Barriers to the Effective Implementation of Lean Construction and Assessment for Non-Value Adding (NVA) Activities in The Construction Industry

BY

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This thesis, written by Abdallah Faris under the direction of his thesis advisor and approved by his thesis committee, has been presented and accepted by the Dean of Graduate Studies, in partial fulfillment of e requirements for the degree of **MASTER OF SCIENCE IN CONSTRUCTION ENGENEERING AND MANAGEMENT.**

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Dedicated to my Mother and my Father, for their endless love and support throughout this journey and without whom this would have never been possible.

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For my family, my gratitude can never be put in words, your love and support have inspired me to complete this journey, and I will forever be in your debt.

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LIST OF ABBREVIATIONS

LC: Lean Construction

NVA: Non-Value Adding

TQM: Total Quality Management

JIT: Just-In-Time

TPS: Toyota Production System

RII: Relative Importance Index

VE: Value Engineering

ABSTRACT

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Lean Construction (LC) is a concept that was transitioned from the manufacturing sector, a socio-technical framework stemming from Production and Operations Management (POM) aimed at reducing waste and increasing productivity. Despite the abundance of examples citing successful implementation of LC in the literature, there seems to be a lack of evidence of application in Saudi Arabia construction industry. Therefore, this study is carried out to explore the barriers hindering the implementation of such concept in the Saudi construction industry. Furthermore, a tool was developed to embrace the sources of Non-Value Adding (NVA) activities within construction operations. The developed tool was validated through a field study.

This research was conducted through semi-structured interviews. The data collected in this research was through survey questionnaires that comprised, first, questions related to 45 identified barriers that hinder the implementation of LC. Secondly, questions related to sources of NVA activities. Surveys were distributed among Grade I and II contractors operating in the eastern province of the kingdom.

The results of implementation barriers revealed 24 hindrances, where the most critical were related to workplace, planning and concurrent design practices. In addition, the findings of the NVA activities study reveal the major sources of waste as perceived by the contractors. The major trends in the results are related to construction material, laborers, ergonomics of the task, intra-organizational and external approval and review process.

ملخص الرسالة

الاسم الكامل: عبدالله يحيى فارس

عنوان الرسالة: معوقات التطبيق الفعال للإنشاء الرشيق وتقييم الأنشطة غير ذات القيمة المضافة في قطاع الانشاءات

التخصص: إدارة وهندسة التشييد

تاريخ الدرجة العلمية: مارس، 2018

أحد المفاهيم التي تم نقلها من قطاع التصنيع هي الإنشاء الرشيق، وهي عبارة عن إطار اجتماعي-تقني، تعود أصوله لفرع الإدارة الإنتاجية والعملية ويهدف إلى تقليل الهدر وزيادة الإنتاجية. رغم وجود العديد من الأمثلة الناجحة على تطبيق الإنشاء الرشيق في أبحاث سابقة، إلا انه لا توجد العديد من الأدلة على تبني هذا المفهوم في صناعة الإنشاء السعودية. للأسباب السابقة، فإن هذه الدراسة تهدف لاكتشاف المعوقات المانعة لتطبيق هذا الممارسة في صناعة الانشاء السعودية بالإضافة لتطوير أداة لاكتشاف أسباب الهدر والأنشطة غير ذات القيمة المضافة في عمليات الانشاء. الأداة المطورة في هذه الدراسة تم استخدامها لاكتشاف الهدر في مشاريع الانشاء عبر مسح ميداني.

تم هذا البحث عبر مقابلات شبه منظمة. تم جمع البيانات الخاصة بهذا البحث عن طريق استبيان مصمم للسؤال أولا عن خمسة وأربعين معوقا لتطبيق مبدأ الانشاء الرشيق. ثانيا، تم السؤال عن مصادر الهدر والأنشطة غير ذات القيمة المضافة. تم توزيع الاستبيان على مقاولي الدرجة الأولى والثانية في المنطقة الشرقية من المملكة العربية السعودية.

تفيد النتائج بوجود أربعة وعشرين معوقا للتطبيق، أبرز هذه المعوقات يتعلق ببيئة العمل، ممارسات التخطيط والتصميم المتزامن. بالإضافة إلى ذلك، فإن نتائج الدراسة الثانية الخاصة بالأنشطة غير ذات القيمة المضافة، تكشف عن المسببات الأساسية في الهدر كما يدركها المقاولون. تشير الدراسة لعدة أسباب رئيسية للهدر تتعلق بالعمال، طبيعة المهام المناطة بهم، مواد الانشاء، وعملية المراجعة والموافقة داخل الشركات وخارجها.

CHAPTER 1: Introduction

The construction industry is a key contributor to the global economy and an important driver for economic development. However, it has struggled to evolve to cope with other industries in improving its efficiency and productivity, consequently, construction projects are falling short of their objectives, incurring cost and duration overruns (McKinsey Global Institute, 2017). Furthermore, the industry has not benefited from developments achieved in the Production and Operation Management (POM) field, as it lacks a production theory that governs the operations and value creation (dos Santos, Powell, & Sarshar, 2002). Thus, construction firms are encouraged to imitate successful managerial practices established in other industries with the aim of achieving similar gains.

Development in the construction industry can start with optimizing the operations. By eliminating processes waste while focusing on the clients' requirements, which in turn improves the quality and labor productivity. Lean Construction (LC) is considered to be helpful in this regard as it provides a holistic approach for performance improvement that combines principles such as elimination of unnecessary flow activities, standardization, customer focus and continuous improvement building upon earlier quality approaches such as Total Quality Management (TQM) and Just-In-Time (JIT). The concept originated from the Japanese industrial revolution post World War II. Since then, Japanese industry succeeded in reducing the inventory costs to the minimum which gave it a competitive edge over many western industries. The success story of lean principles in manufacturing grabbed the attention of other industries practitioners. The Lean concepts started to penetrate the construction industry to improve productivity and reduce costs. Although, the construction industry is less dependent on inventory (compared to manufacturing) still many lean tools are effective for construction projects.

This research explores the barriers that hinder the implementation of Lean Construction principles in the Saudi construction organizations as perceived by the industry practitioners through studying the related conformance factors. Moreover, the research develops an assessment tool for the Non-Value Adding (NVA) activities in project execution. Additionally, this tool was validated through a field study investigating the sources of waste and variability in execution, planning and design. This report addresses the rationale this research is based upon, the methodologies used, and the findings.

Adapting concepts from manufacturing to construction raises some challenges due to the inherent difference between the two industries. The construction industry has three main distinguishing features from manufacturing, namely, on-site production, one-of-a-kind nature and complexity. Firstly, Construction operations can be considered a site-position manufacturing, in contrary to fixed-position manufacturing. Consequently, construction is highly affected by specific site conditions. Secondly, while manufacturing features making standardized units limiting the range of customization, clients in construction play a key role throughout the project, modifying the structure by the issuance of change orders at any stage of construction (Salem, Solomon, Genaidy, & Minkarah, 2006). These differences pose a challenge to derive the lean approach to the construction context. However, academics and practitioners have realized the benefits that such a concept shift would present.

Thus, looking at the Saudi construction industry, some important questions need to be addressed in this regard:

Is the Saudi Construction industry aware of the Lean Construction Principles?

Do practices in the industry conform to the Lean Construction approach?

What factors would hinder the implementation of the Lean Construction concept?

What are the most critical sources of waste?

What are the most important practices that would result in minimization of the non-value adding activities in the jobsite?

What is the level of practice on waste minimization techniques?

1.1.Objectives

This research aims to investigate the application of the principles of Lean Construction in construction organizations in Saudi Arabia. This research is expected to contribute to the body of knowledge on productivity improvement in the Saudi construction through:

1- Exploring the barriers hindering the implementation, and the conforming practices to LC principles in the Saudi construction industry.
2- Development of a Non-Value Adding (NVA) activities assessment tool that targets planning and execution functions. In addition, exploring the source of process waste related to operations.

The findings of this research are expected to contribute in future studies related to the subject. In addition, it is aimed to draw the attention of practitioners to the problem, thus, attracting more research to handle the issues of constructions productivity and quality.

1.2.Thesis Layout

The thesis layout is organized in the following manner:

Chapter 1: Introduction

This chapter provides an introduction about the topic, addresses the need for conducting this research in the Saudi construction industry, states the objectives of the study, present the expected outcomes upon completion.

Chapter 2: Literature Review

This chapter investigates the concept of Lean Construction through an exhaustive literature review. This review includes the origin of the concept, the manufacturing versus construction process, development of the LC concept, critique of the concept, current state of implementation, barriers of implementation, models of LC conformance assessment.

Chapter 3: Research Methodology

This chapter discusses the methodologies adopted in this research in pursuance of its intended objectives. In addition, the data collection approaches, targeted population, sample size calculations, and statistical analysis means used in this study are presented.

Chapter 4: Barriers to The Effective Implementation of Lean Construction

This chapter is aimed to fulfill the requirements of objective 1. It elaborates further on the concept of lean construction through a review of the literature, presents the research methodology in detail, discusses the results and analysis of the collected data, provides general recommendations based on the study and for future research, and concludes with a conclusion drawn from the outcomes of the research.

Chapter 5: Assessment for Non-Value Adding (NVA) Activities in The Construction Industry

This chapter is intended to fulfill objective 2. It includes an extended literature review on the subject of waste and variability as defined in the lean literature. This chapter introduces a tool developed in this study aimed at assessing NVA activities in the typical construction jobsite environment. This tool was validated through a field study, where the findings are presented in this chapter along with discussion of the results and recommendations and conclusion drawn from the outcomes.

Chapter 6: Conclusion and Recommendations

This chapter presents a summary of the conclusion drawn from this research, as well as, recommendations based on Chapter 4 and Chapter 5 findings. Table 1 details the fulfillment of the research objectives along with the intended chapters. Furthermore, Figure 5 details the research methodology scheme followed throughout this study.

Table 1: Fulfillment of research objectives

Objective	Concerned Chapter
Objective 1	Chapter 4
Objective 2	Chapter 5

CHAPTER 2: Literature Review

This chapter summarizes the key studies available to date on lean construction, its origin and development, the concept shift from manufacturing to the construction context, critical views on the concept, state of implementation and LC versus Value Engineering (VE).

2.1.Origin of the Lean Principles

Lean production emerged as a new production philosophy in the Japanese automotive industry in the 1980s, and it has since proven to be a successful one, adding to the competitive advantage of the Japanese manufacturers in comparison to their opponents (Womack, Jones, & Roos, 1990). First developed at Toyota Motor Corporation, lean production is holistic approach for performance improvement with a set of underlying principles as described by Toyota executive and engineer Taiichi Ohno (Ohno, 1988) as:

- Pull-driven production
- Minimization of waste by eliminating non-value adding activities
- Doing things right the first time, implementing quality at the source
- Continuous improvement (Kaizen)
- Long-term relations with the suppliers
- Ability to produce various goods in various quantities
- Teamwork

Similarly, Womack et al. (1996) have identified the following principles as a basis for the lean model: value specification, waste elimination by value stream mapping, flow, pull production and continuous pursuit of perfection. Furthermore, many studies have attempted to conceptualize the lean paradigm, notably, Liker (2004) in his book titled (The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer) has defined lean principles as a pyramid model that is implemented at the shop floor and the organizational level. This model, in addition to the unique classification of lean practices, emphasizes the importance of the social aspects of an organization unlike the early TPS models. The category titled "people and partner" stresses on training and empowering employees as a lean principle, as illustrated in Figure 1. With a close examination of the literature, the lean production model has been researched extensively, referred to as the Toyota Production System (TPS), and nonstock production.

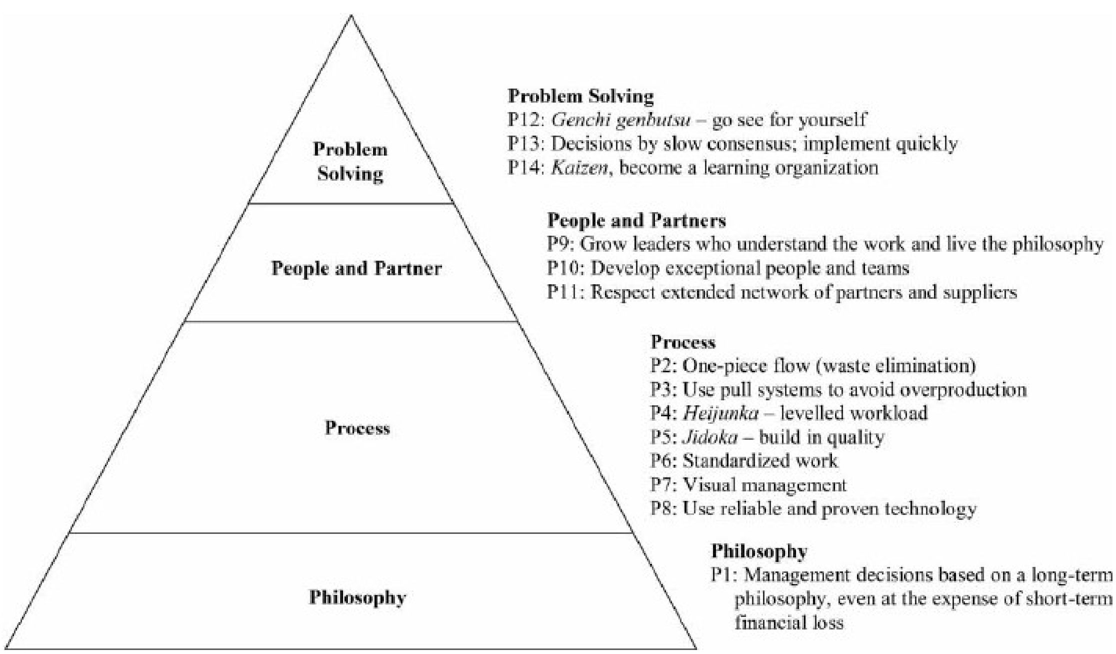

Figure 1: The Toyota Way model, Source: (Liker, 2004)

2.2.The Manufacturing Process versus the Construction Process

The construction industry, while being a U.S. $10 trillion sector globally, has been lagging in terms of projects performance, incurring cost and time overruns. This can be attributed to its remarkably poor productivity through decades in comparison to other sectors. While innovation in the manufacturing sector has resulted into great productivity gains through the emergence of several improvements such as automation and lean production, this suggests that the construction industry could benefit from similar improvement to transform its operations. (McKinsey Global Institute, 2017)

Several researchers have studied the applicability of methods originated in manufacturing to the construction industry. Sanvido & Medeiros (1990) studied areas of cross-fertilization of both industries through computer-integrated techniques that aim to solve productivity issues. Similarly, Crowley (1998) has researched the application of Business Process Reengineering (BPR) to the construction industry through the examination of concepts like Computer Integrated Manufacturing (CIM) and lean production. Moreover, Gann (1996) has described how the Japanese housing industry has benefited from the application of management practices derived from the automotive industry in fields such as design, supply-chain coordination, marketing and sales.

However, the difference between the two industry is quite evident. For instance, while manufacturing is carried out in a controlled environment that remains fairly constant throughout the production cycle, construction production is carried out in the field where equipment and workers are mobilized alongside the production process. Moreover, construction products are relatively more complex and one-of-a-kind, while manufacturing features mass production with less customization (Sanvido & Medeiros, 1990). Furthermore, unlike manufacturing, the construction industry is characterized by its project-based nature, labor intensive tasks and unpredictable demand. Nonetheless, researchers suggest that this gap could be bridged by introducing standardization into the construction process and by implementing an automated manufacturing system of off-site prefabrication and modularization (Crowley, 1998; Gann, 1996; McKinsey Global Institute, 2017).

Despite the discrepancies between the two sectors, both industries produce engineered products through the conversion of raw materials and the assembly of numerous pre-manufactured components that eventually provide a service to the end-user (Sanvido & Medeiros, 1990).

The commonality between the two industries was explained by Ballard & Howell (2003) by describing construction projects as *"temporary production systems linked to multiple, enduring production systems from which the project is supplied materials, information and resources."* This analogy enables the compatibility of the lean principles with the construction operations.

2.3.Development of Lean Construction

The improvements that the lean production concept has brought to the manufacturing industry has attracted the attention of researchers in the construction industry. The early 1990's featured the introduction of lean construction pioneered by Koskela (1992). A year later, the first conference of the International Group for Lean Construction (IGLC) was hosted in Espoo, Finland. This annual academic conference, along with the non-profit Lean Construction Institute (LCI) established in 1997, have supported the research in this field ever since.

However, the lean approach became widely recognized as a vehicle for change and performance improvement in the construction industry after being prescribed by the UK Construction Task Force report, commissioned by the Deputy Minister, as a powerful tool for "eliminating waste and delivering significant sustained improvement in efficiency and quality". Often referred to as the "Egan Report", named after the committee chairman John Egan, the report aimed to study the potential for radical change of the industry to increase its quality and efficiency (Egan, 1998).

Koskela (2000) has adapted the lean manufacturing model to the construction industry through perceiving the commonality between the two industries as being production systems, where values such as value maximization, waste minimization, and delivering the product construct the fundamentals of improvement to such system. Furthermore, Liker (2004) describes the lean construction model as an adaptation of the basic lean motives, such as elimination of waste, reduction of cycle-time, minimization of variability, a pull-driven strategy, continuous flow and continuous improvement, to the construction industry context.

