WASTE CONTROL IN CONSTRUCTION PROJECTS WITHIN THE GAUTENG PROVINCE

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Submitted by: Phuluphedziso Rambuwani

Student Number: 715099

Supervisor: Prof. Anne Fitchett

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DECLARATION

I declare that this research report is my own unaided work. It is being submitted for the MSc. (Eng.) in Civil Engineering to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

Name: PHULUPHEDZISO RAMBUWANI

Student Number: 715099

Date: 05 AUGUST 2021

Signature: Rambuwani P. ___________________________________

ABSTRACT

The motivation of the study is to determine how construction managers control waste on site in Gauteng province. The aim of the study is to establish a better understanding of how to reduce or eliminate construction waste from building construction projects through the application of lean techniques.

The objectives are to identify the causes of construction waste, to determine sustainable methods used during the construction process, to allow construction management to play a part in reducing waste generation, to identify the main types and volumes of construction material waste, and to review this from a lean perspective. The study uses an inductive approach through structured interviews of ten construction managers as a means of data collection. Data analysis is executed by using Microsoft Excel coding to arrange the data into themes and then saved to Microsoft Word.

The findings of the study show that concrete and bricks are the most common material waste generated on site. Material handling, design change, poor supervision, poor management, and inadequate planning are the main causes of physical waste. Adequate material handling, effective management, adequate planning and proper supervision, reuse and recycle of waste are the main methods used to reduce waste. The most common types of lean waste are overproduction and defects. Lean tools most often used are just-in-time and value stream mapping. The challenges faced when implementing lean thinking are cultural diversity and lack of lean awareness. The findings show that few construction companies are implementing a lean approach to waste reduction or elimination on sites. It is therefore recommended that construction managers should be educated about implementing lean principles for waste reduction.

Key words: Construction, Lean Construction, Elimination, Minimisation, Material, Physical and Non-Physical Waste, Lean Tools, Waste Management Plan, Cost and Time

DEDICATION

This research report is dedicated to God Almighty, my creator, my pillar of strength, my source of inspiration, understanding and insight. He has been the source of my strength in this study. I also commit the work to my parents, who encouraged me to continue and whose support ensured that I could give everything I wanted to complete what I began.

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Last but not least, I would like to thank my family; my parents Balanganani Rambuwani and Azwitamisi Rambuwani, my brother Phathutshedzo Rambuwani and my sister Rolivhuwa Rambuwani, also including my partner Mufulufheli Maphasha for the support, prayers, and words of encouragement throughout this journey.

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ABBREVIATIONS AND ACRONYMS

C&D – Construction and Demolition

CIDB – Construction Industry Development Board

DEA – Department of Environmental Affairs

EMP - Environmental Management Program

GB – General Building

GDP – Gross Domestic Product

JIT – Just-In-Time

MLP – Materials Logistics Program

MRP – Material Requirement Planning

PC – Practical Completion

SCM - Supply Chain Management

STATSA – Statistics South Africa

TPS – Toyota Production System

UAE – United Arab Emerates

UK – United Kingdom

USA – United States of America

VSM – Value Stream Mapping

WIP – Work In Progress

WMP – Waste Management Plan

CHAPTER 1: INTRODUCTION

1.1. Background of the Study

The construction industry contributes significantly to any country's economy through infrastructure development. The planning, construction, and maintenance of infrastructure create jobs and growth in the country's Gross Domestic Product (GDP). The construction industry has created 8% of total formal and 17% of total informal employment since 2008 in South Africa (CIDB, 2017). Gauteng province was South Africa's most significant GDP contributor in 2016 at 35% (DEA, 2018). As waste generation is related to the development of products and services, the provinces with higher GDP are likely to put greater strain on waste generation and treatment facilities than those with lower GDP levels (DEA, 2018). According to Nagapan et al. (2012), the rise in the standard of living and the rise in the human population generates a higher demand for infrastructure, which causes the construction industry to expand rapidly. This increase has contributed to the increase in generation of construction waste and waste has been identified as one of the core problems in the industry across the world (Ding et al., 2018).

