ASSESSMENT OF LEAN TECHNIQUE IMPLEMENTATION ON WASTE REDUCTION IN PRIVATE RESIDENTIAL REAL ESTATE COMPANIES IN ADDIS ABABA

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A Thesis Submitted to the Department of civil engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Civil engineering (specialization in construction engineering and management)

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DECLARATION

I hereby declare that this Master Thesis entitled “Assessment of Lean Technique Implementation on Waste Reduction in Private Residential Real Estate Companies in Addis Ababa” is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation

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LIST OF ACRONYMS

AEC	Architecture, engineering & construction industry
AHP	Analytical hierarchical process
CAD	Computer-aided design
CALM	Computer-Aided Lean Management
DEMA	Design for manufacturing & assembly
EU	European union
JIT	Just in time
LC	Lean construction
LCI	Lean construction institute
LPS	Last planner system
MHRA	Manufactured housing research alliance
MPS	Master pulling schedule
PCMAT	Plan of condition & work environment
TPM	Total productive maintenance
TPS	Toyota production system
TQM	Total quality management
TVD	Target value design
VSM	Value stream mapping
WFD	Waste framework directive
WWP	weekly work plan

ABSTRACT

Waste in the construction industry is defined as any loss produced by activities that generate direct or indirect costs but do not add any value. In recent years waste in the construction industry has been the subject of several researches around the world but still continues to be a critical issue. Researchers implement different methods to reduce the amount of waste and one of the effective methods is the application of lean techniques. The objective of this study is to develop an analytical hierarchical model for the implementation of lean techniques for the reduction of construction waste in private residential real estate companies. The study is quantitative which follows the approach of comparative judgment (prioritization). It was conducted on 7 private residential real estate companies which were actively involved in the construction at the time through targeting decision-makers as a respondent. Analytical hierarchical process-based questioner and face-to-face interviews were conducted for the collection of primary data. By using comparison-based survey to quantify relative priorities for a given set of alternatives on a ratio scale based on the judgment of the construction professionals. Based on the questionnaire the Analytical Hierarchy Process method was adopted for the data analysis, which is a hierarchical structure tool used for managing quantitative multi-criteria elements involving in decision-making behavior. Based on the data analysis poor material handling, poor site management, and frequent change in design are identified to be the three most dominant sources of construction waste. It was concluded that the selected companies don't have any waste reduction strategy or practice with the respondents having less awareness about lean techniques and their implementation. And it was recommended that, for construction companies to give proper attention to construction waste, with further studies to be done on lean techniques for better implementation.

Keywords- *Construction waste, Analytical hierarchical process, Lean techniques, Waste reduction,*

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

While acknowledging its significant contribution to the advancement of the society, the Construction industry on accomplishing the objectives of social and economic improvement of nations is continuously going with by distinctive challenges in which 70% of projects are exposed to time delay, 14% of projects are exposed to cost overrun, and 10% of projects' materials cost are wasted. The construction industry has moreover been seen as a major contributor to environmental degradation. Its negative impacts incorporate land depletion and deterioration, energy consumption, strong waste generation, dust and gas emission, noise pollution, and utilization of non-renewable natural assets. According to world measurements in 2010, it was taken note that 45% of the world's energy and 50% of the water have been expended by the construction industry. Besides, 23% of air pollution, 40% of water pollution, and 40% of created waste are caused by construction projects (Ayman, 2018; Coelho & de Brito, 2013; Lu & Yuan, 2011).

According to Wahi et al., (2016b) Construction waste that develops from construction sites has ended up as a major concern to the nation by contributing to the expansive amounts of construction waste that are produced each year. For numerous nations, rising levels of waste generation, due to the fast development of towns and cities, have gotten to be critical issues (Solís-guzmán et al., 2009; Wahi et al., 2016).

Waste is a well-known term within the industry around the world, therefore it is essential to know what is implied by construction waste in this study. Construction professionals tend to intellectualize "waste" as per physical construction waste instead of a more general conception of the term that incorporates both the occurrence of material losses as well as the performance of unnecessary work. The waste created on construction sites has been found to result in two cost factors for the builders., i.e., the cost of transporting and disposing of site waste and the material procurement cost. Subsequently, waste ought to be characterized as any losses produced by activities that create direct or indirect costs but don't add any value (Ayalew et al., 2018; Macozoma, 2002).

As a developing nation with rapid population growth and urbanization rates, presently the construction industry in Ethiopia has been giving a wide variety of buildings, extending from houses to tall rise buildings and from schools and hospitals to factories and shopping centers, and has been carrying out a similarly wide assortment of engineering construction projects, extending from highways to hydroelectric dams and irrigation dams/canals (Alamirew, 2020; Cheru, 2016).

Real Estate development is considered as one of the biggest business investments in the country with the transaction of billions of birrs in the market. Concerning the projected future housing demand, in addition to the existing need, the actors in the sector are increasing in number (Selam, 2016). But unfortunately, Similar to the case with other developing nations, the Ethiopian construction industry shares numerous of the issues and challenges the industry is confronting in other creating nations, perhaps with greater severity. Ethiopia faces challenges forwards on limited resources and environmental impacts related to inefficient energy and waste management.

During the last decades, different strategies are utilized to reduce construction waste and its impacts. One of the innovative approaches in this respect is “Lean Construction”, which was introduced to the construction industry within the 1990s based on a fruitful manufacturing theory, i.e. lean production (Abbasian-hosseini et al., 2012).

Lean construction is an effective management tool to improve efficiency in the construction field. An expansive investigation is being worn out recent past and is a continuous process to adopt lean principles from the manufacturing industry to the construction industry. In arrange to progress the efficiency, reduction of waste, lean construction has been presented as a new management tool(More et al., 2016). Which benefits nations like Ethiopia by increasing effectiveness and productivity. This study aims to build a decision aiding model which can be used as a tool by construction professionals for the implementation of lean techniques on waste reduction.

1.2 Statement of the Problem

The construction industry is a diverse sector of the national economy, which includes a wide range of scarce resources for a given nation by consumes 25% of wood and 40% of the raw stone, gravel, and sand utilized globally each year. On the other hand, one of the foremost common, unsolved, and tough challenges related to the construction industry is the tall rate of waste generation which accounts for between 15 and 30% of urban waste. Moreover, the presence of a significant number of waste types within the construction industry has depleted overall performance and productivity within the industry. Waste within the construction industry is vital not only from the point of view of effectiveness but also an adverse effect of waste materials on the environment. Due to this, waste should be considered a central issue for improvements, and certain serious measures have to be taken to correct the current situation (Kulatunga et al., 2005; Nikakhtar et al., 2015). Developing countries like Ethiopia could benefit from waste reduction due to the involvement of a massive amount of resources in construction activities these days.

Several investigate endeavors have been made towards guaranteeing adequate diversion of construction waste. However, despite these joint efforts, waste proceeds being a challenge especially in developing nations (Ajayi et al., 2014; Formoso et al., 2002). As stated by Teferi, (2017) Construction waste management is a relatively new practice for the Ethiopian construction industry and a study by Ayalew et al., (2018) confirmed that close to 40% of the project time is wasted in performing non-value-adding activities like overproduction and waiting related wastes. According to several researches, lean techniques are found to be the best way for the reduction of construction waste.

1.3 Objective of the Study

1.3.1 General objective

- ✓ To prepare a decision aiding implementation framework for lean techniques to reduce construction waste in Addis Ababa private residential real estate projects.

1.3.2 Specific objectives

- ✓ To compare the major sources of wastes in Addis Ababa private residential real estate projects
- ✓ To assess practices currently used to reduce waste in private residential real estate projects
- ✓ To Compare lean techniques as alternatives for reduction of identified sources of waste

- ✓ Apply Analytical hierarchical process for the evaluation of lean technique implementation for waste reduction

1.4 Research Question

1) What are the major sources of waste in private residential real estate construction?
2) What are the current practices used to reduce waste in private residential real estate companies?
3) What are appropriate lean techniques that can be used as an alternative for waste reduction?
4) How to apply analytical hierarchy process for evaluation of the implementation of lean techniques for the reduction of construction waste?

1.5 Significance of the Study

This study is significant in the Ethiopian construction industry by serving as a tool that can be used during decision-making for the implementation of different lean techniques which can reduce construction waste to a different extent. The model can be used by different construction companies and professionals. Can also serve as referencing material for further studies related to waste reduction and implementation of lean techniques.

1.6 Scope of the Study

Waste is a well-known and broad term to study. The subjective scope of the study is bounded to only studying of reduction of construction waste by lean techniques. Previously done researches on construction waste already quantified the amount of generated waste and categorized according to types. The researchers agreed that waste is a serious problem that needs to be solved soon. On the other hand, many researches showed that lean techniques can be the best way for reducing waste in the construction industry. So, this study uses these ideas as a base for further study and sets its objective on building a decision aiding model for the implementation of lean techniques on waste reduction. To help construction professionals to decide on the selection of lean techniques to be applied to different kinds of sources of waste that are encountered during the construction process. The geographical scope of the study area is limited only to studying selected private residential real estate companies which are found in Addis Ababa.

1.7 Limitation of the Study

It couldn't cover a larger population because of a shortage of data that needs to be provided both by the Investment Bureau and the Ministry of housing and urban development on the number of private residential real estate companies in Addis Ababa to determine the population of the study. Also, the structure of the questioner was a little bit new and hard, so it was mandatory to target only professionals who have a first degree and above, this also impacted the determination of the sample size.

1.8 Structure of Study

The research contains 5 different chapters

CHAPTER ONE: - Introduction

The introduction part includes: - Background of the study, Statement of the Problem, Objective of the Study, Significance of the study, Scope of the study and limitation of the study.

CHAPTER TWO: Literature review

This chapter encompasses of relevant related literature on the concept and overview of waste, what the main sources of construction wastes, what waste management and reduction means, the concept of lean techniques and lean construction. Including implementation of lean techniques for the reduction of construction waste.

CHAPTER THREE: Methodology

This chapter covers how the research is carried out and covers the research methodology, target population, instruments of data collection, data collection techniques and procedures and the data analysis method.

CHAPTER FOUR: Result and Discussion

This chapter presents the analysis of data, that is collected from the questionnaires and interview. Presents detailed analysis of the AHP calculation, and result from the analysis.

CHAPTER FIVE: Conclusion and Recommendations

Based on the findings of the study, this chapter gives conclusion and recommendation for real estate companies, for construction professionals and finally for further study.

CHAPTER TWO

LITERATURE REVIEW

Construction can be defined as the activity involving the creation of physical infrastructure, superstructure, housing, and other related facilities. It contributes a significant portion of the global economy and employs a large population across the globe. It accounts for 13% of the global economy and contributes an annual amount of $12 trillion, which is projected to reach $15 trillion in 2025, according to the year 2013 analysis by Global Construction Perspectives (Ajayi et al., 2017).

Construction by its nature is a complex task that needs tight planning and control systems and tools throughout the project life. The progress of construction can be affected by lots of factors. These problems are poor production planning, weak project management, defective design, poor quality, inferior working conditions, and low safety arrangements. Unfortunately, such problems result in a significant waste level for construction projects like lagging behind the schedule, poor quality work, and cost overrun characterized by low productivity and limited competitiveness(Birhane, 2018).

According to Ajayi et al., (2014) European Commission's described the term “waste” as “something that the producer or holder discards or intends to or is required to discard”. The term wastage refers to the variance if any between the estimated and actual consumption of an individual item. Wastes can be defined as unwanted or discarded materials. Waste also can be defined as any material by-product of a human and industrial activity that has no residual value(Nagapan et al., 2011). This wastes continually causing environmental troubles and global warming problems to the world. Waste may be generated during both the extraction and processing of the raw materials and eventual consumption of final products therein. Rubbles and other waste materials arise from construction activities like demolition, renovation of buildings, and new construction(Fadiya et al., 2014).

2.1 Waste in the Construction Industry

Researchers and authors have different views as to what constitutes construction waste and provided various definitions in the relevant literature. Construction waste is defined as materials or products that need “to be transported elsewhere from the construction site or be used in-situ for other applications than the intended specific purpose of the project due to damage, excess or non-use, or which cannot be used due to non-compliance with the specifications, or which is a by-product of the construction process" (Banihashemi et al., 2018). Also, Ayman, (2018) defined the wastes in construction projects as having more than the minimum amount required in terms of labor, parts, supplies, and equipment, that are used in the production process.

Also, Waste can be described as any inefficiency that results in the use of equipment, materials, labor, or capital in larger quantities than those considered necessary in the construction process. Waste includes both the incidence of material losses and the execution of unnecessary work, which generates additional costs but do not add value to the product, such as delay times, quality costs, lack of safety, rework, unnecessary transportation trips, long distances, improper choice or management of methods or equipment and poor constructability(Nazech et al., 2008).

According to Macozoma, (2002) Construction site waste can be described as a non-hazardous by-product resulting from activities during new construction and renovation. It is generated during the construction process because of factors such as site preparation, material use, material damage, material non-use, excess procurement, and human error. In such a way it includes but are not limited to packaging materials, site clearance, excavation material, and building materials such as metals, gypsum, concrete, brick, insulation, wood, plastic, glass, asphalt, composites, and site sweepings. wastage as the difference between the value of materials delivered and accepted on-site and those properly used as specified and accurately measured in the work after deducting the cost-saving of substituted materials transferred elsewhere in which unnecessary cost and time may be increased by the material wastage (Bekr, 2014). Waste occurs within the lifecycle of buildings, during the construction, modification, and demolition phases. Construction and demolition debris that is dumped into forests, streams, ravines, and empty lots causes erosion, contaminates wells, water tables, and surface waters, attracts pests, creates fire hazards, and detracts from the beauty of natural areas (Esin & Cosgun, 2007). Many scholars view construction waste as any human activity that consumes resources but creates no value, such as mistakes that require rectification, waiting time/waste of time, cost, unwanted production/overproduction, management of work programs, and poor construction.

During the past two decades, the amount of waste has increased significantly, due to the increase in the standard of living, changes in consumption habits, as well as the natural increase in population. Thus, construction waste has become a serious problem in many countries. Numerous reports and studies have investigated issues on waste that lead to a negative impact on the environment, cost, productivity, time, social, and economy. Besides, these issues contribute to a reduced value of construction productivity and reduce the performance of overall projects(Nagapan, et al., 2012).

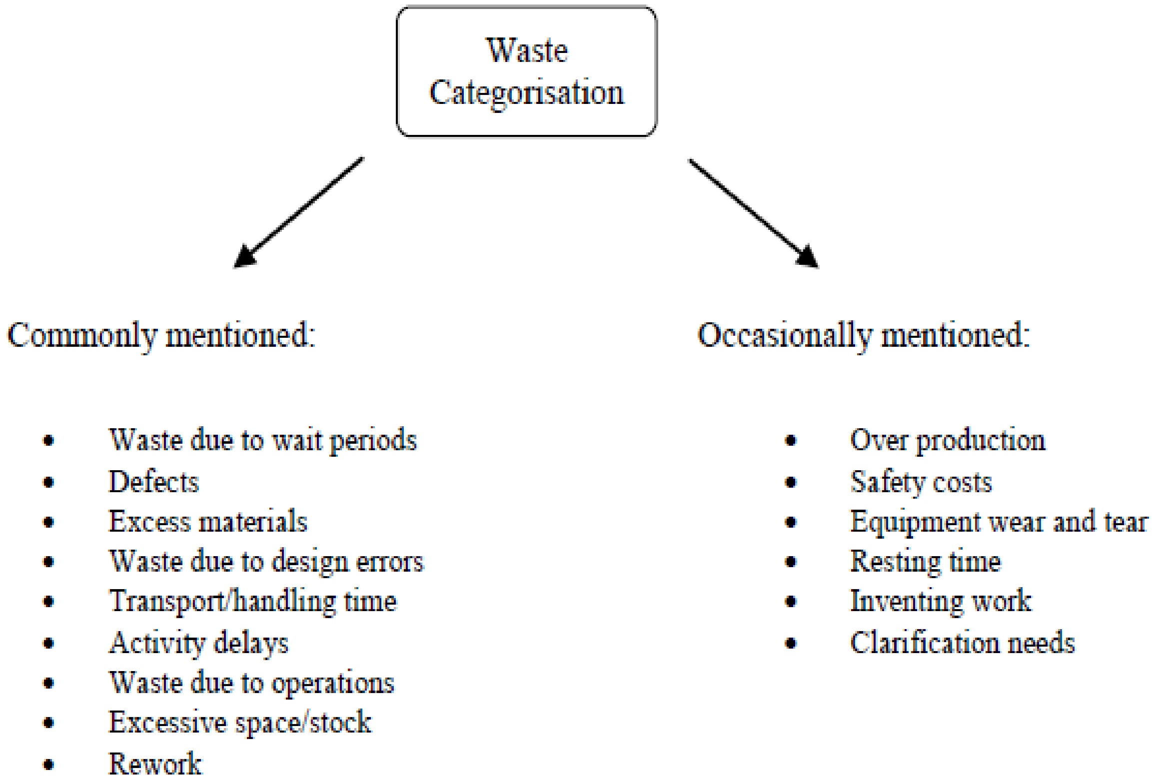

Figure 2.1 Waste categorization (Nikakhtar et al., 2015)

2.2 Source of Waste in Construction

During the construction process, construction managers have to deal with different factors that can negatively affect the performance of the production process, and producing different types of wastes. Wastes can include mistakes, working out of sequence, redundant activity and movement, delayed or premature inputs, and products or services that do not meet customer needs (Ingle & Waghmare, 2015). construction waste is generated throughout the project from inception to completion and the pre-construction stage has related waste sources showed that these fall under four main themes(Osmani, 2012): uncoordinated early involvement of project stakeholders, ineffective project communication and coordination, unclear allocation of responsibilities, and inconsistent procurement documentation.

As stated by Jose et al., (2018) the main causes of waste generation are Lack of waste management plans, Poor supervision and attitude of workers, Inaccuracy in quantity surveys, Complications in order-taking, Issues in material storage, Inferior quality of materials, and Poor materials handling. Waste production on construction sites is often due to(Bekr, 2014): inadequate storage and protection, poor or multiple handling, poor site control, over-ordering of material, bad stock control, lack of training, and damage to the material during delivery. According to Ayman, (2018) There are several causes of waste in construction projects: Frequent Changes in Design, Improper Storing of Materials, Weather Conditions, Poor Planning, Error in Orders, and Mistakes from Workers**.**

According to Li et al., (2013) In construction projects, the source of construction waste mainly involves the transportation of construction materials, storage of construction materials, and on-site construction. There are 5 selected significant factors placed the highest ranked or key position among the other factors (Nagapan et al., 2012); Poor site management and supervision, Lack of experience, Inadequate planning and scheduling, Mistakes and errors in design, Mistakes during construction. Al-Rifai & Amoudi, (2016) explained Construction material waste can also be recognized and classified as follows: Waste of materials as a result of damage which cannot be repaired and utilized anymore, Waste of materials as a result of loss during the construction process, and Waste of materials as a result of errors in construction and excess of actual quantities compared to theoretical quantities in the drawings.

Table 2.1 Sources and causes of construction waste(Fadiya et al., 2014)

No	Source of waste	Causes
1	Procurement	Ordering error, supplier’s error resulting in excessive material on site
2	Design	Change to design, documentation error
3	Material handling	Transportation, off-loading and inappropriate storage
4	Operations	Wrong material and having to remove such materials
5	Weather	Humidity and temperature
6	Vandalism	Inadequate security

7	Misplacement	Untraceable material, abandonment
8	Residual	Cutting material to sizes
9	Others	Lack of waste management plan

Construction waste can be divided into 4 categories as follows (Nazech et al., 2008):

1. Natural Waste- There is a condition where construction waste is not reduceable as the cost to reduce it is much higher than treating the waste. In this condition, there is an acceptable tolerance to the produced waste.
2. Direct Waste- Direct waste is produced in every phase of construction. The waste is produced from various activities on construction sites, such as material delivery; material storage in warehouses or temporary storage; reworks; inexperienced workers; poor management.
3. Indirect Waste- The source of indirect waste includes: material changes; excess materials; contractor mistakes; the possibility of waste in the forms of cost of materials and labor.
4. Consequential Waste- This is a cost associated with delay in the production or reworks to repair any product deficiency.

2.3 Construction Waste Management

The management of construction wastes is a global environmental issue experienced by countries all over the world. It is becoming an integral part of every project delivery process, especially in developed nations(Ajayi et al., 2014). A large and various types of waste with different characteristics are created at all the stages of construction right from site preparation, demolition of existing structures to the final product. The exact quantity and composition of construction waste generated throughout the projects are difficult to be identified as they kept on changing due to the dynamic nature of the construction activities (Gulghane & Khandve, 2015).

Theoretically, all participants in a construction project have responsibility for minimizing construction waste. Hence, the attitudes of key individuals engaged with the project have a high influence on the waste levels. The project flow which involves clients, consultants, builders, and suppliers shows that each individual plays an important role in each stage to coordinate with each other and minimize waste as a whole. Starting from the client who initiates a project, the client has a great influence on the overall waste level as seen from many perspectives. Generally, environmental standards and budgets determined by the client would shape the level that the project team must comply with. This would greatly determine the level of effort the project team is going to put as the client has the ultimate higher decision making despite the advice given. However, construction projects are the output of a team that comprises different professionals and roles. When the supply chain does not follow the requirements set, the hard work of minimizing waste practices will not be paid off. Despite the teamwork in any construction project, it is seemingly more important to pay more attention to supply chain management to curb the problems of waste(Cheng & Mydin, 2014).

The less attention given to construction waste management indicates a low level of financial incentives allocated. As waste management is often regarded as falls out of cost efficiency, the employer percepts that the need of minimizing waste is out of their obligations. Lack of incentives and penalties demotivates the construction practitioner to look up to more practical solutions. Almost both are perceived to have a similar effect, incentives are preferable over penalties in waste reduction. The reward system is best practiced through the construction process as a short and intense measure such as during the design process as it act as a key incentive in boosting performance(Al-Rifai & Amoudi, 2016). The estimation of waste generation rates from various waste streams of construction activities is identified as a meaningful tool to promote construction waste management. It can be used to predict the amount of construction waste generated in a project, which help project stakeholders to prepare proper practices for managing CW and assess the effectiveness of these practices by comparing the estimated waste rates across different projects(Bakshan et al., 2015) Considering and adopting waste management strategy in construction could bring many benefits to construction companies. Al-Rifai & Amoudi, (2016) listed some benefits from adopting waste management strategy, These benefits may: Reduce project costs and enhance profit, Enhance the competitive advantages of construction companies in the market, Demonstrate waste management and environmental protection to the clients of construction companies, Enhance quality and performance within the construction industry at large, Reduce resource and energy consumption and decrease soil and air pollution, Save last user's money because of cost-saving resulting from minimizing construction waste, Promote workforce skills and productivity, Enhance economic, environmental, and social sustainability aspects.