Departing from (Ohno, 1988; Shingo, 1990) manuscripts on the lean manufacturing techniques implemented at Toyota, and a review on several studies relating the compatibility of these techniques with the construction industry, Salem, Solomon, Genaidy, & Minkarah (2006) have identified four areas of improvement that apply to the construction context: flow variability, process variability, transparency and continuous improvement.

Flow variability in the manufacturing context addresses the fluctuation of demand that impacts the production. Therefore, there is a need for production leveling controls that can adjust the production volume along with the resources allocation. This principle affects the construction process as the late delivery of a trade may interfere with the overall completion time of the project. Techniques such as the Last Planner System, developed by Ballard (2000), realizes this fact and assigns the planning of tasks to the people whom are responsible of the completion of those assignments at the operational level.

Process variability underlies two techniques, namely autonomation and fail-safe. Autonomation (or intelligent automation) is implementing quality at the source of production where defects can be detected, investigated and prevented from flowing to the next processes through the implementation of fail-safe devices (Shingo, 1990). In the construction context, quality is assured after the installation by testing the conformance to the quality standards through defect detection, and fail-safe actions can be implemented to insure a first-time compliance on all job tasks. Moreover, the fail-safe technique can be utilized to track safety in the jobsite, through exploring the potential hazards of the work assignments and implementing the appropriate countermeasures (Salem et al., 2006).

Transparency principles implies the housekeeping of the job site through the five S's technique which includes: sort, straighten, standardize, shine and sustain. These actions result in a more transparent jobsite, allowing the efficient flow of materials between storage locations and the job tasks locations (Salem et al., 2006).

Salem et al. (2006) argue that the continuous improvement (Kaizen) cannot be linked to specific technique, where all improvement initiatives imply problem solving and creative thinking as means to continuous improvement. However, the lean approach includes a set of approaches to continuous improvement such as quality circles, huddle meetings, first-run studies and the Plan, Do, Check, Act (PDCA) cycle.

2.4.Critical Views on Lean Construction

Despite the popularity of the lean approach among academicians and industry practitioners, and while the concept is promoted as a socio-technical framework for organizational change towards excellence, some academics argue that the literature on Lean Construction has failed to address some of its shortcomings. While the construction industry lacks a comprehensive production theory, lean construction is presented by its early advocates as a suitable tool for bridging this gap.

Critics of lean construction often cite the contrasting perspectives and the absence of a common definition as one of the major drawbacks of the literature on this concept (Green & May, 2005; Jørgensen & Emmitt, 2008). In fact, various researchers argue that the concept is poorly defined with no clear set of boundaries and has varying interpretations based on localized contexts. Furthermore, the universal applicability of the Lean approach is discredited, where lean principles seem to be taken out of context. Green (1999) argues that lean principles must be perceived within the Japanese industry setting characterized by lifelong employment, in-company enterprise unions and promotion based on the length of service. In addition, the Japanese manufacturer-supplier relation uniqueness, in which a supplier is exclusive to a manufacturer and often located in a proximity, facilitating the Just-In-Time (JIT) practice. Moreover, the protectionism practiced by the Japanese government plays a crucial role in providing a competitive advantage to the manufacturers (Green, 1999).

Green & May (2005) contend that the legitimacy of lean was underpinned by the collusion between promoters and the receiving managers/practitioners. Commercialized and branded, Green & May (2005) assert that lean was further institutionalized by "*government outreach bodies*" and *"sector membership clubs dedicated to industry improvement".*

Another concern of Green (1999) is the implications of LC on the Human Resource Management (HRM), where the overwhelming focus of LC on waste elimination and promoting efficiency could affect the employees' working life quality. The human cost of lean production is evident in the Japanese production plants inside Japan and overseas by instituting long working hours, increased management control, intensification of work. Establishing such practices may affect the ability of firms to attract young, creative professionals to the industry. However, in response to this concern, several models were developed as an adaptation of the original Toyota Production System involving principles related to the employees. For instance, the Liker (2004) framework reviewed earlier, stresses the importance of engaging people in the lean program, where "people-related" principles are positioned higher than "process" aspects.

2.5.The state of implementation of Lean Construction

Conformance studies are carried out to explore the state of application and awareness of an industry to a specific concept. These studies contribute to the body of knowledge by assessing the industry's adoption of new principles, either knowingly or by adopting its basic constructs.

While lean construction concepts have been introduced to the construction industry in the early 1990’s, the level of awareness and application are to be tested verifying that the understanding of the model’s constructs are in place.

One of the early adopters of the lean construction principles was the UK construction industry, driven by governmental reports, namely Latham (1994) “Constructing the Team” and Egan (1998) “Rethinking Construction”, that suggested the appropriateness of the lean approach for enhancing the performance of the industry. Yet, a study on the conformance of the UK construction industry with the lean construction principles has revealed a lack of understanding and application of the fundamentals of lean, where “there appears to be significantly less lean culture in the UK construction companies than is professed.” (Common, Johansen, & Greenwood, 2000).

Similar results were unveiled in the Turkish construction industry, with organizations being alien to the lean construction concept. However, despite the lack of awareness of the concept, evidence shows that they possess relatively high level of readiness, approval of and conformance to the lean construction practices (Tezel & Nielsen, 2013).

A recent report issued by McKinsey Global Institute (2017) titled “Reinventing Construction” in which 144 industry practitioners around the world were surveyed for the level of lean construction adoption in their firms has concluded that lean processes were among the least adopted practices in project management, where only 38 percent of respondents had implemented them.

2.6.Lean Construction Implementation Frameworks

One of the first models for implementing LC in the construction industry is the model developed by Common et al. (2000). The theoretical framework of this study emphasized four characteristics of the lean techniques with regard to procurement, planning, control and suppliers (See Figure 2). The model suggests that lean techniques are enabled by the implementation of a procurement system that put an emphasis on concurrent design and construction. Furthermore, a planning system that is more structured and certain than critical path analysis should be in place. Moreover, the implementation of a control mechanism that enables a prompt identification of program variances, and an improved framework of dealing with the various project participants such as suppliers and subcontractors through Supply Chain Management (SCM) and partnering (Common et al., 2000).

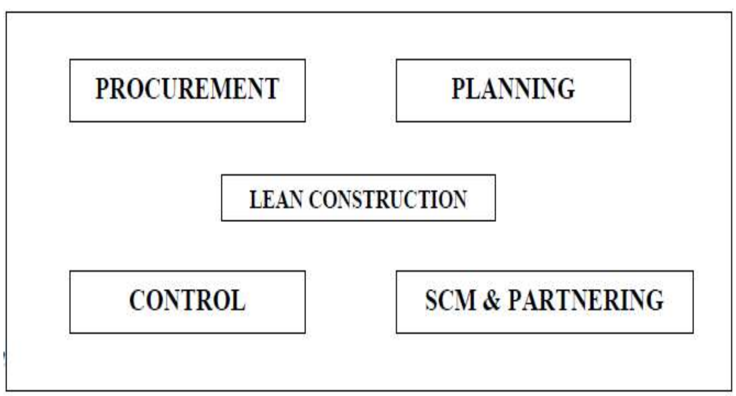

Figure 2: Lean Construction conformance framework constructs (Source: Common et al. 2000)

Diekmann, Balonick, Krewedl, & Troendle (2003) have developed a conformance model that was later adapted to the Turkish construction industry by Tezel & Nielsen (2013). This model included five fundamental principles, further divided into 16 subprinciples (as illustrated in Figure 3)

- Customer focus
    - Flexible resources
    - Optimized value
- Culture/people
    - Training
    - People involvement
    - Organizational commitment
- Standardization
    - Workplace organization
    - Visual management
    - Defined work processes
- Waste elimination
    - Supply Chain Management (SCM)
    - Work content optimization
    - Production system design
    - Process cycle time reduction
- Continuous improvement/built-in quality
    - Production metrics
    - Error proofing
    - Organizational learning
    - Response to defects

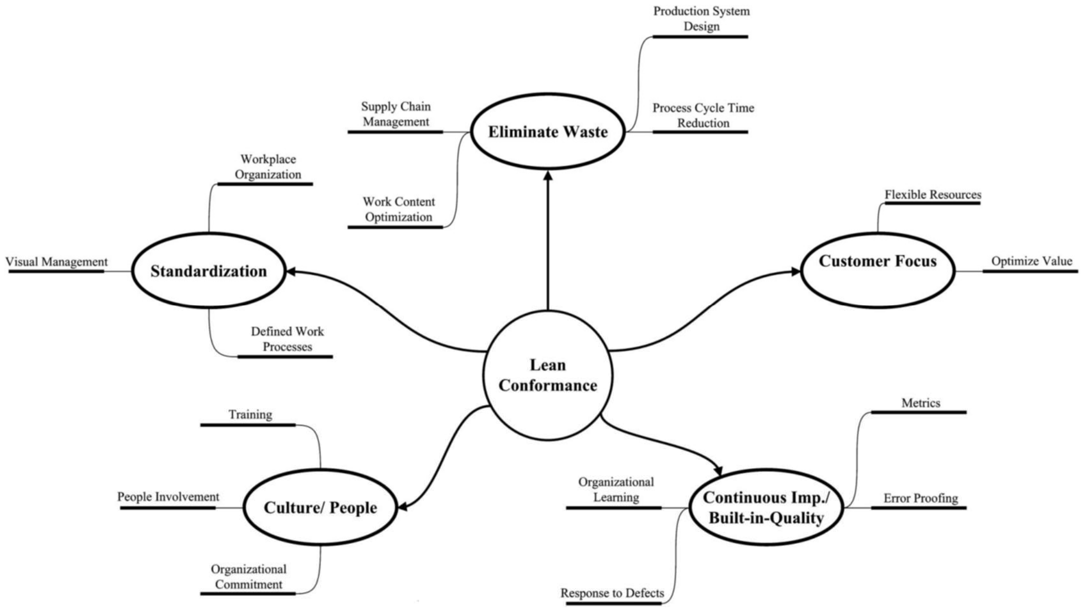

Figure 3: Lean Construction conformance model (Source: (Tezel & Nielsen, 2013)

Building on the previous work by Common et al., (2000), Johansen & Walter (2007) have introduced a more comprehensive model of the lean approach in construction. The authors argue the obsoleteness of the previous model due to the improved understanding for the complexity of the industry along with the mutual dependencies of its participants. The improved model is built upon eight constructs with the development of the lean techniques and with an emphasis on the human aspect of lean construction (Johansen & Walter, 2007). (See Figure 4)

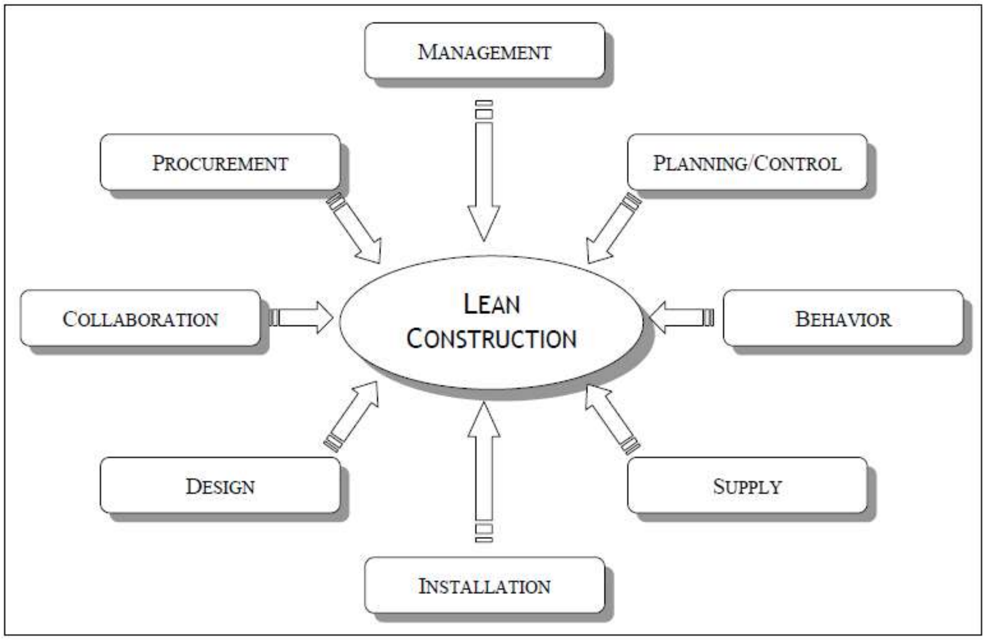

Figure 4: Lean Construction conceptual framework (Source: Johansen and Walter 2007)

2.7.Lean Construction and Value Engineering

Similar approaches to lean had been developed and utilized within the construction industry even before its debut. Integrating such existing techniques can benefit the industry in optimizing its operational model.

Aiming at cost reduction and operational enhancement, Value Engineering (VE) is considered a proven management technique for more than half a century (Chen, Chang, & Huang, 2010). While the main focus of the lean concept is the elimination of NVA activities, Value Engineering (VE) is a systematic approach aiming to enhance project functionality at a minimum cost. However, while Lean and VE have different approaches, a common target is pursued, i.e. fulfillment of the customer's requirement (Ekanayake & Sandanayake, 2017). Table 2 reviews the main differences between LC and VE as cited in the literature.

Table 2: Comparing Lean Construction to Value Engineering. Adapted from: (Ekanayake & Sandanayake, 2017)

	Lean Concept (LC)	Value Engineering (VE)
Origin	Toyota Production System (TPS)	General Electric Coo (GE)
Overview	Philosophy, strategy	Analytical tool
Objective	Waste elimination aimed at maximizing customer value	Ensure customer's value for the money
Performance	Improve performance	Achieving essential functions
Cost	Reducing costs associated with waste while increasing the value	Achieve optimum cost and enhance value
Quality	Perfecting quality at the source	Optimizing quality with regard to cost
Time	Lead time reduction by reduction of unnecessary flow activities	Proposing accelerated project alternatives
Customer satisfaction	Customer value is embodied in every phase of the model	Customer value is addressed in the pre-study phase and during job planning
Use of analytical tools	Flow diagrams, bar charts, production control boards, 5S, Kaizen, Kanban, Value Stream Mapping	Function analysis using FAST diagrams, decision trees, value index, weight matrix, Pareto chart
Operation	Principles to be followed	Phases to be applied

CHAPTER 3: Research Methodology

This study is carried out using semi-structured interviews (survey questionnaire) with selected construction contractors in the eastern province of Saudi Arabia to collect the needed data. The methodology of this research is described in the following steps (as illustrated in Figure 5):

1. An exhaustive review of the literature on the subjects of Lean Construction, barriers, enablers and Non-Value Adding activities (NVA) assessment
2. Identifying the relevant lean barriers to the Saudi construction sector context
3. Developing a tool for the assessment of Non-Value Adding activities
4. Developing a questionnaire survey based on the selected enablers and barriers, identify the barriers and assess the non-value adding activities.
5. Distributing the survey to the targeted industry professionals.
6. Collecting the responses and analyzing them through statistical methods.
7. Providing a conclusion that is drawn out from the results.
8. Drawing out recommendations based on the results for future improvements.

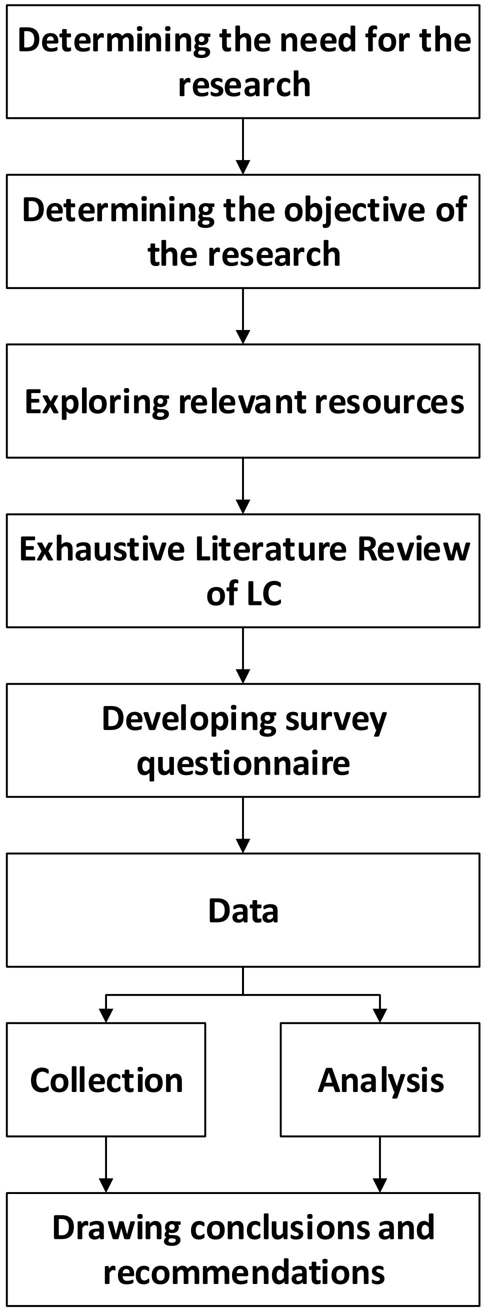

Figure 5: Research methodology scheme

3.1.Identifying Barriers to Implementing Lean Construction

The research starts by an exhaustive literature review to identify the relevant key work in the lean construction. In particular, the reviewed studies address the conformance and barriers of implementing

The model of this study was based on Ohno (1988) criteria of the Toyota Production System, which is the basis of many later studies on the lean approach. The model comprises of seven principles: pull-driven strategy of production, minimization of process wastes by elimination of non-value adding activities, quality assurance/quality at the source, continuous improvement (kaizen), building of long-term relations with suppliers and subcontractors, production leverage, defined as the ability to produce diverse types in various quantities, and teamwork. The barriers and conformance factors reviewed in the literature were categorized under these seven principles to create a comprehensive model for the purpose of this study.