According to Nagapan et al. (2012), construction waste can be divided into two types, namely, physical waste and non-physical waste. Nagapan et al. (2012) describe physical waste as waste arising from building and renovation operations, such as civil and construction, demolition and other construction related activities. Non-physical waste is considered as non-value-added activities such as labour error, overrun costs, project time delay, overproduction, and poor material handling (Nagapan et al., 2012).

Furthermore, methane production from anaerobic material depletion can be caused by enormous amounts of non-biodegradable waste from building projects that are deposited and buried in landfills, along with various other pollutants, creating air, water, and soil contamination (Yuan et al., 2013). It is imperative that construction waste from the site be controlled and managed effectively to reduce negative impacts on the environment. The comparison between waste generated in households and construction shows that construction produces a huge amount of waste which is four times the household waste and more than 50% of construction waste gets dumped in landfills (Nagapan et al., 2011). Moreover, almost 26% of the landfill is occupied with construction waste (Nagapan et al., 2012).

It is reported that in 2017, South Africa produced 42 million tons of general waste (DEA, 2018). The highest contributor to the overall volume of general waste was "other" (35%), followed by organic waste (16%), construction and demolition waste (13%), scrap metal (8%) and commercial and industrial waste (7%) (DEA, 2018). According to South African State of Waste Report (2018), the construction and demolition waste generated was 5.3 million tons, of which 305 761 tons were recycled or recovered, and 5.1 million tons were disposed of on landfill sites.

There are various factors that cause waste generation in the construction industry. Therefore, the causation of waste needs to be identified to avoid waste generation. Nowadays, there is an increase in project complexity to an extent that it becomes a challenge for construction managers to carry out effective waste management, leading to the increase in generation of the construction waste on-site. Construction waste can arise through the decisions taken from the inception phase to the implementation phase. Building waste can arise if not managed well by the construction manager and the project team. The causes of the waste may be attributed to project design mistakes, poor material handling, workers' mistakes, poor management, bad site conditions, procurement practices and external forces (Nagapan et al., 2011).

The lean philosophy is derived from the Toyota Production System (TPS) which aims to improve manufacturing productivity (Koskela et al., 2013). Lean thinking has therefore been adapted in the construction sector: one of the key purposes of lean application is to reduce construction waste. The following are the waste types determined in lean thinking: overproduction, inventory, motion, transportation, overprocessing, waiting and underutilization (Howell and Ballard, 1998). Many of the lean tools were developed as techniques which could be used in the building sector to minimise waste. Various studies show that poka-yoke (error proofing), 5S processes, value stream mapping, and just-in-time (Dos Santos and Powell, 1999; Aziz and Hazef, 2013) have been widely used for waste reduction in construction. According to Ogunbiyi, (2014), Salem et al. (2016), and Ingle and Waghmare (2015), lean construction has advantages on environmental, economic, and social aspects. The application of the lean philosophy would help to reduce non-value-added construction project activities and also increase the efficiency of the project. This study investigates the application of lean construction principles as a means of minimising waste on construction sites.

1.2. Problem Statement and Research Justification

The construction industry is one of the most significant sectors for the growth of the South African infrastructure and economy. South Africa is facing demand for infrastructure caused by population growth, economic growth, income, and level of urbanisation (DEA, 2018). According to Statistics South Africa (2019), Gauteng has the highest population in South Africa, with about 15.2 million people residing in the Province. Gauteng has experienced the greatest population growth in the past 5 years by 674 000 people and per year the population increases by 134 000 people (StatsSA, 2017). The third national baseline analysis estimated that South Africa produced approximately 108 million tons of waste in 2011, of which 98 million tons of waste is disposed of landfill sites (DEA, 2012). Four types of waste comprise the total waste stream: non-recyclable urban waste (35%), construction and demolition (C&D) waste (20%), organic waste (13%) and metals (13%) (DEA, 2018).