There are challenges faced by the waste management practitioner in managing construction waste. According to Saadi et al., (2016), Mallak & Ishak (2012) concluded that six various factors are contributing to the failure of waste management, which are: Lack of awareness; Information problems; Technology problems; Packaging problem; Financial problems; and Poor cooperation by the government.

2.3.1 Waste Hierarchy

To mitigate waste, construction managers have to explore management options. The ‘three Rs’ principle of waste (reduction, reuse, and recycle), otherwise known as the waste hierarchy, has been widely adopted(Osmani et al., 2008). The waste hierarchy principle has existed for approximately 40 years. The concept originates in prioritizing reduction, recycling, and reuse of waste over treatment or disposal, having been started in the United States by the private company 3M and in Europe by the Dutch politician Ad Lansink, who proposed it in the Dutch Parliament in 1979. In 2008, the waste hierarchy principle was included in the Waste Framework Directive 2008/98/EC (WFD and was subsequently transposed into the national law of European Union (EU) the Member States.

The European WFD defines the waste hierarchy as the priority order of operations to be followed in the management of waste: prevention, preparing for reuse, recycling, another recovery (including energy recovery), and disposal. Waste hierarchy has been contemplated in the international and national regulations, although there are no indicators for its implementation. The existing indicators were intended to quantify the performance of specific waste operations(Pires & Martinho, 2019).

As such, strategies for waste management are therefore categorized as reductive measures, re-use, recycling, or in worst-case scenarios, landfilling. While strategies of waste reduction involve processes of minimizing waste at source by decreasing it to the smallest possible quantity, the re-use approach ensures that waste generated still find the place, usually within the project or in another project Reusing and recycling can only reduce the quantity of waste to be eventually disposed to the landfill sites. Since reusing requires less energy and processes in dealing with waste than recycling, reusing should be put in a higher hierarchy than recycling (Ajayi et al., 2014; Teferi, 2017).

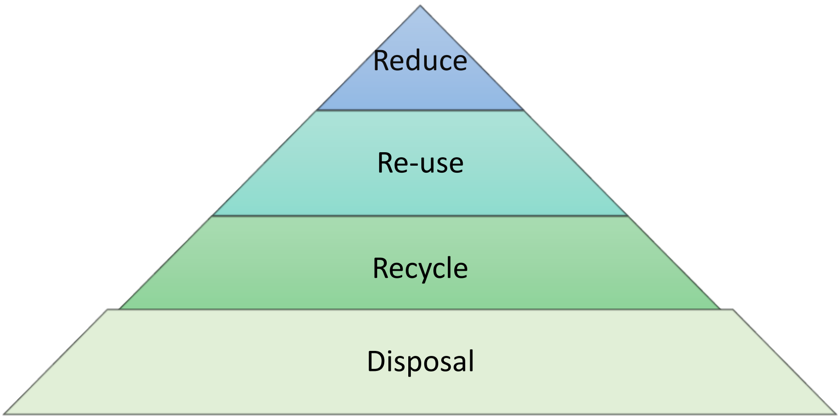

Figure 2.2 Waste hierarchy(Ajayi et al., 2014)

According to Teferi, (2017), the Waste Reduction Framework Plan recommends the following five waste management actions in waste management and disposal:

Table 2.2 Waste management actions (Teferi, 2017)

Waste management actions		
1	Waste avoidance	Waste should not be produced in the first place
2	Waste minimization	If waste production is unavoidable, the quantities should be minimized
3	Waste recovery, recycling, and reuse	The recovery, recycle and reuse of suitable waste materials should be maximized
4	Waste bulk reduction	If it is not possible to recover, recycle or reuse the waste materials, the volume of residual waste should be reduced before final disposal, this might involve incineration or composting
5	Waste disposal	Whenever possible the residual left after bulk reduction will be used for construction purposes or reclamation in preference to being dumped in the landfills

2.3.2 Waste Reduction

Implementation of a construction waste management hierarchy can be an approach to manage and reduce waste. It is about the priority and responsibility of managing waste, which includes waste disposal, waste treatment, waste recycle and reuse, and waste reduction. Source reduction would be the best and most efficient way in minimizing construction waste (Nazech et al., 2008).

Construction waste reduction (CWR) refers to reducing the amount of hazardous waste produced during construction projects to the minimum feasible degree; in turn, reducing the impact of waste on the environment, and promoting sustainable development of the construction industry (Li et al., 2013). The reduction has the highest priority among the waste management options but efficient reduction cannot be achieved without adequate identification of the sources of waste. CWR should first reduce or prevent waste from the source, and then consider the disposal of construction waste. It advocates identifying the root causes of waste, removing those causes with related tools and techniques, and encouraging the prevention of waste rather than reactively attempting to overcome the negative effects of loss. So, waste generation throughout the construction stages needs to be identified and quantified to minimize the wastage Construction waste reduction by lean thinking (Fadiya et al., 2014; Sarhan et al., 2017).

According to Macozoma (2002), Waste reduction concentrates on on-site practice that can determine whether or not waste will be created before or during construction site activity. As the saying goes, the best way to manage waste is not to create it at all. The biggest opportunity to impact waste generation through prevention principles is at (Macozoma, 2002): Design - through design for waste reduction i.e., doing more with less, and design with consideration for reuse and recycling at the end of life of a structure. Operations - through clear communication of designs to the project team to avoid unnecessary waste through errors and re-dos. Procurement - through the engagement of suppliers to encourage a reduction in packaging waste, the use of reusable containers, and through “take back” agreements for unused materials.

Also, the Reduction of waste can be done by practicing an attitude towards Zero wastage, proper decisions at the design stage, site management, proper standardization of construction materials, and Codification of the same. Construction waste can also be reduced by using a waste management system on the project. The project activities are to be planned at every stage by every construction personnel involved, in minimizing the overall waste generation at the project(Gulghane & Khandve, 2015).

Reducing construction site waste can reduce both the cost of raw material purchase and the cost of disposing of the waste created on-site. It can also reduce wastage due to inefficiency on-site. Source separation can reduce the amount of waste resulting from commingled disposal (S. Macozoma, 2002). Reducing waste is not only good for the environment. Other benefits are as follows according to Alamirew, (2020): Reducing waste disposal costs, A high level of client satisfaction could enhance company's image and encourage repeat business, Winning contracts for projects that specify waste reduction procedures and Innovation and challenges can help to attract and retain employees.

CW reduction management is divided into two stages: (1) measures such as on-site material management, personnel management, and low-waste technologies, should be adopted to reduce waste generation from the initial planning stage. These measures are classified into source reduction, i.e. minimizing waste generation before it was generated; and (2) measures such as on-site sorting are adopted to reduce waste emissions after waste was generated. Hence on-site sorting behaviors are important as one of the ‘‘end of pipe reduction treatments”. Effective on-site material and personnel management are significant for reducing waste generation(Ding et al., 2016).

Aimed at maximizing project value while reducing waste and cost, the lean construction (LC) approach was formally and successfully introduced to the architecture, engineering, and construction (AEC) industry in 1993. Waste and waste reduction are some of the main concepts that differentiate lean thinking from other approaches to production planning and control. Since its introduction to the West in the 1980s, the concept of waste reduction has had a major impact on manufacturing. But it is not so in construction. Construction is one of the major industries worldwide and is commonly recognized as having high levels of waste. It can therefore be viewed as something of a paradox that waste reduction has not become a dominant strategy for improving productivity in this industry (Trond, 2016)

2.4 Waste Reduction Using Lean Thinking

2.4.1 The Concept of Lean Thinking

In the early 1990s, to improve the performance of the industry, some researchers advocated developing a production management perspective in construction project management practices through learning from the Japanese manufacturing industry(Tezel et al., 2018).

Also, the term lean has been borrowed from the Japanese and converted to a suitable form for use within construction. The term “lean” originated from the Toyota Production System (TPS) developed in the 1990s. It describes the strategy that the company adopted to enhance the production and consumption efficiency of its auto goods and services. The concept of lean has its foundation in the deployment of reproducible activities by Fredrick Winslow Taylor (Taylor's theory) and its best historical implementation was based on Henry Ford's conveyor belt invention that led to mass production observed in the 19th century. Lean construction was pioneered by Koskela developed the transformation flow view (TFV) theory of production in construction (Ogunbiyi et al., 2014; Sarhan et al., 2017).

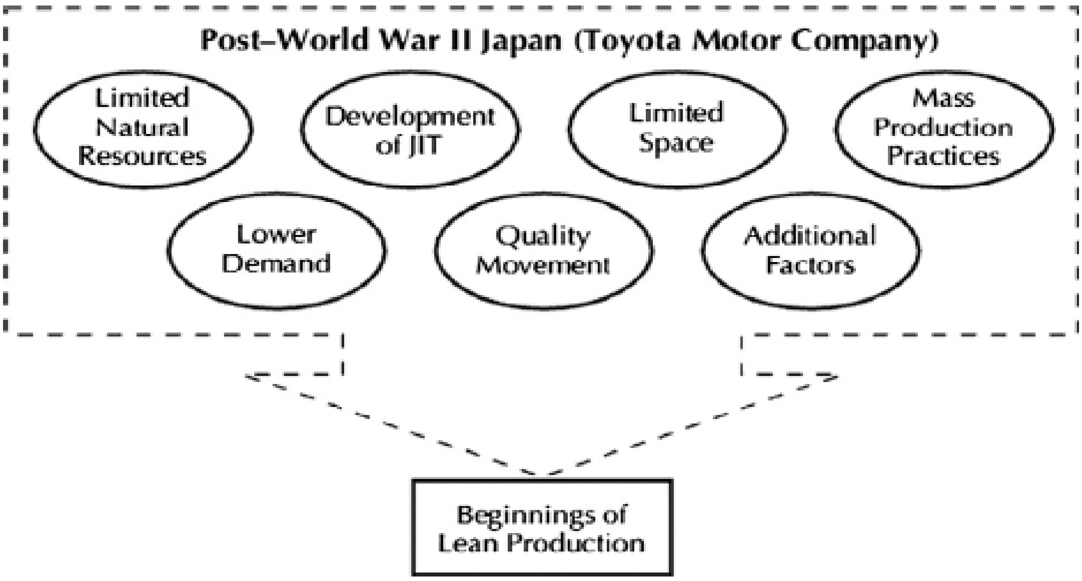

Figure 2.3 Beginning of lean production (Aziz & Hafez, 2013)

Starting from efforts to reduce machine setup time and influenced by TQM, a simple set of objectives was developed for the design of the production system including to (1) Identify and deliver value to the customer value: eliminate anything that does not add value; (2) Organize production as a continuous flow; (3) Perfect the product and create reliable flow through distributing information and decision making, and (4) Pursue perfection: Deliver on order a product meeting customer requirements with nothing in inventory. Lean production aims to design and make things differentiated from mass and craft forms of production by the objectives and technique and to optimize the performance of the production system against a standard of perfection to meet unique customer requirements. At the beginning of the 1990s, the new production philosophy, which is known by several different names, is as follows: (1) world-class manufacturing; (2) lean production; and (3) new production system(Aziz & Hafez, 2013).

Marzouk et al., (2012) mentioned that the construction industry has rejected many ideas from manufacturing because of the belief that construction is different. Manufacturers make parts that go into products, but the design and construction of unique and complex projects in highly uncertain environments, which are carried out under great time and cost pressure, is fundamentally different from typical production. This difference made some researchers start comparing construction to production and listing the differences, others took some Lean production techniques and tools and started modifying them to be applicable in the construction field, while some started from the Lean production principles and tried to develop new techniques and tools for the construction field.

The results and benefits of applying Lean production principles have been proven worthy whenever implied correctly. Consequently, it has always been a goal for other fields to modify the tools and techniques of Lean production to be able to start applying Lean principles in other fields. In the early 1990s, the term 'Lean Construction' appeared. It was an effort of researchers trying to introduce Lean production principles to the construction industry(Marzouk et al., 2012).

Lean construction is an effective management tool to enhance productivity in the construction field. Large research is being done in the recent past and is an ongoing process to adopt lean principles from the manufacturing industry to the construction industry. To improve efficiency, reduce waste, lean construction has been introduced as a new management tool(More et al., 2016). It is a new philosophy oriented toward construction production administration. It sets productive flows in motion to develop control systems to reduce losses throughout the process. Waste elimination, process control, flexibility, optimization, people utilization, continuous and efficient improvement, and value to the customer have been presented as some of the key drivers of lean(Issa, 2013; Ogunbiyi et al., 2014).

LC received great attention from the AEC sector. It aimed to implement lean thinking from manufacturing to construction for improving project quality and efficiency while reducing construction costs and waste generation. Along with the LC concept, scholars have concentrated on LC techniques to achieve higher productivity(Xing et al., 2021). Impacts can be minimized by implementing lean construction strategies that focus on reducing wastes and improving performance, as well as increasing the overall value of the facility to the end-users(Salem et al., 2014).

According to Ogunbiyi et al., (2014), the use of lean production concepts has been identified as a strategy for designing, controlling, improving engineering and construction processes to ensure predictable material and workflow on-site; improving safety management and planning processes to systematically consider hazards and their countermeasures; improving safety-related behaviors-instituting procedures that aim at minimizing unsafe acts. Lean project management differs from traditional project management not only in it pursues, but also in the structure of its phases, the relationship between phases and the participants in each phase(Ayalew et al., 2016).

In the construction industry, according to Tezel et al., (2018) LC deployments can be categorized into three levels with increasing degree of sophistication; (1) process-based LC deployment efforts to reduce waste, variability, information deficiencies and to support production and process flow and stability through some specific LC principles and techniques, (2) arrangements to eliminate adversarial relations and to increase integration in construction supply chains, and (3) a strategic change in the overall project governance toward partnering. Currently, most of the discussions on LC deployments are around process-based deployments. The main LC principles at this level are (1) elimination of the process wastes, (2) effective management of the value stream, (3) maintaining a continuous and reliable flow of the production and process elements, (4) pull-based project planning and control, (5) just-in-time delivery of materials and components and (6) instilling a continuous improvement culture.

2.4.2 Waste Based on Lean Thinking

For many people in the industry, the notion of waste is directly associated with the debris removed from the site and disposed of in landfills. The main reason for this relatively narrow view of waste is perhaps the fact that it is relatively easy to see and measure. Although such waste is very important from an environmental perspective, this approach has been criticized since the beginning of industrial engineering. The economic loss caused by material waste is smaller than the ones related to the inefficiency of human work. A broader definition of waste includes not only material waste, but also waste generated in a construction project such as waiting times, transportation times, and setup times (Abdelrazig, 2015; Formoso et al., 2002). In addition to stressing the physical waste, lean thinking specifically pays a lot of attention to the waste produced in a construction process. Project managers may interpret waste as only physical construction waste which often includes material losses. However, there are other types of waste in a process, related to the execution of unnecessary activities by resources that cause additional costs but do not add value to the product(Nikakhtar et al., 2015).

Nowadays, under lean production philosophies, wastes are defined as “any inefficiency that results in the use of equipment, materials, labor or capital in larger quantities than those considered as necessary in the production of a building”. also defined wastes as “any loss produced by activities that generate direct or indirect costs but do not add any value to the product from the point of view of the client”(Khanh & Kim, 2014a). This reveals the production of non-physical waste within the construction processes, which is the basis of the waste concept adopted by the lean construction approach.

Since then, the wastes are considered as any resource damage related to cost and productivity by not adding a value to final output production. “the value-adding activity is an activity that converts material and/or information towards that which is required by the customer, and the non-value adding activity is an activity that takes time, resources or space but does not add value” (Abdelrazig, 2015; Khanh & Kim, 2014b).

Unavoidable waste is produced due to the nature of the processes. Its percentage is highly dependent on the firm and the level of technological advances. This kind of waste are overproduction and safety costs. Most of the time, reducing the share of this kind of waste is not economic for the contractor. However, redesigning and reengineering the construction process can be effective. In addition to considering commonly known waste, lean construction thinking focuses on those construction activities which consume the time of workers and other resources, but generate no value for the final product. These kinds of activities are called ‘non-value-adding activities’ in terms of the lean thinking theory. Rework, transportation, unnecessary and excessive inventory, and workers’ waiting time are the main non-value-adding work in the processes(Nikakhtar et al., 2015).

2.4.3 Classification of Waste Based on a Lean Approach

Eliminating waste in a process is one of the top priorities in lean construction theory. In general, project managers interpret waste as physical construction waste, which dominantly includes material losses. In addition to stressing the physical waste, lean thinking specifically pays lots of attention to the waste produced over a construction process. Waiting time, non-value-adding works, and material transportations are categorized in this group (Abbasian-hosseini et al., 2012). The goal is to build the project while maximizing value, minimizing waste, and pursuing perfection (Al-aomar, 2012).

During the last decades, many research efforts have been done to classify construction waste according to different attributes such as kind, quantity, etc. Despite different classifications, all of them follow the same basic concept. Excess materials, delays, rework and defects are those wastes commonly mentioned by researchers(Abbasian-hosseini et al., 2012).

According to Nagapan et al., (2013)Construction waste can be divided into two principal categories namely physical and nonphysical waste. However, physical waste is given more concern because most of the raw materials used in construction have come from non-renewable resources. Also, Lee et al., (2013) clustered construction waste into physical waste and non-physical waste. Physical waste is described as loss of materials, damage, cannot be repaired, cannot be used or losses during construction activities. However, the non-physical wastes are related to cost overrun and delay in construction projects

Sarhan et al., (2017) classified waste under two main headings; first, material-related waste, namely over-ordering, over-production, mishandling, bad storage, manufacturing defects, and theft and vandalism. Second, waste is related to time, such as waiting, stoppages, clarifications, variations in information, rework, errors, and interaction between various specialists.

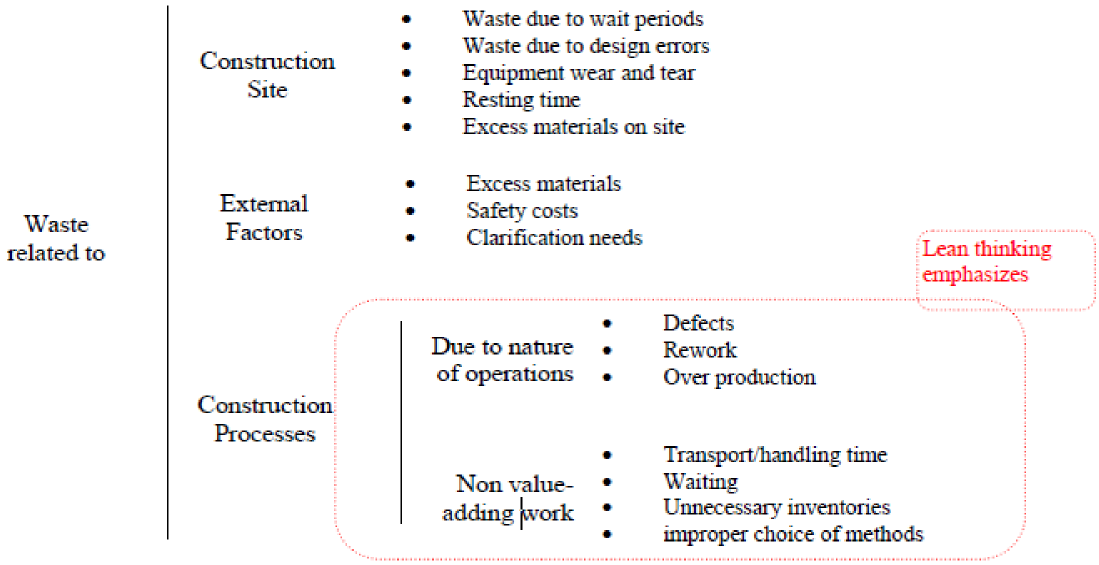

Figure 2.4 Waste categorization considering lean thinking approach(Abbasian-hosseini et al., 2012).

2.4.4 Identification of Common Sources of Waste

To achieve the objective of this study, the first common sources of construction waste are identified through a literature review. According to saaty the ideal number of criteria for AHP model is 5-9. Based on these eight commonly mentioned construction waste sources are identified are listed in Table 2.3.

Table 2.3 Identified sources of waste

No	Sources of construction waste	Sources
1	Poor material handling and storage	Jose et al., (2018), Sarhan et al., (2017), Bekr, (2014), Ayman, (2018), Fadiya et al., 2014)
2	Excess inventory	Bekr, (2014), Abbasian-hosseini et al., (2012), Al-aomar, (2012) , Sarhan et al.,(2017), Fadiya et al., (2014)
3	Poor site management	Bekr, (2014), Osmani, (2012),
4	Frequent change in design	Fadiya et al., (2014), Ayman, (2018),
5	Poor planning	Nagapan, et al., (2012), Ayman, (2018)
6	Rework	Nikakhtar et al., (2015), Abbasian-hosseini et al.,(2012), Ayalew et al.,(2018), Sarhan et al., (2017)
7	Overproduction	Al-aomar, (2012), Ayalew et al., (2018)

8	Delay(waiting)	Lee et al., (2013), Ayalew et al., (2018), Sarhan et al., (2017)

2.4.4.1 Poor Material Handling

Construction material constitutes a major cost component in any construction project. The total cost of installed material may be 50% or more of the total cost. According to Osha, (2001), Handling and storing materials involve diverse operations such as hoisting tons of steel with a crane; driving a truck loaded with concrete blocks; carrying bags or materials manually, and stacking palletized bricks. Wrong material storage and poor materials handling become key factors for physical waste generation. Wrong material storage for physical waste generation are aggressive handling of bricks and blocks during construction leads to cracks and spoil. Apart from this, physical waste does occur due to inappropriate protection strategies used during materials storage. Cement is wrongly stored under a bridge or stored in any open space. These cause the materials to be exposed to moisture and rain. Without proper storage, the materials too will end up as physical waste. Another key factor generating physical waste is poor material handling and the score equals to wrong material storage factor. Mistakenly handle construction material causes material loss or damage to bricks or blocks. Besides that, the wrong material storage also contributes to non-physical waste. If the bricks and cement spoil at the site due to improper storage by the worker, then this leads to a shortage of material during construction. The insufficient stock of construction materials may lead to the stoppage of construction works at the site. The materials need to reorder and cause a longer waiting time to receive materials from the supplier. The manpower of waiting workers during supply and payment of hourly salary always will end up as nonphysical waste. Thus, proper storage of material is necessary to avoid the generation of construction waste. Besides that, a very comprehensive and good storage technique should be adopted for better protection of materials at the site (Nagapan, et al., 2012).