Barriers to the implementation of Lean Construction (LC) were developed utilizing LC conformance criteria described in the literature, namely by (Common et al., 2000; Diekmann et al., 2003; Johansen & Walter, 2007; Tezel & Nielsen, 2013). In addition, selected factors described in LC barriers studies, such as (Abdullah, Razak, Bakar, Hassan, & Sarrazin, 2009; Sarhan & Fox, 2013; Shang & Sui Pheng, 2014), were embedded in the questionnaire as well.

This study follows a similar approach to the work done by (Tezel & Nielsen, 2013) on LC conformance by Turkish contractors. The study featured 44 construction contractors of different classes. Tezel & Nielsen (2013) study was carried out using self-assessment survey questionnaires, which may incur certain amount of bias. Additional limitations as stated by the Tezel & Nielsen (2013) include, include the lack of knowledge by the respondents themselves about lean terminology and concepts. Of course, the survey should be comprehensive about all lean constructions principles and hence, the length of the survey may be felt too long and time consuming by some respondents. We follow similar approach in this research where we approached grade I and II contractors to measure their perception of the key lean barriers.

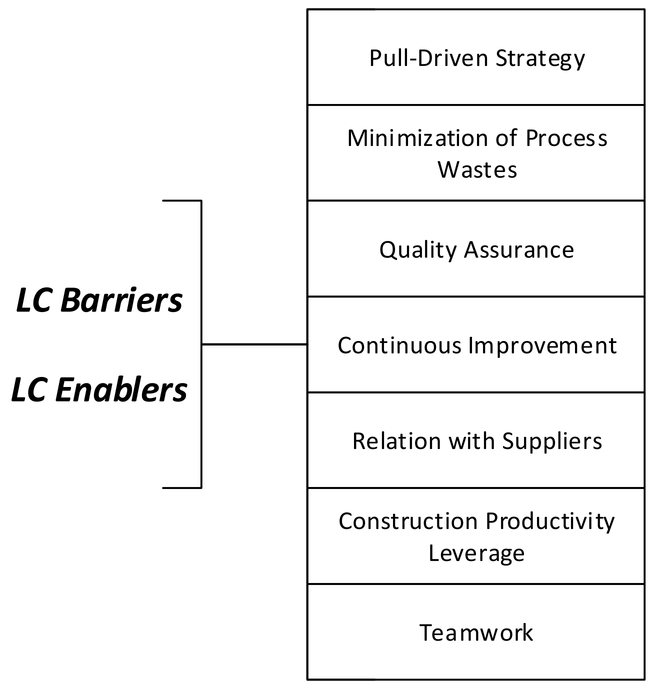

Figure 6: The model of this research

3.1.1. Questionnaire Design

A survey questionnaire is utilized to collect data needed in this study. The questionnaire enlists project management and execution qualities and practices that conform with the lean construction concept, with the assumption that the absence of such sound practices will hinder the adoption of

LC. The respondents are asked to rank the conformance of their organizations and project teams with the given factors. An example of the survey questions is exhibited in Table 3.

Table 3: Example of LC barriers survey questions

	#	Conformance Criteria	Level of conformance				
Pull-Driven strategy	1	Project objectives and the client's requirements are known by all parties involved	N/A	1	2	3	4
	2	Materials are delivered to the jobsite just before their use, keeping storage at a minimum	N/A	1	2	3	4
	3	Clients are involved in the design phase to ensure the compatibility between the proposed design and their needs	N/A	1	2	3	4
	4	The owner/owner's representative approval of submittals and response for requests is prompt	N/A	1	2	3	4

3.2.Development of Non-Value Adding Activities Assessment tool

Building upon (Lim, Ahmed, & Zairi, 1999) investigate, measure and improve (IMI) system which aims for driving continuous improvement. This study utilizes the Investigation circle described by the framework for discovering the potential Non-Value Adding (NVA) activities. The Investigation cycle, based on a 4Ms model, namely man, machine, method and material, was used to identify the relevant sources of wastes in a typical construction site environment. Furthermore, the wasteful processes defined are categorized based on (Ohno, 1988) seven wastes, namely overproducing, over-processing, inventory, transporting, defects, waiting, motion. Figure 7 outlines the NVA activities types assessed in this model.

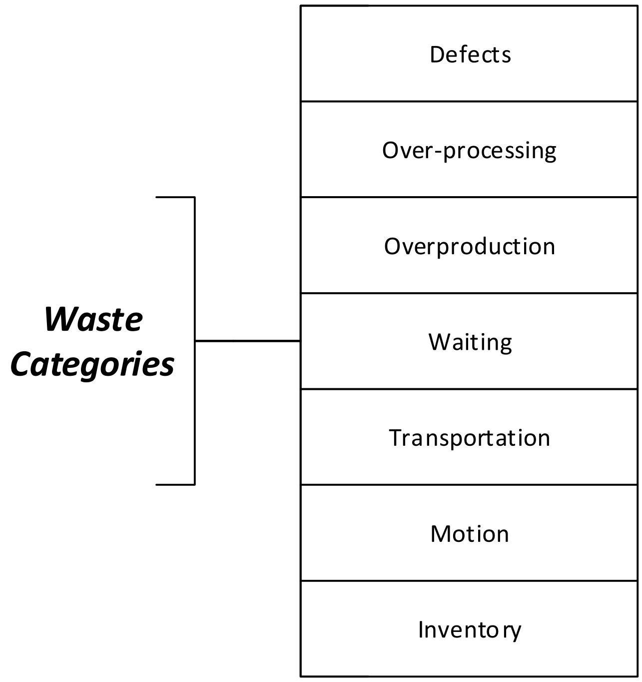

Figure 7: Non-value adding (Waste) classification

3.2.1. Questionnaire Design

Similar to a previous study carried out by Wu, Low, & Jin (2013), where a weighted factor model was developed to guide contractors in identifying the NVA activities to achieve low-carbon installation of precast concrete elements, this study develops a weighted factor tool that aids contractors in identifying the processes that impact the productivity and effectiveness of their construction site operations in general. A questionnaire was designed to incorporate these items, requiring the respondents to rank each item's importance and level of practice in their organization. An example of NVA assessment questionnaire is illustrated in Table 4.

Table 4: Example of NVA Assessment survey questionnaire

Definition		Significance				
Waste of Defects is defined as any rejected or unsatisfactory work that needs to be fixed or rework		1	2	3	4	5
#	**Practice**	**Assessment**				
1	The quality control plan/process is inadequate, which occasionally causes defects and rework	0	1	2	3	4
2	The workers are not aware of the quality acceptance criteria of the assigned task	0	1	2	3	4
3	The workers occasionally cause defects or produce substandard work	0	1	2	3	4

3.3.Limitations

This study was conducted on a sample of building contractors operating in the eastern province of Saudi Arabia. The designed questionnaire was answered by professionals working in projects and engineering by means of self-assessment, which in turn carries an inherent bias, however, we tried to eliminate this bias by asking about specific practices while considering the applicability of the survey in different contexts. In addition, because LC concept is still not widely spread amongst building contractors in Saudi Arabia, some concepts might be misunderstood by the respondents. The statements featured in the questionnaire were worded (through multiple rounds during the pilot phase) to yield the closest representation of reality and keep survey length as short as possible.

The tool developed in the second part of this study features a selected set of NVA activities, however, the inclusiveness of this tool must be validated. In addition, the interaction and correlation between waste categories has not been addressed.

3.4.Survey Layout

This research features a survey questionnaire for the purpose of collecting the needed data. The survey is laid out in three sections. The first section is aimed at identifying the respondent's demographics, such as job position, educational background, years of experience and the firm's capital, in addition, it features two questions regarding their familiarity with the Lean Construction (LC) concept, and whether their organization ever attempted to apply the concept. The second section of the survey deals with the barriers of implementing the LC principles. The respondents are asked to rate the conformance of their organizations with the stated practices. The third part is meant to investigate the sources of waste and the Non-Value Adding activities, where the surveyed professionals are asked to rank the severity of each waste category on operations, and the occurrence of each contributing factor.

3.5.Data Collection

The data needed for this research were collected using questionnaire surveys distributed to the targeted industry practitioners, delivered either by e-mail or by hand.

3.5.1. Population and Sampling

The targeted population of this study was determined to be Grade I and Grade II building contractors in the Eastern Province, a total of 43 contractors according to the Ministry of Municipal and Rural Affairs (MoMRA) classification("Contractors Classification Agency," 2017). To obtain an effective sample size, Kish's formula was used in the calculation as in the following (Kish, 1965):

$$n_0 = \frac{pq}{SEM^2} \dots\dots\dots\dots\dots\dots\dots Eq.1$$

$$n = \frac{n_0}{1 + \frac{n_0}{N}} \dots\dots\dots\dots\dots\dots. Eq.2$$

Where:

$n_0 = the\ first\ sample\ size\ estimation$

$p = proportion\ of\ the\ characteristics\ that\ are\ being\ measured$

$q = 1 - p$

$n = the\ final\ estimate\ of\ the\ sample\ size$

$N = the\ targeted\ sample\ size$

$SEM = maximum\ percentage\ of\ standards\ error\ allowed\ for\ the\ sample\ mean$

Starting at Eq.1. by substituting p with 0.5, q will equal to 0.5 and assuming SEM = 10%, a value of 25 will equal n_0 which is the first estimate of the sample size. Substituting the results into Eq.2. yields a final estimated sample size of approximately 16 contractors. However, the population of such sample is considerably small, and more surveys were distributed for more validation. Refer to Table 5 for population, effective sample size and the actual number of respondents.

Table 5: Population and effective sample size

Population (Contractors Gr. I+II)	Effective Sample Size	Actual Number of Responses
43	16	30

Respondents surveyed in this study are mainly project engineering and management staff, with percentages of 47% and 50% respectively. Respondents with an engineering title category can be further broken into: projects, cost control, design, planning and lean leader, as illustrated in Figure 8. The sample includes professionals with various levels of experience in the construction field, however, the majority of respondents have five years or less of work experience with a share of 43% of the sample, respondents with five to ten years of experience make up about 27%, 13% fall between ten to twenty and 17% have more than twenty years of experience in the field. Furthermore, the participants have different educational backgrounds, however, all with a college degree, where 70% hold a bachelor's degree, and 30% have a higher degree. Refer to Figure 9 for illustration.

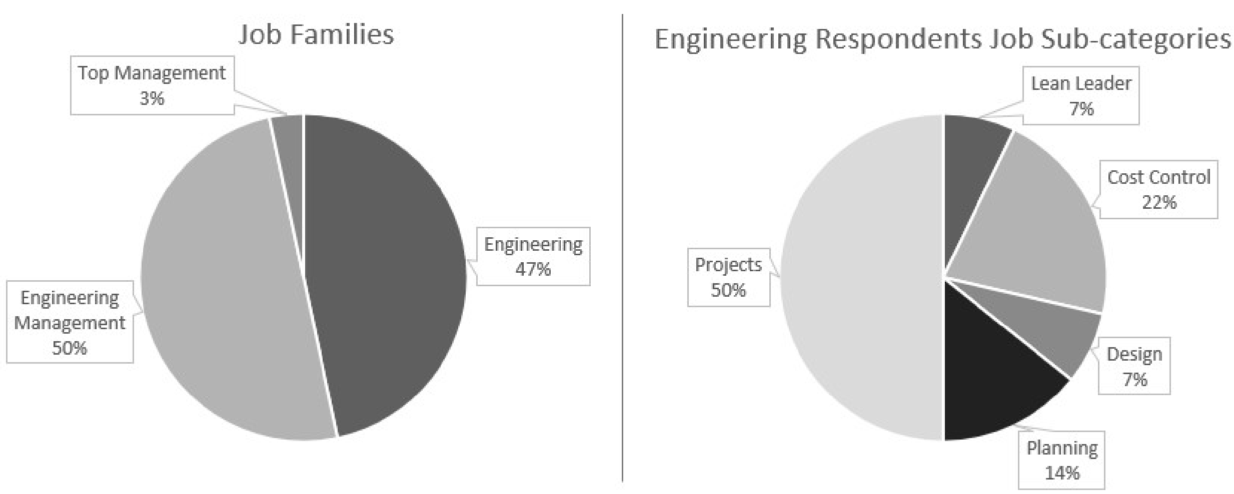

Figure 8: Respondents' job backgrounds

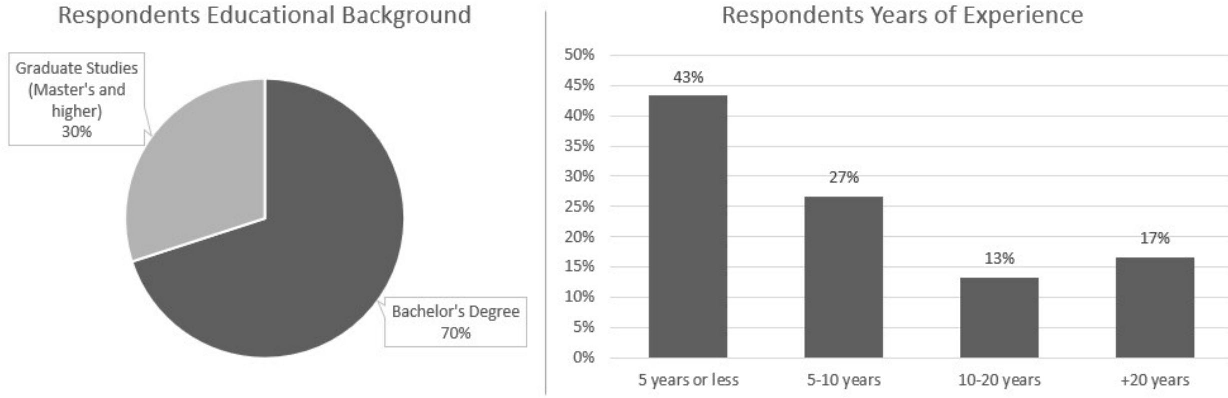

Figure 9: Respondents' education and years of experience

3.5.2. Data Collection Approaches

The respondents were approached in person which serves two purposes, firstly, to ensure that their area of work is relevant to the construction process and the field operations, secondly, to brief them about the concept of Lean Construction, its main constructs and the procedure for filling the survey.

Responses were collected through two methods, in-person as participants manually fill the survey on spot which is the case with the majority of respondents, and some asked for the survey to be e-mailed to them after the interview for their convenience., in which an online survey platform was used to collect their answers. A breakdown of the total number of surveys distributed and responses are explained in Table 6.

Table 6: Data collection approaches statistics

METHOD	TOTAL	RESPONDED	RESPONSE RATE
E-MAIL AND ONLINE PLATFORM	12	9	71%
PERSONAL INTERVIEW	30	21	

The response rate in this survey was calculated to be 71%, which is considered high, however, might be attributed the method followed in this research through conducting in-person interviews beforehand.

3.6.Data Analysis

The data collected from the survey were used to assess the following:

1- Barriers of implementing the lean construction principles
2- The level of conformance of the organizations with the lean practices
3- Prioritize the most significant types of wastes in construction operations
4- Assess the importance of the waste minimization practices in the construction jobsite environment
5- Evaluate the level of practice of waste minimization principles in the jobsite environment

The statistical means that were utilized to achieve these measures included the following:

1- 5-point Likert scale type of questions for assessing the conformance between practice and the lean subprinciples, including a Non-applicable (N/A) to avoid noise in the data.

2- 5-point Likert scale type of questions for evaluating the significance of each type of waste in the construction environment
3- 5-point Likert scale for assessing the importance and level of practice of each waste minimization practice, including a Non-applicable (N/A) to avoid noise in the data.
4- Relative Importance Index (RII) was used to analyze the responses.

Construction Management Research (CMR) is rich with examples of using the Likert scale to capture the respondents' self-assessed attitudes and opinions. Examples of using the Likert scale to assess the lean construction conformance can be found in (Diekmann et al., 2003) and (Tezel & Nielsen, 2013). Coupled with the use of Relative Importance Index (RII) technique, the analysis results in a rank of the waste minimization practices as viewed by the respondents.

In the analysis of the results in the "Barriers to the effective Implementation of Lean Construction" survey, each question was be assigned the same weight, however, the N/A (Not Applicable) answers are added to act as a buffer against unrealistic answers due to lack of knowledge in the subject or lack of understanding of the statement (Tezel & Nielsen, 2013).

CHAPTER 4: Barriers to The Effective Implementation of Lean Construction

The construction industry is in need for new disruptive models to transform its operation and boost its productivity. The poor productivity and the current operational models represent a loss to the world economy and a lost opportunity to the industry. Adopted from the manufacturing sector, the lean approach has proven its ability to revolutionize the operational model of the industry, through the lean motives and an operations-focused project-delivery understanding.

