combining parts that form meaningful relationships with each other. It represents a whole structure that is different from the sum of its parts and has features that are not found in the parts [Barlas, 2002]. The system is greater than the sum of its parts. For example, when an elephant is divided into ten pieces, ten small elephants are not obtained. When the properties of each component are known, the problem can be solved, but when these parts interact, various non-systemic properties emerge. These properties are not a property of the parts.

Every evil system that exists in the world has a reason to survive, nothing happens randomly. If there is a system-related problem and the problem continues, there are factors that cause it to continue [Forrester, 1961]. According to some system experts, since many things in the world are complex in terms of structure and in constant interaction, every event can be seen as a system and system thinking can develop [Sternman, 2000].

The internal structure of the system expresses the mechanism that the relations (variables interacting with each other) in the system form together. Therefore, the systems approach makes it necessary to look at all the relationships, not the details of individual elements.

The principles of systems thinking are [Anderson and Johnson, 1997];

- In order to determine the source of the problem that is wanted to be solved in the system, it is necessary to focus on the big picture. In this way, it is possible to find more effective solutions.
- Both short-term and long-term evaluations should be made in decision-making processes.
- The ever-changing, complex, and interrelated nature of systems should be noted. When we look at the systems in our daily lives, we can clearly see that everything is constantly changing, complex and interrelated.
- There are factors that we can and cannot measure in any system. Systems thinking suggests using both factors, both measurable and unmeasurable. Because every single factor matters. Rather than considering only mathematical data, it is necessary to consider moral values as well.

Systems philosophy deals with problems by modeling real behavior in solving problems in many ways. Systems thinking is needed for many reasons in solving dynamic problems. Although the reductionist approach has been used to solve problems scientifically for a long time, it has not been able to produce a full solution. The reductionist approach, which is effective when the problem can be defined precisely and the goals are clear, has almost lost its use today. The most important features of the problems we face today are that they are constantly changing, complex and interrelated [Aronson, 1956]. The differences point between the systems approach and the reductionist approach are in Table 2.5.

Table 2.5. Reductionist and the systems approach.

Reductionist Approach	Systems Approach
Focuses on individual parts in problem solving	Deals with the whole of the System to solve the problem.
Linear causality is constructed (A causes B.)	Recurring causality is constructed (A to B, B to C, C to A causes)
Gives the only and best answer.	Provides many related answers for the exact solution.
External factors are unimportant.	External factors are important.
Problem is solved at that moment.	Problem is eliminated.

In the book "Industrial Dynamics" by Jay W. Forrester, the stages for system dynamics analysis were first explained. According to Forrester, the steps to be followed in the system dynamics approach [Forrester, 1961].

- Defining the Problem
- Creating Dynamic Hypotheses
- Formulating the Simulation Model
- Performing the Tests
- Policy design and Evaluation

System models should be designed and analyzed as shown in the steps listed above. Variables in the model and accordingly the model may need to be constantly revised. After the problem is handled and evaluated step by step, the next step should

be started when the correct results are obtained. Figure 2.8 presents the description of system models with monitoring and feedback loops.

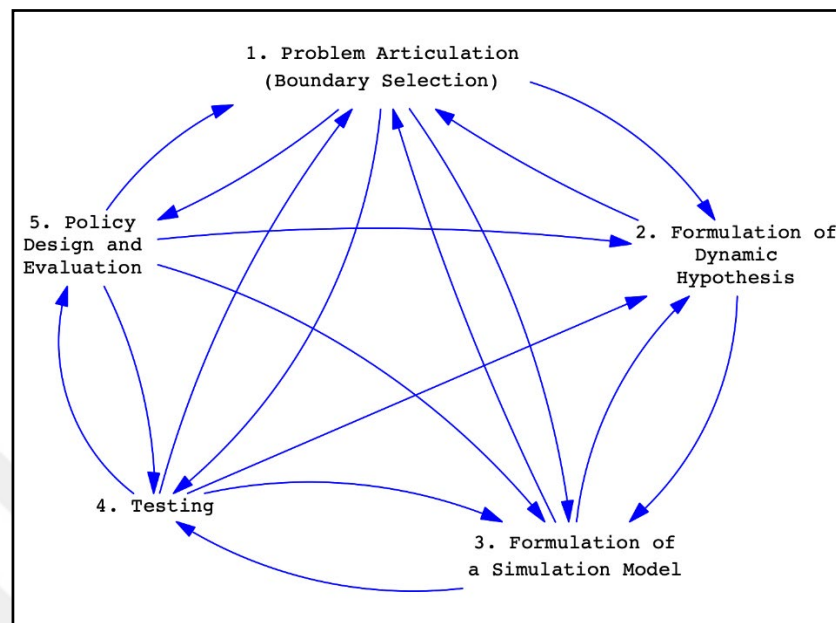


Figure 2.8: Roadmap for system dynamics modeling.

The stages for system dynamics analysis were first described by Jay W. Forrester in his book "Industrial Dynamics". Accordingly, the following steps can be followed in the system dynamics approach [Forrester, 1961].

- Defining the problem
- Isolating the factors producing the symptoms identified as interacting with each other.
- Monitoring the cause-effect relationship of feedback loops that reveal decisions that lead to new decisions and changes in the existing information framework.
- Formulate decision policies that define how decisions are to be reached with available information flows.
- Mathematical modeling of interactions between decision policies and system components.
- Revealing the behavior of the system at a certain time in the model.
- Comparison of results with available information against actual system behavior.
- Continuous reconstruction of the system model until it is acceptably representative.

- Observing changes and redesigning policies by making changes to the model to improve system behavior.
- Changing the real system in the direction that experiments with the model show that its performance will improve.

A few dynamic behavior patterns that can be seen in systems with dynamic properties are shown in Figure 2.9.

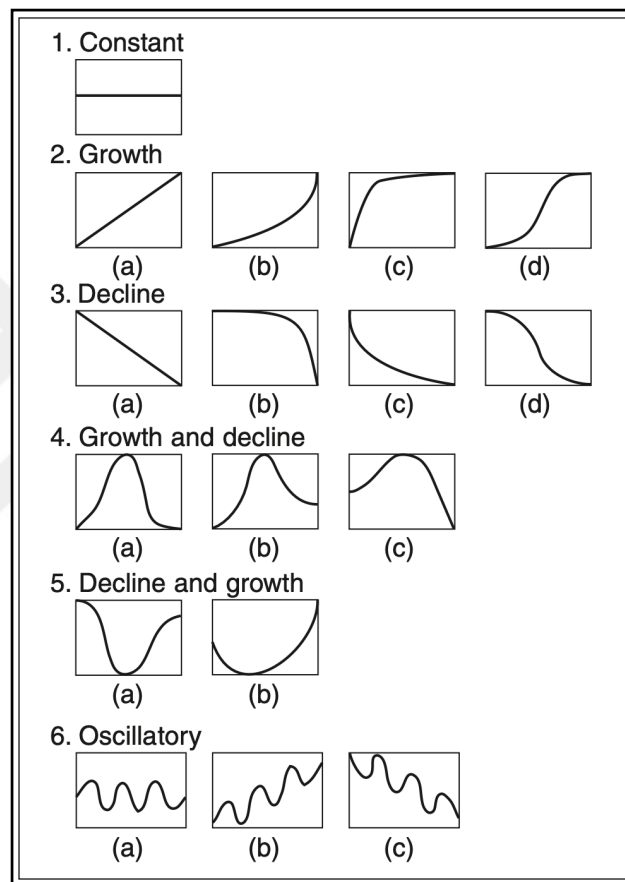


Figure 2.9: Basic dynamic behavior shapes.

A systems-based system's organizational structure may include a variety of intricate linkages. As a result, it's possible that not everything about the system is known. However, the model's variables should be given in their most basic form and should highlight all of the system's unique characteristics. The system model created with this idea should represent the true behavior or the behavior that is most like it. A model should, in its broadest sense, contain the variables and equations that generate the fluc-

tuations that make it up. To ensure the proper operation of the equation systems underlying the model and to acquire the data in the most accurate manner, it is crucial to keep the model's complexity to a minimum. In this way, the model that is essentially time-analyzed offers a model for real-time simulation. The system tools are run within a set time limit and finish their relationships during the simulation procedure. Thus, the length of time that the model will be run is crucial. Finally, based on the system model, sometime delays can be defined to get results that are close to the true behavior of the model tools.

2.4.2. System Dynamics Modeling

System dynamics helps us understand the changes between the short- and long-term consequences of events. In this way, it allows us to immediately see the effects of feedback that will take a long time to occur and take action.

System Dynamics is used to evaluate the solution to a problem or situation and to determine the right policy. While doing this, the first question that comes to mind for solving the problem is what kind of path should be followed, how to approach the problem, and what kind of alternatives should be determined. The answers to these questions should be evaluated before the model of the system is created and analysis is made. It may not be right to start obtaining the necessary data and parameters for the system without answering these questions. After deciding that the problem is dynamic and systemic, the problem should be defined clearly.

According to the systems approach, a solution cannot be obtained without considering a problem in the context of a cause-effect relationship. With the step-by-step determination of cause-effect relationships according to the problem definition, the stocks and flows required for the problem definition should be determined. In general, cause-effect relationships and stocks and flows should be determined according to the necessary parameters of the problem in order to handle the problem and evaluate it according to the systems thinking approach. In constructing the system model, these two modeling techniques must be created in a way that reflects the correct and real behavior.

Causal loop diagrams are established with cause-effect relationships in the system model and mathematical expressions are provided in the model to explain the dynamic and integrated effect of the system after stocks and flows. The dynamic character of the system emerges with the determined mathematical equations. For example, population equals births minus deaths.

If there is a dynamic hypothesis, this hypothesis must become a problem in order to establish the system model. Otherwise, there may be uncertainties about whether the concepts of the hypothesis are required in the model and how these concepts affect each other. In order to make the right start in the preparation phase of the model, it is necessary to prepare the model "Ceterus Paribus", that is, in a situation where all conditions will remain constant. Ceterus Paribus means "all other things being equal" in Latin. That is, the problem must be constructed on a ground where all other cases are considered constant.

The most important parameters for a system model are placed around the stocks. If a stock has been created, it will be ready in the flows for the model at that stage. For example, when a company budget stock is created, the company income stream and company expense stream are formed from the very first moment. In short, since stocks represent increasing and decreasing levels in a system, it will be easier to think about the parameters that increase and decrease that stock with a defined stock. As another example, if a country's population stock is mentioned, the factors that increase and decrease the population are considered as flows. These; It can be births (increasing flow), deaths (reducing flow), Serious diseases (reducing flow), Epidemics (reducing flow), crime rate in the city (reducing flow).

A dynamic system model is one of the best ways to present a good strategy. Through this emerging strategy, policies are determined and the dynamic character problem at the beginning can be solved. The model describes all interactions and provides an opportunity to consider all parameters.

System models provide a common language for solving problems. For this reason, it is necessary to establish uncomplicated models in order to determine the right policies and solve the problems. In order to establish uncomplicated models, stock and flow variables must be correlated as a result of an accurate analysis.

Thanks to the recent advances in computer software, it has become very useful in solving system dynamics problems. "Vensim® is a simulation software used to

measure the most realistic performance of systems, to develop and analyze dynamic feedback models [Web 6, 2017].

Vensim software, one of much software based on System Dynamics principles, is a multi-functional tool used for modeling and analyzing dynamic systems, optimizing models, and analyzing their behavior.

Within the scope of this thesis, Vensim PLE 9.3.5 Version was used for modeling, simulation, and analysis. The Vensim program was established with the PLE version that supports academic studies and is modeled for desired purposes. Vensim PLE provides a simple and flexible way to design simulation models consisting of the causal loop, accumulation, and flow diagrams.

The system dynamics model created within the scope of the thesis was analyzed in the desired time intervals of Vensim software.

To better understand the use of Vensim and the workings of system dynamics, some tools are introduced in the following sections. Some simple system examples are discussed. System model elements at first, simple flowcharts and system dynamics elements are defined with examples.

2.4.3. System Dynamics "Complex Problem"

When the properties of the parts that make up a system are known that problem can be solved. However, if these parts come together and interact, some features of the system emerge. These features are not available in parts. Finally, when you examine the parts in the model you created, many factors can emerge. On the other hand, for a hypothesis to be evaluated with a systems modeling approach, the problem must be dynamic and complex.

According to [Barlas, 2002], there are some features of the complex problem;

- Exhibits dynamic properties.
- Contains feedbacks and loops.
- Contains nonlinear structures.
- Contains Human Factor.
- Contains scale and boundaries.
- Cause-effect relationships differ in the concepts of time and space.

For example, if the furniture production inventory of the past 20 years is taken into consideration, the problems and fluctuations in the furniture inventory depending on the years are not only caused by bad manufacturers or raw material fluctuations. With the complexity of the production system and the relationships of production in that sector, fluctuations occur.

The rapid collapse of fast-growing companies is also one of the systemic problems. The reason why the company went into collapse after rapid growth is due to problems such as poor management conditions, wrong production models, and an inability to cope with financial difficulties as a result of complex relationships. As a result, when many dynamic relations existing in the system cannot be managed with certain policies, it is revealed that the company "causes its collapse as a result of unbalanced growth."

Seeing similar fluctuations in the construction industry is due to similar behaviors. The same effect is seen in the constantly changing working environments that the construction industry depends on. Due to the complexity of the relationships among many stakeholders in the sector at the production stage, many dynamic problems arise from the design to the construction stage. These emerging problems cannot be solved due to constantly changing and short-time production processes and are constantly postponed. The fact that the sector dynamics are high in adapting to new projects and that the innovation management is weak can be shown as among the main reasons for the emergence of this situation.

A dynamic system: the main reason that creates change over time is the internal structure of the system. Since the internal structure of the system changes over time, it has dynamic characteristics. Not all problems may be systemic. Treating a non-systemic (a-systemic) problem as a systemic problem causes errors. For example, if we consider some problems; real estate price fluctuations, fast-growing companies going bankrupt, inventory fluctuations in the supply chain, population growth, Virus growth. The common feature of these problems is that they are systemic in nature and change (dynamically) over time. Each of the problems is related to changes over time. Therefore, actions that occur over time are important.

The internal structure of the system is of great importance in the emergence of dynamic problems. The characteristic feature of the internal structure of the system causes the system to be affected dynamically. In addition, dynamic systemic problems are chronic and need to be managed continuously.

The complexity of systems arises for several reasons. These are some of the reasons.

- Finding delayed cause-effect relationships in system models.
- Too many variables are being entered into the system model.
- Finding intuitive deficiencies.
- Inability to obtain a solution due to the complexity of management systems.
- The need for a method, discipline, and systemic equipment.

2.4.4. System Dynamics Tools

2.4.4.1. Causal Loop Diagrams (CLD)-Cause-Effect Relationships

The first system dynamics studies used causal loop diagrams. Loops are represented by accumulation-flow diagrams and equations. This kind of expression was enough for the engineers. Causal loop diagrams have been created to make the System Dynamics approach accessible to a wider audience [Richardson, 1986].

Causality Loop Diagrams are a form of visual expression used to see the relationship between the elements that make up the system and affect the behavior of the system. The diagram consists of system elements and the causal links (arrows) connecting them. An arrow is drawn from one variable to the other to show the relationship between the variables. Plus, and minus signs at the ends of the arrows show the causal relationship between the elements. If the connected elements change in the same direction, they get a positive sign, and if they change in a different direction, they get a negative sign.

For example, let A and B be considered as two connected elements. The sign is positive if the value of B increases as the value of A increases, or if the value of B decreases as the value of A decreases. Conversely, if the value of B increases while the value of A decreases, or if the value of B decreases while the value of A increases, the sign is negative.

In cause-and-effect relationships, the arrow sign means "leads—causes". An arrow is drawn from variable X to variable Y to show the relationship between variables.

Figure 2.10 depicts the meaning of the arrow sign. A change in the X factor causes a change in the direction of the Y factor.

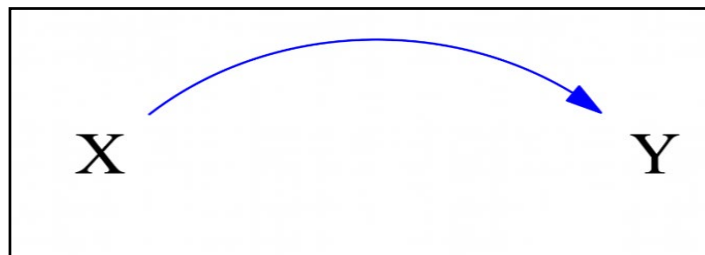


Figure 2.10: Cause-Effect relationship arrows.

The plus (+) sign at the end of the arrow, shown in Figure 2.11, means "effect in the same direction". A change in the X factor leads to a change in the Y factor in the same direction.

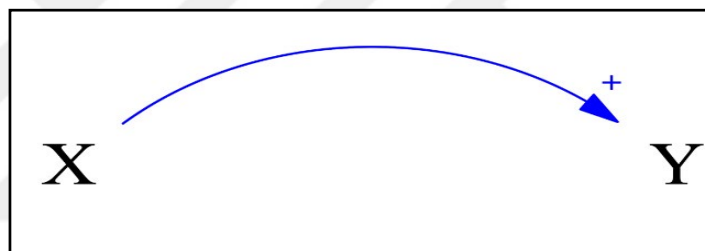


Figure 2.11: Cause-Effect relationship "effect in the same direction" arrow.