As such, organizations need to understand the effects of proper materials management techniques on the effectiveness of project execution. Extensive literature and reports deplore the lack of efficiency and productivity in the construction industry. Too often, construction projects suffer from delays, budget overruns, and claims. A properly implemented materials management program can achieve the timely flow of materials and equipment to the job site, and thus facilitate improved work face planning, increased labor productivity, better schedules, and lower project costs (Subramani et al., 2017). Materials management is an important function to improve productivity in construction projects. It includes planning and material take-off, vendor evaluation and selection, purchasing, expenditure, shipping, material receiving, warehousing and inventory, and material distribution. Good management is carried out to resolve potential problems such as material shortages, materials supply delays, non-schedule, material damage, and wastage, and lack of storage space (Misron et al., 2018). Also, the goal of material management is to ensure that the materials are available at their point of use when needed hence, efficient procurement of material represents a key role in the successful completion of the work (Zeb et al., 2017).

2.4.4.2 Excess Inventory

The term inventory refers to the goods or materials used by a firm for production or sale. Inventory (Stock/Storage Waste) is identified with unnecessary or excessive inventories that prompt material waste (by losses because of insufficient stock conditions at the site, robbery, deterioration, vandalism), and financial losses because of the capital being tied up. Excessive inventory is seen as waste since there is no value activity in stocking inventory. Moreover, inventory occupies space, adversely affects capital, and incurs costs, among others (Ansah et al., 2016).

Inventory control refers to coordinating availability, controlling, utilization, and procuring of materials. It is the course along with activities to get to the right inventory in the right place at the right time and in the right quantity and it is a direct connection to the production functions of any project (Zeb et al., 2017).

2.4.4.3 Poor Site Management

Site management involves a mixture of activities that turn basic resources into a finished product. Construction is seen as the conversion of raw resource inputs into defined functioning output using a managed process. Therefore, the construction site is viewed as a key area where money is made or lost and where there is considerable scope for improving efficiency, productivity, and quality. The increase in construction waste is mainly due to the inefficient waste management practices in construction projects.

2.4.4.4 Frequent Change in Design

Frequent changes in the project design are considered one of the major problems that generate waste in construction projects. Even in well-managed projects, the design changes can directly impact the cost in a range from 2.1% to 21.5% of total construction cost and led to some reworks in construction projects and resulted in a 5 to 20% increase in the project(Aslam et al., 2019). It usually occurs as the client provides several last-minute changes during the activities of the project. This problem is also generated because of a lack of communication between different project parties and a lack of understanding of client requirements. Therefore, any changes in the project design will lead to rebuilding and changing of designs and specifications which consumes time and money. To avoid this cause of waste a lot of attention must be provided to decrease waste during the design stage(Ayman Ahmed & Maha Ahmed, 2018).

2.4.4.5 Poor Planning

Poor planning in construction projects can lead to multiple types and amounts of waste. When proper management is undertaken during all phases of the project, it can extremely influence the rate of wastes. For example, lack of coordinated planning with subcontractors leads to an argument, waiting time, and interference with other trades. Incorrect planning and selection of equipment also cause the work to stop. Furthermore, a lack of control on sub-contractor progress or site workers' attitude will eventually delay the work. Thus, proper planning and controlling is the key supervisory function that should be used to be effective in eliminating these physical and non-physical factors. All management leaders should be paying more attention to these factors on waste generations (Nagapa et al., 2012). Project managers must carefully choose the management team and site supervisors to inspect the different activities of the project and ensure the proper flow of work. Moreover, good planning reduce the wastes in projects by knowing all activities of the project and assigning a certain supervisor to ensure no wastes are generated. Hence, proper planning is a major key that if taken carefully, will eliminate any sources of wastes and their consequences (Ayman, 2018).

2.4.4.6 Rework

Rework in construction projects is referred to as the unnecessary effort of redoing a process or activity that was incorrectly implemented in the first instance. In construction projects, rework can result from an array of factors such as errors, omissions, failures, changes, poor communication, and poor coordination. Rework could adversely affect the performance and productivity and ultimately the profit margins as well. In project-based transactions, any occurrence of rework is mainly considered as an unnecessary/ redundant non-value-adding item that should be mostly avoided not eliminated (Palaneeswaran, 2006). Also, Rework is a major contributor to time wastage and schedule overruns which eventually impact cost, resources, and quality. Rework emerges as overtime, the additional hiring of resources such as labor and plant workers, schedule slippage, and reductions in project scope and quality(Simpeh, 2012).

2.4.4.7 Overproduction

Overproduction is identified with producing more than required or producing earlier than should be expected. This regularly results in quantity and quality issues; an organization realizes that it will lose various units along the process of production so delivers additional to verify that the client request is fulfilled. This may result in misuse of materials, worker hours, or usage of equipment. Overproduction issues can be handled by utilizing the mistake-proofing approach (Poka-yoke) and by understanding the equipment process capacities of the production machines(Ansah et al., 2016).

2.4.4.8 Delay(waiting)

Waiting is identified with idleness which is mostly caused by poor synchronization and material flow leveling, and pace of work by distinctive equipment or groups. Also, waiting occurs at whatever point products are not being processed or moving. The idleness is perhaps created during waiting for engineering, maintenance, raw materials, designing, quality assurance results, inspections, confirmation orders, and so forth. Waste generated through waiting can be reduced drastically by connecting the processes and sustaining the flow of the processes(Ansah et al., 2016).

2.4.5 Lean Techniques for Reduction of Waste

The Lean Construction techniques are the backbone of LC and have evolved since its adoption in the construction industry. Akinradewo et al., (2018) defined Lean Construction Techniques as procedures, structures, conceptions, models, methodologies, and products which when implemented assist corporations apply lean across the workplace.

Lean techniques are applied to the construction process to minimize waste, increase the value of service, and improve performance. Implementing lean techniques on construction projects can also optimize the schedule, budget, and improve safety(Salem et al., 2014). Currently, there exists a variety of lean tools and techniques, including the Last Planner System, Value Stream Mapping (VSM), Standardized Work, The 5S process, Kaizen, Total Quality Management (TQM), increased visualization, Fail-Safe for Quality and Safety, Daily Huddle Meetings, First run studies, The Five Why's, Just in Time (JIT), Plan of Conditions and Work Environment in the Construction Industry (PCMAT), Concurrent Engineering, Pull 'kanban' system, Error Proofing (Poka-yoke), Target value design (TVD), Partnering, Total Productive Maintenance (TPM), Computer-Aided Design (CAD) and Six Sigma(Sarhan et al., 2017). Based on the study Akinradewo et al., (2018) concluded that among others, reduced waste and efficient administration of materials are the main benefits which are the core objectives of the LC technique. Since managing construction waste is one of the most significant management processes necessary to achieve project objectives, it is hereby recommended that companies should use lean construction to identify and analyze waste to improve productivity, minimize time and accidents, improve reliability, improve quality and ensure more client satisfaction. Some of the lean techniques which are used to reduce waste are discussed below.

2.4.5.1 The 5S Process

The 5s process has five steps that can help in eliminating wastes and reducing process inefficiencies in a workplace. These steps involve going through everything in a space, deciding what's necessary and what isn't, putting things in order, cleaning, and setting up procedures for performing these tasks on regular basis. The 5s of lean are sort, straighten, sweep, standardize, and sustain. Sort (Seiri) helps with eliminating tools and other items not used in the construction process. Straighten (Seiton) can help with setting the work-zone in order by arranging tools and equipment by a sequence of their use. Implementing this technique in work zones will also result in considerable cost reductions. Sweep (Seiso) is used for cleaning and keeping the work zone in order. Daily cleaning gives confidence in the ability to find what is needed without wasting much time. Standardize (Seiketsu) requires operations in the work-zone to be consistent and in a standardized fashion. It requires every worker to know their responsibilities. Sustain (Shitsuke) ensures that the management follows the practices mentioned above and does not allow a gradual decline back to the old ways of operation(Salem et al., 2014).

2.4.5.2 Just in Time

The concept of Just-in-Time (JIT) originated in Japan in the early 1950s and was developed in the supply chain arena by Taichi Ohno and his fellow workers at Toyota who realized that excess inventory stocks created cost and production problems. JIT is a controlling procurement process through developing a systematic program that must be followed to reach optimum efficiency (Sahlu, 2017). JIT can also be defined as producing the necessary units, with the required quality, in the necessary quantities, at the last safe moment. It means that companies can manage their resources and allocate them very easily(Subramani et al., 2017).

It is one of the original two pillars of lean production and it enables prompt delivery of materials, information, equipment, drawings, and other inputs required in a project to the required point. It is all about delivering material on time, not before not after; it prevents loss of material due to longer storage time. So, when we are implementing JIT, material that is not needed at that time won’t be purchased. And the purchased materials won’t be stored for a long time. JIT has also been described as one of the common lean construction and site management and environmentally-friendly practices that have been implemented as part of the traditional construction practices. It is an environmentally-friendly lean supply practice because it can help to reduce damage and materials waste and unwarranted movement of vehicles and equipment resulting from an untimely supply of materials and other inputs during the construction phase of projects (Babalola et al., 2019; Sarhan et al., 2017).

A just-in-time delivery strategy is one of the approaches which are highly recommended. It is different from the conventional way of material storage as the time that materials were stored on site is reduced. This relatively reduces the potential that the materials experience damage resulting from poor handling. The materials are ordered and delivered in a precise quantity and the nearest proximity to the commencement of the work. Hence, lesser extra materials are ready on site. It also prevents damage to the materials due to weather site limitations (Cheng & Mydin, 2014).

2.4.5.3 Plan- Do -Check- Act (PDCA)

Plan-Do-Check-Act (also called "PDCA") is a cycle that was originated by Walter Shewhart and made popular by Edward Deming – two of the fathers of modern quality control. It is a project planning tool and is a key element of lean management. It has been used in construction project management as a means of balancing the system and behavioral aspects of management, health, and safety. This concept is a cycle for implementing change when followed and repeated, which would lead to repeated improvements in the process it was applied to. It is an essential part of the lean manufacturing philosophy and a key prerequisite for continuous improvement of people and processes. This can be used to redesign critical activities as an integral part of a continuous improvement effort. Initial results from early industry practice show that the use of Lean tools has great potential to boost the efficiency and quality of industrialized homebuilding operations(Nahmens, 2009).

Plan Do Check Act acts as a framework that was created as a way of structuring problem solving and continuous improvement. It's simple in its approach but very powerful in its delivery. The generic steps of PDCA are presented in Table 2.4:

Table 2.4 Steps of PDCA(Aziz & Hafez, 2013)

PDCA	
Plan	Identify the problem and gather the facts. Start to define the reasons and get to the root causes
Do	Implement the improvement and test
Check	Check if it worked and review the data
Act	If it worked, standardize the improvement. If not, tackle the next problem and repeat PDCA

2.4.5.4 Concurrent Engineering

Concurrent engineering is an attempt to optimize the design of the project and its construction process to achieve reduced lead times, and improved quality and cost by the integration of design, fabrication, construction, and erection activities and by maximizing concurrent and collaboration in working practices.

This is an improved design process characterized by rigorous upfront requirements analysis, incorporating the constraints of subsequent phases into the conceptual phase, and tightening of change control towards the end of the design process. This involves collaborative sharing of information in the process of executing a different task in a project with aim of producing a functional design, a product with good quality, and a production process.

Concurrent engineering attempts to optimize the design of the project and its construction process to achieve reduced lead times, and improved quality and cost by the integration of design, fabrication, construction, and erection activities and by maximizing concurrency and collaboration in working practices''. An examination of the various definitions given to concurrent engineering generally points to the following key issues (Evbuomwan & Anumba, 1998): the need for proper analysis and establishment of customer requirements and specifications; The need for improving and maintaining the quality of a product; The integration of the design of the product and associated manufacturing (construction) and production processes; the consideration of all life cycle issues (both upstream and downstream) which affect product design; Resolution and management of tradeoffs and conflicts in the early stages of design; Reduction of product lead times and product costs and Paralleling the design process.

2.4.5.5 Last Planner System

To achieve lean goals of reducing waste, increasing productivity, and decreasing unpredictability, mainly through a social process, by trying to make planning a mutual attempt and by increasing the reliability of the commitment of team members. In construction, LPS was a method that forms workflow and deals with project variability.

The Last Planner System (LPS) is a workflow method developed by the Lean Construction Institute to increase worker productivity and accountability through tight scheduling and detailed group planning. Last Planner is seen as a managerial approach on how to efficiently run a construction project.

The Last Planner System (LPS) technique, which is an important application of the lean construction concepts and methodologies and is more prevalent, model is based on short-term planning and control of operations approach and has been one of the most used models around constructions following. It could enhance the construction management practices in various aspects and bring numerous advantages so that the construction projects will be more stable and less stressful for all involved stakeholders by reducing dependencies and variations to identify and eliminate waste (non-value adding activities)(Aziz & Hafez, 2013).

The Last Planner System implementation is done through a one-hour weekly work plan meeting, where all the parties currently involved in the construction are present. These meetings are led by the process manager who addressed the following topics discussed in Table 2.5.

Table 2.5 Steps on the implementation of LPS (Akinradewo et al., 2018)

Implementation of last planner system	
Overview of the previous weekly work plan	Checking the activities progress
Obstacle list	Verifies the existent obstacles that hinder the ability to execute the activities
View of the Look ahead plan	Assures that the pre-requisites for activities yet to come in the following weeks are made ready
Overview of Master plan	Verifies if any activities in another part of the project need to be paid attention to and if everything is going according to plan
New weekly work plan	Elaboration of each following week work plan

The use of the Last Planner occurs at different levels. One-level search to minimize waste-reducing downtime, checking the workflow, and reducing the duration of non-value-added steps. The other level looks to maximize the value in delivering a product for the customer to achieve its objective better, increasing system control (ability to achieve the objective), delivering the product on time, minimizing disruption of production, and responding quickly to disturbances in production(Harsha et al., 2013).

2.4.5.6 Process Mapping

Process mapping is a workflow diagram to bring forth a clearer understanding of a process or series of parallel processes. Interactions between resources and activities, and the flow of information in any construction process can be represented by process mapping (Nikakhtar et al., 2015). It is a tool of management, that diagrammatically represents the workflow of a process or several parallel processes, to make a clear understanding of how a process works and help the entity in becoming more effective, by identifying improvement opportunities. The process map as applied to construction can be defined as a way in which the various processes involved in the designing and construction of a project are arranged to efficiently convert the various construction-related inputs into the completed project.

Process mapping uses a flowchart to demonstrate the structural analysis of process flow, which differentiates how work is performed actually and how work should be performed. The construction process map has its steps (Sarhan et al., 2017)

1. Determination of boundaries: first, the start and end of the process are to be determined.
2. Listing steps: the next step to this process is to list out the steps which are to be followed. The flow chart displays enough information to understand the process completely as well as it also describes all the finite actions and decision points.
3. Sequence steps: to sequence the steps in chronological order
4. Drawing appropriate symbol: proper symbol approaches are to be used to create the process flow.
5. System mode: system model approach is applied to draw a flow chart, wherein
    - ✓ Input- utilizes the information depending upon people, machine method, material in
    - ✓ Process- subsets of processes are used in series or parallel
    - ✓ Output- use the desired result or outcome.
    - ✓ Control- rules, and policies are used to put control of the process
    - ✓ Feedback- the survey is to be performed to get the feedback
    - ✓ Check for completeness: process-specific relevant information is to be included, along with the title and date for reference.
6. Finalized the flowchart: to finalize the process, the management should first analyze whether the process is being operated in the manner it should be. Further, they need to identify if there is a consensus of the members for the process, as well as if there is any redundant or missing activity.

Table 2.6 Symbols used in process mapping (Xing et al., 2021)

Symbols	
Start and end to start the process	An oval shape is drawn to indicate the material, information, or action. Further, it can also be used to display the outcome at the end of the process.
Activity	A box or rectangle shape is used with only one arrow which leaves the box to indicate a task or activity carried out in the process
Decision	Whenever there is a decision is to be taken or a yes/no question is being asked, a diamond is drawn. It must be noted that every feedback loop is closed, to ensure that every path takes either back to or ahead to the next step in the process.
Break	To indicate a break in the process, a circle with a letter or number is used
Flow	Arrows are used to indicate the direction or the flow of the process.

2.4.5.7 Inventory Optimization

The term inventory refers to the goods or materials used by a firm for production and sale. It also includes the items, which are used as support materials to facilitate production. A well-managed inventory can be critical to profitability as delayed, misplaced or lost items can incur avoidable delays and unnecessary costs. Inventory optimization is the practice of having the right inventory to meet your target service levels while tying up a minimum amount of capital in inventory. It is also a means by which construction companies and suppliers can keep track of materials, workforce, equipment, and plant. Implementation of Inventory optimization can help us to reduce excess inventory because it prevents the accumulation of excess inventory. proper recording of data also helps by knowing materials we have at hand and what should be purchased for specific construction activity (Salem, 2015).

2.4.5.8 Error Proofing (Poka-Yoke)

Poka-yoke is a Japanese word that can be defined as “error-proofing”. Shingo introduced Poka-yoke as a new element to avoid defective parts from flowing through the process. It is a lean tool that engages all forms of activities and devices that could help avoid an error from happening. This is used in checking the construction process ahead for errors, to avoid the free flow of errors into the construction process. Poka-yoke is a technique for avoiding simple human error in the workplace. Also known as mistake-proofing, goof-proofing, and fail-safe work methods, poka-yoke is simply a system designed to prevent inadvertent errors made by workers performing a process (Tommelein, 2006).

Mistake proofing technique can enhance the performance of the project and improve the accomplished quality by decreasing the time of each task and save time for more critical activities or situations. It can also reduce the effects that may occur in any product or process which will eventually decrease the overall wastes in projects(Ayman Ahmed & Maha Ahmed, 2018). To achieve Poka-yoke, zones in construction sites prone to errors should be identified. These mistakes could be quality problems, delays in delivering a mid-process product, safety issues, and so on. By tracking where the problems are located, the project managers could direct their attention into investigating and resolving the problem. There are six mistake-proofing principles listed in order of preference to fundamentally address mistakes(Nikakhtar et al., 2015):

1) Elimination seeks to eliminate the possibility of errors by redesigning the process so that the task or part is no longer necessary
2) Replacement substitutes a process with a more reliable one to improve consistency
3) Prevention engineers the process so that it is impossible to make a mistake at all
4) Facilitation employs techniques and combines steps to make work easier to perform
5) Detection involves identifying an error before further processing occurs so that the user can quickly correct the problem
6) Mitigation seeks to minimize the effect of errors.

2.4.5.9 Computer-Aided Design

In this approach, engineering designs may be created and tested using computer simulations and then transferred directly to the production floor where the machinery uses the information to perform production functions. Computer-Aided Lean Management (CALM) is a management philosophy that uses computational software to reduce risk and inefficiencies. CALM acts on uncertainties and business inefficiencies to increase profitability through the use of computational decision-making tools that enable opportunities for additional value creation. It is based on the application of software to enable continuous improvement through an Integrated System Model (ISM) of the business’s physical assets, business processes, and machine learning. This unique integration of software applications using lean principles was developed in the aerospace industry and has migrated to the energy industry.

2.4.6 Implementation of Lean Thinking

Lean Construction has been introduced as a new management approach to improve productivity in the construction industry. Most construction companies in the U.S. that are starting to implement lean construction hope to achieve better results from their current projects than from past projects not employing lean construction. Several studies assess lean implementation and focus on the process of each construction activity, but few empirical studies assess lean implementation on the overall project. Companies need success stories to encourage them to employ lean construction in their work processes. Adopting lean concepts and systems into construction projects is difficult. It is a new philosophy that should make construction companies hesitant to employ it, and companies are not sure that lean concepts will produce benefits (Kim & Park, 2006).

Waste in the construction industry has been the subject of several research projects around the world in recent years. Researchers implement different methods to reduce the amount of waste in the construction industry. One of the effective methods is the application of the lean approach to the construction industry (Abbasian-hosseini et al., 2012). According to Ogunbiyi et al., (2014) Salem and Zimmer (2005) discussed whether lean manufacturing principles can be applied to construction and if similar benefits could result. They concluded that lean practices do indeed hold potential for improving construction.

Lean Construction technique allows more but with less of everything, lean use less of human effort, equipment, time, and space. Therefore, the implementation of the LC technique is paramount in reducing waste and enhancing the overall Construction Industry performance. By implementing LC tools and principles, productivity is increased, time and accidents are reduced, and waste generation is significantly minimized. It allows the Construction Industry to improve sustainability by optimizing the utilization of resources and safety during the construction process and minimizing waste through standard procedures (Akinradewo et al., 2018).

Lean construction increased quality and productivity in the construction industry. For instance, according to Sarhan et al., (2017) implementation of lean construction concepts increased the quality and productivity of construction projects by about 77%. Lean construction results in improved working conditions at the construction sites by decreasing physical and psychological stress. Lean construction enhances workflow by reducing upstream variability, which could be achieved via improved project coordination amongst others.

When lean construction is implemented and the work environment is stabilized through modifying the planning system, it becomes possible to reduce variation inflows that improve the downstream operations. implementation of lean construction has identified several benefits when applying lean principles in construction which include; reduce sharing of non-value adding activities, increase the output value through systematic construction of customer requirement, reduce process variability, reduce cycle times, Simplify by minimizing the number of steps parts and linkages, increase output flexibility, increase process transparency, focus on the complete process, build continuous implement into the process and balance flow improvement with conversion improvement and benchmarking. however, revealed that there are barriers to the implementation of lean construction. these barriers are; lack of time for implementing new practices in the projects, lack of training, challenge to create organizational elements, lack of self-criticism to learn from errors, response to some deficiencies, low understanding of the concepts, low use of different elements, inadequate administration, weak communication and transparency and lack of integration of the construction chain(Kim & Park, 2006; Nikakhtar et al., 2015).

Although the construction industries worldwide encountered several challenges when implementing LC, some industries have recognized the opportunity to embrace improvements through lean implementation. Various benefits and advantages have been recognized by the researchers.