This study was carried out to explore the barriers of implementing Lean Construction by Saudi construction contractors. Furthermore, it investigates the conformance between the current practices and the lean construction principles. The study was conducted through a field study utilizing a survey questionnaire where respondents are asked to rate their organizations' current practices against a set of best practices embodied in the lean approach. A statically representative sample of professionals who belong to Grade I and II building contractors in the eastern province of Saudi Arabia were selected to participate in this study. The findings suggest a set of 24 barriers that hinder the adoption of LC by the contractors, including barriers related to the workplace environment and planning and design practices. Furthermore, the respondents showed a high degree of conformance with a set of 11 factors, namely, customer focused strategy, long-term philosophy and utilizing project data.

4.1.Introduction

The evolution of modern management theories, in general, is the result of thorough studies of production. In fact, seminal work and key contributions in the production management, pioneered by Fredrick Taylor, Frank Gilbreth, Hawthorne studies, Tavistock studies, all tackled the issue of improving the productivity of workers in a production environment, and have shaped the modern management school of thought. However, despite the advancement achieved in the production management field, the construction industry shows a sever lack of implementation of such concepts (dos Santos et al., 2002).

The theory of production should involve all phases of production, particularly product design where it guides in design, control and improvement of production systems. The application of a production management theory should lead to enhanced performance, in addition, it provides a benchmark for best practice.

Production management literature in the 20th century defines three theories of production, namely, transformation, flow, and value. Each of these theories were developed individually and each views production from a different perspective, however, Koskela (2000) suggested that these views were *"not alternative, competing theories…but rather partial and complementary"* forming the TFV theory of production. The transformation theory is the classical view of production where it is conceptualized as a transformation of inputs to outputs. However, this view fails to recognize other phenomena in production other than transformation, and does not consider conformance with customer requirements. Secondly, the flow view of production, where priority is given to waste elimination from the flow processes. This view is embodied in the lean approach. Thirdly, the value view recognizes the value maximization for customers through the fulfillment of their requirements (Koskela, 2000).

The importance of Lean Construction is that it introduces a new perspective to how production is viewed in the construction process. Through performance enhancement, concurrent design and construction and proper project control, lean introduces a novel form of production management to construction sector. Moreover, in addition to the traditional transformation view, lean emphasizes the flow view through waste minimization, and the value view is evident in lean's endeavor to meet customers' requirements.

4.2.Lean Practices Within Construction

The lean approach emerged as a new production philosophy in the Japanese automotive industry in the 1980s, particularly in Toyota Motor Corporation and was first identified as the Toyota Production System (TPS), and it has since proven to be a successful one, adding to the competitive advantage of the Japanese manufacturers in comparison to their opponents (Womack et al., 1990).

The lean approach was widely adopted by the manufacturing sector, as it aids in transforming the existing operations, boosting productivity and enhancing quality, while using smaller workforce and occupying smaller space (Womack et al., 1990). This approach has drawn the attention of construction experts, due to its radical improvements on the existing models of production (Ballard & Howell, 1998). While shifting concepts across different industries is common, the applicability and fit of these models must be validated and proven.

Construction and manufacturing share a common long-term goal, to add value to their end-products via high returns on investment, however, each has different means to achieve this purpose. Unlike manufacturing, the construction industry is characterized by its project-based nature, make-to-order production, labor intensive tasks and unpredictable demand. Nonetheless, this gap could be bridged by introducing standardization into the construction process.

The lean approach is characterized by five key concept that are found to be common in the literature, namely, a focus on waste elimination, valuing end customer preference, pull approach towards production and supply chain management, use of processes and processes flow in a production management outlook and adoption of a system's perspective for waste elimination (Jørgensen & Emmitt, 2008). However, lean in the construction context adheres to two main objectives of the lean approach, namely, waste elimination and customer focus.

4.3.Barriers of Implementing Lean Construction

Multiple studies have addressed the hindrances to the successful implementation of Lean Construction principles. In the UK Sarhan & Fox (2013) have identified ten barriers that are related to the nature and culture of the construction industry. Their study has concluded that the most significant barriers to the lean implementation were the lack of awareness, culture and human attitude, and the lack of top management commitment. An earlier study conducted by Abdullah et al. (2009) in the Malaysian construction industry have stated nine barriers that hinder the application of lean principles. Similarly, lack of top management commitment and lack of awareness of the concept were perceived to be the most significant along with lack of proper training.

Furthermore, in a more comprehensive approach, Shang & Sui Pheng (2014) have studied the challenges faced by the Chinese construction organizations when attempting to implement Lean Construction practices. They have identified 22 barriers in their study, and the most significant barriers as perceived by the practitioners were: lack of a long-term philosophy, the absence of a lean culture in the organizations, the use of multi-layer subcontracting. In a more detailed approach, in a study to the Ugandan construction industry, Alinaitwe (2009) has opted to identify the barriers to each of the main constructs of the lean construction model such as just-in-time, teamwork, benchmarking, pull scheduling etc.

4.4.Objectives of the Study

The main focus of this study is to discover the barriers to implementing lean construction in the Saudi construction industry. The hurdles discovered are to be ranked based on their significance. Furthermore, the conformance of Saudi construction contractors with the LC practice is explored. While this study was conducted in the Saudi construction, however, the same tool can be utilized in other geographical contexts.

4.5.Research Methodology

While many researchers refer to different models and frameworks that define the leanness, and the lean production model, the author opted to base this study on the original model described by (Ohno, 1988). This is due to the fact that leanness is highly interpretive and has no universal definition (Jørgensen & Emmitt, 2008). However, the model described by the (Ohno, 1988) is the closest to the original Toyota Production System (TPS), which is a comprehensive socio-technical quality model.

Figure 6 outlines the conformance criteria that used in this research. The criteria are based on (Ohno, 1988) manuscript on the Toyota Production System (TPS), i.e. the lean approach. The relevant processes in the construction industry are categorized in accordance with the model. Focus groups input was included after a semi structured interview with the author. The model underlines seven principles that constitute the lean approach, namely, pull-driven strategy, minimization of process wastes by elimination of non-value adding activities, quality assurance/quality at the source, continuous improvement (kaizen), building of long-term relations with suppliers and subcontractors, production leverage and teamwork. Furthermore, barriers to the implementation of Lean Construction (LC) were developed utilizing LC conformance criteria described in the literature, namely by (Common et al., 2000; Diekmann et al., 2003; Johansen & Walter, 2007; Tezel & Nielsen, 2013). In addition, selected factors described in LC barriers studies, such as (Abdullah et al., 2009; Sarhan & Fox, 2013; Shang & Sui Pheng, 2014), were embedded in the questionnaire as well.

4.5.1. Questionnaire Design

A survey questionnaire approach is utilized to collect data for this study. The participants were interviewed and briefed about the concept of Lean Construction, helping them to have a basic overview of what lean entails prior to responding. The respondents are asked to gauge the level of agreement of their organizations with 46 practices listed, as illustrated in .

Table 7. The basic research question is: *Does your organization conform to the stated practice?*

The merit for the methodology used in this questionnaire is that respondents may not be familiar with the constituents of the lean construction concept, thus they are asked to rate their organizations' conformance with a set of lean construction practices on a 5-point scale from "0= Not-Applicable" to "5=Always", while the absence of these practices would point to the lack of a lean culture and hinder the implementation of the concept. Furthermore, the wording of the survey omits the use lean jargon as possible, in order to avoid any misinformed answers, and the respondents were given the option to answer with Non-applicable (N/A) or Don't-Know (D/K).

4.5.2. Pilot Study

The survey was piloted by a group of experts, professionals and academicians, with construction research focus, in order to review the followed approach. The input of the pilot study respondents was utilized to refine any misleading statements, and to optimize the survey design. The pilot study was also beneficial in recording the time required for participants to fill the survey.

Table 7: LC barriers developed for this study

#	*Barrier*
	Pull-Driven strategy
B1	Inadequate knowledge of project objectives and the client's requirements by all parties involved
B2	Excessive material storage
B3	Excluding clients from the design phase
B4	Stringent owner/owner's representative approval process
	Minimization of process waste
B5	Employees inability to define the non-value adding activities within their work areas
B6	Hierarchies in organizational structures
B7	Material storage remoteness from tasks locations
B8	Underutilization of off-site construction techniques
B9	Disregarding cost of material and field installation costs during the design phase
B10	Excluding contractor from the design phase
B11	Lack of workplaces neatness, misplacing materials and tools from their designated places

B12	Absence of crew size planning with regard to each task
B13	Lack of site layout plans
B14	Lack of a logistics plan defining site access, pathways and the location of work phases
B15	Inadequate planning and scheduling
B16	Failing to identify and monitor long lead items early in the project lifecycle
Quality Assurance	
B17	Inadequate quality plan
B18	Lack of proactive preventative measures
B19	Failing to communicate contractor's quality standards to all contractual parties
B20	Limited use of visual tools for communicating project information
B21	Infrequent update of visual tools and unsuitability for the targeted audience
B22	Insufficient monitoring of tasks around the jobsite by quality assurance/control
Continuous Improvement	
B23	Underutilization of projects' KPIs
B24	Limited use of past project data and employees' experiences in improving the organization's performance
B25	Inconsideration of employees' opinions in enhancing project execution
B26	Disregarding employees' opinions and views in improving project execution
B27	Management's negative attitude towards enhance the organizational culture
B28	Management resistance to change
B29	Employees negative attitude towards improving their own workplaces
B30	Insufficient employees' education and training programs
B31	Lack of a long-term philosophy in organizations
B32	Ineffective cost control and cost saving
B33	Lack of monitoring workplaces and offices for neatness and cleanliness
B34	Obscure definition of work processes and their utilization of resources
Relationship with Suppliers	
B35	Untimely material delivery by suppliers, and lack of adherence to specs
B36	Use of multi-layer subcontracting
B37	Lack of collaborative partnership/long-term agreements with suppliers
Productivity Leverage	
B38	Work flow to the next crew in large bundles
B39	Inability to adapt resource allocation in accordance with clients' changing needs
B40	Inability to meet and adapt to clients' requirements
B41	Design underutilization of available material and repetitive tasks
Teamwork	
B42	Absence of communication and cooperation between departments within the firm
B43	Stringent inter-organizational approval process
B44	Failing to share unutilized resources among multiple projects within the organization
B45	Limited use of IT-based infrastructures in the communication process between departments and divisions

4.6. Theory and Calculations

The approach used in this study aims at ranking the barriers to the implementation of Lean Construction (LC) from a practical point of view. An implementation index was used based on the Relative Importance Index (RII) reflecting the ranking given by the respondents to each factor.

4.6.1. Data Collection

The survey questionnaire was distributed among Grade I and II building contractors (a total of 43 firms) in the Eastern Province of Saudi Arabia. The classification of the contractors is developed by the Contractors Classification Agency operating under the Ministry of Municipal and Rural Affairs and the Eastern Province Chamber of Commerce ("Contractors Classification Agency," 2017). The classification is based on the contractors financial and technical capabilities to undertake government's projects. The respondents work mainly in direct contact with projects on a daily basis where they either work in engineering or project management. The merit behind selecting Grade I and Grade II contractors is the assumption that such firms are large, well-established which helps in implementing a Lean Construction program. This practice was done prior by Abdul-Hadi et al. (2005) in studying the barriers of implementing a Business Process Re-engineering (BPR) program in Saudi Arabia.

4.6.2. Data Analysis

The data collected are analyzed based on the Relative Importance Index (RII) method.

Implementation Index: as cited by (Holt, 2014), formula (1) is used to independently rank the implementation of the stated practices as per the responses to the survey.

Implementation Index (Impl. I.) (%) = $\frac{\sum W}{AN} \times 100$ …….... (1)

Where,

W = the sum of "n" respondents selecting a specific rank (ranges from 0 for N/A to 5 for always applied) multiplied by the rank's integer value.

A = largest rank that can be designated for a specific variable

N = Sample size (30 respondents)

Category Implementation Index: a score is concluded for each category of factors by calculating the average scores of a category's factors.

4.6.3. Ranking Barriers

A scale of (Excellent, Needs Improvement, Barrier and Strong Barrier) was implemented to classify the factors used in this study based on the implementation index described earlier.

1. $[0.75 \leq Impl.I. \leq 1.00]$ indicates that practice is in place and does not represent a barrier
2. $[0.60 \leq Impl.I. < 0.75]$ indicates that the practice is carried out frequently and needs improvement
3. $[0.50 \leq Impl.I. < 0.60]$ indicates that the practice is carried out sometimes and somewhat is a barrier

4. $[Impl.I. < 0.50]$ indicates that it is rarely practiced and is considered a strong barrier

4.7.Results

This section states the results of the field study conducted as part of this research. The section presents the respondents awareness of the concept, barriers and readiness to implementing LC.

4.7.1. Lean Construction Awareness

Two polar questions were included in the survey to test the respondents' awareness of the concept, and whether their organizations ever undertaken an effort to apply it.

Respondents were asked if they were familiar with the concept of Lean Construction where 43% responded positively. The second question addressed the application of Lean Construction in the respondents' organizations on which 33% of respondents answered positively. Refer to Figure 10 for illustration.

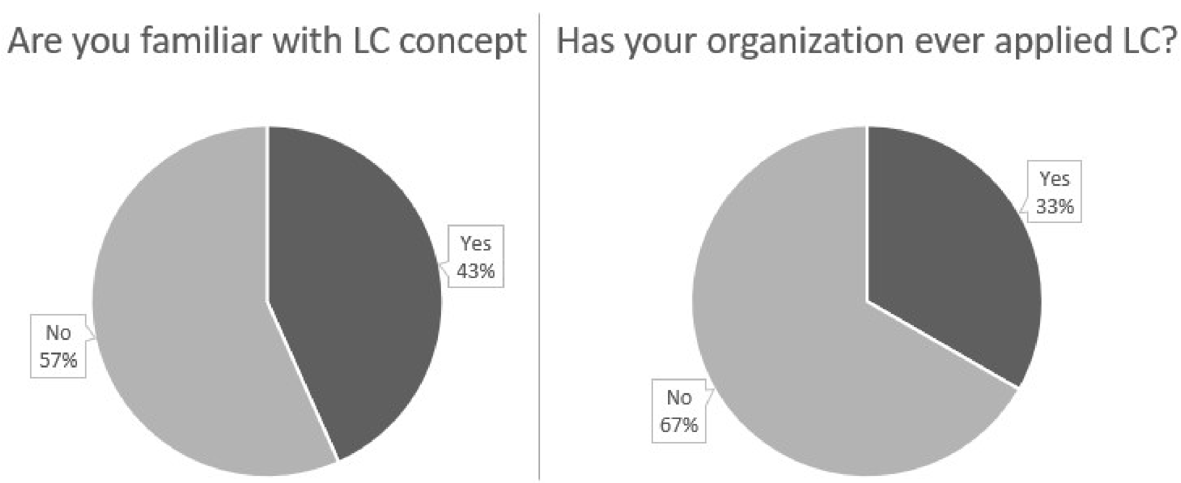

Figure 10: Respondents and organization familiarity with LC

4.7.2. Lean Construction Barriers

Table 8 presents the score of each barrier calculated by using equation (1) and as perceived by the responding Saudi building professionals. It is to be noted that the lower the implementation index score, the greater the significance of the hindrance. The barriers listed in the table are sorted from strongest (most influential) to the weakest. The factors were qualified to be considered a barrier as long as their implementation index is less than 0.60.

Table 8: Ranking of LC barriers

ID	*Barrier*	*Impl.I.*	*Impl.I. %*	*Rank*
B11	Lack of workplaces neatness, misplacing materials and tools from their designated places	0.417	41.7	1
B30	Insufficient employees' education and training programs	0.442	44.2	2
B5	Employees inability to define the non-value adding activities within their work areas	0.467	46.7	3
B6	Hierarchies in organizational structures	0.467	46.7	4
B33	Lack of monitoring workplaces and offices for neatness and cleanliness	0.467	46.7	5
B10	Excluding contractor from the design phase	0.475	47.5	6
B12	Absence of crew size planning with regard to the specifics of each task	0.483	48.3	7
B20	Limited use of visual tools for communicating project information	0.483	48.3	8
B29	Employees negative attitude towards improving their own workplaces	0.483	48.3	9
B21	Infrequent update of visual tools and unsuitability for the targeted audience	0.492	49.2	10
B38	Work flow to the next crew in large bundles	0.492	49.2	11
B26	Disregarding employees' opinions and views in improving project execution	0.508	50.8	12
B41	Design underutilization of readily available material and repetitive tasks	0.508	50.8	13
B18	Lack of proactive preventative measures	0.533	53.3	14
B42	Absence of communication and cooperation between departments within the organization	0.533	53.3	15

B34	Obscure definition of work processes and their utilization of resources	0.542	54.2	16
B45	Limited use of IT-based infrastructures in the communication process between departments and divisions	0.550	55.0	17
B2	Excessive material storage	0.558	55.8	18
B35	Untimely material delivery by suppliers, and lack of adherence to specs	0.567	56.7	19
B22	Insufficient monitoring of tasks around the jobsite by quality assurance/control	0.583	58.3	20
B36	Use of multi-layer subcontracting	0.583	58.3	21
B4	Stringent owner/owner's representative approval process	0.592	59.2	22
B7	Material storage remoteness from tasks locations	0.592	59.2	23
B13	Lack of site layout plans	0.592	59.2	24

It is notable that the concern of the respondents is centered around the physical and social environment of their workplaces. This is expressed in the top five barriers as: neatness, training, ability to define NVA activities and hierarchies within the workplace. This reflects that employees perceive their workplaces as a major barrier to implementing LC. Similar results were reported by Sarhan & Fox (2013), where "Culture & human attitudinal issues" were considered a high ranking barriers to the successful implementation of LC in the UK. In addition, Shang & Sui Pheng (2014) cite "Managerial and organizational barrier" as a significant hindrance in the efforts to adopt LC.