Since births in a city affect the population in an increasing way, there is a plus sign on the arrow. This means that there is an effect in the same direction between the variables. Figure 2.12 shows the Birth-Population relationship.

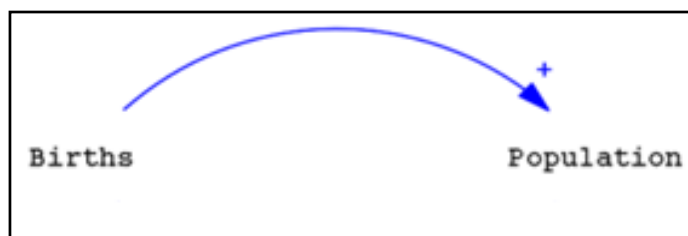


Figure 2.12: Birth-Population Effect.

The plus (-) sign at the end of the arrow shown in Figure 2.13 means "opposite action". A change in the X factor leads to a change in the Y factor in the opposite

direction. If X increases, there is an effect to increase Y. If X decreases, there is a reducing effect in Y.

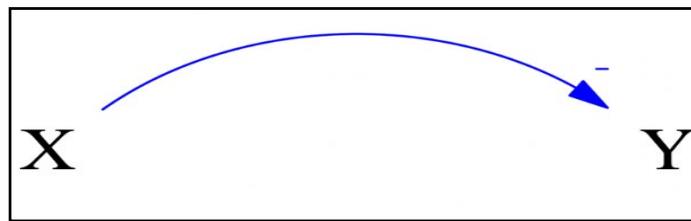


Figure 2.13: Cause-Effect relationship "effect in the opposite direction" arrow.

An increase in the price of a product has a decreasing effect on supply. A negative arrow sign means that there is an opposite relationship between price and supply. The price-supply effect is shown in Figure 2.14. Unless other conditions change (*Ceteris paribus*), if the price increases, there will be a decrease in supply.

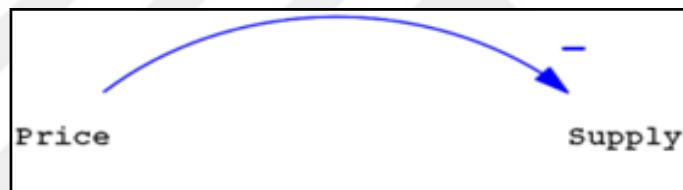


Figure 2.14: Price-Supply Effect.

Cause-and-effect diagrams are used in a dynamic system. Cause-and-effect diagrams show all the relationships in a system and are the wheels that determine the direction of change. For example, if births increase, the population increases. If the model is analyzed over a certain time period, the result is that "increasing population over time increases births". Therefore, the whole picture changes from the definition of the problem to its solution. As soon as cause-and-effect loops are created, a dynamic model is established. Even if cause-and-effect loops are established, the model now becomes a working, live model.

To make a policy analysis on a particular issue using the system dynamics approach, cause-and-effect relationships must be found in the system model. By establishing these relationships, it is possible to obtain data because of the analysis.

Cause-and-effect loops operate with time delays. The time delays of these loops used in the system model need to be defined. These time delays are required for the loops to complete themselves. Time periods such as seconds, months, and years are

defined only for loops. Analysis of other effects outside the loop based on different time delays can also be performed. For example, in earthquake systems, certain time delays are like this. They have a recurrence period of 2,475 years and operate with delays during this time period.

In system dynamics, models are designed to be analyzed over specific time periods. These time periods can be days, weeks, months, or years. The model should work for a certain time, the results obtained should be evaluated within the relevant time period, and scenario analyses should be made.

Cause-and-effect loops are used to design stable and well-functioning systems. Cause-and-effect loops occur by establishing cause-and-effect relationships. These loops exist in every aspect of our lives, such as control systems, aircraft, and mobile phones.

There are two types of loops in the systems modeling approach. These are reinforcing and balancing loops.

The sign of a loop is determined by multiplying the arrow directions of all the effects that make up the loop.

(+) Loop: Reinforced Loop

The increasing loop acts to strengthen the movement. These loops want to move exponentially up or down. These loops want to move exponentially up or down. In addition, reinforcement loops allow variables to change continuously in the same direction or incrementally.

When the product (+) of all the effects in the loop comes out, the loop is a reinforcement loop. In this case, the loop wants to act out of control. The birth and population loop shown in the Figure 2.15 is the reinforcing loop. The Births and Population loop is the reinforcing loop.

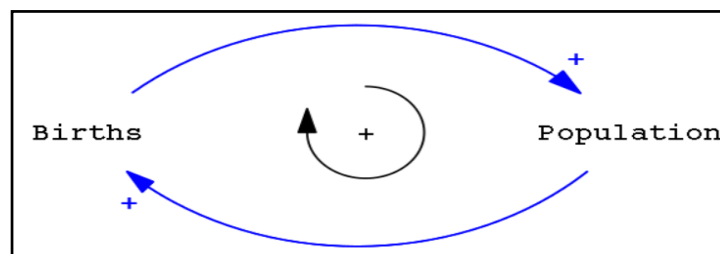


Figure 2.15: Reinforced loop "Birth-Population".

As another example, if we look at the number of marketers, orders, and revenue loop in a company; the number of marketers, orders, and revenue loop is the reinforcing loop. As the number of marketers increases, the orders increase. Increasing orders influence increasing revenues. As revenues increase, the company increases the number of repeat marketers. If the number of marketers increases, more advertisements are made, and the awareness of the company increases. as a result, orders increase. Increased orders increase the company's revenues. Increased revenues have an impact on hiring more marketers. In this way, the factors in the loop interact with each other in the same direction. Figure 2.16 depicts this relationship.

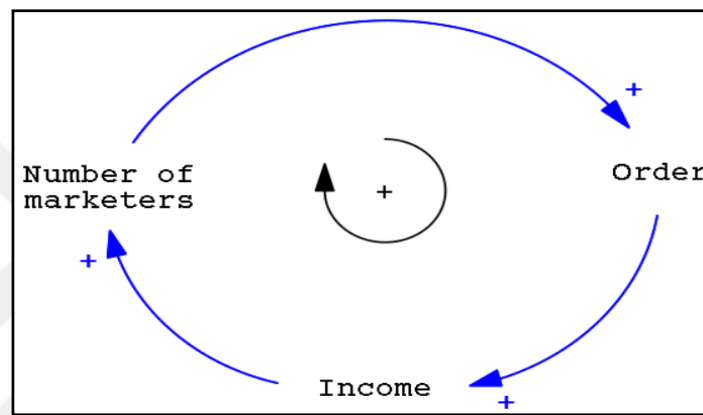


Figure 2.16: Reinforced loop "Marketers-Order-Income".

But for a company, the loop may not always work that way. For this, it is necessary to produce good-quality products, preserve the products well, and manage the order and delivery stages well. Since many companies cannot achieve this balance, decreases may occur in company revenues at certain time intervals. This result indicates the existence of balancing loops.

(-) Loop: Balanced Loop

Balancing loops work to keep variables in balance. If the loop sign is (-), it means that this loop is aiming for balance. For example, automatic control systems and the millions of loops running in the human body have this feature. Balancing loops either have the purpose of balancing or they want to hysterically return. Even if these loops move forward, they tend to reverse. If it is moved up, it wants to move down again. In the event that some existing loops in the system become more dominant, it can be observed that the system either collapses or enters a state of equilibrium. In Figure 2.17, the Price-supply loop is shown as the balancing loop.

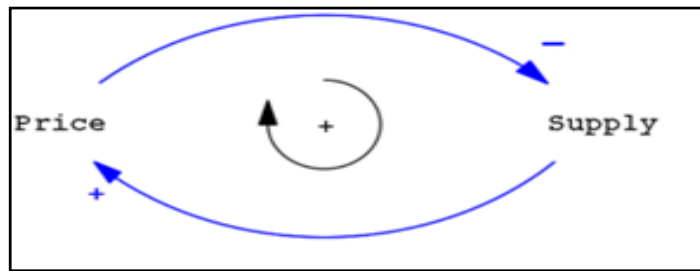


Figure 2.17: Balancing loop "Price-Supply".

The movement and signs of the cycle are determined by mathematically multiplying the signs of cause-and-effect relationships in the cycles. When the product of the effects (-) comes out, the loop is the balancing loop.

Cause and effect relationships are rarely unidirectional, that is, an effect occurs for a reason.

When the system model is created and analyzed according to modeling rules and system thinking, cause and effect can turn into cause depending on the interaction of the variables. This result expresses the structure of systems.

2.4.4.2. Stock-Flow Diagram

For the solution of a problem with a systems approach, the first thing to be evaluated should be the answer to the question, "What are the fundamental accumulations in the problem?" If the most basic variables of concern for the system to work under appropriate conditions are not decided, every model becomes an infinitely complex model. because differential equations are used when creating dynamic models. The large number of unknowns in these equations will also make the solution of the equation difficult. In order to describe an effect in a mathematical sense, it is necessary to write the rate of change numerically. If a differential equation is established for each effect, complex models emerge and become difficult to solve.

The problem to be evaluated with the system dynamics method is handled and modeled with system dynamics tools. There are two important tools for defining variables in the modeling phase. These are stocks and flows. In a studied problem, the main goal should be to conceptualize the problem by creating inventories and flows

and to establish a system model that includes the most basic and most necessary parameters.

Cause-and-effect relationships form the first stage of the model. Then, when we start to build simulation models physically and with equations, a few indispensable variables need to be used. These variables are expressed by stocks and the flow with which they are defined.

Stocks Variables: Stocks are accumulations that reflect the system's status. Rectangles are used to indicate stocks in a system model. For example, population, inventory, company budget.

Flow Variables: Rates that alter the level of stocks are called flows. Pipes and arrows pointing into or out of the stock are used to symbolize inflows and outflows, respectively. For instance, births, deaths, production, and sales.

Additional (Intermediate) Variable: Variables other than the above two basic variable types are referred to as intermediate (translator) variables. They are the most common variables in the model that provide ease of modeling and presentation and enable the expressions to be translated. Additional variables are expressed as neither stock nor flow.

If stocks take shape in a system, it creates a cycle and affects internal and external flows before causal loop diagrams are established. In short, stocks are one of the most important variables in a system model. Figure 2.18 shows the stock, flow and additional variable.

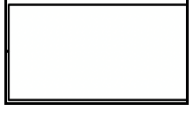
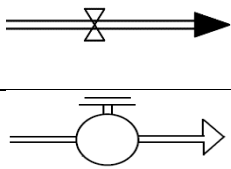
Stock	Flow	Additional Variable
		

Figure 2.18: Variable Types.

In a system, by specifying the relationships between these three types of variables, stock-flow or structure diagrams are obtained.

When stock is created in a system, input and output flows are basically determined. As soon as the population stock is considered, births, deaths, and migrations are mentioned immediately. Production and sales flow begin as soon as a factory's inventory is handled. When the amount of water in the pool is considered, the amount of water entering the pool and the amount of water leaving the pool are determined. Below is a mathematical illustration of the link between stock and flows:

$$Stock(t) = \int_t^{t_0} (Inflow(s) - Outflow(s))ds + Stock(t_0)$$

$$d(Stock)/dt = Inflow(t) - Outflow(t)$$

Figure 2.19: Stock-and-Flow Equations.

Figure 2.20 shows a representation of a stock-and-flow diagram. Figure 2.21 provides an illustration of a stock-and-flow diagram for a typical population accumulation.

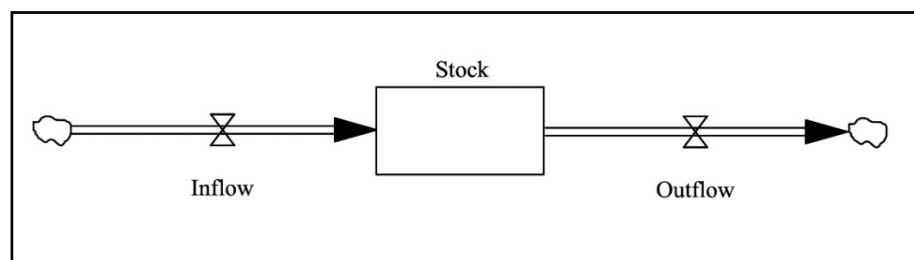


Figure 2.20: Stock-and-Flow Diagram.

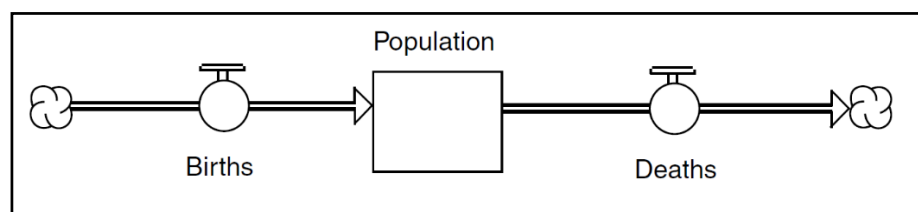


Figure 2.21: Stock-and-Flow Example.

2.4.5. System Dynamics Studies of Lean and BIM Interaction

Lean Construction (LC) and BIM are increasingly used in the construction industry to improve design, construction, and maintenance processes [Bayhan et al., 2021]. However, there are not many studies on the use of these two concepts together in the literature. In the study, as an example, data on production control, standardization, information accuracy, continuous improvement, and improved planning and scheduling will be made in BIM with JIT delivery from lean production tools. However, it is stated that due to the lean-BIM interaction, BIM's predictive performance analysis capability regarding energy will become a more important factor in the future.

The study also serves as a guide for construction companies to evaluate lean and BIM integrations for increased project success and the key driving factors driving BIM implementation in terms of improving lean construction. Production control and standardization are essential for Lean/BIM in the construction industry to keep the 'production line' under control, which aims to eliminate waste and create maximum value, as in the manufacturing industry.

BIM fulfills some of lean construction principles and highly ease fulfillment of other lean principles and the most significant synergies are: BIM reduces variation, shortens cycle time, improves information flows and enables product and process visualisation, simulation and analysis [Sacks et al., 2018], increases efficiency and productivity, improving work schedules, increasing work safety, reducing waste and saving costs [Web 7, 2020]. With the integration of LC processes and BIM, a conceptual framework has been created to link virtual design and construction with lean project delivery processes [Khanzode et al., 2006]. He also concluded that the implementation of computer enhanced visualization tools (CAVT) leads to reduced waste, improved flow, and better customer value, showing significant synergy between lean construction and CAVT [Rischmoller et al., 2006].

The traditional exchange of information in a physical blueprint on paper or a narrow digital format leads to the loss of consequential information during the entire building life cycle, especially, between handovers of design, construction, and operation [Borrmann et al., 2018]. BIM as "a modeling technology and associated set of processes to produce, communicate, and analyze building models", suggests a new method for management and coordinated exchange of information among disciplines

and stakeholders in order to hinder this information loss [Sacks et al., 2018]. Despite the benefits of their independent implementations, the synergies between BIM and LC can bolster the entire building lifecycle, from the design phase to handover and facility management, if all potentials are exploited [Dave et al., 2011] ,[Sacks et al., 2010]. Since the industry is being pushed towards a more collaborative working environment, the acceptance of both BIM and LC, which have collaboration at their cores, should increase. Engaging these two concepts provides improved design and construction processes and increases productivity.

LC and BIM both deal with the complexity, inefficiency, and wasteful nature of the AEC industry. These methods can be considered and applied independently, but the full potential of both can be achieved through their interaction [Sacks et al., 2018].

To better define this interaction, an interaction matrix of lean principles and BIM functions was developed based on deep literature studies [Sacks et al., 2010]. The matrix defines how BIM functions can support the application of lean principles in the construction process. The intersection of each lean policy with each BIM function is evaluated, and a score is assigned to represent the degree of interaction between them. Lean principles evaluated in the matrix include value, waste elimination, continuous flow, pull planning and control, visual management, and continuous improvement. BIM functions include quantification, conflict detection, 4D planning, visualization, prefabrication, and supply chain management. The matrix shows that all lean principles can benefit from the use of BIM, with some functions having a higher level of interaction than others. For example, the lean principle of continuous improvement has a high level of interaction with the visualization and 4D scheduling functions of BIM. Similarly, the lean principle of waste elimination has a high level of interaction with the quantification and prefabrication functions of BIM.

BIM functionality	Lean principles																			
	Reduce variability		Reduce cycle times		Reduce batch sizes		Increase flexibility		Select an appropriate production control approach		Standardize		Institute continuous improvement		Use visual management		Design the production system for flow and value		Ensure comprehensive requirements capture	
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
Visualization of form	1	1,2													3			4		11
Rapid generation of design alternatives	2	1	22										7	7	8					
Reuse of model data for predictive analyses	3	9	9	22			51											1	16	5
Maintenance of information and design model integrity	4		10	12											8				16	5
Automated generation of drawings and documents	5	1,2	1	12														1	1	5
Collaboration in design and construction	6	11	11																	11
Rapid generation and evaluation of multiple construction plan alternatives	7	12	12	22																12
Online/electronic object-based communication	8	11	22	(52)	53											54	54			
	9		23						36						36					
	10	2,13	24				33										43		56	46
	11	14	25	(29)			31								(41)					49
	12		15	25	(29)				37						(41)			44		47
	13	2	40	25	(29)					17			40	40	40					47
	14	29	26	30	30			34							34	(42)				47
	15	18	26	30	30			34		38			38	34	(42)			45		48
	16	19	27				32													49
	17	20	28					35							(42)					
	18	21	30	30				34				39			(42)					47
																			48	

Figure 2.22: Interaction matrix of lean principles and BIM functionalities.