Therefore, the demand for infrastructure results in waste being generated in the construction industry in Gauteng province. Poor planning, poor management, frequent design changes, and poor site conditions on the construction project can all increase the volumes of waste associated with a construction project (Nagapan et al., 2012). Poorly controlled waste will have a major effect on public health, the natural environment, and the economy. Most of the construction waste ends up disposed of in landfills causing negative impacts on the environment (DEA, 2018).

Lean construction is a method used to reduce and eliminate waste in construction projects. There are seven types of lean wastes, which are overproduction, inventory, motion, transport, overprocessing, waiting, and underutilization wastes. Most of these wastes are generated during construction by non-value adding practices. According to Roelandt (2008), lean was first introduced in the construction industry in South Africa in 2006. There are still major challenges ahead to sustain the early successes and to expand the application of lean techniques in the South African construction industry (Roelandt, 2008). While several countries have achieved significant advantages by implementing lean construction (LC) principles, the lean approach in South African building industry seems still insufficient (Monyane et al., 2019).

There appears to be a range of technical and cultural constraints to effective lean building in the South African construction Industry. If the lean manufacturing concepts are applied in South African production, it is anticipated that the avoidance of non-essential value adding operations by means of careful monitoring and sound decision-making based on detailed knowledge and processes, resulting in cost savings and productivity increases (Akinradewo et al., 2018). Therefore, this study aims to investigate the extent to which lean construction principles are used to minimise or reduce construction waste in the Gauteng province.

1.3. Research Question, Aim and Objectives

- What can Construction Managers do to minimize the physical construction waste generated at construction sites as well as limit the fraction of construction waste that ends up at landfills?

This study is intended to establish a better understanding of how to reduce or eliminate physical construction waste from building construction projects in the Gauteng province through the application of lean techniques.

The study has the following objectives:

1. To identify the causes of construction waste and methods utilized by construction managers to manage waste generation during the construction process.
2. To determine sustainable methods which can be implemented in waste control through the construction stages and site management measures which can create efficient waste on construction projects.
3. To find out how top management in construction can play a role in the minimization of waste generation.
4. To determine the main types and the volume of construction material waste in building projects in Gauteng province.
5. To determine the main types of construction waste from a lean perspective in the building projects in Gauteng province and recommend lean techniques to improve waste management.

1.4. Scope of the study

The research is delimited in the following ways:

- **Knowledge area of the study:** The study is focused on waste control strategies in the construction sector in the Gauteng province building projects. The aim of the study is to establish a better understanding of how to reduce or eliminate physical construction waste from building construction projects in the Gauteng province through the application of lean techniques.
- **Approach and instrument:** The research approach uses qualitative method. Structured interviews were executed with 10 construction managers.
- **Geographical:** The research was carried out in Gauteng Province in South Africa. Gauteng province consists of three Metropolitan municipalities namely: Tshwane Metropolitan Municipality (Pretoria), Johannesburg Metropolitan Municipality and Ekurhuleni Metropolitan Municipality.
- **Population and sample:** The research population is construction managers monitoring the daily site activities. The ten sites were selected randomly from the Construction Industry Development Board (CIDB) list. The participants of the study have more than 10 years of experience in the construction industry. The sample size was selected to provide enough information on reliability and a degree of validity.
- **Time:** The research data collection was conducted in August 2020.

1.5. Limitations

The limitations of the study are as follows:

1. The study has been conducted in Gauteng province by interviewing construction managers who are currently working on construction projects.
2. The small sample size of ten construction projects were chosen for the study.
3. The credibility of the research results and findings is dependent on the accuracy and reliability of collected data from experienced professionals.

1.6. Research Structure

Chapter 1 Introduction to the study: This chapter presents the context of the subject, aim and research objectives. Therefore, this chapter covers the nature of the study, study design, and research contribution to knowledge.

Chapter 2 Literature Review: In this chapter the following topics are covered, namely: the definition of construction waste, classification of construction waste, construction waste sources, waste control strategies, lean construction theory, impacts of construction waste to the environment, effects of construction waste to cost and time of the project, and previous studies on construction in different countries across the world.