The most important benefit of using LC in organizations is the reduction of waste. By eliminating waste in the construction, LC encourages the following(Akinradewo et al., 2018): Minimize double handling and movement of equipment and workers; Balance team, coordinate flows; Take off material constraints; Minimize variance in input; Minimize changeovers and difficult setups; Reduce interpersonal dynamics and Meet the needs of the client.

Also, the concept of Lean Construction has been observed as a useful means of performance improvement by improving workflow reliability, planning, and control, particularly in developed and emerging countries like UK, US, Australia, Brazil, Finland, Singapore, Peru, Chile, and Denmark. They further described that some other developing countries like Singapore, Ecuador, Indonesia, and Columbia have also recorded improvements after implementation. Also pointed out that lean construction which results from the application of a new form of production management is one approach for improving the performance of the construction industry(Ayalew et al., 2016).

For example, In England's highways sector, since 2009, LC as a strategy has actively been championed by Highways England, the main client of the supply chain, who can influence the strategic directions of its service providers. They first promoted LC through engagement and contractual configurations with some large-sized main contractors and some specialized sub-contractors operating in key delivery areas like soil works, paving/surfacing, or traffic management(Tezel et al., 2018).

Also, during 2006 the Manufactured Housing Research Alliance (MHRA) which is found in the U.S supported and guided nine industrialized housing plants to incorporate Lean production methods in their operations. These Lean implementations resulted in significant waste reduction (12% production space reduction, 10% raw material damage reduction, and 28% labor reduction) (Nahmens, 2009).

In the Danish construction industry, TrimByg (Trimmed Building) is the name given to the adjustment of the lean concept. The adaptation of the Lean Construction Institute (LCI) models of lean thinking stands out from the usual application by focusing on the value (to the client) parameter and the cooperation between the trades in construction. The process moderator is also an innovation in the implementation of lean philosophy in Denmark. This new individual is the facilitator of the lean approach in construction, acting as the coach of the building site; he implements lean by concentrating on ensuring a good collaboration with and between subcontractors(Henriques & Silva, 2008).

In the case of Ethiopia, A study by Ayalew, (2016) indicated that professionals in the Ethiopian construction industry are somehow aware of Lean Construction but their awareness towards other lean related concepts such as big room, takt time, last planner system, value stream mapping, and Toyota way is very low. The result on the other hand indicated that the level of awareness on prefabrication, modular construction, multiple contracts, just in time, and the target value is good as compared to the above lean related concepts. From these facts, the author concluded that at least there is some level of awareness among professionals about Lean Construction even though Lean Construction is not yet practiced in the Ethiopian construction industry.

The study also revealed that construction professionals think there could be a potential benefit from the implementation of lean construction in Ethiopia is the amount to be greater productivity (89%), improved sustainability/reduced waste (87%), great customer satisfaction (85%), reduced project schedule (77%) and high-quality construction (75%) are the top five expected benefits that Ethiopian Construction industry will be benefited by implementing Lean Construction.

2.5 Summary of Literature Review

Wastes can be defined as unwanted or discarded materials. According to different researchers definition of waste include not only material waste but also waste generated in a construction project such as waiting times, transportation times, and setup time. Construction waste that emerges from construction sites has become a major concern to the nation by contributes to the large quantities of construction waste that are generated by the construction industry every year.

During the last decades, many research efforts have been done to classify construction waste according to different attributes such as kind, quantity, etc. Despite different classifications, all of them follow the same basic concept. Excess materials, delays, rework and defects are those wastes commonly mentioned by researchers. Common sources of wastes that are identified through the literature review are listed in Table 2.3.

A large and various types of waste with different characteristics are created at all the stages of construction right from site preparation, demolition of existing structures to the final product. To mitigate waste, construction managers have to explore management options. The ‘three Rs’ principle of waste (reduction, reuse, and recycle), otherwise known as the waste hierarchy, has been widely adopted.

The reduction has the highest priority among the waste management options but efficient reduction cannot be achieved without adequate identification of the sources of waste. advocates identifying the root causes of waste, removing those causes with related tools and techniques, and encouraging the prevention of waste rather than reactively attempting to overcome the negative effects of loss.

Researchers implement different methods to reduce the amount of waste in the construction industry. One of the effective methods is the application of the lean approach to the construction industry. Impacts can be minimized by implementing lean construction strategies that focus on reducing wastes and improving performance, as well as increasing the overall value of the facility to the end-users. The principle of lean is primarily aimed at eliminating waste in every process activity to reduce the process cycle, improve quality, and increase efficiency.

2.5.1 Research Gap

As part of fulfilling the requirements of these thesis objectives, different literatures and journals were reviewed. History of lean production, lean in construction, tools, and techniques of lean construction, and waste in lean construction were also briefly discussed in this chapter. Many researches have been conducted on construction waste, starting from identifying their source up to assessing waste management and disposal strategies all over the world. Local authors like Seyoum, (2015) and Teferi, (2017) conducted their research on managing and minimizing waste on public projects and assessed construction waste management, further Alamirew, (2020) studied sustainable construction waste management practice in Bahirdar city.

On the other hand, Sahlu (2017) studied construction site waste based on lean thinking by classifying them as value-adding and non-value-adding activities and recommended for a study to be conducted on the implementation of lean techniques to reduce wastage and improve performance in the construction industry. Based on his recommendation and Through intense literature review, the research gap is identified as a study on the implementation of lean techniques on waste reduction. This study also is conducted on real estate companies, because most of the previous researches focused on the other sectors of the construction industry.

CHAPTER THREE

RESEARCH METHODOLOGY

This chapter includes the methodology used in this thesis work and provides information about the research approach, target population, and sample size, research method, questionnaire design, questionnaire content, and tests the consistency of the questionnaire during data analysis.

3.1 Description of the Study Area

The study area for this research is Addis Ababa, which is the capital city of Ethiopia, there are 11 sub-cities. One major activity in Addis Ababa is construction. Real estate is one of the classifications of housing development that are participating to solve the severe housing problem in Addis Ababa. The real-estate business has been popular in the past two decades. Income property includes residential and commercial properties that are leased out and expected to provide returns primarily from periodic rental income. Residential properties include single-family properties (houses, condominiums, cooperatives, and townhouses) and multifamily properties (apartment complexes and buildings). This study only focuses on residential projects.

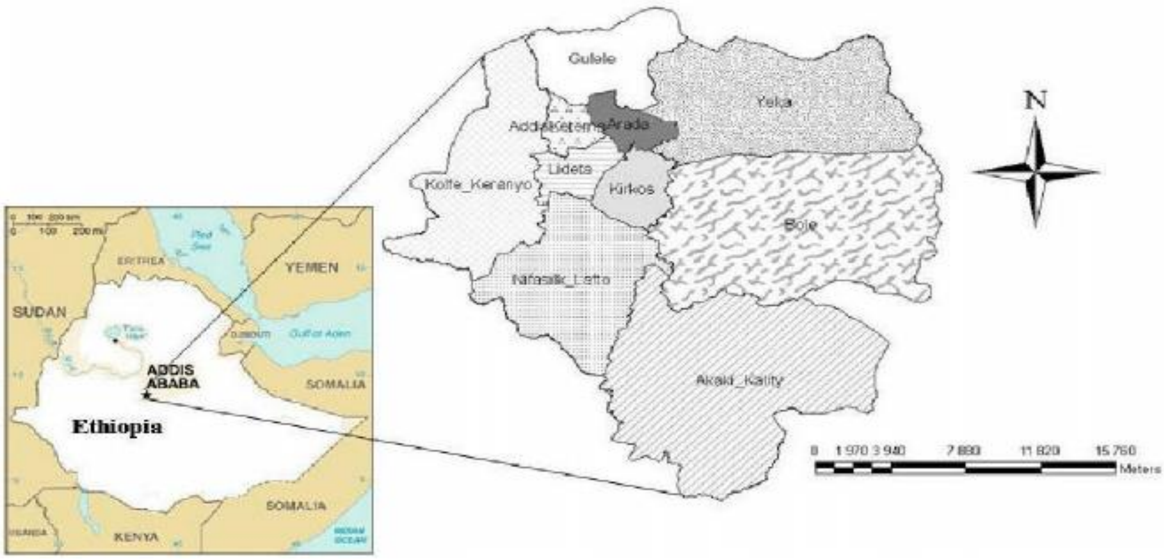

Figure 3.1 Map of Addis Ababa city

3.2 Research Design

This study is both quantitative and qualitative with descriptive nature by following comparative judgment (prioritization) aiming to develop an analytical hierarchical model for the implementation of lean techniques on the reduction of construction waste in Addis Ababa private residential real estate companies. To fulfill the objectives of the study both primary and secondary data are used. For the collection of primary data, an AHP based questionnaire was designed to compare common sources of construction waste and lean techniques as an alternative for waste reduction. And Ms-Excel was used for the computation of the AHP model. On the other hand, an interview was conducted to assess if the companies have their construction waste reduction strategies and if the construction professionals within the companies have knowledge about lean techniques.

For the data analysis, Analytical Hierarchy Process (AHP) method was used which is a hierarchical structure tool for managing qualitative and quantitative multi-criteria elements involving in decision-making behavior. AHP is chosen to be used as a tool for this study because of familiarity with the tool, and also because it is a strong yet simple tool. According to Taherdoost, (2020) the Analytical Hierarchy Process is one of the most inclusive systems is considered to make decisions with multiple criteria because this method gives to formulate the problem as a hierarchical structure. The consistency of the result from the survey is tested by following the necessary steps in computing an AHP model.

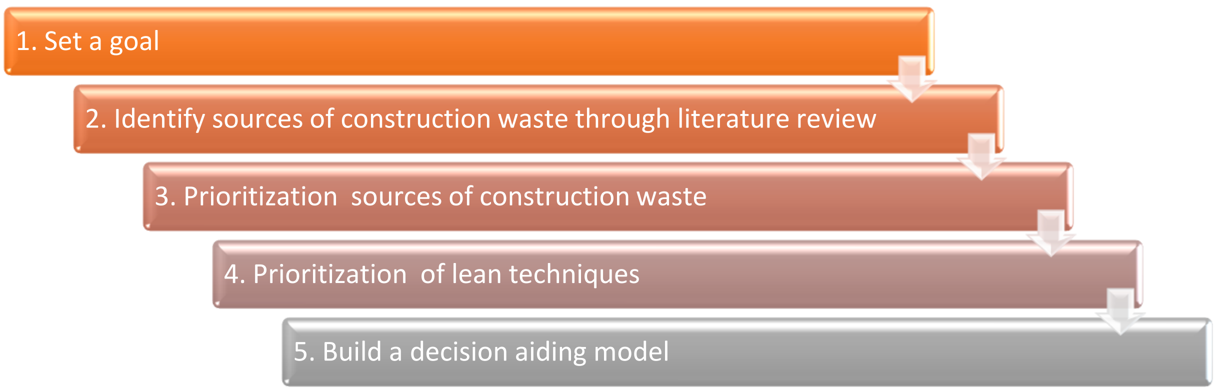

Figure 3.2 Steps in the study

3.3 Population and Sampling Technique

3.3.1 Target Population

The population of this study includes private residential real estate companies in Addis Ababa. According to a field survey by the Ministry of housing and urban development, currently, 7 companies are actively involved in residential real estate investment in Addis Ababa city. Because the companies are few, the 7 companies are taken as a sample for this study. Within these companies, there are 16 projects and by targeting decision-makers like a construction manager, project manager, and engineers (both site and office) are selected as respondents.

3.3.2 Sampling Technique

For this study purposive sampling is used. It is a type of non-probability sampling technique in which researchers relies on own judgement when choosing members of population to participate in the study. Decision makers are purposively selected for this study.

3.4 Sources of Data

In order to fulfill the objective of this study, both primary and secondary data are collected. Primary data is collected to gather information and data from different companies by using questionnaire and face to face interview as data collection instrument. Secondary data was collected from different published journal articles, conference proceedings, and books to assess the current literature on waste reduction and implementation of lean techniques.

3.5 Data Collection Instrument

3.5.1 Questionnaire

The questionnaire is designed and distributed to make an AHP decision aiding model. To make a model, setting a goal is the first step which is identified as the implementation of lean techniques to reduce construction waste.

For the implementation of lean techniques on waste, common sources of waste in construction are identified through a literature review. The survey was conducted based on a comparison of these identified sources as a criterion that relies upon AHP for its methodology. The survey objective is to quantify relative priorities for a given source of construction waste and lean techniques as an alternative on a ratio scale, based on the judgment of the construction professional. A pair-wise comparison matrix has been constructed for all elements within the same level, and each of the lower levels with one matrix for each element in the level immediately above.

Common sources of construction waste which are mentioned by different authors are identified through literature review. Then these identified sources are set to be compared with each other to build a decision aiding model. After the comparison is done, for each compared source of construction waste, there are suggested two lean techniques which are also identified through a literature review as an alternative for waste reduction. So the respondents are asked to compare the two alternatives and decide which one could be more applicable (Refer to the appendix)

The questioner is designed and distributed among the respondents (managers and engineers) to collect their opinion. It is noteworthy that each decision-maker entered their desired amount for each member and then individual judgments (of each respondent) are converted into group judgments (for each one of the paired comparisons) using their geometrical average.

The scale ranges from one to nine where one implies that the two elements are the same or are equally important. On the other hand, number nine implies that one element is extremely more important than the other one in a pairwise matrix. The pairwise scale and the importance value attributed to each number.

3.5.2 Face to Face Interview

The interview is used as a tool to assess the companies' current practice on waste reduction. Interview questions were developed to obtain information on the issues the questionnaire targets.

The interview was meant to supplement the questionnaire and enhance the reliability of data obtained by the questionnaire. Several questions are raised to understand their way of waste reduction and if they have their system or waste management scheme. 77 interviews were conducted with all construction professionals who responded to the questioner survey within the real estate companies.

3.6 Data Analysis Method

3.6.1 The Analytic Hierarchy Process (AHP)

Analytical Hierarchy Process (AHP) is a hierarchical structure that is a strong and helpful tool for managing qualitative and quantitative multi-criteria elements involving in decision-making behavior.it organizes and analyzes complex decisions, using math and psychology.

It was developed by Thomas Saaty in the 1970s. This procedure occupied an assortment of options in the decision and capable to apply sensitivity analysis on the subsequent criteria and benchmarks. Also, it makes judgments and calculations easy because of paired comparisons. Moreover, it demonstrates the compatibility and incompatibility of decisions which is the recompense of multi-criteria decision making (Taherdoost, 2020).

It contains three parts: the ultimate goal, all the possible solutions called alternatives, and the criteria to judge the alternatives on. And this shows the relations between the objectives, evaluation criteria, sub-criteria, and alternatives in a hierarchical way. After structuring the hierarchy, the relative importance of decision criteria is assessed by comparing the decision alternatives to each criterion, and finally, the overall priority for each decision alternative and the overall ranking of the decision alternatives is determined(Temiz & Calis, 2017).

3.6.1.1 Steps for AHP

At the first stage, the issue and goal of decision-making are brought hierarchically into the scene of the related decision elements. Decision-making elements are decision indicators and decision choices (Taherdoost, 2020).

In using the AHP to model a problem, one needs a hierarchic or a network structure to represent that problem. as well as pairwise comparisons to establish relations within the structure. In the discrete case, these comparisons lead to dominance matrices (Saaty & Varga, 2001).

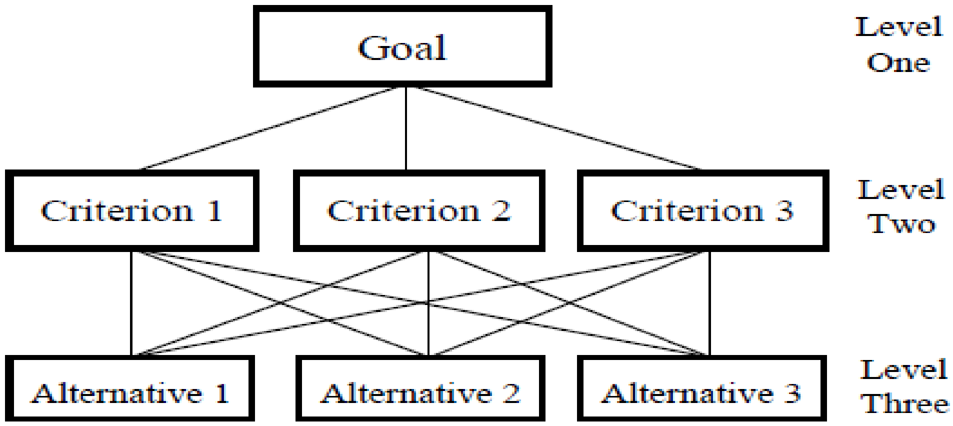

Figure 3.3 Hierarchical tree (Taherdoost, 2020)

To implement this method, the solution steps are as follows (Temiz & Calis, 2017):

Step 1. Definition of the decision problem, identification of the criteria, and alternatives.

Step 2. Establishment of the structural hierarchy.

Step 3. Establishment of the pairwise comparison matrix. The pairwise comparison is conducted based on the answers of either a decision-maker or an expert, who evaluates the importance of each criterion per decision objective(s) by using a scale ranging from 1 to 9.

Table 3.1 Pairwise comparison scale (Temiz & Calis, 2017)

Scale	**Ranking**	**Explanation**
1	Equally important	Both criteria or alternatives contribute to the objective equally
3	Moderately important	Moderate preference is given to one criterion or alternative over the other
5	Strictly important	Strict preference is given to one criterion or alternative over the other
7	Very strictly important	Very strict preference is given to one criterion or alternative over the other
9	Extremely important	The highest preference is given to one criterion or alternative over the other

By using the pairwise comparison scale, a pairwise comparison matrix is formed in which A =[aij] represents the expert's preference (Ai versus Aj for all i,j = 1, 2, 3,.., n). In paired comparisons, two elements i and j are compared concerning a property they have in common. The smaller i is used as the unit and the larger j is estimated as a multiple of that unit in the form (wi/wj)/l where the ratio wi/wj is taken from a fundamental scale of absolute values(Saaty & Varga, 2001).

Step 4. Derivation of the Eigenvalue and Eigenvector. In this step, the values in the comparison matrix are normalized and the Eigenvector is obtained by calculating the average of each line in the normalized comparison matrix. These averages provide an idea of the priorities of the options compared to each other. The Eigen matrix is calculated by multiplying the Eigenvector and the comparison matrix.

1. Sum the value in each column of the pair-wise matrix; $C_{ij} = \sum_{i=1}^{n} cij$ ……*equation 1*
2. Divide each element in the matrix by its column total to generate a normalized pair-wise matrix $X_{ij} = \frac{cij}{\sum_{i=1}^{n} cij} \begin{Bmatrix} W11 & W12 & W13 \\ W21 & W22 & W23 \\ W31 & W32 & W33 \end{Bmatrix}$…………..……………..…*equation 2*
3. Divide the sum of the normalized column of matrix by the number of criteria used (n) to generate weighted matrix (priority vector); $W_{ij} = \frac{\sum_{i=1}^{n} Wij}{n} \begin{Bmatrix} w11 \\ w21 \\ w32 \end{Bmatrix}$ …*equation 3*

3.7 Data Validity and Reliability

The accuracy and consistency of survey is a significant aspects of research methodology which are known as validity and reliability of data. For this study, first face validity measure is conducted by having academicians who understand the topic to go through the questionnaire to evaluate the content, and based on their evaluation and comment the questionnaire is modified. After that, a pilot survey is conducted on the projects where 16 questioners are distributed to be filled by project managers and engineers. By checking if the questionnaires are filled correctly, the data is collected and checked for its reliability by consistency ratio.

Reliability of data is checked by Calculating of consistency ratio. For the validation of comparison, the consistency of the pairwise matrix (*CI*) should be checked by using Eq. 1, where *λmax* represents the maximum Eigenvalue and *n* is the matrix size. Consistency Ratio (*CR*) could be calculated by using Eq. 2, where *RI* is the random consistency index obtained from a randomly generated pairwise comparison, for which Table 2 is used.

$CI = (\lambda max - n)/(n-1)$………………………………………………………. *equation* 4

$CR = CI/RI$ ……………………………………………………………………………...*equation 5*

Table 3.2 Random consistency index values(Taherdoost, 2020).

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
RI	**0.00**	**0.00**	**0.52**	**0.89**	**1.11**	**1.25**	**1.35**	**1.40**	**1.45**	**1.49**	**1.52**	**1.54**	**1.56**	**1.58**	**1.59**

It should be noted that the consistency ratio should be smaller than 0.10 (CR < 0.10) otherwise the calculation is considered inconsistent.

CHAPTER FOUR
RESULT AND DISCUSSION

4.1 Introduction

The main objective of this research is to build an AHP model for the implementation of lean techniques on waste reduction. In this chapter, the findings from the questioner and the interview are discussed. The analysis and interpretation of data is carried out in three phases. The first phase presents the respondents demography, then second phase is the presentation of result from the interview and the third phase presents the result and discussion of the questioner survey. Based on the result, an AHP decision tree is built with prioritized sources of construction waste and their respective lean techniques. The result is presented both in table and graphs.

A total number of 77 questionnaires were distributed for the respondents and 66 survey papers were responded to, 4 survey papers with no response, 2 with incomplete responses, and the rest 5 survey paper with incorrect or inconsistent responses.

Table 4.1 Response rate

Respondents	Total no of questionnaires distributed	Successfully responded	Incomplete response	Incorrect response	Not responded
Construction manager	7	4	1		2
Project manager	16	12		2	2
Office engineer	22	19	1	2	
Site engineer	16	15		1	
Supervisor (consultant)	16	16			
Total	**77**	**66**	**2**	**5**	**4**
Percentage	**100%**	**85.71%**	**2.59%**	**6.49%**	**5.19%**

4.2 Respondent Profile

The designed questioner was distributed to construction professionals in the real estate sector based on the data provided by the Ministry of housing and urban development. Out of the survey distributed, 6.06% of the participant are construction managers, 18.18% are project managers, 28.78% are office engineers, 22.72 % are site engineers and the rest 24.24% are supervisors.