The most significant and required parameters were chosen based on the body of research for developing the common parameters for the lean-BIM interaction examined within the scope of this thesis.

The system model is created using the shared parameters identified for Lean and BIM interaction, which are described in Chapter 2.

3. RESEARCH METHODOLOGY

3.1. A Survey Study

This survey was answered by the construction industry employees consisting of lean and BIM experts. The study is a survey study and was prepared to conduct a study on the interaction of BIM and lean construction. Multiple choice questions were asked about the current situation regarding the effects of the parameters determined for lean construction and BIM within the scope of construction projects on lean and BIM performance and project success, and the obtained data were analyzed.

3.1.1. Aim of the Survey

The purpose of the questionnaire prepared within the scope of the thesis; The factors that create the Lean-BIM interaction determined within the scope of the literature are directed to the lean-BIM experts to determine how these factors interact in practice and depending on the project experiences, unlike the literature studies.

Although the concepts of Lean and BIM are still new, existing studies have concluded that these two project management processes are not sufficiently experienced in practice and some interactions are still lacking within the scope of the literature.

For this purpose, the survey study was created to examine the Lean-BIM interaction in more detail and to better handle the interaction between each other.

3.1.2. Survey Format

Text boxes were added to the survey's content in the introduction section for participants to fill out. At this stage, the participants were asked to fill in the questions about their fields of work, the field in which their company works, the name of the company, and the time spent in the sector.

In the second stage, participants were asked whether the predetermined parameters had a favorable or bad impact on the performance of lean and BIM. Option boxes with two possibilities (positive or negative) were placed to help decide this.

Finally, it was asked to what extent the lean and BIM parameters that the participants encountered in the previous stage affected lean and BIM performance. They were asked to complete the survey by asking them to choose one of the five option boxes. 1. Very Low (0-20%), 2. Low (20-40%), 3. Average (40-60%), 4. High (60-80%), and 5. Very High (80-100%).

3.1.3. Survey Content and Data Collection Process

The Google survey document prepared on the web was shared with the participants via e-mail, and they were asked to answer the Lean-BIM interaction survey. After the questions were answered by the participants, the data were arranged statistically, and the impact factors were obtained.

The following research questions were asked of the participants:

What are the effects of the parameters determined for the interaction of Lean Construction and BIM for lean-BIM performance? Do the chosen parameters have a good or negative impact on Lean performance? To what degree does it eventually impact? How and to what extent do the chosen parameters impact the efficiency of BIM?

Survey participants were asked about their fields of work (construction, engineering, etc.), in which field their company works, the name of the company, and the amount of time spent in each sector. These questions were placed in the survey to help us gain insight into the extent to which their companies have implemented Lean and BIM adoption, based on survey respondents' fields of work and expertise. A sample response image was added to the survey screen over a single variable, as shown in Figure 3.1, in order to help the decision-making process and better understand the common elements affecting Lean and BIM success in the survey study.

For Example :

Please select whether the following parameters affect LEAN Performance Positively or Negatively.

	Positive	Negative
Adoption of Value Engineering	☒	☐

Please select how effective the parameters you set (Positive or Negative) above are.

	Very Low (%0-20)	Low (%20-40)	Average (%40-60)	High (%60-80)	Very High (%80-100)
Adoption of Value Engineering	☐	☐	☐	☐	☒

Management support positively affects lean performance in the range of 80-100%.

Figure 3.1: Example of response (for a single variable).

After the introductory questions, we asked other questions in the survey to measure lean and BIM performance.

We questioned survey respondents on the impact of several factors on the performance of lean construction. Then, we further inquired as to how much it influenced the participants' percentile responses.

Factors affecting lean performance in the survey study:

- Adoption of Value Engineering
- Avoiding Customer Satisfaction
- Avoiding Excess Inventory
- Development of Lean Thinking
- Good Communication
- High Experience
- Management Support
- Sufficient Resources
- Team Collaboration
- Waste Reduction
- Challenges of Regulations
- Lack of Coherent Vision
- Lack of Coordination
- Lack of Funding
- Lack of Sources
- Lack of Standards
- Market Uncertainty
- Poor HR Management
- Resistance to Change
- Resistance to Technology
- Staff Resistance

How does " Adoption of Value Engineering " impact the effectiveness of lean? (Positive or negative). After that, the issue of "how much the adoption of value engineering" impact lean performance was raised. Generally, levels were described as follows: Very Low (0-20%), Low (20-40%), Average (40-60%), High (60-80%), and Very High (80-100%).

Factors affecting BIM performance in the survey study:

- Good Communication
- High Experience
- Management Support
- Sufficient Resources
- Team Collaboration
- Cultural Factors
- Lack of Funding
- Lack of Infrastructure
- Lack of Sources
- Poor HR Management
- Resistance to Change
- Resistance to Technology
- Staff Resistance

For instance, how does " Good Communication " impact the effectiveness of BIM? (Positive or negative). After that, the issue of "how much good communication " impact BIM performance was raised. Levels were described as follows: Very Low (0-20%), Low (20-40%), Average (40-60%), High (60-80%), and Very High (80-100%).

3.1.4. Survey Results and Obtaining Impact Factors

	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7
Field of operation	Construction	Engineering	Construction	Construction	Construction	Construction	Construction
Expertise of your company	Industrial	Industrial	Building	Infrastructure	Transportation	Infrastructure	Industrial
Company	**	**	Rönesans	Alarko	TAV	IHI Inc.	ENKA
Experience in the construction industry	15-20 years	0-5 years	5-10 years	10-15 years	15-20 years	>20 years	10-15 years
Position at the company	Manager	Engineer	Manager	Director	Manager	Director	Engineer

Figure 3.2: Survey participants information.

The coefficients of the variables and equations in the system dynamics model were obtained by answering the questionnaire and analyzing the questionnaire results statistically. The determination of the influencing factors is shown in Table 3.1 and 3.2 by simplifying the data with the assumptions made and creating the coefficients of the variables in the model.

Table 3.1: Lean performance coefficients (survey study).

LEAN Performance	Variables	Coefficient
	Adoption of Value Engineering	0,7429
	Avoiding Customer Satisfaction	0,8571
	Avoiding Excess Inventory	0,8286
	Development of Lean Thinking	0,8857
	Good Communication	0,9714
	High Experience	0,7429
	Management Support	0,9429
	Sufficient Resources	0,8571
	Team Collaboration	1,0000
	Waste Reduction	0,9714
	Challenges of Regulations	0,7714
	Lack of Coherent Vision	0,7429
	Lack of Coordination	0,8286
	Lack of Funding	0,8000
	Lack of Sources	0,8286
	Lack of Standards	0,6857
	Market Uncertainty	0,7714
	Poor HR Management	0,6286
	Resistance to Change	0,8857
	Resistance to Technology	0,8571
	Staff Resistance	0,8286

Table 3.2: BIM performance coefficients (survey study).

BIM Performance	Variables	Coefficient
	Good Communication	0,9143
	High Experience	0,8571
	Management Support	0,8000
	Sufficient Resources	0,8857
	Team Collaboration	0,9429
	Cultural Factors	0,6571
	Lack of Funding	0,8000
	Lack of Infrastructure	0,8571
	Lack of Sources	0,8286
	Poor HR Management	0,6571
	Resistance to Change	0,8857
	Resistance to Technology	0,8857
	Staff Resistance	0,8000

The effect coefficients obtained by the survey study were written to the variables themselves and the defined equations in the system dynamics model. yielded results. The effects of the variables defined in the system model on each other were also examined using these coefficients.

Causal loop diagrams and stock-flow diagrams are proportionally related to the variables by the effect coefficients defined.

Finally, it is important to enter the coefficients correctly for the variables that increase or decrease lean and BIM performance.

Effect coefficients are defined for each variable in the model. In addition, for causal loop diagrams and variables connected to flow variables, an equality definition was made for the relevant variable in the program, and the effect coefficients were added as multipliers to the equations. Equations defined for flow variables are given in the following section, defining equations for model variables.



4. A SYSTEM DYNAMICS MODEL OF LEAN AND BIM INTERACTION

4.1. Problem Definition, Modeling Purpose, And Dynamic Hypothesis

Both qualitative and quantitative techniques are used in the System Thinking methodology. It then moves on to iterative steps of issue definition, dynamic hypothesis development, model construction, model testing, policy creation, analysis, evaluation, and application [Forrester, 1961], [Sterman, 2000].

The thesis study is planned to do quantitative model development and policy analysis. It is focused on presenting the Lean-BIM interaction with problem definition, dynamic hypothesis, and the creation of the qualitative model. Figure 4.1 shows the directions for a road map.

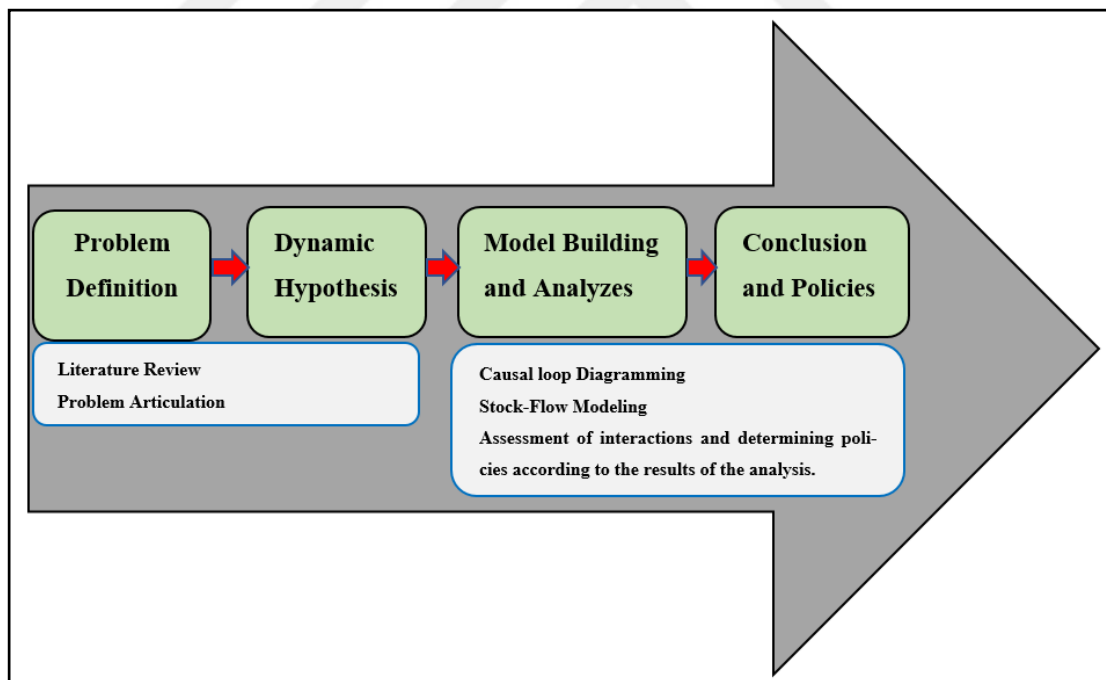


Figure 4.1: Summary of the modeling stages followed in the study.

The focused problem, our dynamic hypothesis, and the goal of the modeling are all defined in this chapter. The "Steps of the System Dynamics Method" section of served as the primary reference for the material of this section [Barlas, 2002].

4.2. Description of the Model

4.2.1. The Names of Variables

The most important feature that variable names should have in system models and causal loop diagrams is that they should consist of a noun and a noun phrase. In addition, the expressions connecting the variables in the model and the variables themselves should consist of verbs. The main task of the causal loop diagrams defined in the system is to determine the interaction between the variables and how a change will occur [Sterman, 2000].

Variable names should contain nouns or noun phrases and clearly indicate the desired direction. Examples of how to name variables are given in Figure 4.2 and Figure 4.3 below. Correct and incorrect variable names are given in the examples.

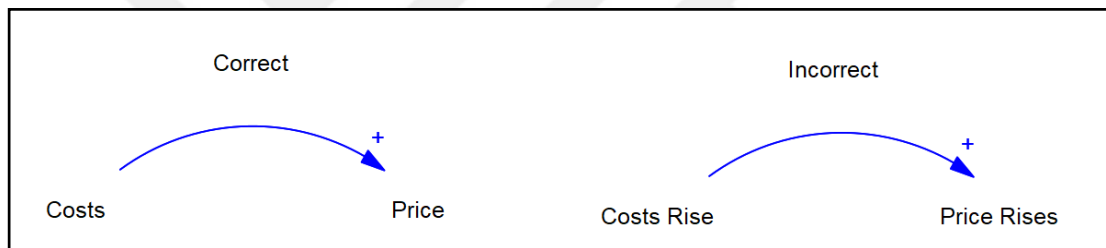


Figure 4.2: True and false definition for variables (1).

The correct representation given on the left in Figure 4.2 is defined more comfortably and realistically because of the correct definition of variable names. If costs go up, the price goes up. If costs go down, the price goes down. In a cause-effect diagram like the one on the right, adding the verb "rise" to the variable name leads to the assumption that costs will only increase. This causes the discussion to become one-sided. Using this incorrect variable name can lead to confusion as it refers to lower costs or lower price increases. Finally, it may cause confusion about whether prices are increasing or decreasing at a decreasing rate.

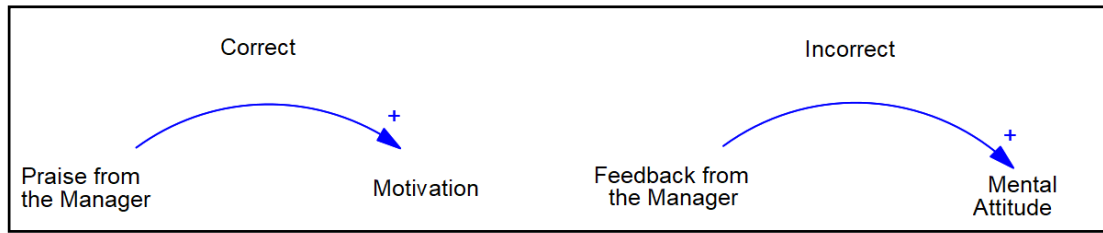


Figure 4.3: True and false definition for variables (2).

As shown in Figure 4.3 Saying that the "Praise from the manager" variable causes a change in the same direction as the "motivation" variable is important for the correct understanding of the system model and the correct definition of the variables. Otherwise, defining the variable as "feedback from the manager" will not result in the direction of the manager's feedback, and it can be said that it will cause misinterpretations about what kind of effect it will have on the "mental attitude" variable, which is also defined incorrectly.

4.2.2. Creation of Causal Loop Diagrams (CLD)

Causal loop diagrams are a tool used to model system dynamics and represent the operation and feedback structure of the system. Using causal loop diagrams, according to [Sterman, 2000];

- It is more comfortable to form hypotheses to explain the sources of dynamics.
- The most crucial stage in the development of the conceptual model is characterized as the relationships between variables that cause and impact one another.
- During system functioning, some obstructions and delays are expected to happen.
- It enables the interaction and communication of feedback that are responsible for the emergence of problems. The interaction of the variables with each other is shown as directly proportional (+) and inversely proportional (-). This change is related to the direction of the arrows. The variable where the arrow ends is the dependent variable, and the other is the independent variable. With signs and arrows, it can be understood how the independent variable changes the dependent variable.

All variables that directly and indirectly affect a variable should be shown in causal loop diagrams after the fundamental variables have been identified. The system's loops should be identified and given names in the following phase [Morecroft, 2015].

4.2.3. Creation of Stock Flow Diagrams

Delays between input and output variables and flow-related accumulations make up level (stock) variables. It represents the value created by the whole sum of internal and external flow variables. Level variables set the state of the system and serve as the foundation for system activities. They function as a sort of "memory" in simulation. System delays are brought on by level variations. Examples of such variables include inventory in manufacturing systems, unfulfilled orders, personnel count, or company financial accounts [Sterman, 2000].

The stock variables defined in the Lean-BIM interaction model are "Lean Performance" and "BIM Performance" variables. In the system model, stock variables, flow variables, and additional (intermediate) variables are used. Stocks variables are modeled as "Level" variable type in Vensim PLE program. On the other hand flow variables are specified as "Auxiliary" variables based on stock elements (levels). Figure 4.4 shows the stock and flow variables in the system model.