Furthermore, communication was perceived as major barrier. In fact, factors such as: B20, B21, B42 and B45, indicate the limited use of communication tools like visual tools and IT-based infrastructures. Another theme that can be observed is barriers related to the design phase, with factors like: *"B41: Design underutilization of readily available material and repetitive tasks"* and *"B10: Excluding contractor from the design phase"*. Similarly, Shang & Sui Pheng (2014) reported that Chinese contractors perceived the limited involvement of contractors in the design stage as a barrier to LC, due to reliance on traditional contracting methods. Sarhan & Fox (2013) cite *"Design/construction dichotomy"* as a major barrier of LC in the UK.

Moreover, the respondents identified barriers related to planning such as B12, B18, B38, lack of crew size planning and proactive preventative measures, and the large work bundles.

The barriers categories were ranked based on the average scores of their constituents, as listed in Table 9.

Table 9: Ranking of barriers categories

Category	*Category Impl.I %*	*Rank*
Minimization of Process Waste	57.78%	1
Quality Assurance	58.47%	2
Productivity Leverage	58.54%	3
Continuous Improvement	59.79%	4
Teamwork	61.04%	5
Relationship with Suppliers	62.22%	6
Pull-Driven Strategy	67.92%	7

Based on the categories raking, it seems that Saudi contractors are lacking most in the efforts to minimize the processes wastes of their operations. In the list of 24 barriers identified by this study, 8 factors are related to waste elimination. These include items that are directly contributing to process waste like the ability of employees to define waste within their work areas, neatness and cleanliness of workplaces, material storage and storage proximity to task locations. Additionally, other factors were taken in consideration due to their indirect, however strong, relation to waste minimization, such as crew size planning, site layout plans, hierarchies in organizational structures.

Ranking second, quality assurance category is concerned with implementing quality at the source as an essential lean principle. Accordingly, the development and communication of quality control and assurance plans, and the implementation of proactive preventative measures are part of this category.

Productivity leverage focuses on the contractor's ability to execute tasks in an efficient manner, and their ability to dynamically change their resources to meet the client's needs. Among the 24 barriers identified, two factors are related to productivity leverage, namely, discontinuous work flow and design limited use of readily available material and repetitive tasks.

4.7.3. Readiness for Lean Construction

Table 10 lists the factors where the surveyed contractors have shown readiness and conformance with. While the lean construction concept may be alien to Saudi building contractors, there is a conformance between some of their practices with the Lean Construction principles.

Table 10: Readiness factors of LC explored by the study

ID	*Barrier*	*Impl.I.*	*Impl.I. %*	*Rank*
B1	Project objectives and the client's requirements are known by all parties involved	0.800	80.00	1
B9	Cost of material and field installation costs are considered during the design phase	0.775	77.50	2
B17	A quality plan is developed for each project. It serves as a reference for staff duties during the project and defines the corrective actions	0.767	76.67	3
B3	Clients are involved in the design phase to ensure the compatibility between the proposed design and their needs	0.767	76.67	4
B28	Management is continuously seeking to improve the performance and efficiency of the organization	0.750	75.00	5
B16	Long lead items are identified early in the project and their progress is monitored to minimize project downtime	0.733	73.33	6
B44	Project resources (such as manpower and equipment) are effectively shared across multiple projects and departments within the organization	0.725	72.50	7

B32	The project team tries to modify the plans in order to reduce costs as long as it conforms to quality standards	0.725	72.50	8
B37	The contractor seeks long-term contracts/partnerships with suppliers rather than short-term contracts that are based on cost alone	0.717	71.67	9
B40	The contractor is often able to reorganize and meet changing customer requirements such as minimizing the cost or performing complex tasks	0.700	70.00	10
B23	Metrics about production are systematically utilized, documented and analyzed to evaluate project successes	0.700	70.00	11

The findings suggest that contractors, in general, possess an awareness of customer focused strategy, in familiarity and communication of the clients' requirements, involving owners in the design phase, dynamically allocate their resources in accordance with the changing needs of the clients. Another notable notion is the long-term philosophy adopted by contractors in seeking long-term contracts/partnerships with suppliers and vendors. Finally, contractor's pursuit towards operational excellence is evident in their endeavor to develop quality plans, management effort in seeking efficiency and in utilizing projects' Key Performance Indices (KPIs) to evaluate their success.

In general, while the above-mentioned factors indicate readiness and conformance with Lean Construction concepts, some of these results might be affected by wishful thinking of the respondents. Nonetheless, this conformance can be exploited to refine and disseminate this practice among other contractors across the country.

4.8.Discussion and Conclusion

The lean approach has drawn the attention of construction practitioners as it aims at transforming existing operations, achieving greater quality and productivity while using less workforce and space, eventually meeting clients' expectations (Womack et al., 1990). Lean Construction focuses on waste elimination and value maximization for clients (Koskela, 1992). This study is unique in its perspective towards the factors that hinder the implementation of Lean Construction, as it inspects the barriers from a practical point of view. In addition, the study adds to the scarce literature on lean construction in the Saudi construction industry.

The barriers to implementing Lean Construction among Saudi building contractors were developed through a field study, in which the implementation of 46 factors was studied as per the responses provided by Saudi construction professionals. These factors were identified through a comprehensive literature review. The factors were grouped seven main categories, namely, pull-driven strategy of production, minimization of process wastes by elimination of non-value adding activities, quality assurance/quality at the source, continuous improvement (kaizen), building of long-term relations with suppliers and subcontractors, production leverage and teamwork. The implementation index of each factor is calculated using the Relative Importance Index (RII) method, and the lower the index the more this factor hinders the implementation of LC.

In general, the obtained results have revealed that the Saudi construction, while some effort is done to implement Lean Construction, have 24 barriers that may hinder the application of such initiative. The majority of these barriers can be grouped under four themes, they are, people and workplace related, design, planning and communication.

4.8.1. General Recommendations

In order for construction firms to escape their low productivity and efficiency trap, a radical initiative must be carried out to transform their operations. Lean Construction has the ability to revolutionize the way construction firms operate through a set of principles that have proven to be successful in other sectors.

While changing the traditional operating model can be hard, especially with the tendency of the construction industry of resisting change, and may require a major overhaul, however, the outcomes could be very positive.

upon the findings of this study, construction firms are advised to implement the following to overcome the previously mentioned barriers:

- Improve workplaces by engaging the employees and workers in the decision-making process, enhance their physical environment, invest in training and educational programs, minimize hierarchies within the organization.
- Establishing effective communication within the organization helps in creating a sense of responsibility and accountability among employees, this could require investing in IT-based infrastructures, such as Enterprise Resource Planning (ERP) software, and visual tools.
- Standardize processes and utilize modular designs whenever possible. The process of standardization leads to savings in time and money, especially with operations where there is a learning curve, or material that needs to be modified. Additionally, the use of off-site construction methods contributes significantly.
- Improve the planning of processes and tasks. Creating a continuous workflow helps in minimizing downtime for crews and equipment. Moreover, establishing site layout plans helps in optimizing pathways and storage locations around the jobsite.

- Implement a rigid quality assurance/control plan and communicate it to all subcontractors and field workers. Implementing quality at the source is a key principle in Lean Construction. In doing so, the cost of correcting a defect can be minimized. In addition, avoid using multi-layer subcontracting as possible, as one of the issues associated with it is non-compliance with quality criteria.
- Consult construction and procurement teams at the beginning of the design phase, building a cross-functional team reduces the probability of errors later on in the lifecycle of the project and brings different areas of expertise into the project.

4.8.2. Recommendations for Future Research

The barriers identified in this study can help practitioners identify their existence in their work areas. This study can be reproduced in different construction contracting companies such as, mechanical, electrical and plumbing (MEP) works, transportation, industrial construction. Also, this study can be undertaken in different countries and regions. A detailed study can build on the findings of this study to explore in depth what hiders the implementation of lean construction in the developing countries.

CHAPTER 5: Assessment for Non-Value Adding (NVA) Activities in The Construction Industry

The construction industry is known to be wasteful, driven by the continuously increasing complexity of projects and the multiplicity of parties involved. A corner stone of the lean approach is the elimination of waste in operations. The lean approach views value creation as the target for each task performed in production, where value is as perceived by the end-user or client, however, variability and inefficiencies “waste” is inherent in most tasks reducing the end value. The existence of these inefficiencies is pervasive in construction, where construction sites, in general, suffer from suboptimal conditions.

This research aims at developing a weighted factor tool for assessing the NVA activities in a typical construction jobsite. Furthermore, the tool was validated through a field study incorporating responses of Saudi construction practitioners in an effort to discover the most significant sources of waste in the industry, as viewed by the lean concept. The study was conducted through a field study utilizing a survey questionnaire where respondents are asked to rate their organizations’ current practices against a set of best practices embodied in the lean approach. A statically representative sample of professionals who belong to Grade I and II building contractors in the eastern province of Saudi Arabia were selected to participate in this study. The findings reveal a set of 24 critical waste sources that is perceived by the respondents as the most evident in the construction jobsite. The trends in these factors are related to construction material, laborers, ergonomics of the task, intra-organizational and external approval and review process.

5.1.Introduction

Production management theorists have for the most part of the 20^{th} century conceptualized production as a series of transformation processes, a mere input-output system, better described as a black box, where the production process itself is not discussed. However, breaking down the transformation process into smaller units, it is apparent that production systems include processes that do not contribute to an output, such as transfer of material. Following the dominance of the transformation view, a new model of production emerged in the 1980's, namely, flow model. The uniqueness of this model lies in its introduction of time as an input/resource. While the concept of time has long been used in production management fields, however, for other purposes, such as scheduling (Koskela, 2000).

The observation of time as a production resource implies that time is consumed during any production related activity, whether being transformative or not. This gives notion to the need of making transformation activities more efficient and trying to eliminate non-transformation activities, i.e. non-value adding. Therefore, the flow concept is embodied in the lean approach where it aims at minimizing the share of non-value adding activities, meanwhile, improving the time consumed on value-adding activities by workers. (Hosseini, Nikakhtar, Wong, & Zavichi, 2011; Koskela, 1992).

5.2.Process Waste Concept as Viewed in Lean

The elimination of waste is an essential concept to the lean approach. This practice was pioneered by Toyota and was oriented towards productivity improvement to drive the competitive advantage inside organizations (Hines & Rich, 1997). As evident in a study by Lewis (2000) arguing that the productivity improvement carried out by the lean approach has proven to enhance the competitive advantage of organizations through better financial performance.

Koskela (1992) notes that while project managers may interpret waste as physical construction waste including material losses, the lean approach, while considering physical waste, stresses the importance of process wastes produced over a construction activity, such as, waiting and inventory.

Productivity-oriented improvement techniques define three types of activities in the internal manufacturing context, these three types are classified as:

1. Non-value adding (NVA)
2. Necessary but non-value adding (NNVA)
3. Value-adding (VA)

The first category is considered as pure waste, such as waiting time and double handling, which can be completely omitted. On the other hand, the necessary but non-value adding (NVA) activities, such as unpacking deliveries and handing one tool from one to another, although might be wasteful, however, are important for the current job setting. Major changes to the operation system is required in order to eliminate such wastes. Finally, the value-adding activities underlie conversion or processing of raw materials and semi-finished product, which are essentially inherent in the job (Hines & Rich, 1997). Likewise, from the viewpoint of the customer, value-adding activities are those operations that add to the value perceived by the customer, while non-value adding activities do not (Hosseini et al., 2011). Rawabdeh (2005) has defined waste from the resources utilization viewpoint as *"anything other than the minimum amount of resources which are essential to add value to the product*".

The types of wastes emphasized in the lean approach can be categorized as: overproduction, waiting, transportation, inappropriate processing, unnecessary inventory, unnecessary motion, defects.

Furthermore, addressing an essential principle of the lean concept, namely waste elimination, Diekmann, Balonick, Krewedl, & Troendle (2003) have compared the definitions of the seven wastes in both manufacturing and construction industry, as detailed in Table 11.

Table 11: Comparing definition of waste in Lean Manufacturing vs. LC, Source: (Diekmann et al., 2003)

Type of Waste	Manufacturing	Construction
Overproduction	Production of excess units or parts caused by push manufacturing	Overbuilding a particular aspect of a project, either because it was over-engineered, or work done before is needed
Waiting	Time spent waiting for the next batch of parts to arrive from the previous process. Time spent waiting for a machine to finish.	Time spent waiting for other work crews to finish their particular conversion process so that the next
Transport	Wasted effort to transport materials, parts or finished goods into or out of storage between processes	Waste effort transporting building components or tools into or out of job trailers or storage between processes
Over-processing	Doing more work than is required	Rework, double handling, or storage caused by defects in design, fabrication or construction
Inventory	Maintaining excess inventory of raw materials, parts in process or finished goods.	Storing excess construction equipment, components, or tools
Motion	Waste associated with unnecessary worker/equipment movement between work stations.	Unnecessary worker/equipment movement around the jobsite
Defects	Repair or rework	Deficiencies in the final product, requiring additional work, or rework to correct the punch list items

5.3.Reducing the share of Non-Value Adding activities (NVA)

According to Koskela (2000), there are three root causes of waste in operations:

- The production system structure governing the physical flow of material and information
- The way the production system is controlled, where:
  - Control principles may contribute to waste
  - Deficiencies in conforming to the control principles
- The inherent nature of production

In order to reduce the waste caused by the aforementioned causes, Koskela (2000) proposes the following principles:

1. Reduce lead time

   Lead time of a typical construction process comprises of: processing time, inspection time, wait time, move time. Compression of lead time entails the compression of these elements, and in turn reduces the share of NVA activities. Another important relationship is the proportionality between lead time and work-in-progress.
2. Reduce variability

   (Hopp & Spearman, 1996) describe two types of variability that need to be reduced for the sake of improving the process, namely, process-time variability and flow variability. Process-time variability refers to the time required for completing a task at a workstation, and flow variability is the inconsistency of jobs arriving at a single workstation.
3. Introduce simplicity

Simplification of processes is the result of introducing standardization, reducing the number of steps and components in a material or information flow path. A good practice would include the use of cross functional teams.

4. Increase flexibility

   The flexibility in this context refers to the production leverage.

5. Increase transparency

   The transparency in operations can aid in detecting errors, and consequently increases the motivation of workers for improvement.

5.4.Process Waste Assessment

Waste assessment is an essential step in the waste elimination process as per the lean approach. Multiple models have suggested assessment frameworks and tools to be implemented in the industry.

A holistic model that was developed by observing the Japanese corporate practices is the one suggested by Lim et al. (1999). This model builds upon the seven types of wastes defined by (Ohno, 1988) to form the IMI system, an abbreviation for Investigation, Method and Implementation. These three concepts are defined as cycles for improvement. However, in the waste assessment context, the first process cycle is to be emphasized, namely the Investigation cycle. This cycle is aimed at discovering the hindrances to the performance improvement of the four constraints that typically need to be addressed in a production environment, namely man, machine, material and method (4Ms), as stated by Ishikawa (1985). (Lim et al., 1999) (See Figure 11)

A case study that was carried out by (Thomas, Horman, de Souza, & Zavřski, 2002) has relied upon workflow and labor productivity variability in relation with project performance to establish global Project Waste Index (PWI). Although the study is done through statistical correlation and data collected at the jobsite, not including details of the tasks, such as ergonomics, it concludes that waste elimination contributes to the improvement of flow reliability, which in return enhances the project performance.

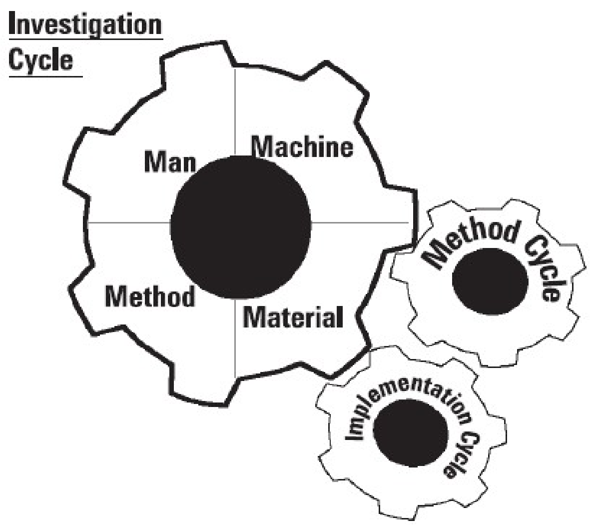

Figure 11: The Investigation cycle of the IMI approach featuring the 4Ms framework (Source: Lim et al. 1999)

Process waste assessment can also be achieved through discrete event simulation accompanied with Value Stream Mapping (VSM) technique, which refers to mapping the flow of material and information in the system. This technique can be implemented at different levels ranging from outlining whole systems to single processes, at the macro or micro levels (Yu, Tweed, Al-Hussein, & Nasseri, 2009).