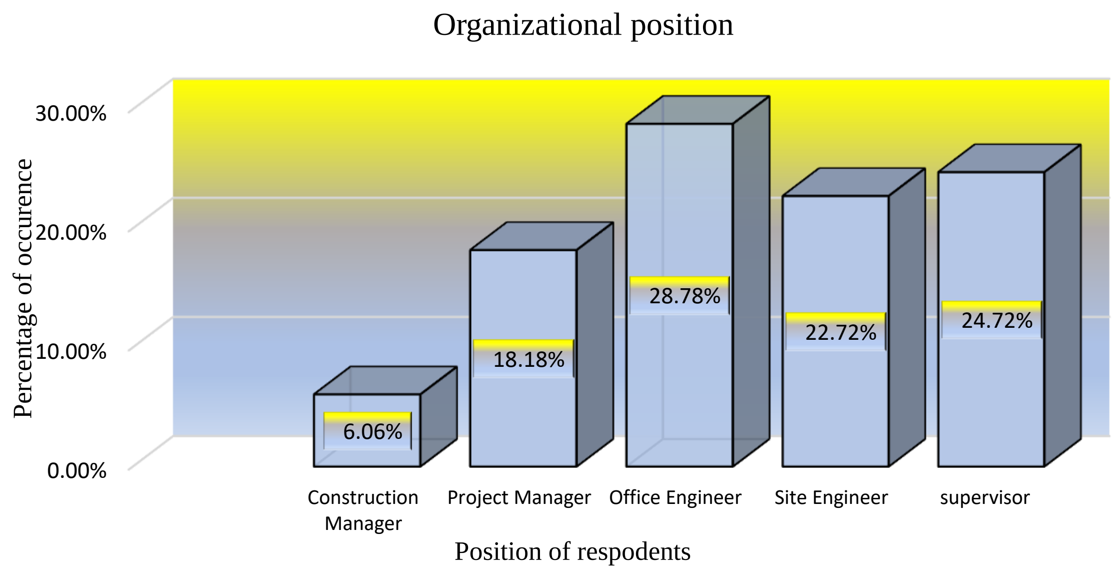

Figure 4.1 Organizational position of respondents

The respondent's educational background, this study targets construction professionals with a first degree and above, accordingly 81.08% of the respondents have a first degree, and 18.92% have a second degree.

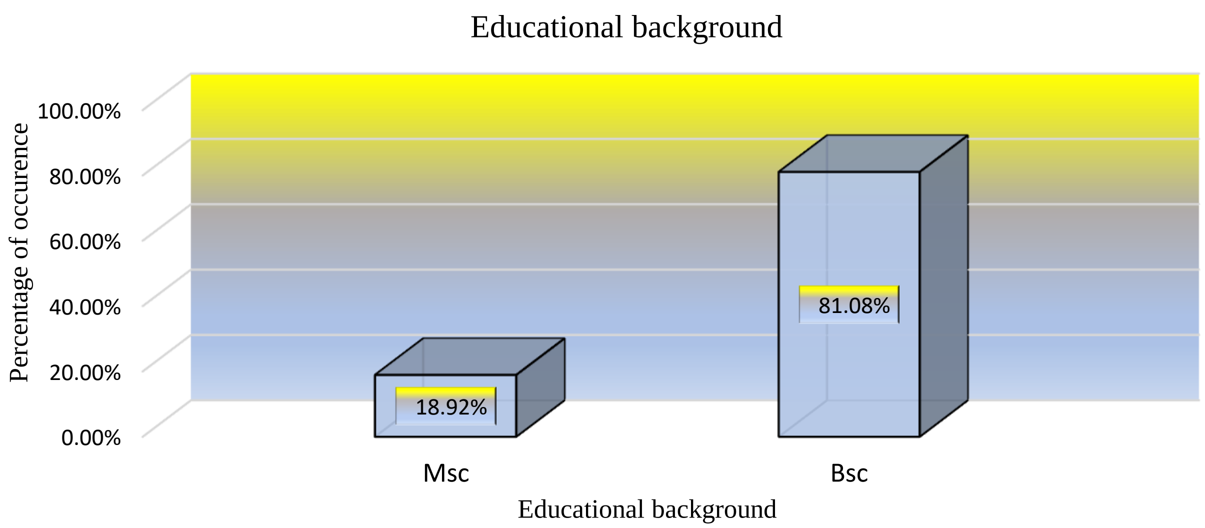

Figure 4.2 Educational background of the respondents

The other thing is respondents experience in the construction industry, 37.84% of the respondents have 1-5 years of experience, 48.65% of the respondents have 6-10 years of experience, 8.1% of the respondents have experience of 11-20 years and the rest 5.4% of the respondents have experience of more than 20 years. This implies that more than half of the respondents have experience of 5 years and above years of experience.

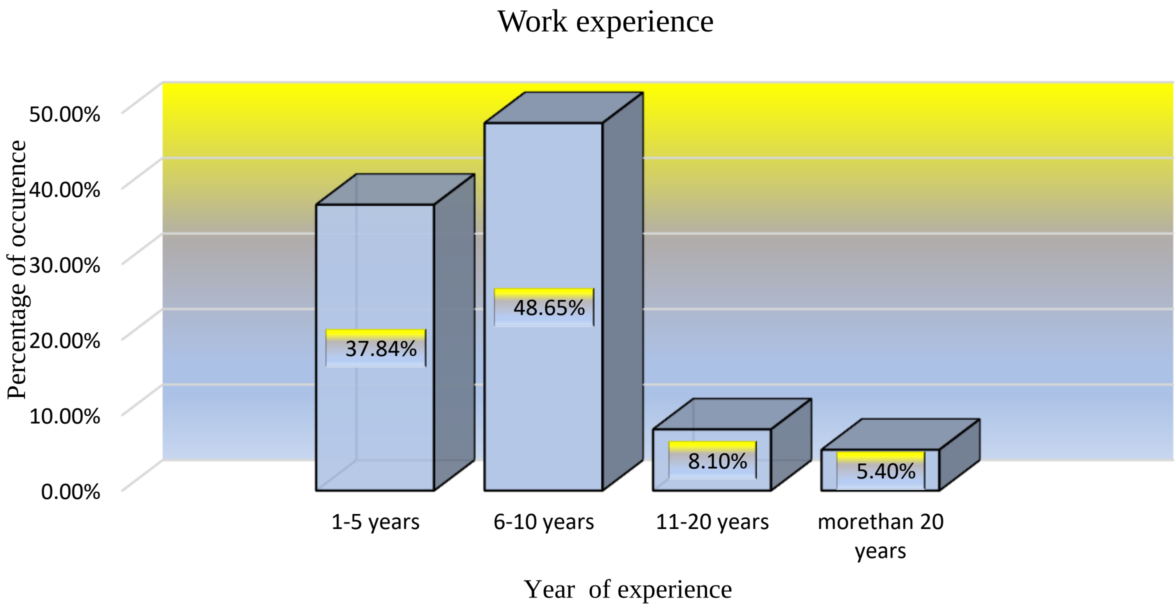

Figure 4.3 Work experience of respondents

4.3 Waste Reduction Practice in Private Residential Real Estate Companies

As a researcher, before working on a way to reduce waste first, the company's current waste reduction practice needed to be assessed, and also study if they have any technique or system to work on waste reduction. The other aspect that needed to be assessed was their awareness of lean construction and lean techniques. For this matter, a face-to-face interview was conducted.

The interviews were conducted with all construction professionals who also responded to the survey. Based on their response 53 (80.3%) of the respondents have no awareness about lean techniques and their application in the construction industry. And the rest 13 (19.7%) of the respondents have little awareness about lean techniques but don't know how to implement this technique on waste reduction. The interview demonstrates that all the companies have no waste reduction system at all. The result also illustrates that even large companies do not pay considerable attention to waste reduction. A study by Alamirew,

(2020) also stated that all interviewed companies in Bahirdar city don’t have their construction waste management policy in the organization. This implies that a proper attention is not given for a way to reduce construction waste by professionals within the industry.

4.4 Prioritization of Sources of Construction Waste

According to Saaty & Varga, (2001) In using the AHP to model a problem, one needs a hierarchic or a network structure to represent that problem, as well as pairwise comparisons to establish relations within the structure. Sources of Construction waste, which are identified through literature review, are set to be compared with each other by construction professionals. These identified sources are 8 in number and then turned into a questioner which includes 36 paired comparison questions, for each criterion to be prioritized.

Table 4.2 Sources of waste

No	Criteria	Code name
1	Poor material handling and storage	Cr 1
2	Excess inventory	Cr 2
3	Poor site management	Cr 3
4	Frequent change in design	Cr 4
5	Poor planning	Cr 5
6	Rework	Cr 6
7	Overproduction	Cr 7
8	Delay (waiting)	Cr 8

According to Saaty, (2008) to make comparisons, it need a scale of numbers that indicates how many times more important or dominant one element is over another element concerning the criterion or property for which they for compared. The matrix was arranged and a score range of 1 to 9 was selected and allocated, where a maximum score implies that the row is more important than the column. The diagonal of the matrix was allocated at a score of 1. Proceeding column-wise, the value in the corresponding column just below the diagonal is reciprocal of the scores in the corresponding row. Likewise, all the columns were calculated and added to arrive at the total.

Finally, after judgments have been made on the impact of all the elements and priorities have been computed for the hierarchy as a whole. Then to evaluate the result of the questioner, A 8 by 8 comparison was matrix created. A basic, but very reasonable, assumption is that if attribute A is more important than attribute B and is rated at 9, then B must be less important than A and is valued at 1/9.

The matrix was established by making rows and columns have the same parameters. For example, the first row is poor material handling and storage, the first column is also poor material handling and storage; if the second row is excess inventory, the second column is also excess inventory. The weight of each criterion is shown below in Table 4.3.

Table 4.3 Comparison matrix

Criteria	Cr 1	Cr 2	Cr 3	Cr 4	Cr 5	Cr 6	Cr 7	Cr 8
Cr 1	1	7	3	3	3	5	5	3
Cr 2	1/7	1	1/5	1/5	1/5	1/3	1/3	1/5
Cr 3	1/3	5	1	1	3	3	5	1
Cr 4	1/3	5	1	1	3	3	3	1
Cr 5	1/3	5	1/3	1/3	1	3	3	1
Cr 6	1/5	3	1/3	1/3	1/3	1	1	1
Cr 7	1/5	3	1/5	1/3	1/3	1	1	1/3
Cr 8	1/3	5	1	1	1	1	3	1

After obtaining the pair-wise judgments in table 4.3, the next step is the computation of a vector of priorities or weighting of elements in the matrix. In terms of matrix algebra, this consists of calculating the priority vector (eigenvector) of the matrix by adding the members of each column to find the total. To normalize each column to sum to 1.0 or 100%, divide elements of that column by the total of the column and sum them up. When we see step by step procedure, to compute the priorities, scores were normalized first. This step is to normalize the matrix by totaling the numbers in each column. For the matrix of the pair-wise matrix; $\begin{Bmatrix} C11 & C12 & C13 \\ C21 & C22 & C23 \\ C23 & C32 & C33 \end{Bmatrix}$

1. Sum the value in each column of the pair-wise matrix; $C_{ij} = \sum_{i=1}^{n} cij$

Table 4.4 Summation of each column for normalization

Criteria	Cr 1	Cr 2	Cr 3	Cr 4	Cr 5	Cr 6	Cr 7	Cr 8
Cr 1	1.00	7.00	3.00	3.00	3.00	5.00	5.00	3.00
Cr 2	0.14	1.00	0.20	0.20	0.20	0.33	0.33	0.20
Cr 3	0.33	5.00	1.00	1.00	3.00	3.00	5.00	1.00
Cr 4	0.33	5.00	1.00	1.00	3.00	3.00	3.00	1.00
Cr 5	0.33	5.00	0.33	0.33	1.00	3.00	3.00	1.00
Cr 6	0.20	3.00	0.33	0.33	0.33	1.00	1.00	1.00
Cr 7	0.20	3.00	0.20	0.33	0.33	1.00	1.00	0.33
Cr 8	0.33	5.00	1.00	1.00	1.00	1.00	3.00	1.00
Sum	2.8762	34	7.0667	7.2	11.867	17.333	21.333	8.5333

2. Divide each element in the matrix by its column total to generate a normalized pair-wise matrix $X_{ij} = \frac{cij}{\sum_{i=1}^{n} cij} \begin{Bmatrix} W11 & W12 & W13 \\ W21 & W22 & W23 \\ W31 & W32 & W33 \end{Bmatrix}$

Table 4.5 Normalized pair-wise matrix

Criteria	Cr 1	Cr 2	Cr 3	Cr 4	Cr 5	Cr 6	Cr 7	Cr 8
Cr 1	0.35	0.21	0.42	0.42	0.25	0.29	0.23	0.35
Cr 2	0.05	0.03	0.03	0.03	0.02	0.02	0.02	0.02
Cr 3	0.12	0.15	0.14	0.14	0.25	0.17	0.23	0.12
Cr 4	0.12	0.15	0.14	0.14	0.25	0.17	0.14	0.12
Cr 5	0.12	0.15	0.05	0.05	0.08	0.17	0.14	0.12
Cr 6	0.07	0.09	0.05	0.05	0.03	0.06	0.05	0.12
Cr 7	0.07	0.09	0.03	0.05	0.03	0.06	0.05	0.04
Cr 8	0.12	0.15	0.14	0.14	0.08	0.06	0.14	0.12
sum	1	1	1	1	1	1	1	1

3. Divide the sum of the normalized column of matrix by the number of criteria used (n) to generate weighted matrix (priority vector); $W_{ij} = \frac{\sum_{i=1}^{n} Wij}{n} \begin{Bmatrix} w11 \\ w21 \\ w32 \end{Bmatrix}$

Table 4.6 Weighted matrix

Criteria	Cr 1	Cr 2	Cr 3	Cr 4	Cr 5	Cr 6	Cr 7	Cr 8	Criteria weight
Cr 1	0.35	0.21	0.42	0.42	0.25	0.29	0.23	0.35	0.318
Cr 2	0.05	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.0257
Cr 3	0.12	0.15	0.14	0.14	0.25	0.17	0.23	0.12	0.1679
Cr 4	0.12	0.15	0.14	0.14	0.25	0.17	0.14	0.12	0.1564

Cr 5	0.12	0.15	0.05	0.05	0.08	0.17	0.14	0.12	0.1057
Cr 6	0.07	0.09	0.05	0.05	0.03	0.06	0.05	0.12	0.0604
Cr 7	0.07	0.09	0.03	0.05	0.03	0.06	0.05	0.04	0.0485
Cr 8	0.12	0.15	0.14	0.14	0.08	0.06	0.14	0.12	0.1170

4.4.1 Checking for Consistency

To accept the criteria weight of the above calculation, first, we need to check for the consistency of the data. Consistency is associated with the internal coherence of the decision-maker when their judgment is considered in the pairwise comparison matrices. It is the most important measurement of the results from the pairwise comparison in the AHP. A true consistency ratio is calculated by dividing the consistency index for the set of judgments by the index for the corresponding random matrix. Saaty suggests that, the ratio exceeds 0.1, then the set of judgments may be too inconsistent to be reliable.

Table 4.7 Calculation for λ_{max}

Criteria	Cr 1	Cr 2	Cr 3	Cr 4	Cr 5	Cr 6	Cr 7	Cr 8	Weighted sum value	Ratio
Cr 1	0.318	0.1799	0.5037	0.4692	0.3171	0.302	0.2425	0.351	2.6834	8.438
Cr 2	0.4452	0.0257	0.03358	0.03128	0.02114	0.0199	0.016	0.0234	0.6162	7.271
Cr 3	0.1049	0.1285	0.1679	0.1564	0.3171	0.1812	0.2425	0.1170	1.4155	8.430
Cr 4	0.1049	0.1285	0.1679	0.1564	0.3171	0.1812	0.1455	0.1170	1.3185	8.430
Cr 5	0.1049	0.1285	0.0554	0.0516	0.1057	0.1812	0.1455	0.1170	0.8898	8.418
Cr 6	0.0636	0.0771	0.0554	0.0516	0.0348	0.0604	0.0485	0.1170	0.56	9.271
Cr 7	0.0636	0.0771	0.03358	0.0516	0.0348	0.0604	0.0485	0.0386	0.40819	8.416
Cr 8	0.1049	0.1285	0.1679	0.1564	0.1057	0.0604	0.1455	0.1170	1.1427	9.766
Criteria weight	0.318	0.0257	0.1679	0.1564	0.1057	0.0604	0.0485	0.1170	Sum of ratio	68.44

Lambda Max (λ_{max}) is the maximum eigenvalue of the matrix and it is needed to calculate consistency index (C.I). The ratio column in table 4.7 represents the finding of λ_{max}, by dividing all the elements of the weighted sum matrix by priority vector for each criterion.

Table 4.8 Calculation of consistency

Consistency calculation	
λ_{max} = sum of ratio/ no	8.555
Consistency index = $\frac{\lambda max - n}{n-1}$	0.0793788
Random Index (R.I) for $n=8$	1.41
Consistency ratio= $\frac{Consistency\ index}{Random\ index}$	0.0560
0.056 < 0.1 (Acceptable)	

The consistency ratio verifies that the comparison is consistent and reliable enough to use the criteria weight for rating. Based on this, the table below represents the eight criteria that are compared with each other and their rating accordingly.

Table 4.9 Criteria weight

No	Criterion	Code name	Rank	Weights
1	Poor material handling and storage	Cr 1	1	31.8%
2	Poor site management	Cr 3	2	16.8%
3	Frequent change in design	Cr 4	3	15.6%
4	Delay(waiting)	Cr 8	4	11.7%
5	Poor planning	Cr 5	5	10.6%
6	Rework	Cr 6	6	6.0%
7	overproduction	Cr 7	7	4.9%
8	Excess inventory	Cr 2	8	2.6%

4.5 Prioritization of Lean Techniques as an Alternative for Waste Reduction

After prioritizing sources of waste, the next step is to find a way for us to reduce these wastes to the minimum amount possible. To achieve this, some lean techniques are identified through literature review. Under each factor of waste, two lean techniques are there to be prioritized for implementation.

4.5.1 Poor Material Handling and Storage

According to respondents, poor material handling and storage is found to be the most dominant source of waste with a 31.8% priority rate. Also, according to Ayman, (2018) The most common cause of wastes is the inappropriate storing of materials as most of these problems are due to the techniques of handling. Also, according to Fadiya et al., (2014) poor material handling and storage is the third dominant source of construction waste. This implies that poor material handling is also a major source of construction waste in different countries. On the other hand, 2 different lean techniques are set to be compared as an alternative for waste reduction caused by poor material handling and storage. These lean techniques are just in time and the 5s process. And the respondent's prioritized, just in time to be more applicable with a priority rate of 58.3% and the rest 41.6% goes to the 5s process.

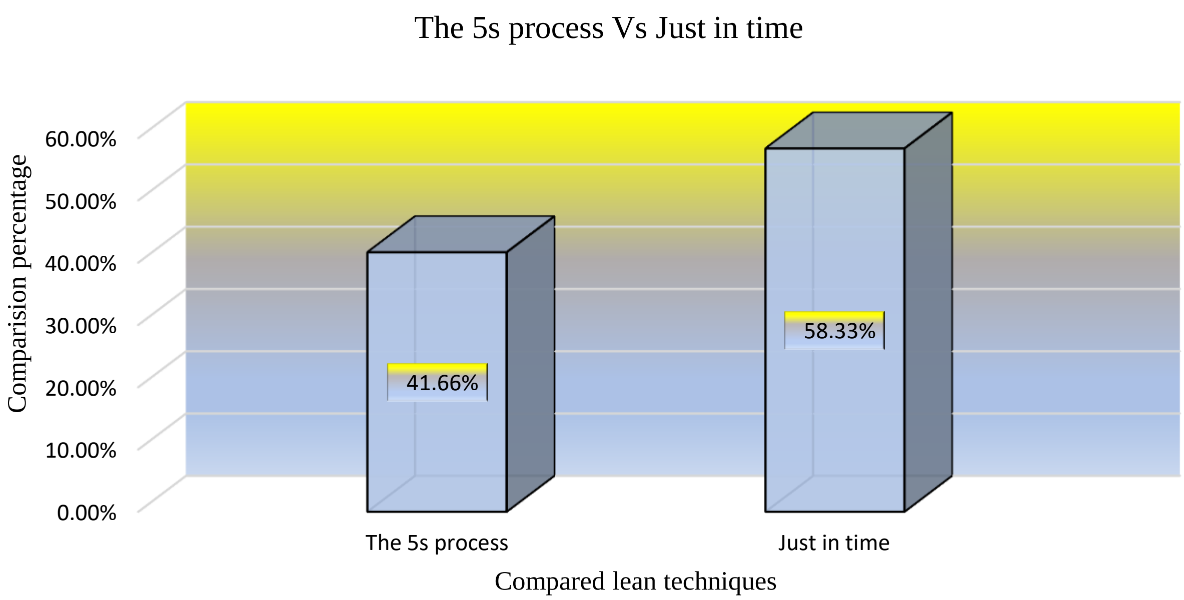

Figure 4.4 Prioritization of lean techniques for Poor material handling and storage

On the other hand, Bygballe & Sward, (2014) listed the 5s as a technique that results in a workplace that is clean, uncluttered, safe, and well organized to help reduce waste and optimize productivity. This also illustrates that the construction site is clean and well organized it can reduce wastage caused by poor material handling and storage by following steps which involve going through everything in a space, deciding what's necessary and what isn't, putting things in order, cleaning, and setting up procedures for performing these tasks on regular basis. This technique also helps us to know what materials we have at hand to reduce excess inventory.

4.5.2 Excess Inventory

Excess inventory is estimated with a 2.6% priority rate as a source of construction waste. As described in the interview result, the companies perform a checkup on the material purchase request which is sent from the sites. And before approving the request for material purchase, engineers at the office check the amount of material requested to reduce excess inventory. So, excess inventory is given less priority. However, a study by Xing et al., (2021) listed excess inventory as the main source of construction waste that needs to be taken care of.

Two lean techniques are set for the reduction of excess inventory these are proper recording of data and inventory optimization. 54% of the respondents prioritized that proper recording of data could reduce waste when implemented. The rest 46% goes for the implementation of inventory optimization for better reduction of waste.