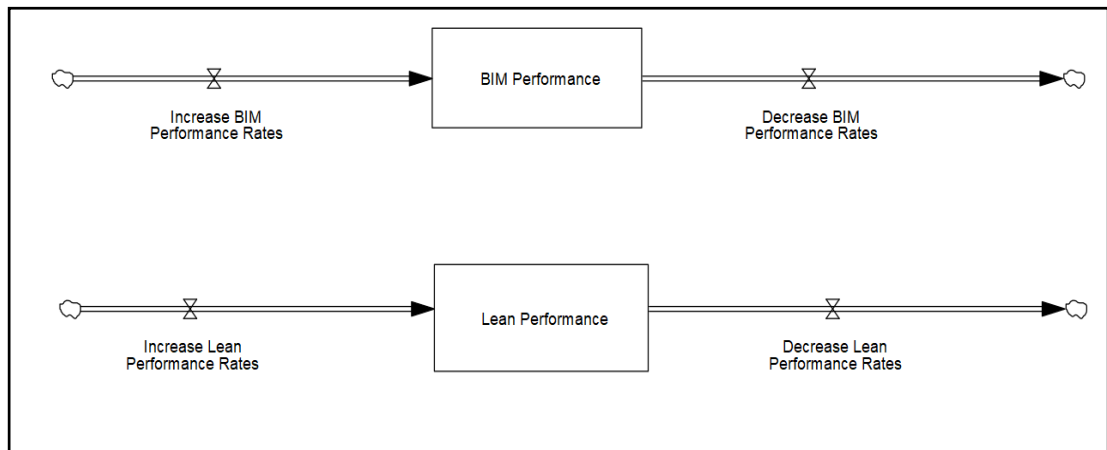


Figure 4.4: Stocks and flow variables in the system model.

The flow variable defined as "Increase Lean Performance Rates" is linked to the "Lean Performance" stock as an increased flow. The "Decrease Lean Performance Rates" flow acts as a flow that reduces the "Lean Performance" stock. Both the lean

performance increase flow and the lean performance decrement flow are included in the system model's lean performance stock. As a result, variables that increase and decrease lean performance are added to the flow variables.

4.2.4. Creation of Variables

With the determination of stock, flow and additional variables, variable types in the Figure 4.5 and variables are defined to the program. Then, modeling was done with causal loop diagrams, stock-flow variables, and additional variables.

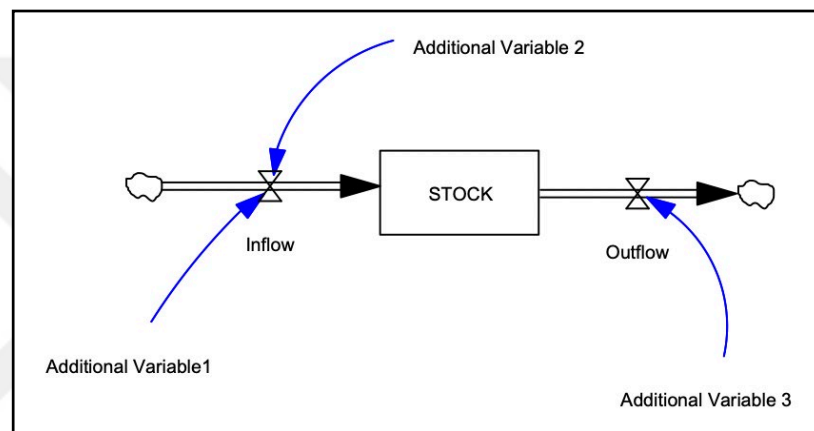


Figure 4.5: Instance variable types of model (Vensim PLE).

Parameters defined by different variable types in the system model are given below. At this stage, the variables associated with the system are expressed with arrows.

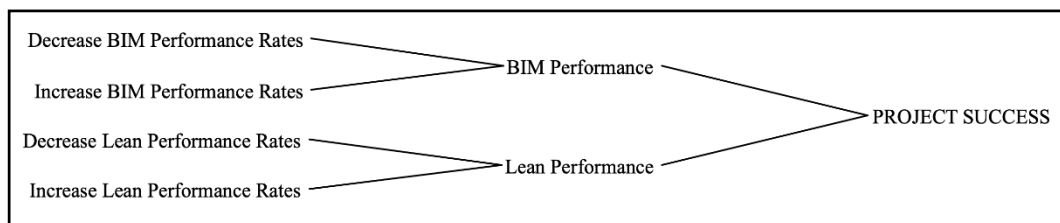


Figure 4.6: Variables associated with project success.

The elements created within the parameters of the literature study and influencing lean performance are shown in Figure 4.7.

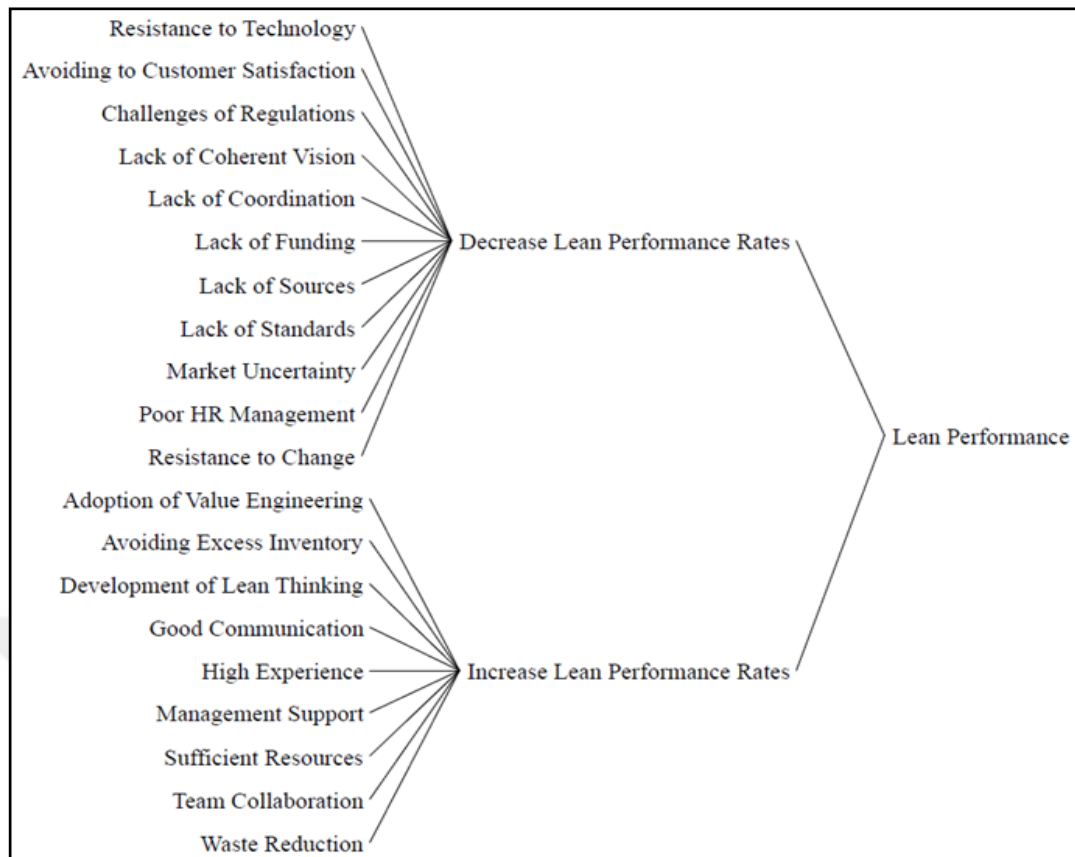


Figure 4.7: The components of lean performance.

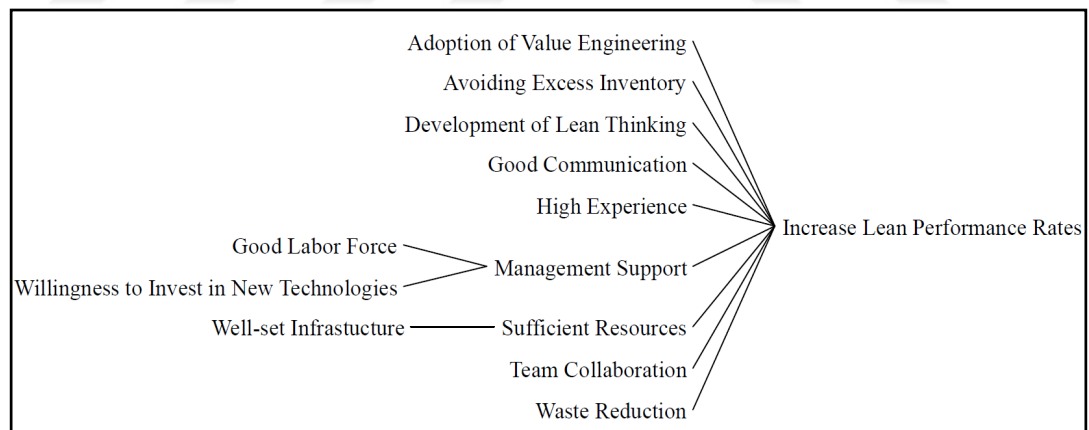


Figure 4.8: Components that increase lean performance.

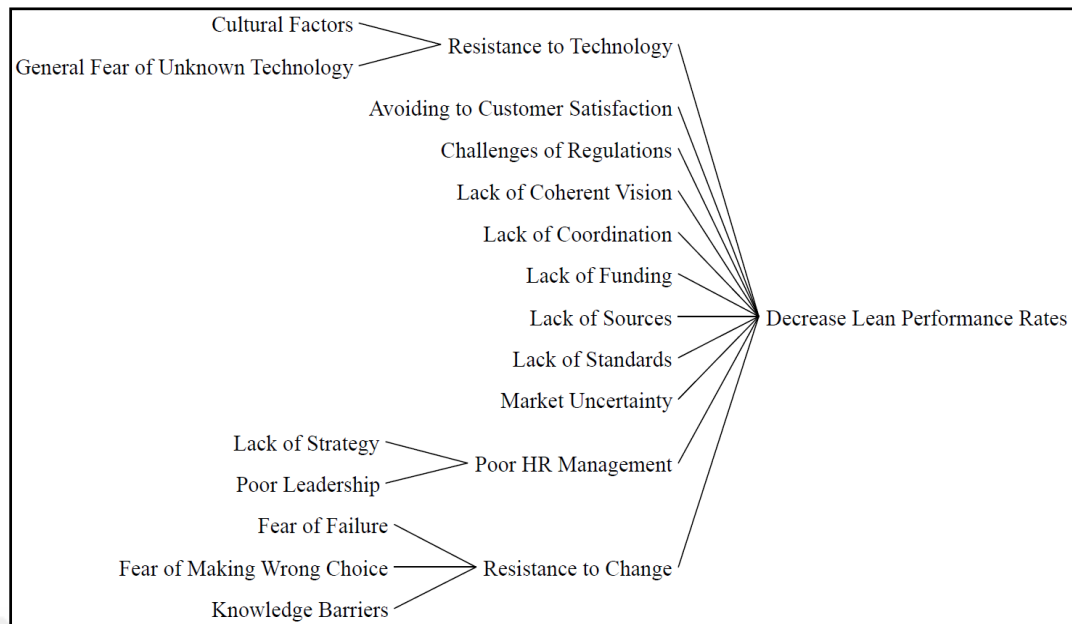


Figure 4.9: Components that decrease lean performance.

The flow variable defined as "Increase BIM Performance Rates" is linked to the "BIM Performance" stock as an increased flow. The "Decrease BIM Performance Rates" flow acts as a flow that reduces the "BIM Performance" stock. Both the BIM performance increase flow and the BIM performance decrement flow are included in the system model's BIM performance stock.

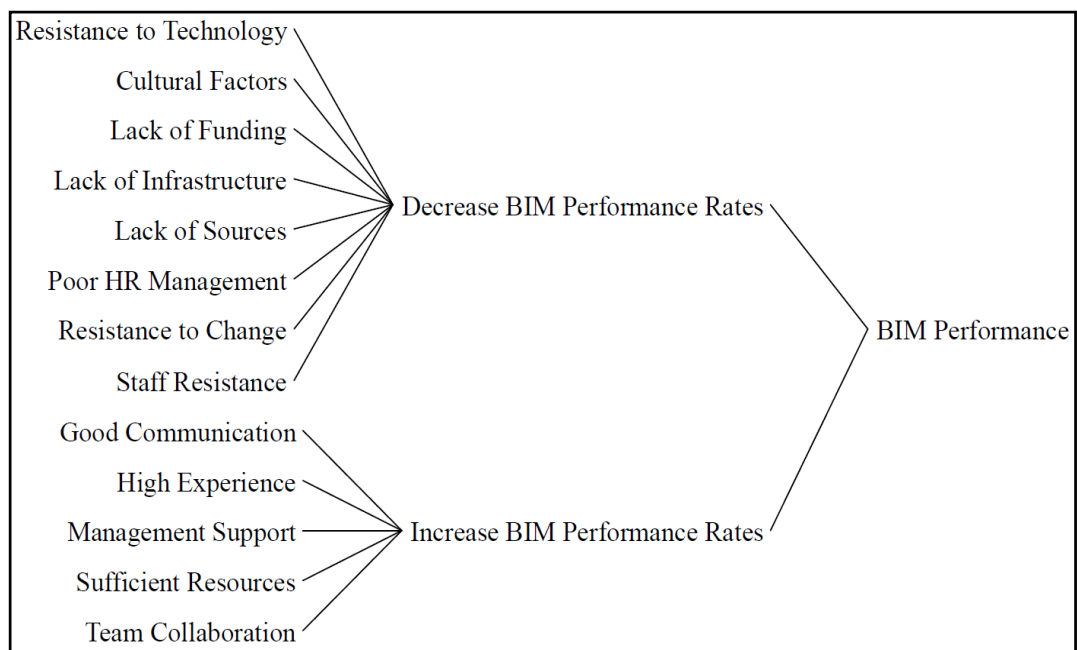


Figure 4.10: The components of BIM performance.

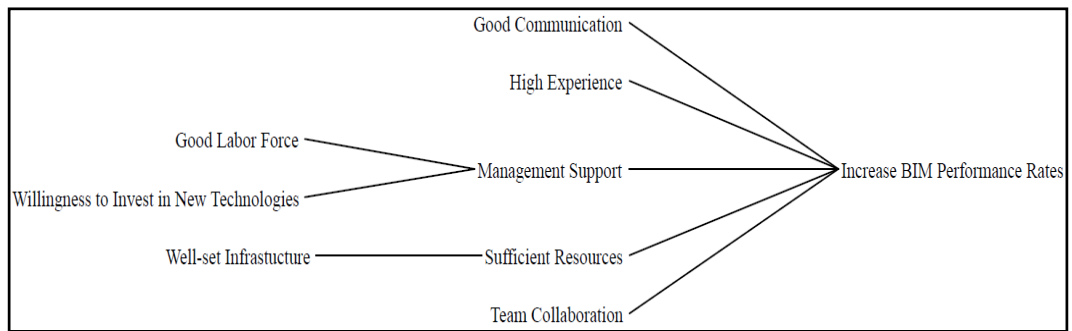


Figure 4.11: Components that increase BIM performance.

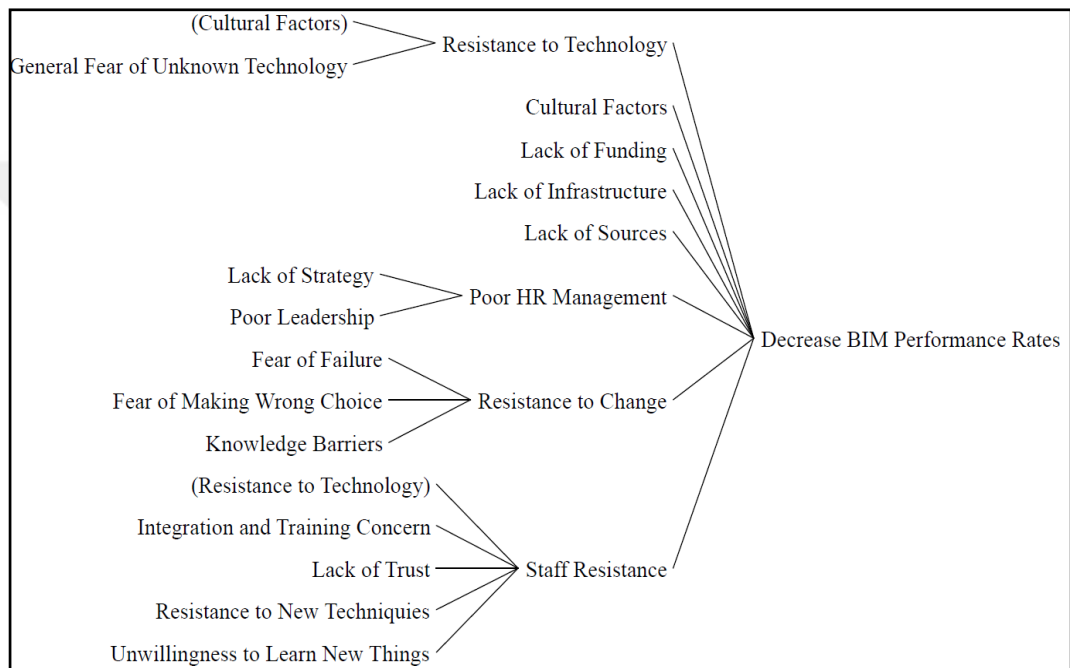


Figure 4.12: Components that decrease BIM performance.