Multiple studies have followed the self-assessment methodology to develop a tool that allows managers to allocate the sources of waste and their significance. Rawabdeh (2005) has followed a similar methodology, in which the (Ohno, 1988) seven types of wastes was utilized along with the 4Ms model, namely man, machine, material and money, to develop a comprehensive tool for waste allocation and assessment in the shop floor environment. (See Figure 12)

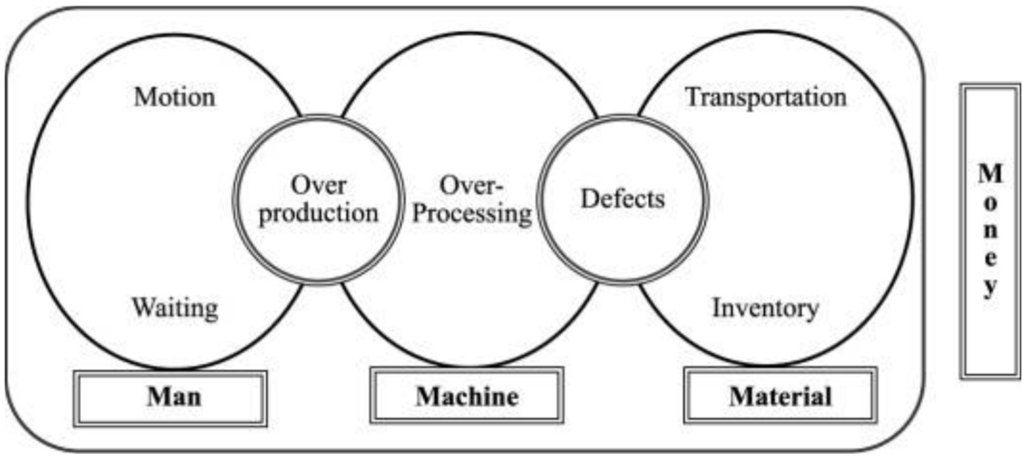

Figure 12: Waste assessment utilizing the 4Ms model (Source: Rawabdeh 2005)

While the concept of waste elimination is an essential part of the Just-In-Time (JIT) principle, few systematic approaches had been developed in order to address the waste identification procedure (Rawabdeh, 2005).

5.5.Objectives of the Study

The main objectives of this study are: (1) to develop a Non-Value Adding (NVA) activities assessment tool that targets planning and execution functions. (2) to discover the source of process waste in the planning and operations functions. While this tool is demonstrated via a survey questionnaire in the Saudi construction industry, it can be utilized by practitioners as a self-assessment tool to discover sources of process waste in their own jobsites.

Figure 13: Objectives of the study

5.6.Research Methodology

In order to achieve the objectives of this study, an exhaustive literature review was conducted touching areas such as, quality theories, lean construction, waste identification and elimination and non-value adding activities in the construction process. Identifying waste is not an easy task by any means due to the complexity and number of parameters in the construction site and the overlap between those parameter (Rawabdeh, 2005). The difficulty of identifying relies also in the attributes of the construction industry, being project-based where operation is of a make-to-order nature. Overall, each project is unique, and every task is different.

Lim et al. (1999) have proposed an approach for driving continuous improvement. The system proposed, called the IMI cycle, includes three inter-connected elements, they are: investigation, method and implementation cycles. This study utilizes the Investigation circle described by the framework for discovering the potential Non-Value Adding (NVA) activities. The Investigation cycle, based on a 4Ms model, namely man, machine, method and material, is used to identify the relevant sources of wastes in a typical construction site environment. Furthermore, the wasteful processes defined were categorized based on (Ohno, 1988) seven wastes, namely, overproducing, over-processing, inventory, transporting, defects, waiting, motion. The research methodology is outlined in Figure 14. Moreover, the tool developed in this study was verified through a survey questionnaire aimed at discovering the sources of process waste as perceived by Saudi constructions practitioners.

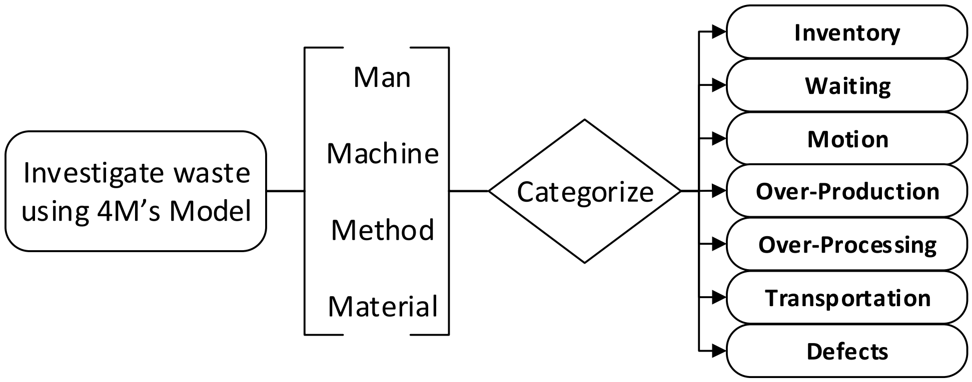

Figure 14: Research methodology

5.6.1. Development of NVA Assessment Tool

The development of a Non-Value Adding (NVA) activities assessment tool is the main focus of this study. The constituents of this tool were established through thorough examination of the literature and close observation of the typical construction operation environment in Saudi Arabia. 39 factors were discovered that contribute to the waste in a typical construction jobsite environment. Overall, to construct the scope of this study, the waste categories were defined, as illustrated in Table 12. Eventually, the sources of waste were identified through observation and review of the relevant literature, which are caused by either of the 4MS, man, machine, method and material. The waste factors are listed in Table 13.

Table 12: Definitions of waste categories

Category	Definition
Waste of Defects	Rejected or unsatisfactory work that needs to be fixed or rework
Waste of Over-processing	Unnecessary processes that do not contribute to the value of the final product and could be omitted
Waste of Overproduction	Unnecessary work, or work that is done earlier than needed
Waste of waiting	Project delays, idle time of equipment and workers
waste of transportation	Internal movement of material and equipment around the jobsite
Waste of motion	Unnecessary or inefficient movement of workers
Waste of inventory	Excessive storage of material in the job site, inventory control and bulk purchasing

A comprehensive study on the application of lean manufacturing principles to construction conducted by Diekmann et al., (2003) was used in the development of this tool. Under waste elimination, the study states the following principles for waste elimination:

1- Process Optimization:

   a. Minimize double handling and worker and equipment movement
   b. Balance crews, synchronize flows
   c. Remove material constraints, use kitting, reduce input variation
   d. Reduce difficult setup/ changeover
   e. Reduce scrap
   f. Use Total Productive Maintenance (TPM)

2- Supply Chain

   a. Institute Just in Time (JIT) delivery.

3- Production Scheduling

   a. Use production planning and detailed crew instructions, predictable task times.

   b. Implement last planner, reliable production scheduling, short interval schedules

   c. Practice the last responsible moment, pull scheduling.

   d. Use small batch sizes, minimize work-in-progress (WIP)

   e. Use decoupling linkages, understand buffer size and location

4- Product Optimization:

   a. Reduce the parts count, use standardized parts.

   b. Use pre-assembly and prefabrication

   c. Use preproduction engineering and constructability analysis

Table 13: Waste factors used in the study

ID	FACTOR
	WASTE OF DEFECTS
F1	Inadequacy of quality control plan/process
F2	Workers lack of awareness of quality acceptance criteria of the assigned task
F3	Workers production of substandard work or defects
F4	Unsupervised work execution
F5	Poor performance of construction equipment
F6	Complex construction methods
	WASTE OF OVER-PROCESSING
F7	Modification or extensive processing of procured material
F8	Stringent approval and review process
F9	Unnecessary double checking in the quality assurance/control plan
F10	Issuance of many change orders altering the project scope, deeming some finished work unnecessary
F11	Project startup and closure include extra steps over the plan approved by the client
	WASTE OF OVERPRODUCTION
F12	Work is occasionally performed earlier than needed/planned

F13	Project tasks are poorly defined in terms of quantity, often leads to producing more than needed (e.g. unnecessary steel rebar fabrication)
F14	Crews assigned to a task are occasionally larger than needed
F15	The selected equipment's capacity is occasionally larger than what's needed for the task
F16	Over-ordering of material more than the actual need happens frequently
WASTE OF WAITING	
F17	Some workers are often idle due to overmanning of crews
F18	Laborers occasionally wait for material and equipment to arrive to the task location
F19	The project is frequently delayed due to not incorporating long lead items in the schedule
F20	Delay of permits and approvals occasionally disrupt the site operations
F21	The tools and equipment are often not readily available for use at the scheduled task's location
F22	Suppliers frequently cause delays to the project by not delivering on time
F23	Safety incidents are happening frequently, causing interruption the work flow
F24	Workers stand idle during downtimes instead of being directed to other tasks (such in the case of an equipment failure)
F25	Workers are spending more time on breaks than their assigned break period
WASTE OF TRANSPORTATION	
F26	A site layout plan detailing material and work flow is not utilized
F27	Material-handling equipment (such as forklifts and cranes) are inadequate for the lifting tasks
F28	The materials and equipment are moved too often on the jobsite
F29	The material and equipment transported are occasionally damaged due to poor handling
F30	Material/equipment delivered by the suppliers are usually double handled by the contractor to the point of use
WASTE OF MOTION	
F31	Workers are often searching for tools and equipment at the task location with Workspaces lacking neatness
F32	The tasks often require workers to walk long distances to retrieve tools and equipment
F33	The tasks usually require workers to bend, reach or lift heavy objects
F34	The scarcity of tools forces workers to hand them from one hand to another
WASTE OF INVENTORY	
F35	Large quantities of material are stored onsite
F36	The on-site material inventory is poorly-organized, and materials cannot be retrieved easily
F37	Materials stored are frequently damaged due to improper storage (e.g. steel rebar corrosion)
F38	Procured material are ordered in bulk rather than small unitized loads
F39	Procurement activities are done much earlier than the actual use of material in the project

5.6.2. Questionnaire Design

A survey questionnaire design was utilized to put the tool into test, benefit from the feedback of professionals into the design of the tool, discover waste areas and sources as perceived by Saudi contractors.

The survey incorporates all the factors developed in this tool, however, the respondents are asked to rank their level of agreement with a set of statements that each describe a source of a potential waste on a scale from “0= Never” to “4= Always”. Respondents are also asked to assign weight (from 1 to 5) to each waste category according to its significance and effect on the construction operation. The factors are stated as scenarios in the questionnaire, and the participant is asked to rate the estimated frequency of each happening.

5.7. Theory and Calculations

The approach used in this study aims at ranking the sources of waste in conformance with the Lean Construction (LC) concept. An importance index was used based on the Relative Importance Index (RII) reflecting the ranking given by the respondents to each factor.

5.7.1. Data Collection

The survey questionnaire was distributed among Grade I and II building contractors (a total of 43 firms) in the Eastern Province of Saudi Arabia. A total number of 30 responses were received, which forms a statically representative sample of the population as calculated per (Kish, 1965).

The classification of the contractors is developed by the Contractors Classification Agency operating under the Ministry of Municipal and Rural Affairs and the Eastern Province Chamber of Commerce ("Contractors Classification Agency," 2017). The classification is based on the contractors financial and technical capabilities to undertake government's projects. The respondents work mainly in direct contact with projects on a daily basis where they either work in engineering or project management.

5.7.2. Data Analysis

The data collected are analyzed through the following statistical means and indices:

Local Importance Index: as cited by (Holt, 2014), formula (1) is used to independently give weight to each factor as per the responses to the survey.

Local Importance Index (L I. I.) (%) = $\frac{\Sigma W}{AN} \times 100$ …….. (1)

Where,

W = the sum of "n" respondents selecting a specific rank (ranges from 0 for never to 4 for always) multiplied by the rank's integer value.

A = largest rank that can be designated for a specific variable

N = Sample size (30 respondents)

Category significance: the significance of each waste category (formula 2) is simply the average of given weight by all respondents.

Category Significance (Cat. S.) (%) = $\frac{\sum W}{AN} \times 100$ ……... (2)

Where,

W = the sum of "n" respondents selecting a specific rank (ranges from 1 for not significant to 5 for very significant) multiplied by the rank's integer value.

A = largest rank that can be designated for a specific variable

N = Sample size (30 respondents)

Waste Index: the waste index (formula 3) is calculated as a product of the local importance index and the category significance, and gives a global ranking in order for the factors to be compared against each other.

Waste Index (W.I.) (%) = [L.I.I. (%) * Cat. S. (%)]/100 ……... (3)

5.7.3. Evaluating Waste

An arbitrary selected scale was created for classifying the factors based on their Waste Index value: (Critical Wasteful, Wasteful, Moderately Wasteful, Low Waste)

1. $[0.40 \leq W.I. \leq 1.00]$ indicates that the practice is critically wasteful
2. $[0.35 \leq W.I. < 0.40]$ indicates that the practice is wasteful
3. $[0.30 \leq W.I. < 0.35]$ indicates that the practice is moderately wasteful
4. $[W.I. < 0.30]$ indicates that the practice hardly causes any waste

5.8.Results and Discussion

The results of this survey are presented in Table 14. The factors are ranked based on the corresponding waste index calculated for each factor. The Waste Index scores are a result of the answers provided by the survey participants. The factors are qualified for this list if their Waste Index value is higher than or equal 30%. Since the waste index developed in this study incorporates the significance of each waste category and the importance of each factor, the comparison between these factors is valid.

Table 14: Non-Value Adding (NVA) activities ranking

ID	FACTOR	WASTE INDEX (%)	RANK
F18	Laborers occasionally wait for material and equipment to arrive to the task location	45.00	1
F36	The on-site material inventory is poorly-organized, and materials cannot be retrieved easily	44.33	2
F35	Large quantity of material is stored onsite	43.70	3
F30	Material/equipment delivered by the suppliers are usually double handled by the contractor to the point of use	40.80	4
F3	Workers production of substandard work or defects	39.87	5
F25	Workers are spending more time on breaks than their assigned break period	39.44	6
F20	Delay of permits and approvals occasionally disrupt the site operations	38.89	7
F5	Poor performance of construction equipment	38.84	8
F26	A site layout plan detailing material and work flow is not utilized	37.80	9
F31	Workers are often searching for tools and equipment at the task location with Workspaces lacking neatness	37.72	10
F22	Suppliers frequently cause delays to the project by not delivering on time	37.22	11
F38	Procured material are ordered in bulk rather than small unitized loads	36.73	12
F28	The materials and equipment are moved too often on the jobsite	36.60	13

F24	Workers stand idle during downtimes instead of being directed to other tasks (such in the case of an equipment failure)	35.00	14
F37	Materials stored are frequently damaged due to improper storage (e.g. steel rebar corrosion)	33.57	15
F33	The tasks usually require workers to bend, reach or lift heavy objects	33.41	16
F19	The project is frequently delayed due to not incorporating long lead items in the schedule	32.78	17
F1	Inadequacy of quality control plan/process	32.20	18
F34	The scarcity of tools forces workers to hand them from one hand to another	31.79	19
F17	Some workers are often idle due to overmanning of crews	31.67	20
F8	Submittals (such as shop drawings, material data, samples) approval or review process is lengthy and includes unnecessary steps	31.24	21
F27	Material-handling equipment (such as forklifts and cranes) are inadequate for the lifting tasks	31.20	22
F39	Procurement activities are done much earlier than the actual use of the material in the project	30.40	23
F21	The tools and equipment are often not readily available for use at the scheduled task's location	30.00	24

The ranking of waste causes reveals trends in the industry based on the responses provided by the participants. The ranking shows that significant waste is caused by material delivery, handling, inventory, and on-site storage system. In fact, 7 factors out of 24 NVA activities defined are related to material inventory and transportation among which is the top four factors. The ranking also concluded that waste caused by material contributes to categories such as, inventory, waiting, transportation. This can be attributed to the common perception of construction waste being physical, e.g. material surplus from demolition.

Another source of waste according to the IMI system is manpower, the findings suggest that multiple categories of waste are influenced by it. For instance, waiting, motion and defects, this can be attributed to the nature of construction operations being labor intensive. Another waste source (F33) related to workers that has its origins in lean production, is the ergonomics of the assigned task and workstation design. Ergonomics studies relates to the human body and its limits, achieving maximum output without physical harm to workers, e.g. bending, stretching, reaching ... etc.

The ranking reveals some external factors that have a significant impact on the site operations, they are, the inter-organizational and external approval and review of submittals, the delays that result from suppliers' untimely deliver. Furthermore, equipment may cause disruption to the site operations, due to inferior performance, their inadequacy to the task in hand, and being extensively moved around the jobsite.