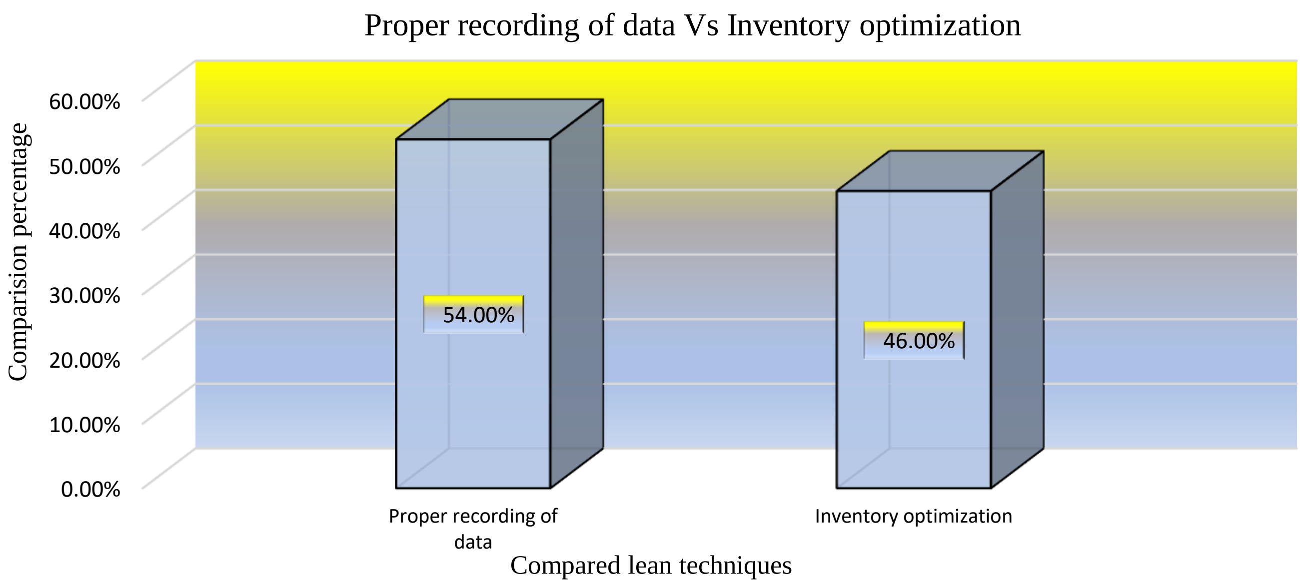

Figure 4.5 Prioritization of lean techniques for excess inventory

Both prioritized lean techniques on Figure 4.5, helps to know the material which are already at the site and which material should be purchased to execute a certain construction activity. This helps us not to purchase excess inventory by mistake, because excess inventory tides up companies' capital, and also longer storage of material leads to loss and deterioration of construction materials. It is also a means by which construction companies and suppliers can keep track of materials, workforce, and equipment.

4.5.3 Poor Site Management

Poor site management is given a rate of 16.8% when it is compared to the other factors. But Nagapan et al., (2012) ranked poor site management to be the highest factor causing construction waste. To reduce wastage related to poor site management, also two lean techniques to be compared for their implementation.

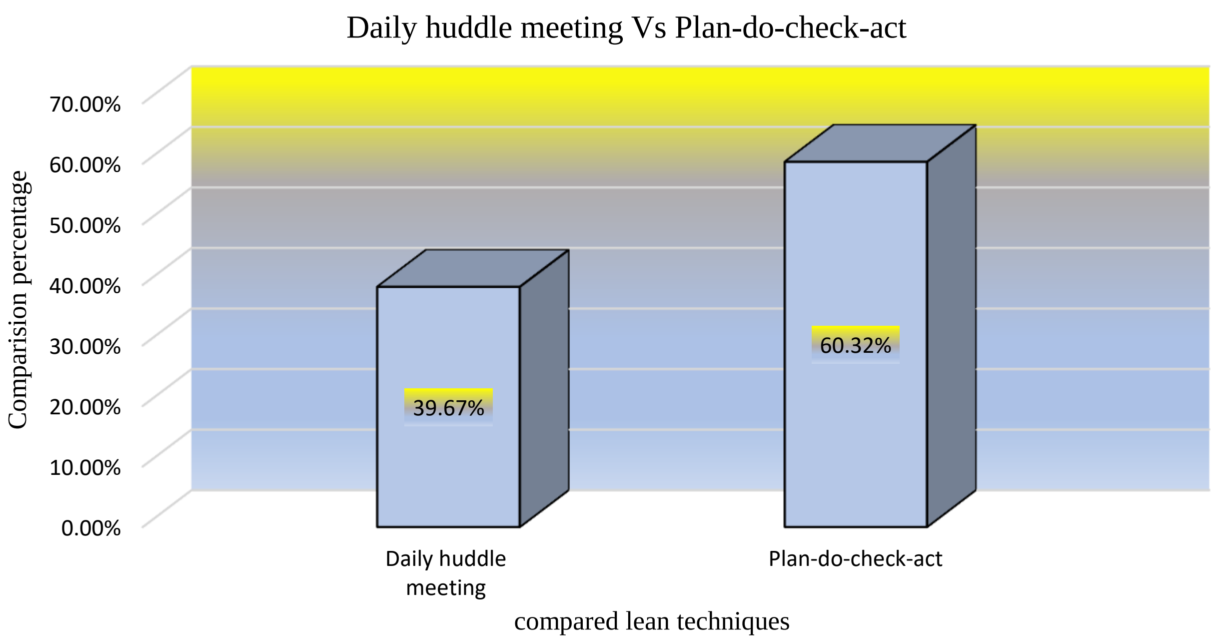

Figure 4.6 Prioritization of lean techniques for poor site management

The respondents gave priority to plan-do-check-act with 60.32% and daily huddle meetings with 39.67%. Daily huddle meeting was presented as the most used lean technique by Ogunbiyi et al., (2014). Daily huddle meeting with different professionals at the site helps to improve communication and workflow. And the PDCA technique aims to improve processes occurring in a company and help eliminate recurring mistakes (Nahmens, 2009).

4.5.4 Frequent Change in Design

Frequent change in design is only given a 15.6% priority rate by respondents. But as mentioned by Fadiya et al., (2014), change in design is the most dominant source of construction waste. Also, Bekr, (2014) and Nagapan et al., (2012) mentioned frequent design change as the main contributor to waste generation.

According to the interview, in real estate projects, change in design mainly occurs due to the owner's request for the modification of the design. So, the two lean techniques set to be implemented on frequent change in design might not work because it is based on avoiding design error.

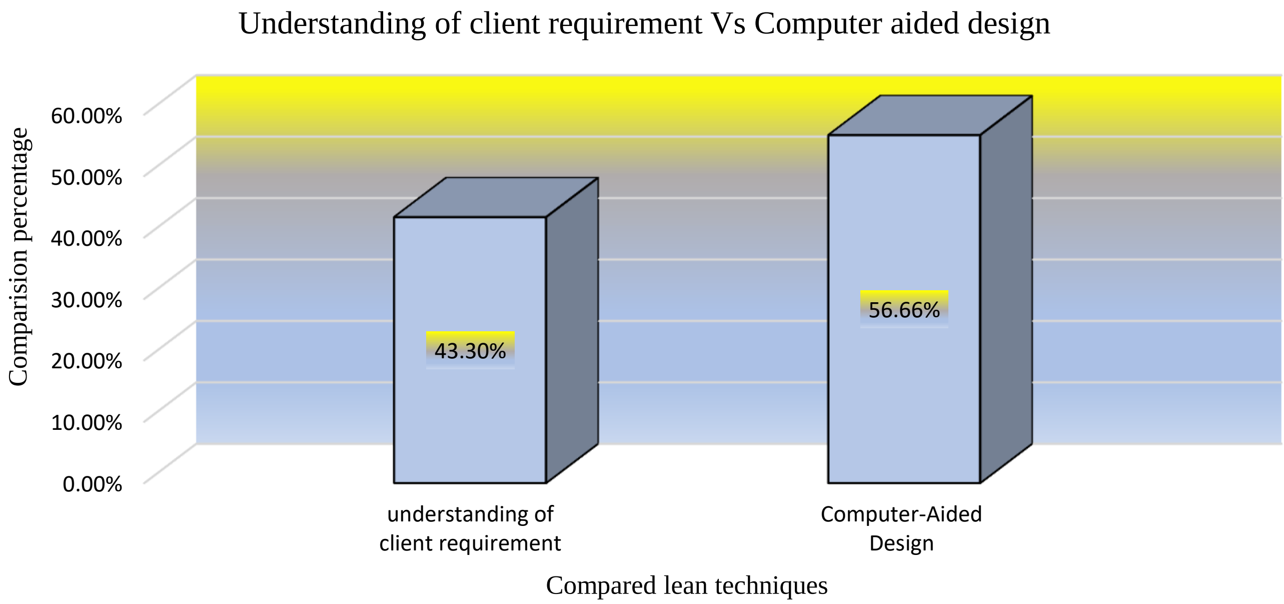

Figure 4.7 Prioritization of lean techniques for frequent change in order

But if the change in design is requested because there is an error in the design, Two lean techniques are set as an alternative, and computer-aided design is prioritized with the rate of 56.66% and proper understanding of client requirement with 43.3%. Sarhan et al., (2017) also agree that CAD is the most important tool/technique, which is a common design tool used by many construction professionals. also using BIM can reduce waste to a recognizable amount by detecting an error in design.

4.5.5 Poor Planning

By comparing several factors, poor planning is given a 10.6% priority rate. However, in a study by Khanh & Kim, (2014b), poor planning is ranked to be one of the most dominant sources of construction waste. Two lean techniques were compared for waste reduction. And last planner system is rated with 56.83% and process mapping with 43.17%.

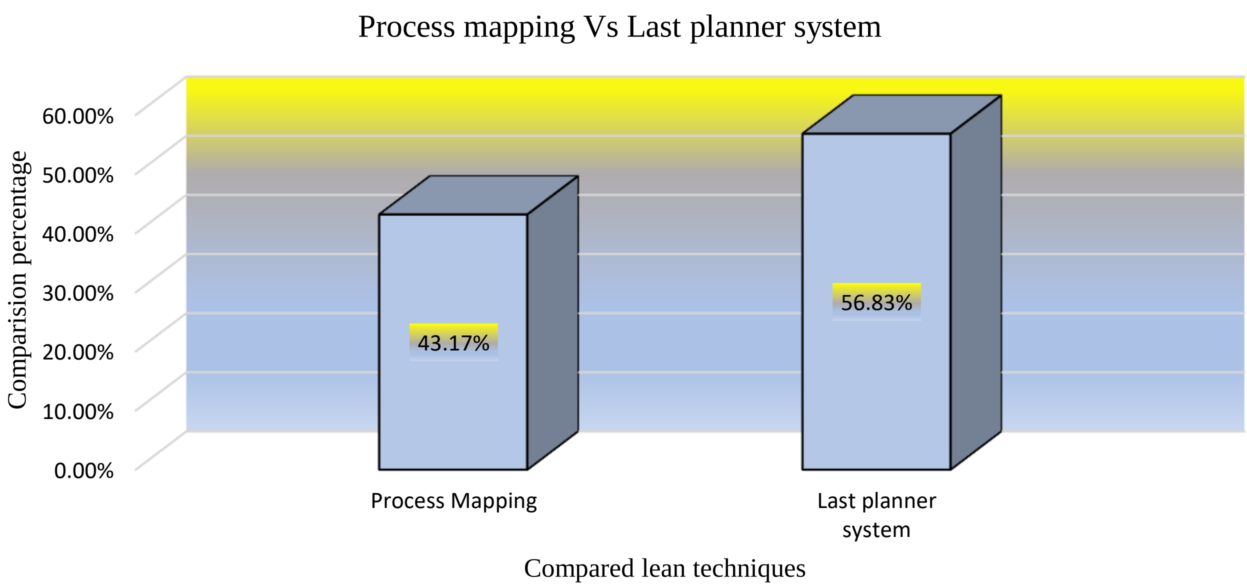

Figure 4.8 Prioritization of lean techniques for poor planning

Jose et al., (2018) described that, If the planned sequences are not convenient and needed re-planning, one of the best-known lean techniques is the Last Planner System (LPS). It is an important tool for the construction management process and a monitor for planning efficiency to assist the smooth workflow variations, reducing the uncertainties plaguing construction processes and development of foresight.

Also, Ayman Ahmed & Maha Ahmed, (2018) mentioned that the last planner system to be the most common lean tool that is used in Egypt. Nikakhtar et al., (2015) mentioned process mapping implementation helps to develop the road map to tackle improvement areas to bridge the gap between the existing state and the proposed state of different construction activities.

4.5.6 Rework

Rework is when the completed work does not comply with the actual contract. And it is rated with 6% as a source of waste by respondents. Based on a study by Bekr, (2014), rework was ranked at second place. The two lean techniques; Proper monitoring accounts for 85% and error-proofing with 15% as an alternative for waste reduction. Error proofing can be implemented to reduce construction waste by avoiding simple human error in the workplace by identifying activities that are prone to errors and help avoid an error from occurring.

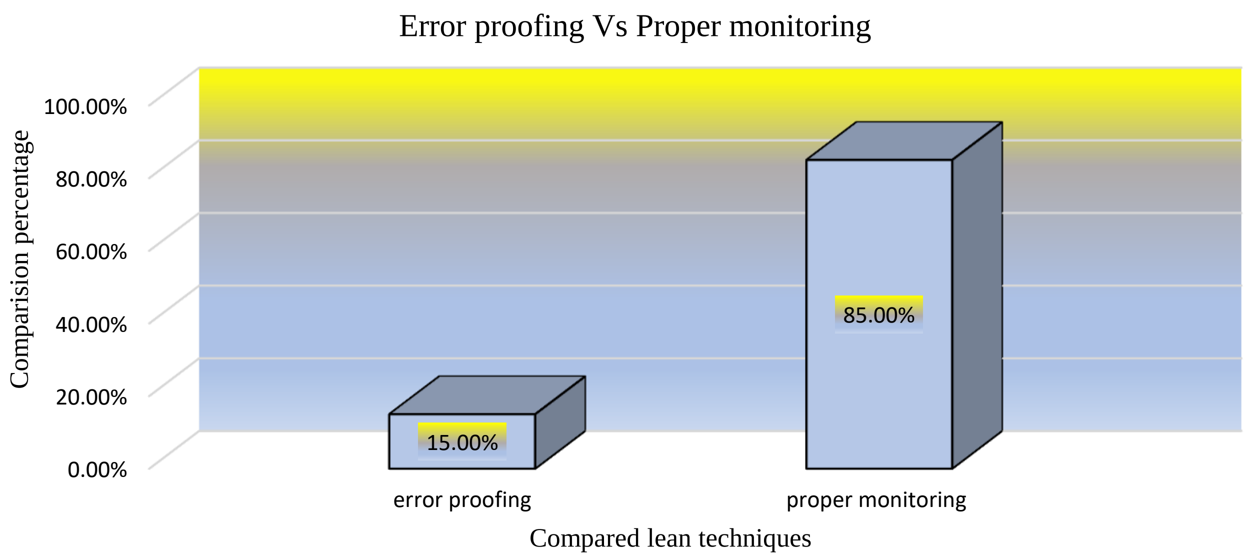

Figure 4.9 Prioritization of lean techniques rework

4.5.7 Overproduction

Overproduction is the fabrication of products before their need or excess in amount. And it is rated with 4.9% when it compared to other factors. Using accurate information is prioritized with 52.29% and having a clear schedule and work plan with 47.71% as a waste reduction technique.

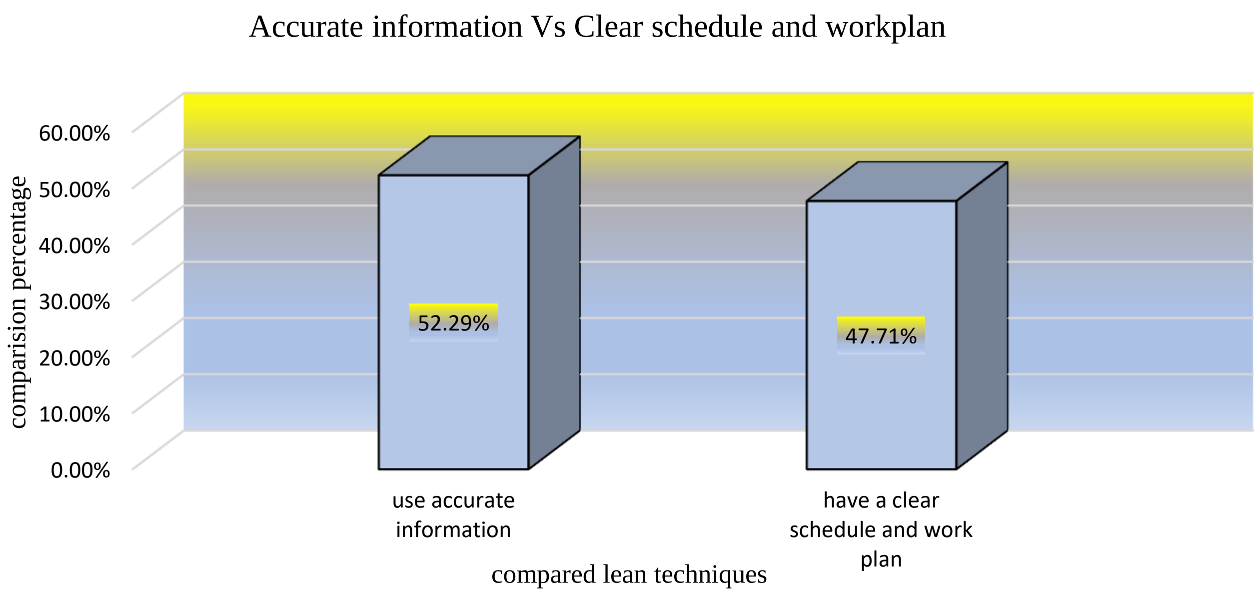

Figure 4.10 Prioritization of lean techniques for overproduction

4.5.8 Delay(waiting)

Waiting for a delivery of material or the completion of the preceding activity is prioritized to be 11.7% as a source of waste. Sarhan et al., (2017) and (Al-aomar, 2012) showed that "waiting" is the most common type of waste in construction projects in Saudi Arabia. Concurrent engineering is rated with 68.79% to be more implementable on waste related to waiting and the rest 31.21% goes to the just-in-time technique for its implementation. Concurrent engineering eliminates a lot of that wait time by identifying activities that can overlap and integrated. Also, just in time can eliminate waiting time by delivering construction material on time.

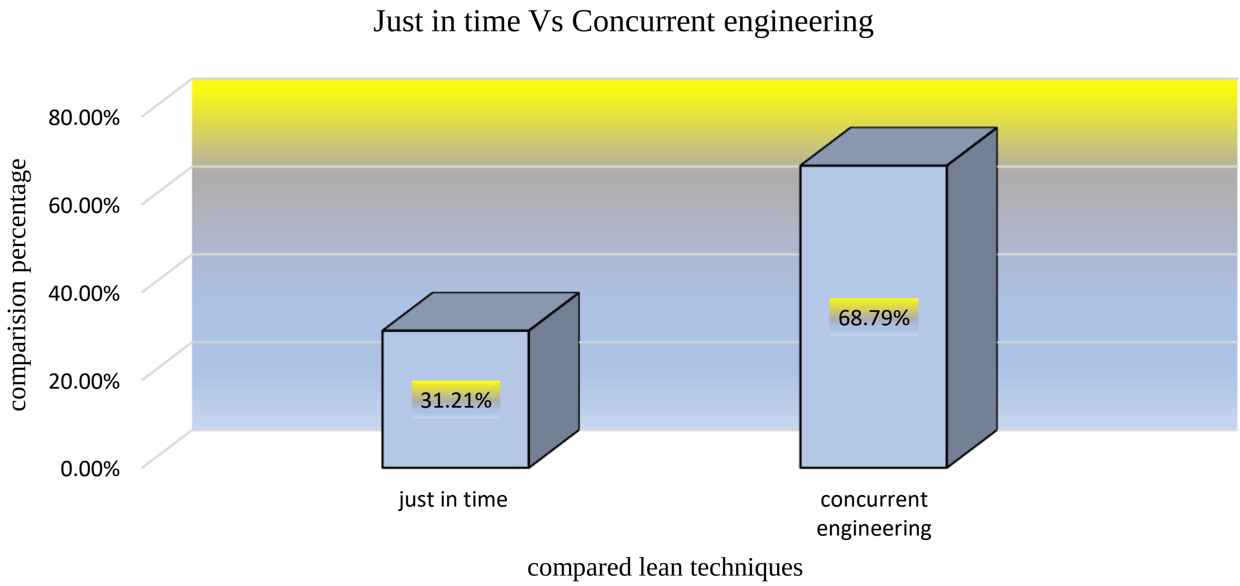

Figure 4.11 Prioritization of lean techniques delay(waiting)

4.6 Implementation of Lean Techniques on Waste Reduction

The approach of this research is to identify the major sources of waste and take action by implementing the approach of lean technique. The questioner was designed purposely to build an AHP model, which contains a comparison of major sources of waste in construction which are identified from previously done researches through literature review and lean techniques which can be implemented to reduce construction waste.