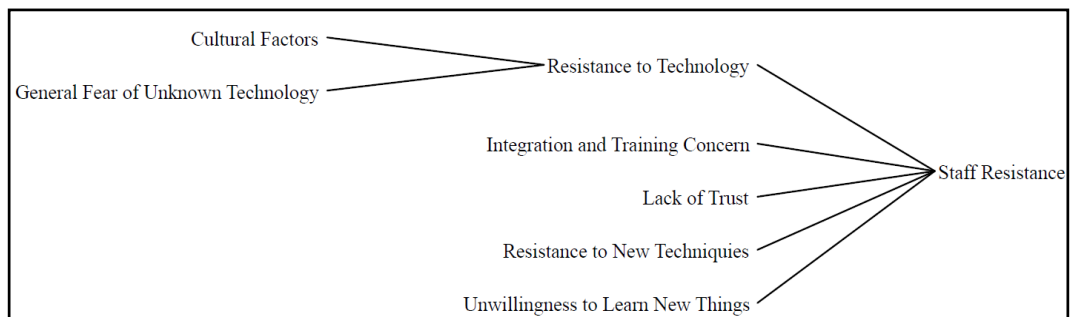


Figure 4.13: Components of staff resistance.

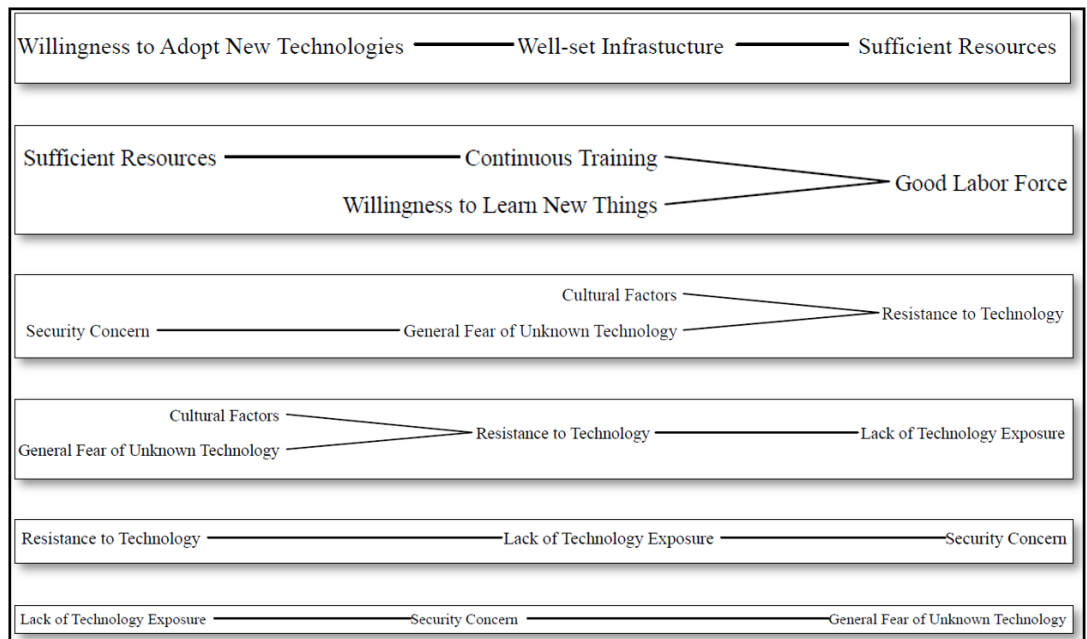


Figure 4.14: Other component relationships.

The feedback loop is a process where a system's output influences its own future behavior. Feedback loops can be good or negative, depending on how an influence is operating, and crucial in describing how systems change over time. Understanding the feedback loops that make up a system allows one to forecast and influence the behavior of the system.

Positive feedback loops intensify a system's changes. When an increase in demand for a product causes an increase in production, which then increases demand for the product, and production of the good is influenced by demand, which in turn influences demand, and so on. Positive feedback loops can cause a system to evolve quickly and exponentially.

Increase Lean-BIM Performance: Loop 1: Reinforced loop (+)

Sufficient Resources → (+) Continuous Training → (+) Good Labor Force → (+) Willingness to Learn New Things → (+) Willingness to Adopt New Technologies □ (+) Well-set Infrastructure → (+) Sufficient Resources.

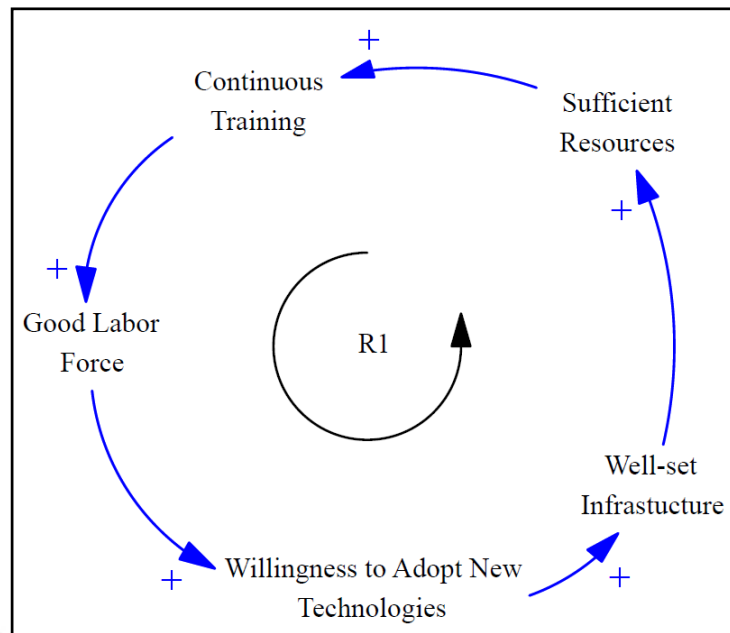


Figure 4.15: Reinforced loop 1(R1).

Decrease LEAN-BIM Performance: Loop 2: Reinforced loop (+)

Resistance to Technology → (-) Lack of Technology Exposure → (-) Security Concern
 → (-) General Fear of Unknown Technology → (-) Resistance to Technology.

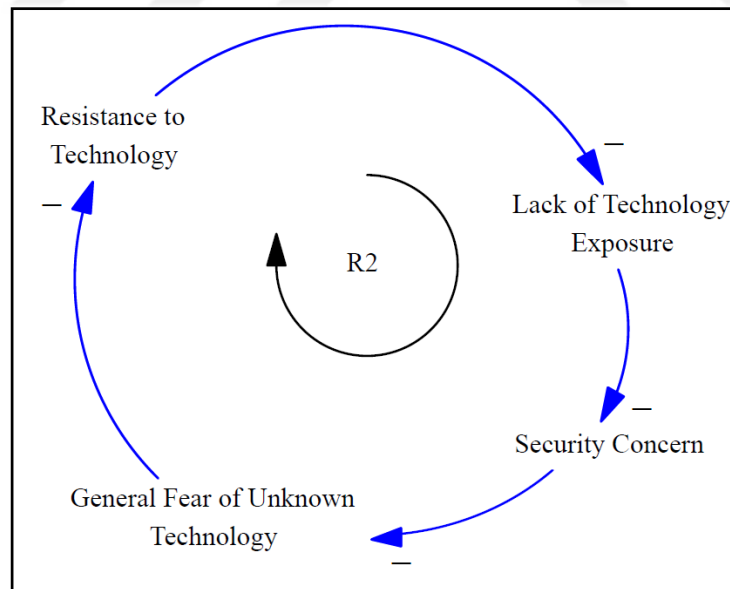


Figure 4.16: Reinforced loop 2(R2).

Negative feedback loops stifle or counteract developments in a system. A negative feedback loop is created, for instance, if an increase in the price of a product causes a drop in demand, which then causes a drop in the price of the product. The product's

high price decreases demand, which lowers the price further down the line. Negative feedback loops have the tendency to preserve equilibrium and stabilize a system.

4.2.5. Defining Impact Factors and Mathematical Equations

The impact factors determined by the survey study were added to the initial values of the variables during the modeling.

Impact factors for 4 stock levels are written in the equation section for stock levels in the program. It has been tried to determine the effect ratios of the variables on the stock level with the established equations and the coefficients added to the equations.

The impact factors are expressed below, both with the images taken from the program and by writing the mathematical equations as equations.

The screenshot shows a software interface for editing a variable. The title bar reads "Edit: Decrease BIM Performance Rates". The interface is divided into two main sections: "Variable Information" on the left and "Edit a Different Variable" on the right.

Variable Information:

- Name:** Decrease BIM Performance Rates
- Type:** Auxiliary (dropdown menu)
- Sub-Type:** Normal (dropdown menu)
- Units:** Dmnl (dropdown menu) with a "Check Units" button and a "Supplementary" checkbox.
- Group:** untitled3 v11-son ea (dropdown menu) with "Min" and "Max" buttons.
- Equations:** A text area containing the following equation:

$$0.6571 * (\text{Cultural Factors}) + 0.8 * (\text{Lack of Funding}) + 0.8571 * (\text{Lack of Infrastructure}) + 0.8286 * (\text{Lack of Sources}) + 0.6571 * (\text{Poor HR Management}) + 0.8857 * (\text{Resistance to Change}) + 0.8857 * (\text{Resistance to Technology}) + 0.8 * (\text{Staff Resistance})$$

Edit a Different Variable:

- A dropdown menu set to "All".
- Buttons: "Search Model", "New Variable", "Back to Prior Edit", and "Jump to Hilite".
- A list of variables: "Unwillingness to Learn New Things", "Waste Reduction", "Well-set Infrastructure", "Willingness to Adopt New Technol...", "Willingness to Invest in New Techn...", and "Willingness to Learn New Things".

Figure 4.17: Defining mathematical equation "Decrease BIM Performance".

Decrease BIM Performance Rates= $0.6571 * (\text{Cultural Factors}) + 0.8 * (\text{Lack of Funding}) + 0.8571 * (\text{Lack of Infrastructure}) + 0.8286 * (\text{Lack of Sources}) + 0.6571 * (\text{Poor HR Management}) + 0.8857 * (\text{Resistance to Change}) + 0.8857 * (\text{Resistance to Technology}) + 0.8 * (\text{Staff Resistance})$.

Figure 4.18 shows the 'Edit: Increase BIM Performance Rates' dialog box. The 'Variable Information' section includes fields for Name, Type (Auxiliary), Sub-Type (Normal), Units (Dmnl), and Group (.untitled3 v11-son ea). The 'Equations' section displays the mathematical formula: $0.9143 \times (\text{Good Communication}) + 0.8571 \times (\text{High Experience}) + 0.8 \times (\text{Management Support}) + 0.8857 \times (\text{Sufficient Resources}) + 0.9429 \times (\text{Team Collaboration})$. The 'Edit a Different Variable' section on the right provides a list of variables to choose from, including 'Unwillingness to Learn New Things', 'Waste Reduction', 'Well-set Infrastructure', 'Willingness to Adopt New Technol...', 'Willingness to Invest in New Techn...', and 'Willingness to Learn New Things'.

Figure 4.18: Defining mathematical equation "Increase BIM Performance".

Increase BIM Performance Rates=0.9143*(Good Communication) +0.8571*(High Experience) +0.8*(Management Support) +0.8857*(Sufficient Resources) +0.9429*(Team Collaboration).

Figure 4.19 shows the 'Edit: Decrease Lean Performance Rates' dialog box. The 'Variable Information' section includes fields for Name, Type (Auxiliary), Sub-Type (Normal), Units (Dmnl), and Group (.untitled3 v11-son ea). The 'Equations' section displays the mathematical formula: $0.7714 \times (\text{Challenges of Regulations}) + 0.7429 \times (\text{Lack of Coherent Vision}) + 0.8286 \times (\text{Lack of Coordination}) + 0.8 \times (\text{Lack of Funding}) + 0.8286 \times (\text{Lack of Sources}) + 0.6857 \times (\text{Lack of Standards}) + 0.7714 \times (\text{Market Uncertainty}) + 0.6286 \times (\text{Poor HR Management}) + 0.8571 \times (\text{Resistance to Technology}) + 0.8857 \times (\text{Resistance to Change}) + 0.8571 \times (\text{Avoiding to Customer Satisfaction})$. The 'Edit a Different Variable' section on the right provides a list of variables to choose from, including 'Unwillingness to Learn New Things', 'Waste Reduction', 'Well-set Infrastructure', 'Willingness to Adopt New Technol...', 'Willingness to Invest in New Techn...', and 'Willingness to Learn New Things'.

Figure 4.19: Defining mathematical equation "Decrease Lean Performance".

Decrease Lean Performance Rates= 0.7714*(Challenges of Regulations) +0.7429*(Lack of Coherent Vision) +0.8286 *(Lack of Coordination) +0.8*(Lack of Funding) +0.8286*(Lack of Sources) +0.6857*(Lack of Standards) +0.7714*(Market Uncertainty) +0.6286*(Poor HR Management) +0.8571*(Resistance to Technology) +0.8857*(Resistance to Change)+0.8571*(Avoiding to Customer Satisfaction)

Edit: Increase Lean Performance Rates

Variable Information		Edit a Different Variable	
Name	Increase Lean Performance Rates	All	Unwillingness to Learn New Things
Type	Auxiliary	Search Model	Waste Reduction
Sub-Type	Normal	New Variable	Well-set Infrastructure
Units	Dmnl	Back to Prior Edit	Willingness to Adopt New Technol...
Check Units	☐	Jump to Hilit	Willingness to Invest in New Techn...
Supplementary	☐		Willingness to Learn New Things
Group	.untitled3 v11-son ea		
Min			
Max			
Equations $0.7429 \cdot (\text{Adoption of Value Engineering}) + 0.8286 \cdot (\text{Avoiding Excess Inventory}) + 0.8857 \cdot (\text{Development of Lean Thinking}) + 0.9714 \cdot (\text{Good Communication}) + 0.7429 \cdot (\text{High Experience}) + 0.9429 \cdot (\text{Management Support}) + 0.8571 \cdot (\text{Sufficient Resources}) + 1 \cdot (\text{Team Collaboration}) + 0.9714 \cdot (\text{Waste Reduction})$			

Figure 4.20: Defining mathematical equation ": Increase Lean Performance".

Increase Lean Performance Rates = $0.7429 \cdot (\text{Adoption of Value Engineering}) + 0.8286 \cdot (\text{Avoiding Excess Inventory}) + 0.8857 \cdot (\text{Development of Lean Thinking}) + 0.9714 \cdot (\text{Good Communication}) + 0.7429 \cdot (\text{High Experience}) + 0.9429 \cdot (\text{Management Support}) + 0.8571 \cdot (\text{Sufficient Resources}) + 1 \cdot (\text{Team Collaboration}) + 0.9714 \cdot (\text{Waste Reduction}) + 0.8571 \cdot (\text{Resistance to Technology}) + \text{Unwillingness to Learn New Things}$.

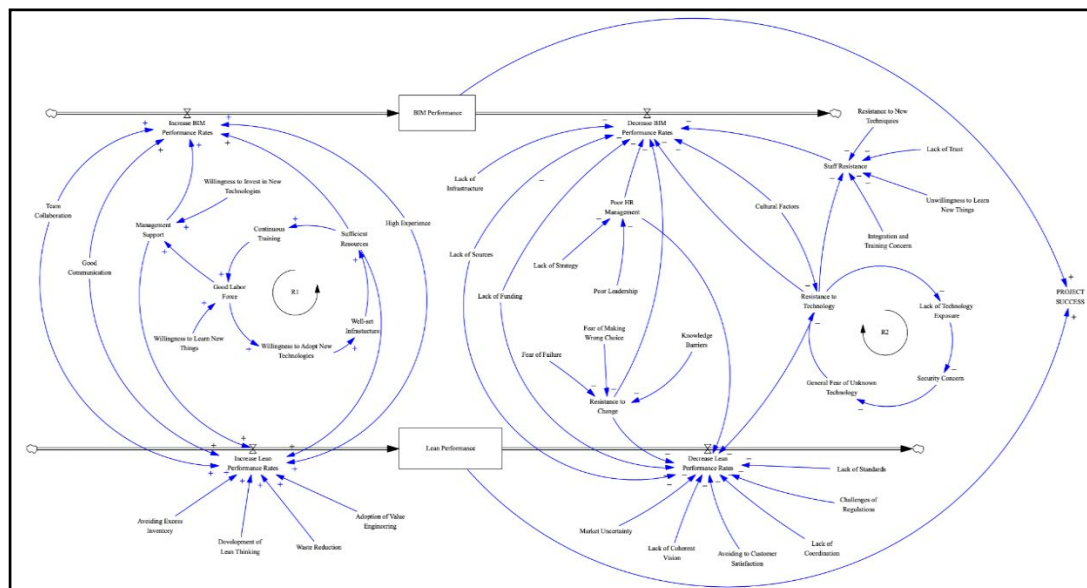


Figure 4.21: Completion of the modeling phase.