Chapter 3 Research Methodology: The research methodology chapter covers the research strategy, research approach, research method, data collection method and tools, sample selection and participants, data analysis, reliability and validity, and ethical consideration.

Chapter 4 Results: The findings of structured interviews are presented in this chapter. These results are presented in this chapter after interpretation of the findings.

Chapter 5 Discussion and Data Analysis: The results of structured interviews are discussed and analysed in chapter 5. The results were discussed in relation to previous studies as analysed in the Literature Review.

Chapter 6 Conclusion and Recommendations: According to the final results, recommendation and conclusion of the research is discussed in this chapter. In addition, a recommendation is proposed for lean tools implementation in Gauteng province projects. This is according to principles derived from the literature review.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction to Literature Review

Waste has become a major problem in the construction industry worldwide (Nagapan et al., 2011; Nitivattananon and Borongan, 2007; Tam et al., 2007). Due to the high rate of contamination and a huge amount of heterogeneity, building waste becomes difficult to recycle and reuse (Formosa et al., 2002). Some construction waste is recycled and reused, but a large amount of waste is disposed of in landfills (Nagapan et al., 2012). Nevertheless, waste disposed of in landfills continues to adversely affect the environment and pollute the air and land. Construction waste may also lead to cost overrun and subsequent delays that may result in poor performance (Van Wyk, 2014).

The responsibility of the construction manager is to manage the physical process within the built environment, including coordination, supervision, and management of resources (Valence, 2012). The study mainly focuses on how construction managers control waste on-site and factors that cause waste generation that construction managers need to pay attention to, throughout the construction process, to minimize waste generation. An example is that the construction managers need to prepare for waste management in the project to prevent waste generation during the construction process (Udawatta et al., 2015).

Many researchers have studied construction waste. They identify the sources of waste and establish areas in which waste can be mitigated in construction projects (Formosa et al., 2002; Nagapan et al., 2012; Osmani et al., 2008). Researchers have developed models that can be used to minimize the generation of construction waste. Some of the sources of construction waste production are insufficient planning, inadequate material handling, poor coordination, and ineffective resource management (Formoso et al., 2002). Waste control strategies include the implementation of lean theory, efficient coordination and management, and effective planning (Osmani et al., 2008).

The literature review covers concepts of construction waste, waste classification, construction waste sources, the cost and time effect of waste, and waste control strategies, including the lean approach.

2.2. Definition of Construction Waste

Construction waste has been identified in several forms to the degree that construction waste may be classified and recognized. Tam et al. (2007:2) identify building waste as by-products of renovation, construction and demolition on construction sites and civil engineering works such as highways, stormwater, and dams. Construction waste is also defined as any material, matter or thing that is produced as a result of construction work and discontinued, whether processed or stored before abandonment (Yuan et al., 2013:5).

Formosa et al. (2002:317) define waste as a loss of resources, materials, time, labour, equipment, and capital produced by direct or indirect cost operation, but which do not add value to the customer's product. According to the current design philosophy, Inge and Waghmare (2015:20) describe waste in construction as any inefficiency resulting in the usage in greater amounts of equipment, materials, labour, or capital than is thought appropriate for building production.

Nikakhtar et al. (2015:464) state that the concept of lean construction as regards waste can be explained by proposing a wider definition of waste, not only for material waste, but for waste related to inefficiency and the output of the product generated during the building process (such as waiting and transport time). Construction waste can begin at any period of the project development, and its underlying foundations may lie in design choices, the technique for construction or even with the dispositions of individuals (Nagapan et al., 2018).

In this study, construction waste is defined as any activity that results in any output without any added value to the construction project.

2.3. Classification of Construction Waste

Numerous models have been presented to classify the types of construction waste. Waste occurs in various forms, mostly influenced by the type of the industry and the working processes. Thus, some waste can be classified according to its state, namely solid, liquid, or gaseous (Al-Hajj and Hamani, 2011). Some types of waste can be classified according to characteristics such as inert, combustible, biodegradable, hazardous or nuclear.