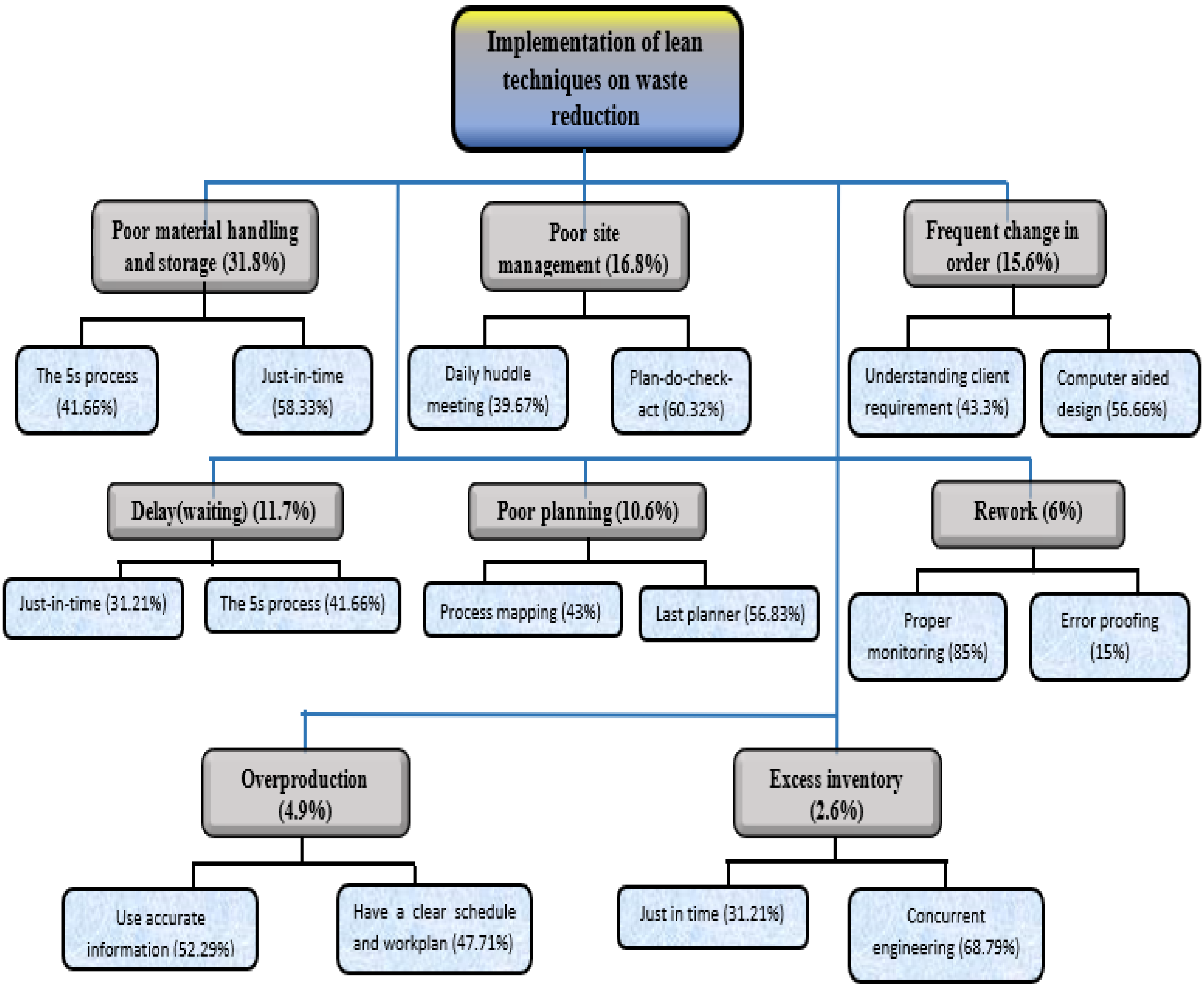

Figure 4.12 Summary of the overall analysis

The first level of the hierarchy represents the objective of the model which is the implementation of lean techniques for construction waste reduction. The second level of the hierarchy represents the major sources of waste in the construction and their priority rate when compared to each other. Poor material handling, poor site management, and frequent change in order prioritized to be the top three sources respectively. An AHP model by Abdelrazig, (2015) identified that Controllable waste associated with Management Activities and Flows are the most important factors in reducing process waste. The third level of the hierarchy represents lean techniques for the implementation and their respective rate according to respondents based on rating on which can be more applicable and which can be effective.

This hierarchical tree can serve as a tool to decide on identifying sources of construction wastes and which lean technique to use to reduce them. The decision-maker can easily identify which lean techniques are appropriate for different sources of construction waste, which are commonly faced by the industry.

The previously described survey results, not only facilitated in gaining an understanding into the way of how lean construction techniques could improve the construction process but also provided the basis for prioritizing alternatives for the construction professional's decision-making. Moreover, it provided a checked consistency for the goal accomplished, therefore ensuring that the decision was based on sound logic.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the data analysis, a conclusion is made

1) Lean techniques can be used for the reduction of construction wastes. Based on the interview made for this study, it was concluded that the selected companies don't have any waste reduction strategy or practice. And it was illustrated that even larger companies don't give attention to construction waste. Also, 80.3% of the respondents have no awareness about lean techniques and the rest 19.7% have awareness but don't know how to implement these techniques on construction waste reduction.
2) The survey analysis prioritized poor material handling, poor site management, and frequent change to be the top three sources of construction waste with a priority rate of 31.8%, 16.8%, and 15.6% respectively.
3) Many alternatives of lean techniques were identified to support in reaching the optimum goal and prioritized as a tool for the reduction of construction waste.
4) The study implement in which lean theory can be put into practical experience through the analytical hierarchical process approach.

5.2 Recommendation

Recommendation for Real Estate Companies

- ✓ Construction companies to be aware that waste is a very crucial aspect that affects the productivity of projects.
- ✓ For Construction companies to adapt their waste reduction strategy to minimize waste to an acceptable amount. Since managing construction waste is one of the most significant management processes necessary to achieve project objectives, it is hereby recommended that companies can use lean techniques to reduce construction waste.

- ✓ Based on the result of the study, it is recommended that construction companies to give more attention to material and site management because of being the common sources of construction waste.
- ✓ Also, attention to be given to waste factors like waiting and overproduction because even if are not given much attention but they are the major contributors to waste in the construction industry.
- ✓ Construction companies can give training for their employees about construction waste. Also, Companies can create a system where they can give incentives for professionals within a project whose performance leads to less waste generation to motivate others for better waste reduction.

Recommendation for Construction Professionals

- ✓ Construction professionals consider that the production of construction materials consumes a huge amount of natural resources. So, they must be used properly and wisely.
- ✓ For construction professionals to give attention not only to physical waste but also to non-physical waste (waiting time and unnecessary movement, etc.…)
- ✓ Construction professionals can reduce waste by ordering the right amount of materials and by storing them properly.
- ✓ Besides proper planning, organizing, and periodical monitoring, construction professionals can implement lean techniques to reduce construction waste.
- ✓ Familiarity gained about waste and lean techniques from this thesis could also be combined into training techniques for leaders in the construction industry to ensure successful project completion.

Recommendation for Further Study

- ✓ Further study needs to be done on each type of lean technique so that it is clear for the construction professionals for its implementation in the construction industry.

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REFERENCE

Abbasian-hosseini, A., Nikakhtar, A., & Zavichi, A. (2012). Implementing Lean Construction Theory into Construction Processes ' Waste Management. *ICSDC*, *41204*(July 2015). https://doi.org/10.1061/41204(426)52

Abdelrazig, Y. E. (2015). *Using Lean Techniques to Reduce Waste and Improve* (Issue May) [The University of Texas at Arlington]. https://rc.library.uta.edu/uta-ir/bitstream/handle/10106/25028/ABDELRAZIG_uta_2502M_13057.pdf?sequence=1&isAllowed=y

Ajayi, S. O., Oyedele, L. O., Akinade, O. O., Bilal, M., Alaka, H. A., Owolabi, H. A., & Kadiri, K. O. (2017). Attributes of design for construction waste minimization: A case study of waste-to-energy project. *Renewable and Sustainable Energy Reviews*, *73*(October 2016), 1333–1341. https://doi.org/10.1016/j.rser.2017.01.084

Ajayi, S. O., Oyedele, L. O., Akinade, O. O., Bilal, M., Owolabi, H. O., & Alaka, H. A. (2014). Ineffectiveness of construction waste management strategies: Knowledge gap analysis. *Proceedings of the First International Conference of the CIB Middle East and North Africa Research Network (CIB-MENA 2014)*, *June 2015*, 261–280. https://doi.org/10.13140/RG.2.1.4788.8480

Akinradewo, O., Oke, A., Aigbavboa, C., & Ndalamba, M. (2018). Benefits of Adopting Lean Construction Technique in the South African Construction Industry. *Proceedings of the International Conference on Industrial Engineering and Operations Management*, *Lc*, 1271–1277.

Al-aomar, R. (2012). Analysis of lean construction practices at Abu Dhabi construction industry. *Lean Construction Journal*, *3*(1), 105–121.

Al-Rifai, J., & Amoudi, O. (2016). Understanding the key factors of construction waste in Jordan. *Jordan Journal of Civil Engineering*, *10*(2), 244–253. https://doi.org/10.14525/JJCE.10.1.3540

Alamirew, Y. (2020). *A Study On Sustainable Construction Waste Management Practices : The Case of Building Construction Projects in Bahir Dar City , Ethiopia* [Bahir Dar University]. http://hdl.handle.net/123456789/11001

Ansah, R. H., Sorooshian, S., & Mustafa, S. Bin. (2016). Lean construction: An effective approach for project management. *ARPN Journal of Engineering and Applied Sciences*, *11*(3), 1607–1612.

Aslam, M., Baffoe-Twum, E., & Saleem, F. (2019). Design Changes in Construction Projects – Causes and Impact on the Cost. *Civil Engineering Journal*, *5*(7), 1647–1655. https://doi.org/10.28991/cej-2019-03091360

Ayalew, T., Dakhli, Z., & Lafhaj, Z. (2016). The Future of Lean Construction in Ethiopian Construction Industry. *International Journal of Engineering Research and Technology(IJERT)*, *5*(02).

Ayalew, T., Dakhli, Z., & Lafhaj, Z. (2018). Characterization of waste in Ethiopian building construction projects. *IGLC 2018 - Proceedings of the 26th Annual Conference of the International Group for Lean Construction: Evolving Lean Construction Towards Mature Production Management Across Cultures and Frontiers*, *2*(September), 797–806. https://doi.org/10.24928/2018/0505

Ayman Ahmed, E. O., & Maha Ahmed, A.-Z. (2018). Lean Construction for Reducing Construction Waste in the Egyptian Construction Industry. *2nd Internatinal Conference "Sustainable Construction and Project Management - Sustainable Infrastructure and Transportation for Future Cities," February*.

Aziz, R. F., & Hafez, S. M. (2013). Applying lean thinking in construction and performance improvement. *Alexandria Engineering Journal*, *52*(4), 679–695. https://doi.org/10.1016/j.aej.2013.04.008

Babalola, O., Ibem, E. O., & Ezema, I. C. (2019). Implementation of lean practices in the construction industry : A systematic review. *Building and Environment*, *148*(May 2018), 34–43. https://doi.org/10.1016/j.buildenv.2018.10.051

Bakshan, A., Srour, I., Chehab, G., & El-Fadel, M. (2015). A field based methodology for estimating waste generation rates at various stages of construction projects. *Resources, Conservation and Recycling*, *100*, 70–80. https://doi.org/10.1016/j.resconrec.2015.04.002

Banihashemi, S., Tabadkani, A., & Hosseini, M. R. (2018). Integration of parametric design into modular coordination: A construction waste reduction workflow. *Automation in Construction*, *88*(December 2017), 1–12. https://doi.org/10.1016/j.autcon.2017.12.026

Bekr, G. A. (2014). Study of the Causes and Magnitude of Wastage of Materials on Construction Sites in Jordan. *Journal of Construction Engineering*, *2014*, 1–6. https://doi.org/10.1155/2014/283298

Birhane, G. (2018). Reflections on the Challenges of the Ethiopian Construction Industry. *Ethiopian E-Journal for Research and Innovation Foresight*, *10*(2), 21–49.

Cheng, K. J., & Mydin, M. A. O. (2014). Best Practice of Construction Waste Management and Minimization Material. In *Analele Universităţii "Eftimie Murgu" Reşiţa Anul* (Issue 1).

Cheru, M. (2016). *Solid Waste Management in Addis Ababa: A new approach to improving the waste management system*. Helsinki Metropolia University of Applied Science.

Coelho, A., & de Brito, J. (2013). Environmental analysis of a construction and demolition waste recycling plant in Portugal - Part II: Environmental sensitivity analysis. *Waste Management*, *33*(1), 147–161. https://doi.org/10.1016/j.wasman.2012.09.004

Ding, Z., Yi, G., Tam, V. W. Y., & Huang, T. (2016). A system dynamics-based environmental performance simulation of construction waste reduction management in China. *Waste Management*, *51*, 130–141. https://doi.org/10.1016/j.wasman.2016.03.001

Esin, T., & Cosgun, N. (2007). A study conducted to reduce construction waste generation in Turkey. *Building and Environment*, *42*(4), 1667–1674. https://doi.org/10.1016/j.buildenv.2006.02.008

Evbuomwan, N. F. O., & Anumba, C. J. (1998). An integrated framework for concurrent life-cycle design and construction. *Advances in Engineering Software*, *29*(7–9), 587–597. https://doi.org/10.1016/S0965-9978(98)00024-6

Fadiya, O. O., Georgakis, P., & Chinyio, E. (2014). Quantitative Analysis of the Sources of Construction Waste. *Journal of Construction Engineering*, *4*, 54–69.

Formoso, C. T., Soibelman, L., De Cesare, C., & Isatto, E. L. (2002). Material Waste in Building Industry: Main Causes and Prevention. *Journal of Construction Engineering and Management*, *128*(4), 316–325. https://doi.org/10.1061/(asce)0733-9364(2002)128:4(316)

Gulghane, A. A., & Khandve, P. P. V. (2015). *Management for Construction Materials and Control of Construction Waste in Construction Industry : A Review*. *5*(4), 59–64.

Harsha, N., Suresh, A. V, & Nagaraj, N. (2013). Implementation Of Lean Concepts In The Construction Engineering Project. *International Journal of Engineering & Technology (IJERT)*, *2*(5), 1078–1085.

Henriques, P. G., & Silva, P. D. F. (2008). *Implementation of lean construction principles in Portugal: " Adaptation of good practices from a Danish Case Study ."* University of Lisbon.

Ingle, A., & Waghmare, A. P. (2015). Advances in Construction: Lean for Productivity

Enhancement and Waste Minimization. *International Journal of Engineering and Applied Sciences Ijeas*, *2*(11), 19–23.

Issa, U. H. (2013). Implementation of lean construction techniques for minimizing the risks effect on project construction time. *Alexandria Engineering Journal*, *52*(4), 697–704. https://doi.org/10.1016/j.aej.2013.07.003

Jose, J. P. A., Prasanna, P. R., Prakash, F., & Engineering, C. (2018). Lean Design Strategy of Waste Minimization in Construction Industries. *International Journal of Applied Engineering Research*, *13*(6), 4593–4598. https://doi.org/ISSN 0973-4562

Khanh, H. D., & Kim, S. Y. (2014a). Evaluating Impact of Waste Factors on Project Performance Cost in Vietnam. *Journal of Civil Engineering*, *18*(7), 1923–1933. https://doi.org/10.1007/s12205-014-1219-2

Khanh, H. D., & Kim, S. Y. (2014b). Identifying Causes for Waste Factors in High-Rise Building Projects : A Survey in Vietnam. *Journal of Civil Engineering*, *18*, 865–874. https://doi.org/10.1007/s12205-014-1327-z

Kim, B. D., & Park, H. (2006). Innovative Construction Management Method : Assessment of Lean Construction Implementation. *KSCE Journal of Civil Engineering*, *10*(6), 381–388.

Kulatunga, U., Amaratunga, D., Haigh, R., & Rameezdeen, R. D. (2005). Sources of construction material wastage in Sri Lankan sites. *2nd Scottish Conference for the Postgraduate Researchers of the Built and Natural Environment, 16th - 17th November*, 601–610.

Lee, C. F., Abdul Rahman, I., Asmi, A., Nagapan, S., & Khalid, K. I. (2013). Classification and quantification of construction waste at housing project site. *International Journal of Zero Waste Generation*, *1*(1), 1–4. http://www.zwgm.org/index.php/zerowastejournal/article/view/4

Li, J., Ding, Z., Mi, X., & Wang, J. (2013). A model for estimating construction waste generation index for building project in China. *Resources, Conservation and Recycling*, *74*, 20–26. https://doi.org/10.1016/j.resconrec.2013.02.015

Lu, W., & Yuan, H. (2011). A framework for understanding waste management studies in construction. *Waste Management*, *31*(6), 1252–1260. https://doi.org/10.1016/j.wasman.2011.01.018

Marzouk, M. M., Bakry, I., & El-said, M. (2012). APPLICATION OF LEAN PRINCIPLES TO DESIGN. *International Journal of Construction Supply Chain Management*, *1*, 43–

55. https://doi.org/10.14424/ijcscm101011-43-55

Misron, N. F., Khoiry, M. A., & Hamzah, N. (2018). A Framework of Efficient Material Storage Management on Congested Construction Site. *ICCEE*, 1–14. https://doi.org/10.1051/e3sconf/20186503005

More, V. D., Charhate, S., & Sinha, M. (2016). Lean Construction Techniques in Indian Construction Industry : Some Analysis. *International Journal of Civil Engineering Research*, *7*(1), 59–65.

Nagapan, S., Abdul Rahman, I., & Asmi, A. (2012). Factors Contributing to Physical and Non-Physical Waste Generation in Construction Industry. *International Journal of Advances in Applied Sciences*, *1*(1), 1–10. https://doi.org/10.11591/ijaas.v1i1.476

Nagapan, S., Rahman, I. A., & Asmi. (2011). A Review of Construction Waste Cause Factors. *Conference of Real Estate: Sustainable Growth Managing Challenges, Johor Bahru, Malaysia*. http://eprints.uthm.edu.my/2665/

Nagapan, S., Rahman, I. A., Asmi, A., & Adnan, N. F. (2013). Study of site's construction waste in Batu Pahat, Johor. *Procedia Engineering*, *53*, 99–103. https://doi.org/10.1016/j.proeng.2013.02.015

Nagapan, S., Rahman, I. A., Azis, A. A. A., Memon, A. H., & Zin, R. M. (2012). Identifying Causes of Construction Waste – Case of Central Region of Peninsula Malaysia. *International Journal of Integrated Engineering, Issue on Civil and Environmental Engineering*, *4*(2), 22–28.

Nahmens, I. and L. H. ikum. (2009). An empirical examination of the relationship between lean construction and safety in the industrialized housing industry. *Lean Construction Journal*, 1–12.

Nazech, E. M., Zaldi, D., & Trigunarsyah, B. (2008). Identification of construction waste in road & highway construction projects. *EASEC-11 - Eleventh East Asia-Pacific Conference on Structural Engineering and Construction*.

Nikakhtar, A., Hosseini, A. A., Wong, K. Y., & Zavichi, A. (2015). Application of lean construction principles to reduce construction process waste using computer simulation: A case study. *International Journal of Services and Operations Management*, *20*(4), 461–480. https://doi.org/10.1504/IJSOM.2015.068528

O.Salem, M. Luegring, J. Solomon, A. G. (2015). Site implementation and assessment of lean construction techniques Site Implementation and Assessment of Lean Construction Techniques. *Lean Construction Journal*, *2*(1555–1369).

Ogunbiyi, O., Oladapo, A., & Goulding, J. (2014). An empirical study of the impact of lean construction techniques on sustainable construction in the UK. *Construction Innovation, 14*(1), 88–107. https://doi.org/10.1108/CI-08-2012-0045

OSHA. (2001). Materials handling and storage. In *Quarry Management* (Vol. 28, Issue 11, p. 23). https://doi.org/10.1201/9780429293054-28

Osmani, M. (2012). Construction Waste Minimization in the UK: Current Pressures for Change and Approaches. *Procedia - Social and Behavioral Sciences*, *40*, 37–40. https://doi.org/10.1016/j.sbspro.2012.03.158

Osmani, M., Glass, J., & Price, A. D. F. (2008). Architects' perspectives on construction waste reduction by design. *Waste Management*, *28*(7), 1147–1158. https://doi.org/10.1016/j.wasman.2007.05.011

Palaneeswaran, E. (2006). Reducing Rework to Enhance Project. *Proceedings of the One Day Seminar on Recent Developments in Project Management*, 1–10.

Pires, A., & Martinho, G. (2019). Waste hierarchy index for circular economy in waste management. *Waste Management*, *95*, 298–305. https://doi.org/10.1016/j.wasman.2019.06.014

S. Macozoma, D. (2002). Construction Site Waste Management and Minimisation. *International Report for International Council for Research and Innovation in Building and Construction (CIB)*.

Saadi, N., Ismail, Z., & Alias, Z. (2016). A review of construction waste management and initiatives in malaysia. *Journal of Sustainability Science and Management*, *11*(2), 101–114.

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Science*, *1*(1), 83–98.

Saaty, T. L., & Varga, L. G. (2001). *Models, Methods, Concepts Sc Applications of the Analytic Hierarchy Process* (1st ed.). Springer Science+Business Media, LLC.

Sahlu, A. (2017). *Studying construction site wastes based on lean thinking on selected Addis Ababa building construction sites: A case study*. Addis Ababa University.

Salem, O., Pirzadeh, S., Sudipta, G., & Abdel-Rahim, A. (2014). Reducing environmental, economic, and social impact of work-zones by implementing lean construction techniques. *Sustainability, Green and Lean Proceedings IGLC-22*, *1*(315), 145–155.

Sarhan, J. G., Xia, B., Fawzia, S., & Karim, A. (2017). Lean Construction Implementation in the Saudi Arabian Construction Industry. *Construction Economics and Building*, *17*(1), 46–69.

Selam, Y. (2016). *Experience and Prospects of private Residential Real Estate Development in alleviating housing problems in Addis Ababa*.

Seyoum, A. (2015). *Managing and minimizing waste of construction materials on selected public building projects in Addis Ababa* (Issue April). Addis Ababa University.

Sharareh Pirzadeh, S. G. and A. A.-R. O. S. (2014). Implementing lean construction: A practice perspective. *Proceedings IGLC-22*, 3–14.

Simpeh, E. (2012). *An analysis of the causes and impact of rework in construction projects* (Issue June) [Cape Peninsula University]. http://digitalknowledge.cput.ac.za/jspui/handle/11189/1054

Solís-guzmán, J., Marrero, M., Montes-delgado, M. V., & Ramírez-de-arellano, A. (2009). A Spanish model for quantification and management of construction waste. *Waste Management*, *29*(9), 2542–2548. https://doi.org/10.1016/j.wasman.2009.05.009

Subramani, T., Nair, V. B., David, A., Ghouse, B. M., & Kumar, N. S. (2017). A Study Of Inventory Management System In Construction Industry. *International Journal of Application or Innovation in Engineering & Management (IJAIEM)*, *6*(5), 304–311. www.ijaiem.org

Taherdoost, H. (2020). Decision Making Using the Analytic Hierarchy Process (AHP); A Step by Step Approach. *International Journal of Economics and Management Systems*, *2*(2367–8925).

Teferi, E. (2017). *Assessment of construction waste management and disposal strategies. The case of gelan condomminium construction project site*. Addis Ababa science and technology university.

Temiz, I., & Calis, G. (2017). Selection of Construction Equipment by Using Multi-criteria Decision Making Methods. *Procedia Engineering*, *196*(June), 286–293. https://doi.org/10.1016/j.proeng.2017.07.201

Tezel, A., Koskela, L., & Aziz, Z. (2018). Current condition and future directions for lean construction in highways projects: A small and medium-sized enterprises (SMEs) perspective. *International Journal of Project Management*, *36*(2), 267–286. https://doi.org/10.1016/j.ijproman.2017.10.004

Tommelein, I. D. (2006). *‘ Poka Yoke ’ or quality by mistake proofing design and construction system*. University of California.