4.3. Analyzing the System Model

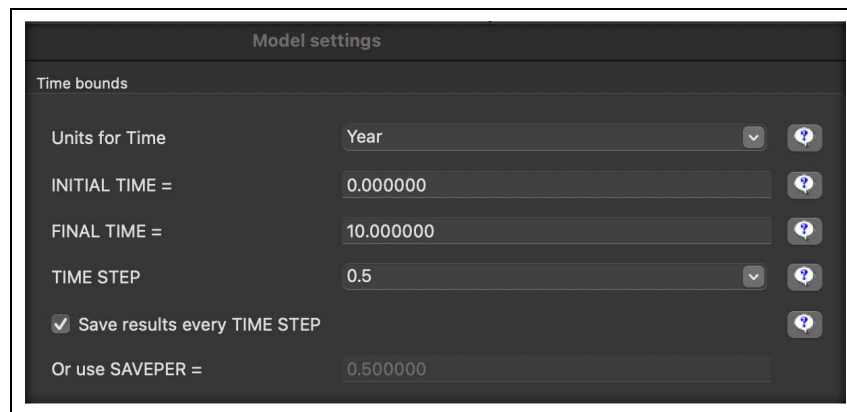


Figure 4.22: Determining model time settings.

The system model created for the Lean-BIM interaction was analyzed in line with the ten-year definition.

The increase amounts for the defined ten-year time period were determined as half a year in January and the results were visualized according to this increased amount.

With the analyzes made, the time-dependent effects of the variables in the system model were observed, and the Lean-BIM interaction and the effect of this interaction on the project success were tried to be measured.

As seen in the Figure 4.23, there are 59 symbols in total in the system model. With this model, lean performance and BIM performance were tried to be measured. For this, 2 inventory variables, named Lean Performance and BIM performance, are defined in the system model. There are increasing and decreasing flows that affect these two performances. The increasing and decreasing flows, consisting of 4 variables in total, are defined with the "Level" feature in the Vensim PLE program. This means that the variables associated with them affect the stock level.

Model settings	
Model information	
Symbols :	59
Lookups :	0
Levels :	4
Auxiliaries :	17
Data :	0
Initial :	0
Constants :	31
Total :	53

Figure 4.232: Variables defined in the model.

Euler's equation method was used as the integration method for model analysis.

For model analysis, the variable units were checked and then the model was analyzed.

Additional(intermediate) variables are defined in the system model as "Constant" and "Auxiliary" and as the constant variable types.

2 types of loop diagrams are defined for additional variable types in the system model. These cycles were named R1 and R2 in the model and exhibited reinforcing properties.

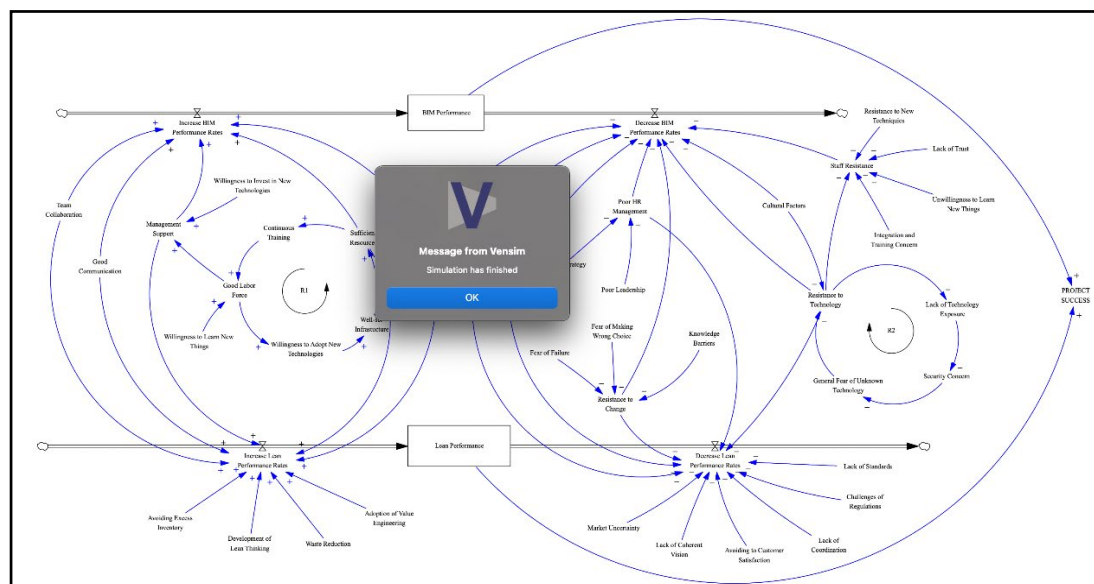


Figure 4.24: Completion of model analysis.

4.4. Assessment of Model Results

The system model has been revised several times to include variables in the most basic sense and to remove unnecessary variables from the system model. Then, analyzes were carried out depending on the model that was qualitatively examined and evaluated.

With the model analysis, the effects of the variables on each other were examined. The variables created for Lean principles and BIM were put into interaction with causal loop diagrams, and results were obtained for determining the interactions. Following these results, some policy recommendations were made.

Lean tools and methods evaluated in the literature were examined in detail and the effects of these tools on lean performance in the system model were also added to the model.

While there are nine variables in the model that affect the increase in lean performance, there are five variables that decrease lean performance.

The BIM processes discussed in the literature are examined in detail and the effect of this project management process on the project success depends on the BIM performance and lean construction interaction in the system model included in the model [Nguyen et al., 2019], [Schöttle et al., 2014].

There are 8 variables in the system model that reduce BIM performance.

BIM is a revolution in the construction industry with its innovations and contributions to project management processes [Eastman et al., 2011]. The new method brought by BIM, technological developments [Kagioglou et al., 2011] and the digitalization process [Eadie et al., 2013], along with the shortening of project durations [Koskela et al., 2002], the increase in productivity [Travaglini et al., 2014], in the sector, and the productivity increase of the sector stakeholders are given as examples of these developments [Nadeem et al., 2008]. In addition, the difficulties in the implementation [Demirkesen et al., 2019] and adoption of BIM and the disruptions in the transition to BIM necessitate the continuation of traditional project management processes [Tivendale et al., 2015].

While there are five variables that decrease lean and BIM performance in the system model, there are five variables that affect the increase of BIM and Lean performance.

The analysis of the model is set to run for ten years (one hundred twenty months). After the analysis, the results of the dynamic model, which worked for ten years, were explained with graphics in order to see the results of the interactions and make evaluations.

The horizontal axis of the graphs is to show the changes that have occurred over a ten-year period. The vertical axis of the graphs is expressed as a dimensionless unit (Dmnl) showing time-dependent changes.

There is no harm in expressing the vertical axis as dimensionless since the aim is to evaluate time-dependent relationships and to determine some policies.

According to the model results, some evaluations were made by examining the changes on an annual basis and they are as follows.

The change in BIM performance over ten years is given in the Figure 4.25 below.

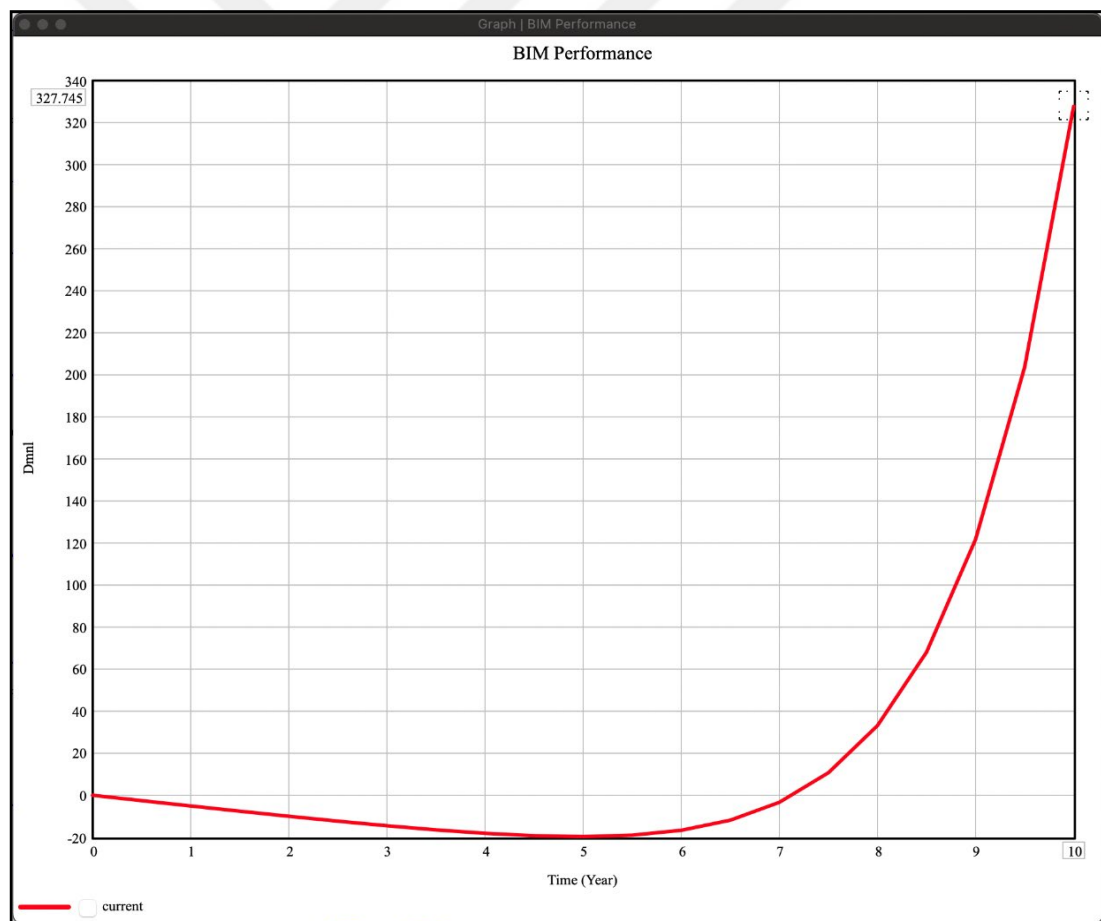


Figure 4.25: Change of BIM performance over the years.

According to the results of the analysis, BIM thinking and BIM in the sector applications are not quite common [Singh et al., 2011] and some problems occur in

the transition to BIM as discussed in the previous sections [Tauriainen et al., 2016] etc. Due to the circumstances, BIM performance affects project success in the first years of interaction in a negative way as opposed to a positive one [Bryde et al., 2013]. There are many reasons, such as the lack of adoption of BIM among these stakeholders, the persistence of resistance to change in the first years, and inefficiencies in the workforce due to the problem of qualified personnel [Tezel et al., 2020].

As discussed in the challenges in going to BIM before, companies or firms are considering technological innovations and some changes in the transition to BIM [Tulenheimo, 2015]. Because the use of BIM and BIM-based programs brings with it some difficulties such as learning, using the programs, and following some developments and processes for cooperation [Ullah et al., 2019].

As a result of the effects of some variables on the model that affect BIM and Lean performance in the definition of the system model in the first seven years, BIM performance exhibits a bad negative. Then, depending on the active use and implementation of BIM processes in the next 3-year period, it allows sector stakeholders to adopt BIM and to overcome the obstacles to BIM adoption, allowing BIM performance to be positive [Sacks et al., 2010].

In short, when BIM performance is evaluated over a ten-year period, it is concluded that adapting to BIM has a positive effect on project success after its seventh year. When the ten-year period determined within the scope of the study is increased, it is thought that the increase in BIM performance will continue and increase exponentially.

The change in lean performance over the years is shown in the Figure 4.26.

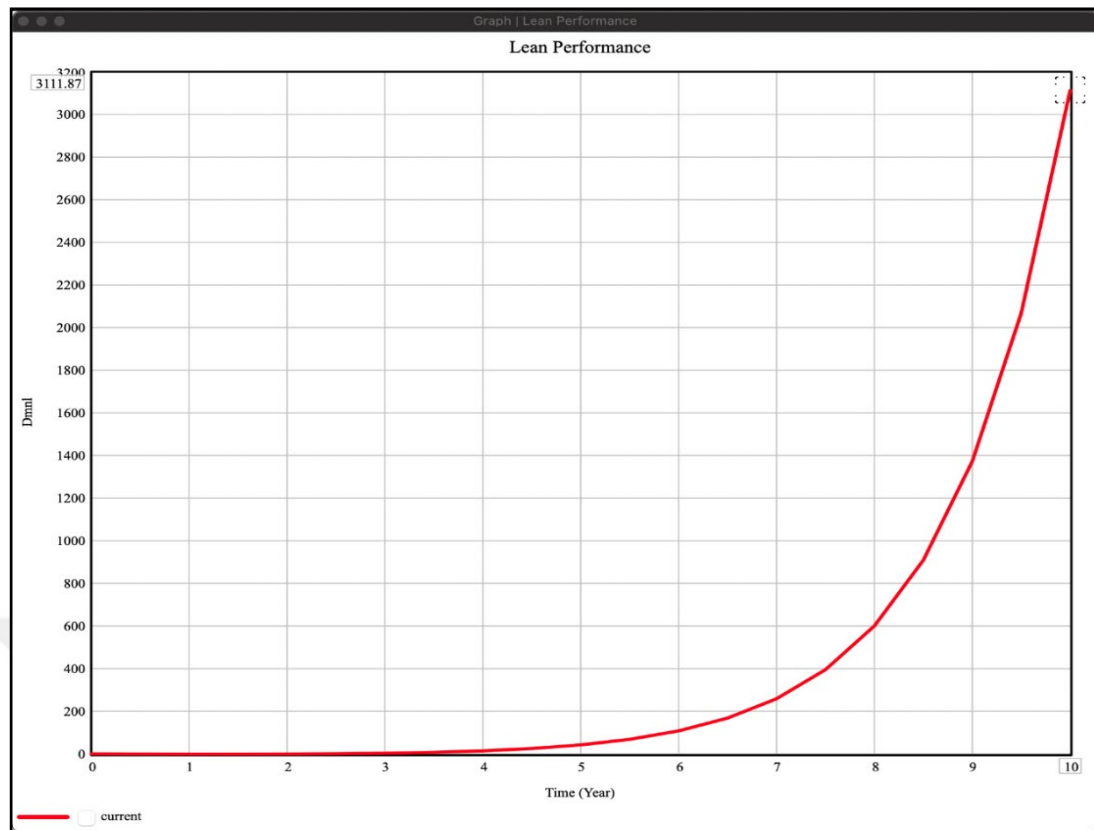


Figure 4.26: Change of LEAN performance over the years.

From the first moment of the ten-year period, lean performance will enable the lean philosophy to be adopted in much better conditions, with the continuous use of lean tools and applications. Accordingly, it is thought that lean principles together with continuous improvement and new methods to be used for the construction sector will reveal an indispensable management approach for the construction sector.

In addition, project success and BIM performance will also be positively affected, thanks to a lean performance that provides continuous improvement and transformation [Sacks et al., 2010].

The lean performance will make it possible for the lean concept to be applied in much better circumstances from the very beginning of the ten-year term, with the constant usage of lean tools and applications [Alarcón, 1997], [Zhang and Chen, 2016]. Accordingly, it is anticipated that applying lean concepts, continuous improvement, and innovative techniques will disclose a crucial management strategy for the construction industry [Sepasgozar et al., 2020], [Tezel et al., 2020].

The lean performance that offers continual improvement and transformation will also have a favorable impact on project success and BIM performance.

Lean performance and BIM performance results are expressed on the same Figure 4.27 Lean performance increases from the first moment and BIM performance increases from the seventh year.

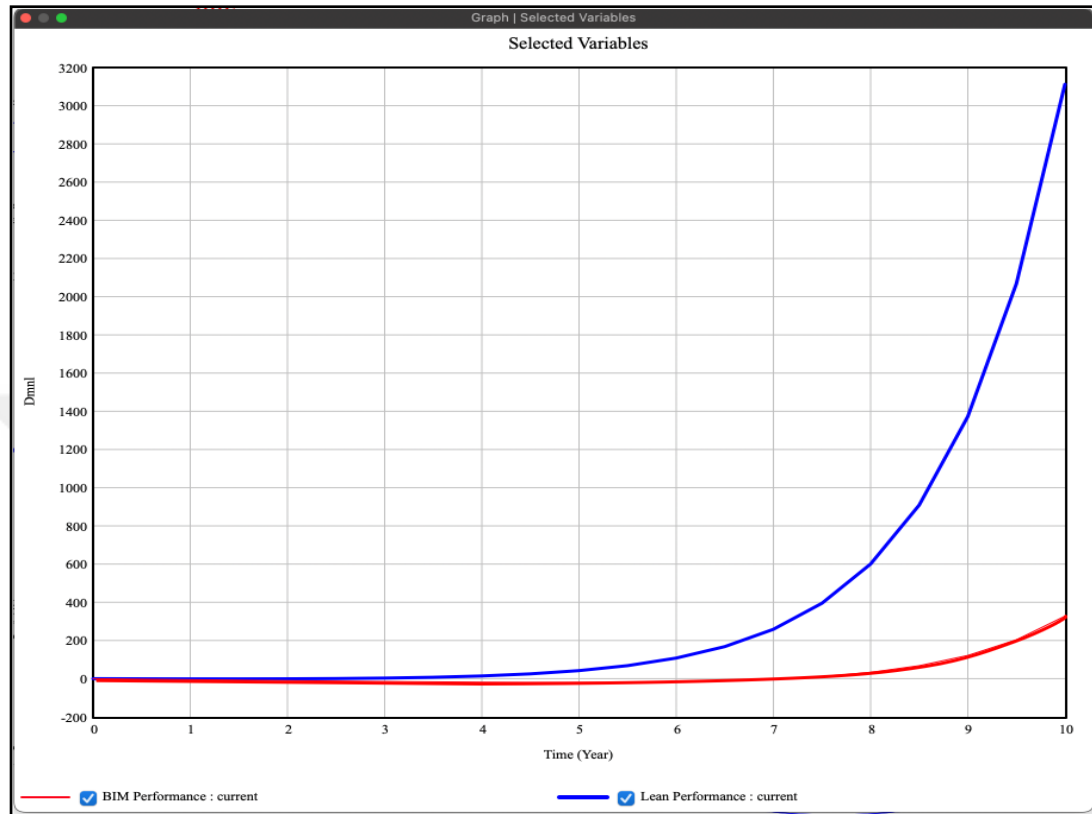


Figure 4.27: Lean and BIM performance.