Table 15: Waste categories ranking

CATEGORY	AVG CAT. I. (%)	RANK
INVENTORY	37.75	1
WAITING	35.49	2
TRANSPORTATION	35.16	3
MOTION	32.87	4
DEFECTS	31.94	5
OVER-PROCESSING:	24.09	6
OVERPRODUCTION	21.46	7

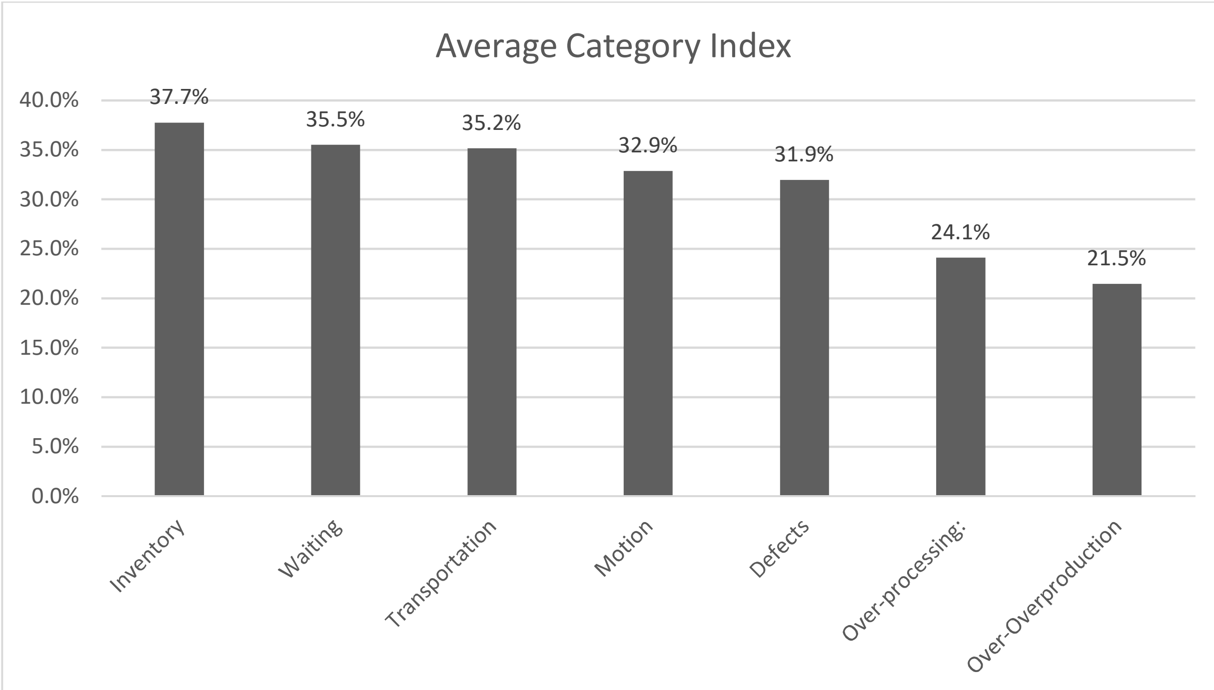

Figure 15: Average category index percentages

As illustrated by the category ranking in Table 15 and Figure 15, the top three categories that contribute to waste in construction jobsites in Saudi Arabia are inventory, waiting, and transportation. in support of this ranking, a simulation study conducted by Al-Sudairi (2007) have stated that inventory and material availability is the main source of uncertainty and increased cycle time. The lowest ranking categories were overproduction and over-processing by a significant margin. This raises a question about the applicability of these two categories in the construction industry context.

In addition to the seven types of waste described by the literature on lean and included in this study, some respondents added an eighth type which is the underutilization of people with special trades experiences or skills.

5.9.Conclusion

While project managers may interpret waste as physical waste, e.g. material surplus resulted from demolition, the lean approach extends this definition to other sources such as time, motion, and any non-adding value work produced over the length of the construction process.

Lean practitioners define waste as anything other than the minimum amount of resources utilized to add value to the client. Waste elimination, as featured in the lean approach, focuses particularly on productivity gains rather than quality enhancement, where a leaner operation can drive quality by exposing the system. This study has developed a weighted factor tool for assessing the Non-Value Adding (NVA) activities around the construction jobsite. This tool was utilized to discover the sources of waste as perceived by Saudi building contractors. A list of 39 factors was developed utilizing an exhaustive literature review and survey responses by 30 Saudi construction experts were statistically analyzed and ranked by quantified relative importance index. The analysis was undertaken to enlighten researchers and practitioners on the emphasis of waste elimination effort in the kingdom.

The results obtained identify inventory and material as the salient factor affecting the construction operations, corroborating the significance role of material handling and storage practices and the involvement of suppliers in the process. The findings also suggest that significant waste is created at the micro level, i.e. workers. This might be attributed to the labor intensity of construction operation, and the high variability of tasks. Labor skills and work manner should be addressed in efforts to minimize the process waste and enhance productivity.

This tool can be used as a self-assessment tool by project personnel to discover the root causes of waste around the site. The tool incorporates a 5-point Likert scale to determine the significance of each waste category on the operation, and the occurrence some common causes of waste and variability in the jobsite.

5.9.1. General Recommendations

The elimination of waste in construction operations can lead to great gains in productivity and quality, optimizing process and product, improved supply chain and production scheduling. In order to attain these benefits, it is recommended to adopt the following:

- Use Process Mapping and Value Stream Mapping (VSM) along with simulation techniques as a diagnostic tool exploring waste in each process. While this practice can be laborious, however, the gains in productivity and quality, along with savings in labor and material costs, reduction of cycle times may outweigh the drawbacks.
- Reduce on-site inventory by instituting Just-In-Time (JIT) delivery of material to the jobsite practices in companion with the suppliers and vendors. This practice in turn reduces the need for double handling.
- Creating logistical and material moving plans earlier in the project, and adhere to them throughout the project lifecycle
- Increasing the efficiency of the administrative processes of an organization can influence the productivity of its operations. This is vividly evident in the approval and review of submittals, issuance of permits etc.

- Establish coordination and effective communication between the different units in the organization can aid in minimizing downtime of the project.

5.9.2. Recommendations for Future Research

The tool developed in this study can aid practitioners in assessing the root causes of waste in the construction process. Although this tool is comprehensive, yet it is general in nature, different versions can be produced for different trades and sectors of construction such as, environmental, transportation, industrial construction. A detailed study can build on the findings of this study to explore in depth the causes of waste in the construction jobsite.

CHAPTER 6: Conclusion and Recommendations

In this chapter, a summary of the followed research methodology and results is provided, included also are the concluded remarks drawn out from this research. Lastly, this chapter discusses general recommendations as well as recommendation for future research with regards to the subject.

6.1.Summary and Conclusions

This study is conducted with two research objectives, firstly, to prioritize the barriers to implementing Lean Construction (LC) in the Saudi construction firms, secondly, to develop a Non-Value Adding (NVA) activities assessment tool.

In order to achieve the first objective, namely, prioritizing barriers to the effective implementation of Lean Construction, a field study comprised of a survey questionnaire was conducted, asking participants to rate their organizations in terms of implementation of a set of Lean Construction practices and enablers. The identified barriers are grouped into seven main categories, they are, pull-driven strategy of production, minimization of process wastes by elimination of non-value adding activities, quality assurance/quality at the source, continuous improvement (kaizen), building of long-term relations with suppliers and subcontractors, production leverage, and teamwork. The barriers' scores are calculated through an implementation index, based on the Relative Importance Index (RII) method, describing the level of adoption of each factor as expressed by the respondents to the survey. As for the second objective of this study, that is, developing an assessment tool for Non-Value Adding (NVA) activities, 39 factors were developed through a review of the literature, grouped under seven categories of waste as stated in the Lean literature, namely, overproducing, over-processing, inventory, transporting, defects, waiting, motion. Furthermore, this tool was validated through a field study including semi-structured interviews with practitioners, aimed at rating the significance of each waste group and the occurrence of each waste root cause in their projects.

The findings of the first part of the study reveal a list of 24 barriers that are perceived by Saudi construction practitioners to be the most influencing and the least implemented. These barriers have major trends that were identified in the study as: barriers related to the social and physical environment of the workplace, barriers related to inbound communication, and barriers related to the design and planning phases of the project. However, while major barriers were manifested in this study, contractors possess a relatively readiness for, approval of and conformance to some Lean Construction practices. A list of 11 factors have particularly scored high in the implementation index developed, indicates that Saudi contractors have the ability to exploit these sound practices into adopting a lean construction based initiative, taking into account that the majority of practitioners have expressed familiarity with the concept.

The findings of the second part expose the sources of process waste as perceived by the respondents. The study has unraveled the root causes of waste in the typical construction jobsite environment. 24 factors were identified as the major source of waste, categorized under major trends such as, material inventory transportation and handling. Other sources are manpower, ergonomics of the task, equipment, and external factors.

6.2.Contribution of the Study

Lean Construction (LC) is an approach that combines operational research and practical development in an endeavor for improving productivity, maximizing the value creation and ultimately enhance the quality of the construction process, with a minimum cost, and considering the client needs. Lean construction is holistic approach, in which it involves all the project participants, like owners, designers, contractors, suppliers and end-users in this endeavor. The proposition of such concept to the construction industry in the modern time is highly imperative. The rationale behind change in the construction industry is the inevitable increasing complexity of projects, heightened consumer expectations while the industry is slow pacing in terms of innovation and productivity.

The Saudi construction industry in particular is highly dependent on the governmental capital expenditure. However, the government's introduction of Vision 2030 which, among other reforms, aims at increasing the private sector contribution from 40% to 65% of GDP through the adoption new models for publicly funded projects through frameworks such as Public Private Partnerships (PPP). In light of these facts, the Saudi construction industry faces a challenge to embrace a change to its operational model, characterized by poor labor productivity and cost and duration overruns.

This research looks at hurdles that hinder the implementation of Lean Construction, adopting such concept can radically change the on-site execution, reducing waste and variability. The study of barriers to implementation is major phase in adopting a new model. Along with automation, digitization and IT-based systems, such as Building Information Modelling (BIM), the integration of these techniques with the lean approach can yield a highly effective model for the future of the industry.

Another focus of this study is the discovery and assessment of root causes of variability and waste within the on-site execution areas. The tool developed in this study can serve as a general framework for waste discovery in a typical construction environment. The benefits of this tool could be attained if implemented as a standard procedure in each project as part of an operational excellence endeavor, aimed at achieving continuous improvement in the construction industry.

This study is a contribution to alleviate research and development in an industry that is lacking in terms of innovation, yet being a key contributor to the global economy.

6.3.Future Directions

In order for construction firms to escape their low productivity and efficiency trap, a radical initiative must be carried out to transform their operations. Lean Construction has the ability to revolutionize the way construction firms operate through the different set of principles that have originated in other sectors.

While changing the traditional operating model can be hard, especially with the tendency of the construction industry of resisting change, and may require a major overhaul, however, the outcomes could be very rewarding. Upon the findings of this study, construction firms are advised to implement the following:

- Improve workplaces by engaging the employees and workers in the decision-making process, enhance their physical environment, invest in training and educational programs, minimize hierarchies within the organization.
- Establishing effective communication within the organization helps in creating a sense of responsibility and accountability among employees, this could require investing in IT-based infrastructures, such as Enterprise Resource Planning (ERP) software, and visual tools. This also can aid in minimizing downtime of the project.
- Standardize processes and utilize modular designs whenever possible. The process of standardization leads to savings in time and money, especially with operations where there is a learning curve, or material that needs to be modified. Additionally, the use of off-site construction methods contributes significantly.
- Improve the planning of processes and tasks. Creating a continuous workflow helps in minimizing downtime for crews and equipment. Moreover, establishing site layout plans helps in optimizing pathways and storage locations around the jobsite.
- Implement a rigid quality assurance/control plan and communicate it to all subcontractors and field workers. Implementing quality at the source is a key principle in Lean Construction. In doing so, the cost of correcting a defect can be minimized. In addition, avoid using multi-layer subcontracting as possible, as one of the issues associated with it is non-compliance with quality criteria.
- Consult construction and procurement teams at the beginning of the design phase, building a cross-functional team reduces the probability of errors later on in the lifecycle of the project and brings different areas of expertise into the project.

- Use Process Mapping and Value Stream Mapping (VSM) along with simulation techniques as a diagnostic tool exploring waste in each process. While this practice can be laborious, however, the gains in productivity and quality, along with savings in labor and material costs, reduction of cycle times may outweigh the drawbacks.
- Reduce on-site inventory by instituting Just-In-Time (JIT) delivery of material to the jobsite practices in companion with the suppliers and vendors. This practice in turn reduces the need for double handling.
- Creating logistical and material moving plans earlier in the project, and adhere to them throughout the project lifecycle
- Increasing the efficiency of the administrative processes of an organization can influence the productivity of its operations. This is vividly evident in the approval and review of submittals, issuance of permits etc.

While this research was conducted in the Saudi construction industry, particularly, building contractors, a similar study can be undertaken for various categories and trades of contractors such as, specialized, transportation, industrial construction. This study can be also used to benchmark other developing countries against the results obtained for Saudi Arabia. Furthermore, in-depth studies may be required to check the validity of the findings presented by this study. the definitions for the waste categories presented in this study might be tested against the lean literature as they are broad in nature.

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APPENDIX A

Survey Questionnaire (1): Barriers to the Effective Implementation of Lean Construction and Assessment

Dear Respondent,

Thank you for taking the time to fill the questionnaire, your contribution to the industry improvement is highly appreciated. Kindly answer the questions in the following section then read the instructions below to guide you in completing the survey.

I. General Information

1. Job Position

----

2. Educational Background (Bachelor's Degree and/or higher)

----

3. Years of Experience

----

4. Company's Capital (millions)   "Optional"

----

5. Are you familiar with the Lean Construction concept?
   a. Yes
   b. No
6. Has your organization applied/attempted to apply any of the Lean Construction Principles?
   a. Yes
   b. No

II. Assessing Lean Construction Conformance

In the following section, you will be provided with project management practices that stem from the Lean Construction principles. Kindly rate the statements based on the level of their conformance with project management practices in your organization.

- Answer with "1" if the stated practice is rarely exercised in your organization, and "5" if the practice is always applied.
- Answer with N/A if the stated practice has never been applied before, or does not apply to the context of the organization.

	#	Conformance Criteria	Level of conformance				
Pull-Driven strategy	1	Project objectives and the client's requirements are known by all parties involved	N/A	1	2	3	4
	2	Materials are delivered to the jobsite just before their use, keeping storage at a minimum	N/A	1	2	3	4
	3	Clients are involved in the design phase to ensure the compatibility between the proposed design and their needs	N/A	1	2	3	4
	4	The owner/owner's representative approval of submittals and response for requests is prompt	N/A	1	2	3	4
Minimization of process waste	5	Employees can define the non-value adding activities within their work areas	N/A	1	2	3	4
	6	A flat organizational structure (with minimized hierarchy) is highly adopted	N/A	1	2	3	4
	7	Materials are stored at the possible closest location to the point of use to minimize workers' unnecessary motion during job execution	N/A	1	2	3	4
	8	Off-site construction techniques (such as prefabrication and pre-assembly) are utilized	N/A	1	2	3	4
	9	Cost of material and field installation costs are considered during the design phase	N/A	1	2	3	4
	10	Contractors are involved in the design phase to minimize the need for change orders later in the project's lifecycle	N/A	1	2	3	4
	11	Workspaces are neat and organized with tools and materials in their designated place	N/A	1	2	3	4
	12	Crew sizes are planned considering the unique features of each task	N/A	1	2	3	4
	13	A site layout plan is created, specifying storage locations at the work site	N/A	1	2	3	4

	14	A logistics plan is implemented to define site access, pathways and the location of work phases	N/A	1	2	3	4
	15	A detailed plan and schedule is developed early in the project and the project team follows it throughout the project lifecycle	N/A	1	2	3	4
	16	Long lead items are identified early in the project and their progress is monitored to minimize project downtime	N/A	1	2	3	4
Q/A	17	A quality plan is developed for each project. It serves as a reference for staff duties during the project and defines the corrective actions	N/A	1	2	3	4
	18	Project defects are minimized using proactive preventive measures (e.g. preventive maintenance for equipment)	N/A	1	2	3	4
	19	The contractor's quality standards are communicated to all contractual parties to ensure their proper implementation	N/A	1	2	3	4
Q/A	20	Visual tools such as boards and progress charts are used to communicate project info (such as schedule, productivity and safety) to staff and workers	N/A	1	2	3	4
	21	Visual tools (such as visual boards) are updated frequently and prepared to be suitable for the targeted audience	N/A	1	2	3	4
	22	The contractors' office site quality assurance/control actively monitors the tasks around the site	N/A	1	2	3	4
Continuous Improvement	23	Metrics about production are systematically utilized, documented and analyzed to evaluate project successes	N/A	1	2	3	4
	24	Past project data and employees' experiences are documented and utilized to improve the productivity and efficiency of the organization's future projects	N/A	1	2	3	4
	25	Employees are consulted in the efforts to enhance the performance of projects and to improve the organization as a whole	N/A	1	2	3	4
	26	Employees opinions and views are considered and implemented in the endeavor to improve the organization/project execution	N/A	1	2	3	4
	27	Upper-level management seeks to enhance the culture of its employees which reflects positively upon their performance	N/A	1	2	3	4
	28	Management is continuously seeking to improve the performance and efficiency of the organization	N/A	1	2	3	4

	29	Employees are actively seeking to improve their own workplaces	N/A	1	2	3	4
	30	The organization constantly holds educational/training programs of its employees	N/A	1	2	3	4
	31	The company has long-term objectives and vision on the organizational level and it is committed to them	N/A	1	2	3	4
	32	The project team tries to modify the plans in order to reduce costs as long as it conforms to quality standards	N/A	1	2	3	4
	33	Offices and construction sites are well-organized and are continuously monitored for their neatness and cleanliness	N/A	1	2	3	4
	34	Work processes are clearly defined and continuously monitored along with their utilization of the different resources	N/A	1	2	3	4
Suppliers Relation	35	Suppliers deliver material in a timely manner and adhere to the ordered specifications	N/A	1	2	3	4
	36	The organization limits the use of multi-layer subcontracting to assure the quality of work performed by subcontractors	N/A	1	2	3	4
	37	The contractor seeks long-term contracts/partnerships with suppliers rather than short-term contracts that are based on cost alone	N/A	1	2	3	4
Productivity Leverage	38	Work is passed on to the next crew (like subcontractors) in small batches or continuous flow rather than large bundles	N/A	1	2	3	4
	39	The organization can dynamically change its resources allocation according to changing customer needs (like expediting work in part of the project)	N/A	1	2	3	4
	40	The contractor is often able to reorganize and meet changing customer requirements such as minimizing the cost or performing complex tasks	N/A	1	2	3	4
	41	Design utilizes readily available material and repetitive tasks	N/A	1	2	3	4
Teamwork	42	Communication and cooperation between the departments and business units within the organization is effective	N/A	1	2	3	4
	43	The response to requests and submittals inside the organization is prompt and effective	N/A	1	2	3	4

	44	Project resources (such as manpower and equipment) are effectively shared across multiple projects and departments within the organization	N/A	1	2	3	4
	45	An IT-based infrastructure is utilized in the communication process between the organizations' divisions (such as Enterprise Resource Planning [ERP] systems)	N/A	1	2	3	4

APPENDIX B

Survey Questionnaire (2): Assessment for Non-Value Adding (NVA) Activities in the Construction Industry

III. Non-Value Adding (NVA) Activities Assessment

In the following section, you will be provided with typical causes of process waste in the construction jobsite environment.