Trond Bølviken and Lauri Koskela. (2016). Why hasn’t waste reduction conquered construction? *24th Annual Conference of the International Group for Lean Construction*.

Wahi, N., Joseph, C., Tawie, R., & Ikau, R. (2016). Critical Review on Construction Waste Control Practices: Legislative and Waste Management Perspective. *Procedia - Social and Behavioral Sciences*, *224*(August 2015), 276–283. https://doi.org/10.1016/j.sbspro.2016.05.460

Xing, W., Li, J., Qian, L., Tam, V. W. Y., & Sikora, K. S. (2021). Implementing lean construction techniques and management methods in Chinese projects : A case study in Suzhou , China. *Journal of Cleaner Production*, *286*, 124944. https://doi.org/10.1016/j.jclepro.2020.124944

Zeb, A., Khan, D., Sajid, M., & Khattak, S. B. (2017). Inventory Analysis of Construction Industry. *Proceedings of The First International Conference on Industrial Engineering and Management Applications*, *July*, 68–74.

Zelele, T., & Zakaria, D. (2016). The Future of Lean Construction in Ethiopian Construction Industry. *International Journal of Engineering Research*, *5*(02), 107–113.

Appendix

Appendix A

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF CIVIL ENGINEERING AND ARCHITECTURE

CONSTRUCTION ENGINEERING AND MANAGEMENT

Questionnaire survey for thesis paper on

Analytical hierarchy process for the implementation of lean techniques on waste reduction in private residential real estate companies in Addis Ababa

This research survey is designed to fulfill an academic requirement for MSc program in Construction Engineering and Management at the Adama science and technology university. Those who involve in the construction of private residential real estate projects in Addis Ababa are kindly requested to contribute to this research work.

The result of this survey is intended to serve only for academic purpose and will be treated with strict confidentiality. The name of institutions participated will be recorded confidentially. Thank you in advance for your willingness to fill the questionnaires and returning them back on time. Your open response is highly appreciated.

Fitsum Ayfokru

0922470512

Advisor- Bahiru Beweket (PhD)

Advisor signature ……………….

General Information

1. Name of the organization?

___

2. Respondents position in the organization.

___

3. Level of education of the respondent

___

4. Relevant working experience

☐ 1-5 years ☐ 11-20 years

☐ 6- 10 years ☐ more than 20 years

Survey Questions

Objective of the study

The general objective of this thesis is to develop a decision aiding model for the implementation of lean techniques to reduce construction waste in Addis Ababa private residential real estate projects.

Method

Conduct a pair-wise computation to identify the weight of several criteria as a source of construction waste and to calculate an overall score of the criteria using the Analytic Hierarchy Process (AHP). AHP is a decision-aiding method which aims at quantifying relative priorities for a given set of alternatives on a ratio scale, based on the judgment of the Decision-Maker.

Instruction

The source listed on the survey table are commonly mentioned sources of wastes in construction. The respondent is required to compare these criteria according to their importance.

Example

If you think poor material handling and management is a major source of waste when it's compared to excess inventory, you can mark the numbers on the left according to its importance. If it is extremely important source of waste, you can circle on number 9, which represents extreme importance just like the table below.

Or if you think excess inventory is moderately, strictly, very strictly or extremely important when it's compared to the other you can circle on 3,5,7 or 9 respectively from the right side. Or if they have equal importance, you can circle on 1 at the middle.

No	Criteria	*Extremely important*	*Very strictly important*	*Strictly important*	*Moderately important*	*Equally important*	*Moderately important*	*Strictly important*	*Very strictly important*	*Extremely important*	Criteria
1	Poor material handling and management	9	7	5	3	1	3	5	7	9	Excess Inventory

Scale	Ranking	Explanation
1	Equally important	Both criteria contribute equally
3	Moderately important	Moderate preference is given to one criteria over the other
5	Strictly important	Strict preference is given to one criteria over the other
7	Very strictly important	Very strict preference is given to one criteria over the other
9	Extremely	Highest preference is given to one criteria over the other

No	**Criteria**	***Extremely important***	***Very strictly important***	***Strictly important***	***Moderately important***	***Equally important***	***Moderately important***	***Strictly important***	***Very strictly important***	***Extremely important***	**Criteria**
1	Poor material handling and management	9	7	5	3	1	3	5	7	9	Excess Inventory
2	Poor material handling and management	9	7	5	3	1	3	5	7	9	Poor site management
3	Poor material handling and management	9	7	5	3	1	3	5	7	9	Frequent change in design
4	Poor material handling and management	9	7	5	3	1	3	5	7	9	Poor planning
5	Poor material handling and management	9	7	5	3	1	3	5	7	9	Rework
6	Poor material handling and management	9	7	5	3	1	3	5	7	9	Overproduction
7	Poor material handling and management	9	7	5	3	1	3	5	7	9	Delay (waiting)
8	Excess Inventory	9	7	5	3	1	3	5	7	9	Poor site management

9	Excess Inventory	9	7	5	3	1	3	5	7	9	Frequent change in design
10	Excess Inventory	9	7	5	3	1	3	5	7	9	Poor planning
11	Excess Inventory	9	7	5	3	1	3	5	7	9	Rework
12	Excess Inventory	9	7	5	3	1	3	5	7	9	Overproduction
13	Excess Inventory	9	7	5	3	1	3	5	7	9	Delay (waiting)
14	Poor site management	9	7	5	3	1	3	5	7	9	Frequent change in design
15	Poor site management	9	7	5	3	1	3	5	7	9	Poor planning
16	Poor site management	9	7	5	3	1	3	5	7	9	Rework
17	Poor site management	9	7	5	3	1	3	5	7	9	Overproduction
18	Poor site management	9	7	5	3	1	3	5	7	9	Delay (waiting)
19	Frequent change in design	9	7	5	3	1	3	5	7	9	Poor planning
20	Frequent change in design	9	7	5	3	1	3	5	7	9	Rework
21	Frequent change in design	9	7	5	3	1	3	5	7	9	Overproduction
22	Frequent change in design	9	7	5	3	1	3	5	7	9	Delay (waiting)
23	Poor planning	9	7	5	3	1	3	5	7	9	Rework
24	Poor planning	9	7	5	3	1	3	5	7	9	Overproduction
25	Poor planning	9	7	5	3	1	3	5	7	9	Delay (waiting)
26	Rework	9	7	5	3	1	3	5	7	9	Overproduction

27	Rework	9	7	5	3	1	3	5	7	9	Delay (waiting)
28	Over production	9	7	5	3	1	3	5	7	9	Delay (waiting)

Instruction 2- The techniques listed down on the table below are lean techniques which can be implemented to manage and reduce the common sources of waste in construction. For each criteria, there are 2 techniques in order to be compared with the other. Please Refer the short definition of the techniques in order to determine the applicable one.

Techniques	**Definition**
Just in time (JIT)	JIT Delivery, or just in time in construction, is an inventory management approach designed to eliminate waste by "receiving goods only as they [are needed] for production processes."
Plan-Do-Check-Act (PDCA)	is an iterative four-step management method used for the control and continuous improvement of processes.
Concurrent engineering	Concurrent engineering eliminates a lot of that wait time by overlapping and integrating tasks. By one estimate, this approach can reduce the total design effort by as much as 30%.
Computer aided design	Computer-aided design (CAD) is the use of computers (or workstations) to aid in the creation, modification, analysis, or optimization of a design. It helps cut down the time factor and helps to **reduce** the possibility of **error** to bare minimum amount.
Last planner system (LPS)	The Last Planner System (LPS) is a workflow method developed by the Lean Construction Institute to increase worker productivity and accountability through tight scheduling and detailed group planning.
Process Mapping	A process map visually shows the steps of a work activity and the people who are involved in carrying out each step. process mapping is the task of defining what exactly a activity does, who is responsible, and what is the standard by which the success of a business process can be judged.
The 5s process	The 5s process described as "sort", "set in order", "shine", "standardize" and "sustain". The list describes how to organize a work space for efficiency and effectiveness by identifying and storing the items used, maintaining the area and items, and sustaining the new order.
Inventory optimization	inventory optimization is the practice of having the right inventory to meet your target service levels while tying up a minimum amount of capital in inventory.
Error Proofing (Poka-yoke)	Poka-yoke is a Japanese word that can be defined as “error-proofing”. Shingo introduced Poka-yoke devices as new elements to avoid defective parts from flowing through the process. It is a lean tool that engages all forms of activities and devices that could help avoid an error from happening.

For the above compared sources of waste, related lean techniques are listed down below to be compared. Please mark the more appropriate technique to implement on poor material handling and storage

1	Just in time	9	7	5	3	1	3	5	7	9	The 5s process

Please mark the appropriate technique to implement on excess inventory

2	Proper recording of data	9	7	5	3	1	3	5	7	9	Inventory optimization

Please mark the appropriate technique to implement on poor site management

3	Daily huddle meeting	9	7	5	3	1	3	5	7	9	Plan-Do-Check Act (PDCA)

Please mark the appropriate technique to implement on frequent change in design

4	Understanding client requirement	9	7	5	3	1	3	5	7	9	Computer aided design

Please mark the appropriate technique to implement on poor planning

5	Last planner system	9	7	5	3	1	3	5	7	9	Process mapping

Please mark the appropriate technique to implement on rework

6	Proper monitoring	9	7	5	3	1	3	5	7	9	Error proofing

Please mark the appropriate technique to implement on over production

7	Use accurate information	9	7	5	3	1	3	5	7	9	Have a clear schedule and work plan

Please mark the appropriate technique to implement on delay (waiting)

8	Just in time	9	7	5	3	1	3	5	7	9	Concurrent engineering

Appendix B

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF CIVIL ENGINEERING AND ARCHITECTURE

CONSTRUCTION ENGINEERING AND MANAGEMENT

Interview questions for thesis paper on

Analytical hierarchy process for the implementation of lean techniques on waste reduction in private residential real estate companies in Addis Ababa

These interview questions are designed to fulfill an academic requirement for MSc program in Construction Engineering and Management at the Adama science and technology university. Those who involve in the construction of private residential real estate projects in Addis Ababa are kindly requested to contribute to this research work.

Fitsum Ayfokru

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Advisor- Bahiru Beweket (PhD)

Advisor signature ……………….

Interview questions

1. Are you familiar with lean related concepts?
2. Current approach practiced in order to decrease waste in construction?
3. If any, explain to what extent you decreased construction waste in your project?
4. What is the strength and weakness of the techniques that you used to reduce waste?
5. Factors affecting the effectiveness of current technique used for waste reduction?

Appendix C

Data analysis result

implementation of lean techniques								
Pairwise Comparison Matrix								
	poor material ha	**excess inventor**	**poor site manag**	**frequent chang**	**poor planning**	**rework**	**overproduction**	**delay(waiting)**
poor material handling and ma	1	7	3	3	3	5	5	3
excess inventory	1/7	1	1/5	1/5	1/5	1/3	1/3	1/5
poor site management	1/3	5	1	1	3	3	5	1
frequent change in order	1/3	5	1	1	3	3	3	1
poor planning	1/3	5	1/3	1/3	1	3	3	1
rework	1/5	3	1/3	1/3	1/3	1	1	1/3
overproduction	1/5	3	1/5	1/3	1/3	1	1	1
delay(waiting)	1/3	5	1	1	1	3	1	1

Column totals	2.8762	34.0000	7.0667	7.2000	11.8667	19.3333	19.3333	8.5333
	Cw (Normalised)							
1	0.347682119	0.205882353	0.424528302	0.416666667	0.252808989	0.25862069	0.25862069	0.3515625
2	0.049668874	0.029411765	0.028301887	0.027777778	0.016853933	0.017241379	0.017241379	0.0234375
3	0.11589404	0.147058824	0.141509434	0.138888889	0.252808989	0.155172414	0.25862069	0.1171875
4	0.11589404	0.147058824	0.141509434	0.138888889	0.252808989	0.155172414	0.155172414	0.1171875
5	0.11589404	0.147058824	0.047169811	0.046296296	0.084269663	0.155172414	0.155172414	0.1171875
6	0.069536424	0.088235294	0.047169811	0.046296296	0.028089888	0.051724138	0.051724138	0.0390625
7	0.069536424	0.088235294	0.028301887	0.046296296	0.028089888	0.051724138	0.051724138	0.1171875
8	0.11589404	0.147058824	0.141509434	0.138888889	0.084269663	0.155172414	0.051724138	0.1171875

AHP-1	CA	Lambda	CI	CI/RI
0.315	0.9047	8.555651917	0.0793788	0.05629705
0.026	0.89222			
0.166	1.17231			
0.153	1.10132			
0.109	1.28786			
0.053	1.01944			
0.060	1.16265			
0.119	1.01515			

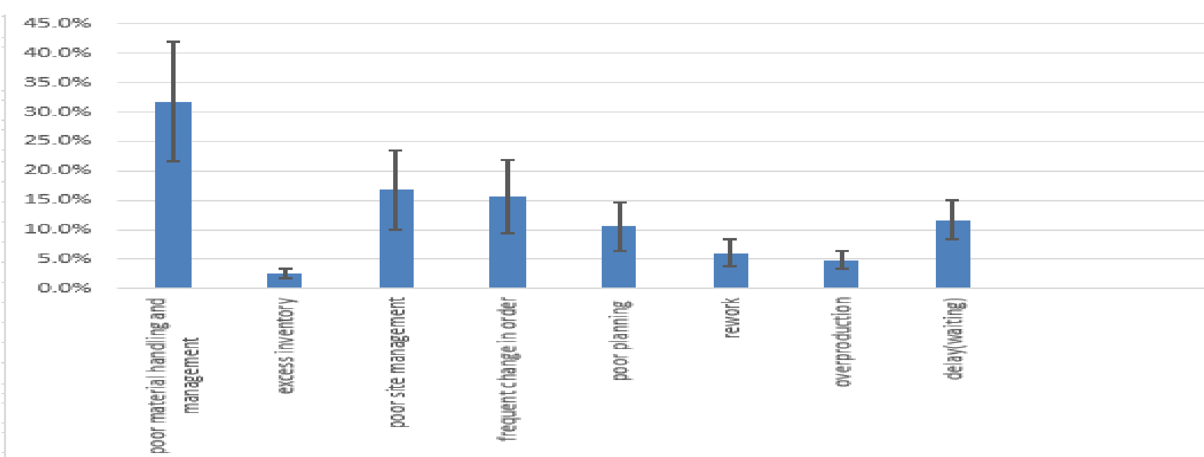
Randomness Index,RI		
3	0.58	1.41
4	0.9	
5	1.12	
6	1.24	
7	1.32	
8	1.41	

Matrix		poor material handling and mananement	excess inventory	poor site management	frequent change in ord	poor planning	rework	overproductic	delay(waiting)	0	0	**normalized principal Eigenvector**
		1	2	3	4	5	6	7	8	9	10	
poor material	1	1	7	3	3	3	5	5	3	-	-	31.81%
excess inventory	2	1/7	1	1/5	1/5	1/5	1/3	1/3	1/5	-	-	2.57%
poor site management	3	1/3	5	1	1	3	3	5	1	-	-	16.79%
frequent change in	4	1/3	5	1	1	3	3	3	1	-	-	15.64%
poor planning	5	1/3	5	1/3	1/3	1	3	3	1	-	-	10.58%
rework	6	1/5	3	1/3	1/3	1/3	1	1	1	-	-	6.05%
overproduction	7	1/5	3	1/5	1/3	1/3	1	1	1/3	-	-	4.86%
delay(waiting)	8	1/3	5	1	1	1	1	3	1	-	-	11.71%

AHP	Analytic Hierarchy Process (10x10 Matrix)										8	
	Power Method (Dominant Eigenvalue)											
											Iterations	
	1	2	3	4	5	6	7	8	9	10	0	20
1	1.00	7.00	3.00	3.00	3.00	5.00	5.00	3.00	-	-	3.00	8.44
2	0.14	1.00	0.20	0.20	0.20	0.33	0.33	0.20	-	-	0.26	0.68
3	0.33	5.00	1.00	1.00	3.00	3.00	5.00	1.00	-	-	1.93	4.46
4	0.33	5.00	1.00	1.00	3.00	3.00	3.00	1.00	-	-	1.73	4.15
5	0.33	5.00	0.33	0.33	1.00	3.00	3.00	1.00	-	-	1.40	2.81
6	0.20	3.00	0.33	0.33	0.33	1.00	1.00	1.00	-	-	0.72	1.60
7	0.20	3.00	0.20	0.33	0.33	1.00	1.00	0.33	-	-	0.64	1.29
8	0.33	5.00	1.00	1.00	1.00	1.00	3.00	1.00	-	-	1.33	3.11
9	-	-	-	-	-	-	-	-	1.00	-	0.10	0.00
10	-	-	-	-	-	-	-	-	-	1.00	0.10	0.00
Sum (col)	2.8762	34	7.0667	7.2	11.867	17.333	21.333	8.5333	0	0	**Scaling**	

												Normalization	
	0.35	0.21	0.42	0.42	0.25	0.29	0.23	0.35	-	-		0.2674	0.318105
	0.05	0.03	0.03	0.03	0.02	0.02	0.02	0.02	-	-		0.0233	0.025703
	0.12	0.15	0.14	0.14	0.25	0.17	0.23	0.12	-	-		0.1723	0.167946
	0.12	0.15	0.14	0.14	0.25	0.17	0.14	0.12	-	-		0.1545	0.15644
	0.12	0.15	0.05	0.05	0.08	0.17	0.14	0.12	-	-		0.1248	0.105753
	0.07	0.09	0.05	0.05	0.03	0.06	0.05	0.12	-	-		0.0642	0.06045
	0.07	0.09	0.03	0.05	0.03	0.06	0.05	0.04	-	-		0.0570	0.048551
	0.12	0.15	0.14	0.14	0.08	0.06	0.14	0.12	-	-		0.1188	0.117052
	-	-	-	-	-	-	-	-	-	-		0.0089	2.59E-21
	-	-	-	-	-	-	-	-	-	-		0.0089	2.59E-21
												Eigenvalue:	8.439357
Check	4E-09										err:	1.0E-08	5.17E-30
	8.4394										Iterations:	5.0E+00	1.93E-30
		8.4394									check:	3.8E-09	4.63E-32
			8.4394										1.77E-30
I*I				8.4394									8.91E-31
					8.4394								2.1E-31
						8.4394							1.35E-31
							8.4394						1.56E-32
								8.4394					1.73E-31
									8.4394				3.71E-40
										8.4394			3.71E-40

	-7.439	7.00	3.00	3.00	3.00	5.00	5.00	3.00	-	-
	0.14	-7.439	0.20	0.20	0.20	0.33	0.33	0.20	-	-
	0.33	5.00	-7.439	1.00	3.00	3.00	5.00	1.00	-	-
A-I*I	0.33	5.00	1.00	-7.44	3.00	3.00	3.00	1.00	-	-
	0.33	5.00	0.33	0.33	-7.44	3.00	3.00	1.00	-	-
	0.20	3.00	0.33	0.33	0.33	-7.44	1.00	1.00	-	-
	0.20	3.00	0.20	0.33	0.33	1.00	-7.44	0.33	-	-
	0.33	5.00	1.00	1.00	1.00	1.00	3.00	-7.439	-	-
	-	-	-	-	-	-	-	-	-7.439	-
	-	-	-	-	-	-	-	-	-	-7.439
(A-I*I)x	6E-14	6E-14	6E-14	6E-14	6E-14	6E-14	6E-14	6E-14	6E-14	6E-14



Comparison for lean techniques

Poor material handling and storage

Matrix		1 Just in time	2 The 5s process	3 0	4 0	5 0	6 0	7 0	8 0	9 0	10 0	normalized principal Eigenvector
Just in time	1	1	1 2/5	-	-	-	-	-	-	-	-	58.33%
The 5s process	2	5/7	1	-	-	-	-	-	-	-	-	41.67%

Excess inventory

Matrix		1 Proper recording of data	2 Inventory optimization	3 0	4 0	5 0	6 0	7 0	8 0	9 0	10 0	normalized principal Eigenvector
Proper recording of	1	1	1 1/5	-	-	-	-	-	-	-	-	54.55%
Inventory optimization	2	5/6	1	-	-	-	-	-	-	-	-	45.45%

Poor site management

Matrix		1 Dailly huddle meeting	2 Plan do check act	3 0	4 0	5 0	6 0	7 0	8 0	9 0	10 0	normalized principal Eigenvector
Dailly huddle meeting	1	1	1 1/2	-	-	-	-	-	-	-	-	60.00%
Plan do check act	2	2/3	1	-	-	-	-	-	-	-	-	40.00%

Frequent change in design

Matrix		Error proofing	Computer aided design	0	0	0	0	0	0	0	0	normalized principal Eigenvector
		1	2	3	4	5	6	7	8	9	10	
Error proofing	1	1	3/4	-	-	-	-	-	-	-	-	43.48%
Computer aided design	2	1 1/3	1	-	-	-	-	-	-	-	-	56.52%

Poor planning

Matrix		last planner system	root cause analysis	0	0	0	0	0	0	0	0	normalized principal Eigenvector
		1	2	3	4	5	6	7	8	9	10	
last planner system	1	1	1 1/3	-	-	-	-	-	-	-	-	56.52%
root cause analysis	2	3/4	1	-	-	-	-	-	-	-	-	43.48%

Rework

Matrix		proper monitoring	error proofing	0	0	0	0	0	0	0	0	normalized principal Eigenvector
		1	2	3	4	5	6	7	8	9	10	
proper monitoring	1	1	6	-	-	-	-	-	-	-	-	85.71%
error proofing	2	1/6	1	-	-	-	-	-	-	-	-	14.29%

Overproduction

Matrix		use accurate information	have a clear schedule and workplan	0	0	0	0	0	0	0	0	normalized principal Eigenvector
		1	2	3	4	5	6	7	8	9	10	
use accurate	1	1	1 1/9	-	-	-	-	-	-	-	-	52.38%
have a clear schedule	2	1	1	-	-	-	-	-	-	-	-	47.62%

Delay

Matrix		just in time	concurrent engineering	0	0	0	0	0	0	0	0		normalized principal Eigenvector
		1	2	3	4	5	6	7	8	9	10		
just in time	1	1	4/9	-	-	-	-	-	-	-	-		31.25%
concurrent engineering	2	2 1/5	1	-	-	-	-	-	-	-	-		68.75%