Due to some reasons, especially hardware and cultural problems in the transition to BIM, BIM does not show an increase in lean performance from the first moment. However, according to the model results, it can be said that BIM also provides benefits for companies and firms at the end of the seventh year [Sacks et al., 2010]. In fact, BIM is very beneficial for stakeholders and project processes from the very first moment. However, it can be concluded that business processes and stakeholders will be adversely affected, since there are some investment costs from the first moment and companies face serious difficulties in the transition to BIM [Evans and Farrell, 2021]. However, it can be said that these two innovative approaches help to break the resistance created by the sector stakeholders and the barriers to adoption.

In Figure 4.28, where Lean Performance, BIM performance and Project success are given together, three main levels in the System model are examined.

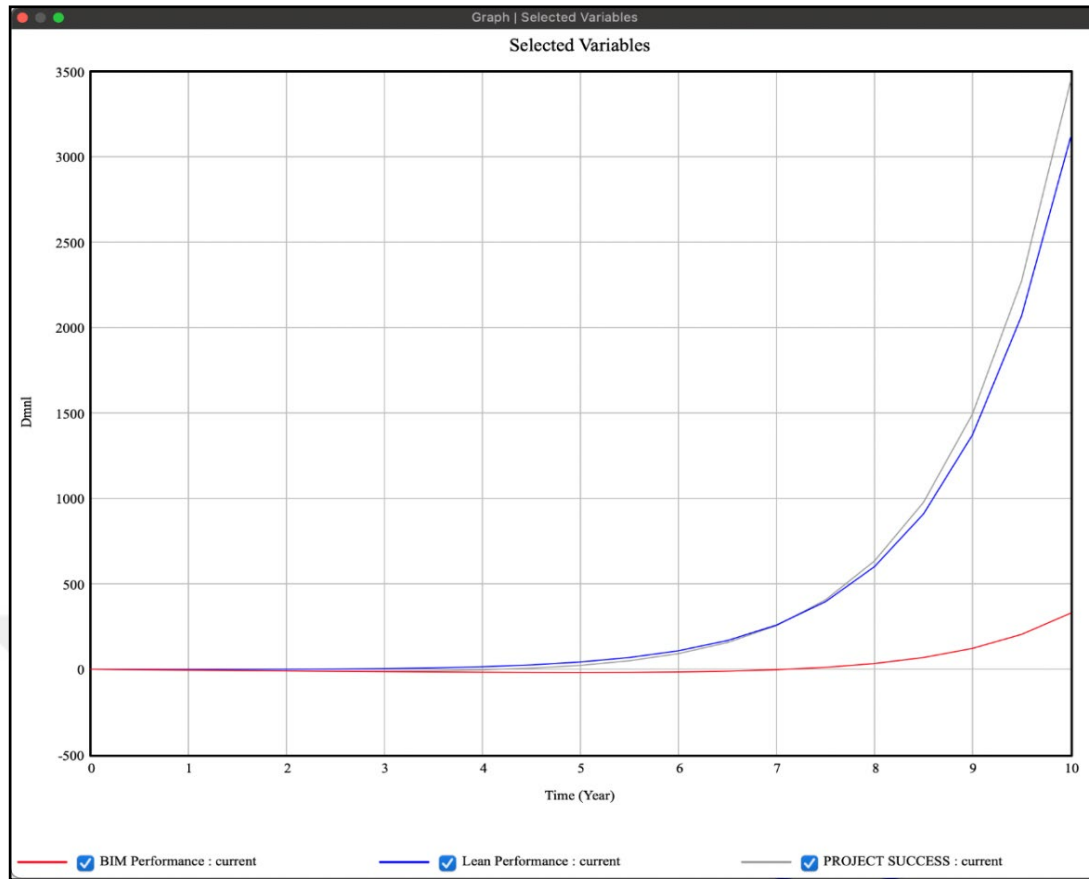


Figure 4.28: Performance of lean and BIM, project success interaction graph.

According to the result of this graph, it is observed that lean and BIM interaction are actually very beneficial as a contribution to the literature. Lean principles and BIM are not widely used for many reasons, especially the bad image of the construction industry and resistance to change year [Sacks et al., 2010], [Demirkesen et al., 2019], [Tezel et al., 2020]. However, as can be seen from the interaction graph, they bring very useful and useful solutions for the construction industry. Both lean and BIM performance increase project success.

4.5. Model Testing and Validity

In this chapter, the validity of the model is analyzed. For the validity of a system model, it is defined as the demonstration of some usefulness according to the objectives of the problem addressed [Barlas, 2002]. Therefore, some validation procedures were used to discuss "how useful" the model is, considering its purpose [Sansarcı, 2016].

4.5.1. Boundary Adequacy Test

This test is called the boundary fit test. This test is a test performed to determine whether the concepts in the evaluated system model are internal or external to the model, depending on the dynamic hypothesis. With this test, it is determined whether the boundaries of the model formed within the framework of the variables determined for the model are sufficient [Sterman, 2000].

It is the type of test that defines that the boundaries of the emerging model should not be exceeded from the moment the more dynamic hypothesis and complex problem are defined.

The internal and external parameters set for the model determine the boundaries of the system model and dynamic problem. In previous studies, it was examined how the problem and similar problems defined in this thesis were handled and concluded and how they were consistent with the results obtained in the system model. Within the scope of the literature, the effects of the variables discussed in the previous sections on each other were correctly determined, and by examining the model results, it was determined that the relations between the variables were sufficient within the model limits.

Secondly, the system model created within the scope of the dynamic hypothesis can be shared with experts, and approval of the model can be obtained.

With the boundary adequacy tests, the system model was finalized after a few stages by determining the boundaries of the most basic variables and the relations between these variables and evaluated.

4.5.2. Structure Assessment Test

This test is performed to evaluate the structure of the system model. It is carried out to determine whether the direction of the cause-and-effect arrows in the model, the direction of the stock-flow diagrams, and the relationships between all variables in the model are correct.

In general, this type of test is mostly supported by literature studies. If an evaluation is made of the lean-BIM interaction discussed in this thesis, it is thought that lean

and BIM processes described in the literature have very beneficial effects on project management processes in the construction industry.

However, due to insufficient academic studies and practices, this situation has not been adequately investigated. It is possible to say that the system model developed as part of the thesis, as well as the lean and BIM processes, bring many innovations to the construction industry.

Evaluations were made for the solution of this problem with the system model and dynamic relations. Within the framework of established relationships, it has determined which variable influenced lean and BIM performance. While the effects of some variables on each other and on the project, success are very clear, the effects of some variables on the model and on the project, success are expressed more clearly thanks to the system model.

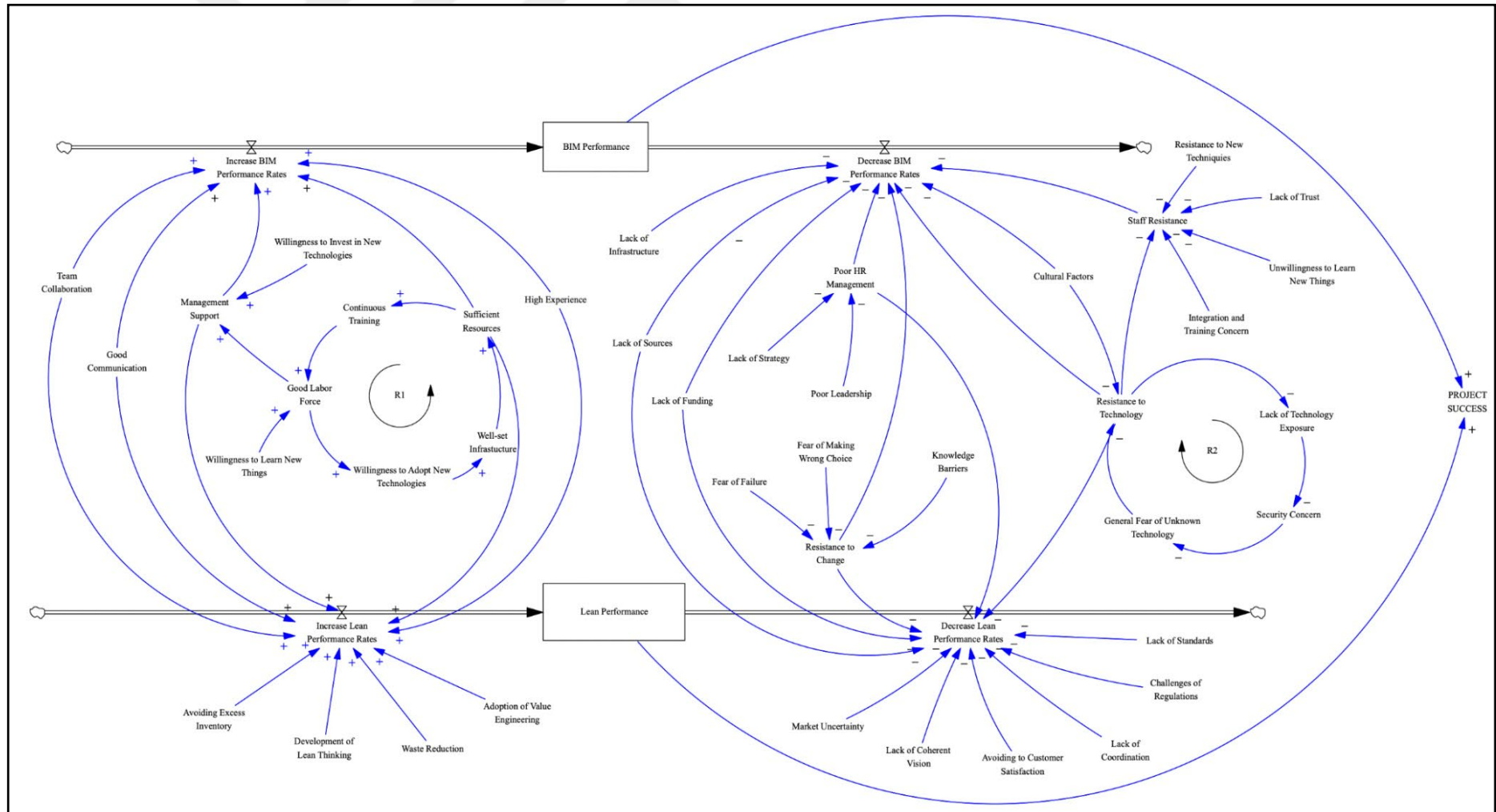


Figure 4.29: Lean and BIM interaction SD model.

5. CONCLUSIONS

5.1. Conclusions

In this study, the connections between lean applications and BIM tools were revealed based on an in-depth literature review. A comprehensive literature study was conducted for lean, BIM, lean-BIM interaction, and system dynamics approach. Existing studies and lean-BIM tools were examined in detail and components of lean applications and BIM tools were determined. Interviews were held with experts to explore the integration of lean applications and BIM tools. Then, the effects of these components were asked of the experts through a questionnaire study. A conceptual system dynamics model was created according to the determined components and the results of the survey study. The interaction between the system dynamics model and this synergy was explained and tested through a conceptual model.

Depending on the tests performed, the effects of the variables considered on each other were determined correctly. The results of the analysis model were examined, and it was determined that the relations between the variables were sufficient within the model limits.

Lean principles and BIM are not widely used for many reasons, including a bad image of the construction industry, finding the industry's complex and dynamic dynamics, and resistance to change. However, in the analysis results, such as the explanations, the lean-BIM interaction resulted in very useful and useful solutions for the construction industry. Both lean principles and BIM practices have been found to improve the processes and performance of construction projects.

According to the analysis results of the model, BIM did not increase the success of the project from the first moment. The reason for this is that there are some reasons, especially hardware and cultural problems in the transition to BIM. BIM was far behind for interruptions and project processes from the first moment, but it was concluded that business processes and results would be adversely affected as there are some investment costs from the first moment and companies will face serious difficulties in transitioning to BIM. However, according to the model hardware, at the end of the seventh year, it was seen that BIM also benefited their loads and companies.

Based on the analysis archives, the first and the moment lean performance was adopted for a project contributed to the success of the project. In addition, project success and BIM performance also affect positively thanks to lean performance. It showed the spread of project results and project success due to the creation of much better work with the adoption and consumption of lean tools and measures. It has been revealed that the use of continuous views and many simple methods for the construction sector will reveal an indispensable understanding of management for the construction sector from lean principles.

5.2. Suggestions and Further

As the proliferation and adoption of lean principles and BIM tools in the construction industry increases, it is likely that they will become more valuable and necessary for construction projects. Depending on the interaction of Lean and BIM, processes will show continuous improvement. Apart from this, the solution to the postponed problems of the sector will only be possible by bringing and adopting this and similar approaches to the sector. In addition, the rapid adoption and application of lean and BIM in the construction industry will positively affect project costs, industry relations, better quality collaborations, and the quality of work. With the benefits of BIM software, it is important to reduce the workload and unnecessary working time, which is one of the biggest wastes. For this reason, lean and BIM processes need to find a place in the construction sector in order for radical changes in the sector to occur. In this context, the effects and innovations of lean and BIM interactions on construction projects or project processes should be further investigated within the framework of analysis, survey, and case studies.

Models such as the lean-BIM interaction system model developed based on the survey study should be established, analyses should be expanded, and studies should be carried out for different scenarios. Finally, there is a need for further work on some of the problems given below and their solutions.

Awareness and leadership training should be organized for industry stakeholders, especially white-collar workers, and project managers, on lean construction and BIM. It is recommended to support academic studies and to cooperate with industry

representatives and the academia-private sector. In addition, it is recommended to include, and process lean and BIM concepts in engineering, architecture, and business departments in education curricula.

The vision and desire of the “Customer”, which consists of the largest customer states as well as private sector representatives, should be increased. The concept of value needs to be embraced, from industry employees to the customer at the top of the pyramid to the industry representative at the bottom. With the incentives and demands of customers, it will be possible for lean construction and BIM processes to become widespread in the construction industry. More work should be done on the barriers to this.

Depending on the benefits and contributions of lean construction and BIM concepts to the industry, training, live training, sessions, and studies should be created and supported. It is necessary to conduct specific training for industry stakeholders who know and know lean principles but do not have sufficient knowledge about BIM or for industry employees who have knowledge of BIM but do not have an idea about lean principles.

Awareness and coping with problems training should be organized for resistance to innovations and technological developments, especially personnel resistance. Instead of producing superficial solutions to frequently encountered problems, radical solutions should be provided. In addition, it is necessary to identify the lack of knowledge and equipment and to adopt training for the solution of these problems.

Following and adapting the lean production philosophy, depending on the lack of understanding of the definition of "value" in the construction industry. In order to solve this problem, it should be investigated why the sector employees adhere to such a situation. The low sector image should be replaced by a sector image that creates value and aims for continuous improvement.

BIM and lean construction processes need to be implemented in a sustainable way throughout the project lifecycle, from the design stage to the implementation stage and even the management of the facility. Larger studies should be conducted to identify barriers to this problem.

It is necessary to train qualified human resources specialists in order to prevent the lack of human resources.

Industry stakeholders need to be encouraged to implement lean and BIM. In the construction sector, short-term relations and short-term perspectives should be replaced by long-term project management approaches and seeking to add value to the sector.



REFERENCES

- Ahmed S., Hossain M. M., Haq I., (2021), "Implementation of lean construction in the construction industry in Bangladesh: awareness, benefits and challenges", *International Journal of Building Pathology and Adaptation*, 39(2), 368-406.
- Alarcón L., (1997), "Lean construction", CRC Press.
- Anderson V., Johnson L., (1997), "Systems Thinking Basics: From Concepts to Causal Loops", Pegasus Communications Inc.
- Arayici Y., (2015), "Building Information Modeling", 978870310986, Bookboon Publisher.
- Aronson D., (1996), "Overview of systems thinking", *Systems Thinking*, 781, 398-9700.
- Ayman R., Alwan Z., McIntyre L., (2020), "BIM for sustainable project delivery: review paper and future development areas", *Architectural Science Review*, 63(1), 15-33.
- Azhar S., Ghaffarianhoseini A., Tookey J., Ghaffarianhoseini A., Naismith N., Efimova O., Raahemifar K., (2017), "Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges", *Renewable and sustainable energy reviews*, 75, 1046-1053.
- Barlas Y., (2002), "System Dynamics: systemic feedback modeling for policy analysis", *Knowledge for Sustainable Development: An Insight into the Encyclopedia of Life Support Systems*, 1131–1175.
- Bayhan H. G., Demirkesen S., Zhang C., Tezel A., (2021), "A lean construction and BIM interaction model for the construction industry", *Production Planning and Control*, 1-28.
- Bew M., Richards A., (2008), "BIM maturity levels 1-5 an integrated approach to BIM implementation", In *Proceedings of the 4th International Conference on Innovation in Architecture Engineering and Construction (AEC)*, Rotterdam, Netherlands, 15-17 June 2008.
- Bhatla A., Leite F., (2012), "Integration framework of BIM with the last planner system", *20th Annual Conference of the International Group for Lean Construction*, 28-36, San Diego, California, USA, July 2012.
- BIMgenius, (2018), "Türkiye BIM Raporu: Genel Eğilim ve Beklentiler Araştırma Raporu", BIMgenius, 1-21.
- BIS, (2011), "A Report for the Government Construction Client Group Building In-

formation Modelling (BIM) Working Party Strategy Paper”, Department for Business, 1-107, London, UK, 20 March 2011.