- Kindly, at the top each table, evaluate the significance of the defined waste type.
    - [1: Not Significant, 5: Very Significant]
- Rank each statement according to their level of agreement with the current state in your organization.
    - [0: Never, 1= Rarely, 2= Sometimes, 3= Mostly and 4= Always]

Defects:

Definition		Significance				
Waste of Defects is defined as any rejected or unsatisfactory work that needs to be fixed or rework		1	2	3	4	5
#	**Practice**	**Assessment**				
1	The quality control plan/process is inadequate, which occasionally causes defects and rework	0	1	2	3	4
2	The workers are not aware of the quality acceptance criteria of the assigned task	0	1	2	3	4
3	The workers occasionally cause defects or produce substandard work	0	1	2	3	4
4	Rework is frequently needed due to unsupervised work execution	0	1	2	3	4
5	Construction equipment inferior performance occasionally causes defects	0	1	2	3	4
6	The construction methods used often require rework (e.g. due to their complexity)	0	1	2	3	4

Over-processing:

Definition		Significance				
Waste of Over-processing is defined as unnecessary processes that do not contribute to the value of the final product and could be omitted		1	2	3	4	5
#	Practice	Assessment				
7	The procured materials usually require modification or extensive processing	0	1	2	3	4
8	Submittals (such as shop drawings, material data, samples) approval or review process is lengthy and includes unnecessary steps	0	1	2	3	4
9	The project quality assurance/control plan includes unnecessary double-checking	0	1	2	3	4
10	The project scope is often altered by the issuance of many change orders, deeming some finished work unnecessary	0	1	2	3	4
11	The project startup and closure include extra steps over the plan approved by the client	0	1	2	3	4

Overproduction:

Definition		Significance				
Waste of Overproduction is defined as unnecessary work, or work that is done earlier than needed		1	2	3	4	5
#	Practice	Assessment				
12	Work is occasionally performed earlier than needed/planned	0	1	2	3	4
13	Project tasks are poorly defined in terms of quantity, often leads to producing more than needed (e.g. unnecessary steel rebar fabrication)	0	1	2	3	4
14	Crews assigned to a task are occasionally larger than needed	0	1	2	3	4
15	The selected equipment's capacity is occasionally larger than what's needed for the task	0	1	2	3	4
16	Over-ordering of material more than the actual need happens frequently	0	1	2	3	4

Waiting:

Definition		Significance				
Waste of waiting is defined as project delays, idle time of equipment and workers		1	2	3	4	5
#	Practice	Assessment				
17	Some workers are often idle due to overmanning of crews	0	1	2	3	4
18	Laborers occasionally wait for material and equipment to arrive to the task location	0	1	2	3	4
19	The project is frequently delayed due to not incorporating long lead items in the schedule	0	1	2	3	4
20	Delay of permits and approvals occasionally disrupt the site operations	0	1	2	3	4
21	The tools and equipment are often not readily available for use at the scheduled task's location	0	1	2	3	4
22	Suppliers frequently cause delays to the project by not delivering on time	0	1	2	3	4
23	Safety incidents are happening frequently, causing interruption the work flow	0	1	2	3	4
24	Workers stand idle during downtimes instead of being directed to other tasks (such in the case of an equipment failure)	0	1	2	3	4
25	Workers are spending more time on breaks than their assigned break period	0	1	2	3	4

Transportation:

Definition		Significance				
The waste of transportation is concerned with the internal movement of material and equipment around the jobsite		1	2	3	4	5
#	Practice	Assessment				
26	A site layout plan detailing material and work flow is not utilized	0	1	2	3	4
27	Material-handling equipment (such as forklifts and cranes) are inadequate for the lifting tasks	0	1	2	3	4

28	The materials and equipment are moved too often on the jobsite	0	1	2	3	4
29	The material and equipment transported are occasionally damaged due to poor handling	0	1	2	3	4
30	Material/equipment delivered by the suppliers are usually double handled by the contractor to the point of use	0	1	2	3	4

Motion:

Definition		Significance				
Waste of motion is any unnecessary or inefficient movement of workers		1	2	3	4	5
#	**Practice**	**Assessment**				
31	Workers are often searching for tools and equipment at the task location with Workspaces lacking neatness	0	1	2	3	4
32	The tasks often require the workers to walk long distances to retrieve tools and equipment	0	1	2	3	4
33	The tasks usually require the workers to bend, reach or lift heavy objects	0	1	2	3	4
34	The scarcity of tools forces the workers to hand them from one hand to another	0	1	2	3	4

Inventory:

Definition		Significance				
Waste of inventory is defined as the excessive storage of material in the job site, inventory control and bulk purchasing		1	2	3	4	5
#	**Practice**	**Assessment**				
35	Large quantities of material are stored onsite	0	1	2	3	4
36	The on-site material inventory is poorly-organized and materials cannot be retrieved easily	0	1	2	3	4
37	Materials stored are frequently damaged due to improper storage (e.g. steel rebar corrosion)	0	1	2	3	4

38	Procured material are ordered in bulk rather than small unitized loads	0	1	2	3	4
39	Procurement activities are done much earlier than the actual use of the material in the project	0	1	2	3	4

Comments or types of wastes not mentioned in the survey:

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APPENDIX C

Responses to Survey Questionnaire (1) and Rank of Barriers to Implementing Lean Construction

Category	Factor	0	1	2	3	4	N	IMPT.I (%)	Cat. IMT.I %	Cat. Rank
Pull-Driven Strategy	1	0	1	6	9	14	30	80.0%	**67.92%**	**1**
	2	3	5	9	8	5	30	55.8%		
	3	0	2	5	12	11	30	76.7%		
	4	2	7	6	8	7	30	59.2%		
Minimization of Process Waste	5	4	8	9	6	3	30	46.7%	**57.78%**	**6**
	6	2	10	9	8	1	30	46.7%		
	7	1	5	11	8	5	30	59.2%		
	8	2	2	5	13	8	30	69.2%		
	9	0	2	5	11	12	30	77.5%		
	10	5	8	7	5	5	30	47.5%		
	11	4	9	11	5	1	30	41.7%		
	12	4	6	10	8	2	30	48.3%		
	13	1	7	8	8	6	30	59.2%		
	14	1	5	9	9	6	30	61.7%		
	15	1	5	8	10	6	30	62.5%		
	16	0	3	7	9	11	30	73.3%		
Quality Assurance	17	0	2	6	10	12	30	76.7%	**58.47%**	**5**
	18	3	5	10	9	3	30	53.3%		
	19	0	5	10	7	8	30	65.0%		
	20	3	8	10	6	3	30	48.3%		
	21	4	7	8	8	3	30	49.2%		
	22	3	2	10	12	3	30	58.3%		
Continuous Improvement	23	0	3	8	11	8	30	70.0%	**59.79%**	**4**
	24	1	5	8	7	9	30	65.0%		
	25	1	5	8	9	7	30	63.3%		
	26	3	9	7	6	5	30	50.8%		
	27	3	5	5	9	8	30	61.7%		
	28	0	2	7	10	11	30	75.0%		
	29	3	9	8	7	3	30	48.3%		
	30	5	8	8	7	2	30	44.2%		
	31	1	4	7	11	7	30	65.8%		
	32	0	2	8	11	9	30	72.5%		
	33	5	8	7	6	4	30	46.7%		
	34	5	4	7	9	5	30	54.2%		
Relation w/ suppliers	35	2	5	9	11	3	30	56.7%	**62.22%**	**2**
	36	1	5	12	7	5	30	58.3%		
	37	0	4	5	12	9	30	71.7%		
Productivity Leverage	38	5	5	9	8	3	30	49.2%	**58.54%**	**5**
	39	2	6	5	7	10	30	64.2%		
	40	1	1	9	11	8	30	70.0%		
	41	6	3	10	6	5	30	50.8%		

Category	Factor	0	1	2	3	4	N	IMPT.I (%)	Cat. IMT.I %	Cat. Rank
Teamwork	42	2	8	8	8	4	30	53.3%	61.04%	3
	43	1	6	6	10	7	30	63.3%		
	44	0	3	8	8	11	30	72.5%		
	45	4	5	7	9	5	30	55.0%		

#	Barrier	Rank
B11	Lack of workplaces neatness, misplacing materials and tools from their designated places	1
B30	Insufficient employees' education and training programs	2
B5	Employees inability to define the non-value adding activities within their work areas	3
B6	Hierarchies in organizational structures	4
B33	Lack of monitoring workplaces and offices for neatness and cleanliness	5
B10	Excluding contractor from the design phase	6
B12	Absence of crew size planning with regard to each task	7
B20	Limited use of visual tools for communicating project information	8
B29	Employees negative attitude towards improving their own workplaces	9
B21	Infrequent update of visual tools and unsuitability for the targeted audience	10
B38	Work flow to the next crew in large bundles	11
B26	Disregarding employees' opinions and views in improving project execution	12
B41	Design underutilization of available material and repetitive tasks	13
B18	Lack of proactive preventative measures	14
B42	Absence of communication and cooperation between departments within the organization	15
B34	Obscure definition of work processes and their utilization of resources	16
B45	Limited use of IT-based infrastructures in the communication process between departments and divisions	17
B2	Excessive material storage	18
B35	Untimely material delivery by suppliers, and lack of adherence to specs	19
B22	Insufficient monitoring of tasks around the jobsite by quality assurance/control	20
B36	Use of multi-layer subcontracting	21
B4	Stringent owner/owner's representative approval process	22
B7	Material storage remoteness from tasks locations	23

#	Barrier	Rank
B13	Lack of site layout plans	24
B14	Lack of a logistics plan defining site access, pathways and the location of work phases	25
B27	Management's negative attitude towards enhance the organizational culture	26
B15	Inadequate planning and scheduling	27
B25	Inconsideration of employee’s opinions in enhancing project execution	28
B43	Stringent inter-organizational approval process	29
B39	Inability to adapt resource allocation in accordance with clients' changing needs	30
B19	Failing to communicate contractor's quality standards to all contractual parties	31
B24	Limited use of past project data and employees' experiences in improving the organization's performance	32
B31	Lack of a long-term philosophy in organizations	33
B8	Underutilization of off-site construction techniques	34
B23	Underutilization of projects' KPIs	35
B40	Inability to meet and adapt to clients' requirements	36
B37	Lack of collaborative partnership/long-term agreements with suppliers	37
B32	Ineffective cost control and cost saving	38
B44	Failing to share unutilized resources among multiple projects within the organization	39
B16	Failing to identify and monitor long lead items early in the project lifecycle	40
B28	Management resistance to change	41
B3	Clients are uninvolved in the design phase	42
B17	Inadequate quality plan	43
B9	Disregarding cost of material and field installation costs during the design phase	44
B1	Inadequate knowledge of project objectives and the client's requirements by all parties involved	45

APPENDIX D

Responses to Survey Questionnaire (2) and Rank of Waste Categories

Category: Factor	Rank					IMPT. I	N	L IMPT I %	Significance		G IMPT I	G IMPT I %	AVG CAT G I %
	0	1	2	3	4				AVG	%			
Defects									**3.067**	**61.3%**			**31.9%**
1	1	10	8	7	4	0.525	30	53%			0.322	32.2%	
2	5	6	11	4	4	0.467	30	47%			0.286	28.6%	
3	0	6	7	10	7	0.650	30	65%			0.399	39.9%	
4	5	8	11	4	2	0.417	30	42%			0.256	25.6%	
5	0	6	8	10	6	0.633	30	63%			0.388	38.8%	
6	6	7	10	3	4	0.433	30	43%			0.266	26.6%	
Over-processing:									**2.467**	**49.3%**			**24.1%**
7	6	9	11	4	0	0.358	30	36%			0.177	17.7%	
8	2	5	7	7	9	0.633	30	63%			0.312	31.2%	
9	8	11	5	5	1	0.333	30	33%			0.164	16.4%	
10	4	7	7	6	6	0.525	30	53%			0.259	25.9%	
11	2	6	8	7	7	0.592	30	59%			0.292	29.2%	
Overproduction									**2.367**	**47.3%**			**21.5%**
12	8	6	4	9	3	0.442	30	44%			0.209	20.9%	
13	10	7	8	0	5	0.358	30	36%			0.170	17.0%	
14	5	5	4	9	7	0.567	30	57%			0.268	26.8%	
15	7	7	10	3	3	0.400	30	40%			0.189	18.9%	
16	3	7	10	7	3	0.500	30	50%			0.237	23.7%	
Waiting									**3.333**	**66.7%**			**35.5%**
17	6	6	7	7	4	0.475	30	48%			0.317	31.7%	
18	3	4	4	7	12	0.675	30	68%			0.450	45.0%	
19	2	10	8	7	3	0.492	30	49%			0.328	32.8%	
20	3	6	6	8	7	0.583	30	58%			0.389	38.9%	
21	8	5	7	5	5	0.450	30	45%			0.300	30.0%	
22	2	9	7	4	8	0.558	30	56%			0.372	37.2%	
23	4	9	9	6	2	0.442	30	44%			0.294	29.4%	
24	3	6	7	13	1	0.525	30	53%			0.350	35.0%	
25	4	4	6	9	7	0.592	30	59%			0.394	39.4%	

Category: Factor	Rank					IMPT. I	N	L IMPT I %	Significance		G IMPT I	G IMPT I %	AVG CAT G I %
	0	**1**	**2**	**3**	4				**AVG**	**%**			
Transportation									**3.600**	**72.0%**			**35.2%**
26	5	5	8	6	6	0.525	30	53%			0.378	37.8%	
27	6	8	7	6	3	0.433	30	43%			0.312	31.2%	
28	2	10	7	7	4	0.508	30	51%			0.366	36.6%	
29	5	13	5	2	5	0.408	30	41%			0.294	29.4%	
30	2	7	7	9	5	0.567	30	57%			0.408	40.8%	
Motion									**3.233**	**64.7%**			**32.9%**
31	3	6	4	12	5	0.583	30	58%			0.377	37.7%	
32	6	10	4	5	5	0.442	30	44%			0.286	28.6%	
33	3	10	5	6	6	0.517	30	52%			0.334	33.4%	
34	4	9	6	6	5	0.492	30	49%			0.318	31.8%	
Inventory									**3.800**	**76.0%**			**37.7%**
35	4	3	8	10	5	0.575	30	58%			0.437	43.7%	
36	4	3	10	5	8	0.583	30	58%			0.443	44.3%	
37	6	7	9	4	4	0.442	30	44%			0.336	33.6%	
38	5	8	5	8	4	0.483	30	48%			0.367	36.7%	
39	7	8	7	6	2	0.400	30	40%			0.304	30.4%	

Category	AVG Cat. G. I. (%)	Rank
Inventory	37.75	1
Waiting	35.49	2
Transportation	35.16	3
Motion	32.87	4
Defects	31.94	5
Over-processing:	24.09	6
Over-Overproduction	21.46	7

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Academic Background: Graduated with a Bachelor's in Civil Engineering, focused on structural design, construction material, and environmental design. Pursued a Master's degree in Construction Engineering and Management. My Master's research thesis focus is the hurdles faced by Saudi construction practitioners in implementing a performance enhancement initiative, namely, Lean Construction, and the assessment of the Non-Value Adding activities. My research interests extend beyond performance and quality enhancement to construction finance and law, specifically financing construction projects under Public-Private Partnerships (PPP) schemes and the regulatory and judicial framework for resolving construction claims and disputes.