Borrmann A., König M., Koch C., Beetz J., (2018), “Building information modeling: Why? what? how?”, Springer International Publishing, 1-24.

Bryde D., Broquetas M., Volm J. M., (2013), “The project benefits of building information modelling (BIM)”, *International journal of project management*, 31(7), 971-980.

Chau K. W., Anson M., Zhang J., (2004), "Four-dimensional visualization of construction scheduling and site utilization", *Journal of construction engineering and management*, 130(4), 598-606.

Cheung F. K., Rihan J., Tah J., Duce D., Kurul E., (2012), "Early stage multi-level cost estimation for schematic BIM models", *Automation in Construction*, 27, 67-77.

Messner J., Anumba C., Dubler C., Goodman S., Kasprzak C., Kreider R., Zikic N., (2019), “BIM Project Execution Planning Guide (v. 2.2)”, CICRP (Computer Integrated Construction Research Program), PA, USA, July 1 2019.

Computer Integrated Construction Research Program, (2013), "BIM Planning Guide for Facility Owners, Version 2.0 ", The Pennsylvania State University, PA, USA, June 2013.

Connaughton J., Langdon D., (2011), "BIM: Report for the Government Construction Client Group, Department for Business, 1-107, London, UK, 20 March 2011.

Daniotti B., Pavan A., Lupica Spagnolo S., Caffi V., Pasini D., Mirarchi C., Mirarchi C., (2020), “Collaborative working in a BIM environment (BIM platform)”, *BIM-based collaborative building process management*, 71-102.

Dave B., Boddy S., Koskela L., (2011), “Visilean: Designing a production management system with lean and BIM”, In 19th Annual conference of the international group for lean construction, 477-487, Lima, Peru, 1 Dec 2011.

Demirkesen S., Bayhan H. G., (2020), “A lean implementation success model for the construction industry”, *Engineering Management Journal*, 32(3), 219-239.

Demirkesen S., Wachter N., Oprach S., Haghsheno S., (2019), “Identifying barriers in lean implementation in the construction industry”, In Proceedings of the 27th Annual Conference of the International Group for Lean Construction (IGLC), 157-168, Dublin, Ireland, 3-5 Jul 2019.

Doğan S. Z., ÇALĞICI P. K., Arditi D., GÜNAYDIN H. M., (2016), “Critical success factors of partnering in the building design process”, *METU Journal of the Faculty of Architecture*, 32(2).

Eadie R., Browne M., Odeyinka H., McKeown C., McNiff S., (2013), “BIM implementation throughout the UK construction project lifecycle: An analysis”, *Automation*

in construction, 36, 145-151.

Eastman C. M., Teicholz P., Sacks R., Liston K., (2008), "BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors", 3th Edition, John Wiley and Sons.

Eastman C., Teicholz P., Sack R., Liston K., (2011), "BIM Handbook, a Guide to Building Information Modelling", 2th edition, In John Wiley and Sons Inc.

Elhag M.Y., Al-Hussein M.H., Al-Hussein A., (2018), "An analysis of barriers to implementing building information modelling (BIM) in construction projects", Journal of Engineering Design and Technology, 16(3), 385-404.

Elsonoki M., Yunus R., Trigunarsyah B., (2021), "Factors Influencing Value Engineering Adoption Among the Libyan Construction Organizations: Mediating Role of Innovativeness", Central Asia and the Caucasus, 22(5), 650-675.

Evans M., Farrell P., (2021), "Barriers to integrating building information modelling (BIM) and lean construction practices on construction mega-projects: A Delphi study", Benchmarking: An International Journal, 28(2), 652-669.

Forrester J. W., (1997), "Industrial dynamics", Journal of the Operational Research Society, 48(10), 1037-1041.

Hines P., Holweg M., Rich N., (2004), "Learning to evolve: a review of contemporary lean thinking", International journal of operations and production management, 24(10), 994-1011.

Howell G., Ballard G., (1994), "Implementing Lean Construction: Reducing Inflow Variation", 2nd Annual Conference on Lean Construction, 243-258, Santiago, Chile, September 1994.

Huang B., Wang X., Kua H., Geng Y., Bleischwitz R., Ren J., (2018), "Construction and demolition waste management in China through the 3R principle, Resources Conservation and Recycling, 129, 36-44.

Kagioglou M., Arayici Y., Coates P., Koskela L., Usher C., O'Reilly K., (2011), "Technology adoption in the BIM implementation for lean architectural practice", Automation in Construction, 20(2), 189-195.

Kamat V. R., (2017), "Cultural influence on building information modeling (BIM) adoption in the AEC industry", Automation in Construction, 81, 94-102.

Kassem M. A., Ali K. N. Alhajlah H. H., (2022), "Collaboration and Risk in Building Information Modelling (BIM): A Systematic Literature Review", Buildings, 12(5), 571.

Kent D., Becerik-Gerber B., (2010), "Understanding Construction Industry Experience and Attitudes Toward Integrated Project Delivery", ASCE Journal of Construction Engineering and Management, 136(8), 815-825.

Khanzode A., Fischer M., Reed D., Ballard G., (2006), "A guide to applying the principles of virtual design and construction (VDC) to the lean project delivery process", CIFE, 1-47, Palo Alto, California, USA.

Khodeir L. M., Nabawy E. M., (2021), "Responsive human resource framework for design and building of mega housing development projects in Egypt", *Ain Shams Engineering Journal*, 12(2), 2371-2383.

Khosrowshahi F., Arayici Y., (2012), "Roadmap for implementation of BIM in the UK construction industry", *Engineering construction and architectural management*, 19(6), 610-635.

Kim H., Shen Z., Kim I., Kim K., Stumpf A., Yu J., (2016), "BIM IFC information mapping to building energy analysis (BEA) model with manually extended material information", *Automation in Construction*, 68, 183-193.

Kim K.P., Ma T., Baryah A.S., Zhang C., Hui K.M., (2016), "Investigation of readiness for 4D and 5D BIM adoption in the Australian construction industry", *Management Review: An International Journal*, 11(2), 43-64.

Kumar B., (2015), "A practical guide to adopting BIM in construction projects", *Whittles Publishing*, 120-144.

Kymmell W., (2008), "Building information modeling: Planning and managing construction projects with 4D CAD and simulations", *McGraw-Hill Education*, 7(1), 24-36.

Lansley P., (1996), "Innovation: the role of research, education and practice: in Harlow", *Construction Papers*, 59, Ascot, UK.

Li Q., Li J., Wang H., (2017), "A critical review of BIM implementation in the construction industry", *Automation in Construction*, 80, 1-11.

Liang X., Shen G. Q., Guo L., (2015), "Improving management of green retrofits from a stakeholder perspective: A case study in China", *International journal of environmental research and public health*, 12(11), 13823-13842.

Lines B. C., Smithwick J. B., (2019), "Best practices for organizational change management within electrical contractors", *International journal of construction education and research*, 15(2), 136-159.

Lkhagva-Erdene S., (2018), "Yapı Bilgi Modellemesi Kapsamında Hesaplama Komplekslerinin Entegrasyonu", *Yüksek Lisans Tezi*, Atatürk Üniversitesi.

Lu W., Chi B., Bao Z., Zetkalic A., (2019), "Evaluating the effects of green building on construction waste management: A comparative study of three green building rating systems", *Building and Environment*, 155, 247-256.

Luo L., Jin X., Shen G. Q., Wang Y., Liang X., Li X., Li C. Z., (2020), "Supply chain

management for prefabricated building projects in Hong Kong”, *Journal of management in engineering*, 36(2), 1-15.

Madanayake U., (2015), “Application of Lean Construction Principles to Enhance the Construction Performance and Flow”, *The 4th World Construction Symposium*, Colombo, 109-126, Sri Lanka, 12-14 June 2015.

Martinez P., Livojevic M., Jajal P., Aldrich D. R., Al-Hussein M., Ahmad R., (2020), “Simulation-driven design of wood framing support systems for off-site construction machinery”, *Journal of Construction Engineering and Management*, 146(7), 1-12.

Masrom A. N., Skitmore M., (2010), “Sustainability performance of construction: Conceptual models of satisfaction levels in construction projects”, In *Rethinking sustainable development: Urban management engineering and design*, IGI Global, 286-295.

Mention A. L., (2011), "Co-operation and competition as open innovation practices in the service sector: Which influence on innovation novelty?", *Technovation*, 31(1), 44-53.

Morecroft J. D., (2015), “Strategic modelling and business dynamics: A feedback systems approach”, 2th Edition, John Wiley and Sons Inc.

Nadeem A., Azhar S., Mok J. Y., Leung B. H., (2008), “Building Information Modeling (BIM): A new paradigm for visual interactive modeling and simulation for construction projects”, *First International Conference on Construction in Developing Countries*, 1, 435-46.

Nawari N.O., (2012), “BIM standard in off-site construction”, *ASCE Journal of Architectural Engineering*, 18(2), 107-113.

Nguyen P., Akhavian R., (2019), “Synergistic effect of integrated project delivery, lean construction and building information modeling on project performance measures: a quantitative and qualitative analysis”, *Advances in Civil Engineering*, 2019.

NIBS N., (2007), “National building information modeling standard, version 1, Part 1: Overview, principles, and methodologies”, National Institute of Building Sciences.

Özorhon B., (2018), “Yapı Bilgi Modellemesi İBB İstanbul Anadolu Yakası Raylı Sistem Projeleri”, 1th Edition, Abaküs Yayıncılık.

Pekeriçli M.K., Sarı R., Tanyer A.M., (2017), “Türkiye’deki mimarlık ve mühendislik firmalarında yapı bilgi modellemesi olgunluğu üzerine bir araştırma”, 11. Mimarlıkta Tasarım Ulusal Sempozyumu, 214-227, Ankara, TÜRKİYE, June 14-15.

Porwal A., Hewage K. N., (2013), “Building Information Modeling (BIM) partnering framework for public construction projects”, *Automation in Construction*, 31, 204-214.

RICS., (2014), "International BIM implementation guide", 1st edition, ICE Publishing.

Richardson G. P., (1986), "Problems with causal-loop diagrams", *System Dynamics Review*, 2(2), 158–170.

Rischmoller L., Alarcón L. F., Koskela L., (2006), "Improving value generation in the design process of industrial projects using CAVT", *Journal of management in engineering*, 22(2), 52-60.

Sacks R., Koskela L., Dave B. A., Owen R., (2010), "Interaction of lean and building information modeling in construction", *Journal of construction engineering and management*, 136(9), 968-980.

Sabol L., (2008), "Challenges in cost estimating with Building Information Modeling", *IFMA World Workplace*, 1-16.

Schöttle A., Haghsheno S., Gehbauer F., (2014), "Defining cooperation and collaboration in the context of lean construction", *22nd Annual Conferences of Lean Construction*, 1269-1280.

Sahil A.Q., (2016), "Adoption of Building Information Modeling in Developing Countries: A Phenomenological Perspective", Master's thesis, Colorado State University.

Sansarcı E., (2016), "Enflasyonun Sistem Dinamiği Modeli", Doktoral Thesis, İstanbul Teknik Üniversitesi.

Sayyadi R., Awasthi, A., (2017), "A system dynamics based simulation model to evaluate regulatory policies for sustainable transportation planning", *International Journal of Modelling and Simulation*, 37(1), 25–35.

Senge P. M., (2016), "Beşinci Disiplin: Öğrenen Organizasyon Sanatı ve Uygulaması, 17st edition, Yapı Kredi Yayınları.

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.

Sfakianaki E., Kakouris A., (2019), "Lean thinking for education: development and validation of an instrument", *International Journal of Quality and Reliability Management*, 36(6), 917-950.

Shen X., Liu K., Tang L. C., (2013), "Cost Estimation in Building Information Model", In *Proceedings of the 19th International Conference on Automation and Computing*, 555-566, London, UK, September 12-13.

Singh V., Gu N., Wang X., (2011), "A theoretical framework of a BIM-based multidisciplinary collaboration platform", *Automation in construction*, 20(2), 134-144.

Staub-French S., Poirier E. A., Calderon F., Chikhi I., Zadeh P., Chudasma D., Huang

S., (2018), "Building information modeling (BIM) and design for manufacturing and assembly (DfMA) for mass timber construction", BIM Topics Research Lab University of British Columbia, 1-101, Vancouver, BC, Canada, 8 November.

Sterman J. D., (2000), "Business Dynamics: Systems Thinking and Modeling for a Complex World", 1st Edition, McGraw-Hill.

Succar B., (2009), "Building information modelling framework: A research and delivery foundation for industry stakeholders", *Automation in Construction*, 18(3), 357-375.

Tauriainen M., Marttinen P., Dave B., Koskela L., (2016), "The effects of BIM and lean construction on design management practices", *Procedia engineering*, 164, 567-574.

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.

Tivendale L., Liu S., Xie B., Liu C., (2015), "Critical barriers to BIM implementation in the AEC industry".

Travaglini A., Radujković M., Mancini M., (2014), "Building information modelling (BIM) and project management: a stakeholders perspective", *Organization technology and management in construction: an international journal*, 6(2), 1001-1008.

Tulenheimo R., (2015), "Challenges of implementing new technologies in the world of BIM—Case study from construction engineering industry in Finland", *Procedia Economics and Finance*, 21, 469-477.

Ullah K., Lill I., Witt E., (2019), "An overview of BIM adoption in the construction industry: Benefits and barriers", In 10th Nordic conference on construction economics and organization, 2, 297-303.

Umar T., (2022), "Challenges of BIM implementation in GCC construction industry", *Engineering Construction and Architectural Management*, 29(3), 1139-1168.

Vass S., Gustavsson T. K., (2017), "Challenges when implementing BIM for industry change", *Construction management and economics*, 35(10), 597-610.

Web 1, (2020), <https://www.autodesk.com/industry/aec/bim>, (Erişim Tarihi: 03/02/2022).

Web 2, (2020), <https://bimforum.org/LOD>, (Erişim Tarihi: 20/02/2022).

Web 3, (2019), <https://campus.tekla.com/bim-maturity-levels>, (Erişim Tarihi: 20/02/2022).

Web 4, (2016), <https://bimaplus.org/news/imagining-constructions-digital-future-by-rajat-agarwal-shankar-chandrasekaran-and-mukund-sridhar>, (Eriřim Tarihi: 20/02/2022).

Web 5, (2017), <https://systemdynamics.org/what-is-system-dynamics>, (Eriřim Tarihi: 19/01/2023).

Web 6, (2017), <https://vensim.com/vensim-software/#ple>, (Eriřim Tarihi: 19/01/2023).

Web 7, (2020), <https://www.lean.org.tr/yalin-insaat-yonetimini-desteklemek-icin-bimden-yararlanma>, (Eriřim Tarihi: 11/02/2023).

Wong A., Wong F. K., Nadeem A. (2009), “Comparative roles of major stakeholders for the implementation of BIM in various countries”, *Proceeding of Changing Roles*, 23-33.

Xie H., Palani D., (2018), “Analysis of overstock in construction supply chain and inventory optimization”, In *Construction Research Congress 2018*, 29-39.

Xu J., (2017), "Research on application of BIM 5D technology in central grand project", *Procedia Engineering*, 174, 600-610.

Zadeh P., Staub-French S., Calderon F., Chikhi I., Poirier E., Chudasma D., Huang S., (2018), “Building Information Modeling (BIM) and Design for Manufacturing and Assembly (DfMA) for Mass Timber Construction”, *BIM TOPiCS Research Lab University of British Columbia, Vancouver, BC, Canada*, 8 November.

Zhang D., Gao Z., (2013), “Project time and cost control using building information modeling”, In *ICCREM 2013: Construction and Operation in the Context of Sustainability*, 545-554.

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

Zhao P. A., Wang C. C., (2014), “A comparison of using traditional cost estimating software and BIM for construction cost control”, In *ICCREM 2014: Smart Construction and Management in the Context of New Technology*, 256-264.

Zhao X., Wu P., Wang X., (2018), “Risk paths in BIM adoption: empirical study of China”, *Engineering Construction and Architectural Management*, 25(9), 1170-1187.

Zhou Y., Yang Y., Yang J. B., (2019), “Barriers to BIM implementation strategies in China”, *Engineering Construction and Architectural Management*, 26(3), 554-574.

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