Al-Hajj and Hamani (2011) further state that waste can be classified according to its origin and its properties such as kind, quantity, and location. The waste from the construction process can be classified in two ways: (a) based on the nature of the processes and, (b) caused by activities of non-value-adding nature (Nikakhtar et al., 2015).

In addition, according to Nagapan et al. (2012), construction waste can be divided into two types: physical waste and non-physical waste, as shown in Figure 2.1. Nagapan et al. (2012) describe physical waste as waste arising from building and renovation operations, such as civil and construction, demolition and other construction related activities. Major physical waste generated from construction activities is identified as material waste such as leftovers of concrete, demolished debris, scrap metal and others (Nagapan et al., 2012). Non-physical waste is considered as non-value-added activities such as labour error, overrun costs, project time delay, overproduction, and poor material handling (Nagapan et al., 2012). Non-physical waste typically occurs during the construction process.

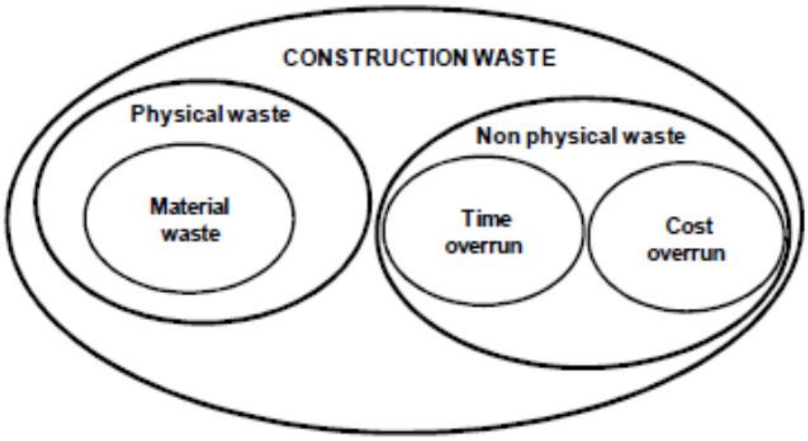

Figure 2.1: Construction waste classification of physical and non-physical waste

Source: Nagapan et al. (2012)

2.4. Construction Waste Sources

Many studies have identified numerous sources of waste in construction projects. There are different factors that cause physical waste and non-physical waste, summarised in Table 2.1. Nagapan et al. (2012), classified seven waste generation categories which are design, procurement, management, handling of materials, site conditions, workers, and external factors.

2.4.1. Design

The following factors can contribute to the generation of construction waste, such as design detailing complexity, construction detail mistakes, vague or inadequate specifications, poor coordination and communication, and late distribution of revised drawings (Osmani et al., 2008). Wahab and Lawal (2011) found that last minute changes in client requirements leads to design variation causing waste and which affect the construction cost. Frequent design changes may also lead to the generation of waste in construction projects (Esa et al., 2017).

2.4.2. Procurement

The procurement during construction plays a role in the waste generated, if wrong items that are not in the specification are ordered, or there is over allowance caused by not being able to purchase small quantities, or supplier errors of delivering wrong materials (Nagapan et al., 2015). Moreover, the project contract may contribute to waste arising from the errors in contract documentation and the use of unsatisfactory contract documents during the construction phase (Nagapan et al., 2018). According to Dosumu et al. (2017), the inadequate time to prepare contract documents, using inexperienced designers to prepare contract documents and incompetence may be reasons for errors in the contract documentation. In addition, frequent variation orders, waiting for replacements, materials that are not in compliance and various estimation methods can also contribute to construction waste generation (Al-Hajj and Hamani, 2011). Furthermore, poor supply chain management, poor quality of materials, purchase of inadequate materials, poor advice from suppliers, and no 'take back' policies by the suppliers are aspects that can generate construction waste.

2.4.3. Management

There is a high possibility for waste to be generated at the construction site when there are inefficient on-site management plans. The poor planning for quantities needed for the project, lack of communication on sharing information on types and size of the required materials, insufficient on-site material control, lack of management and supervision (Osmani et al., 2008) are some of the management problems that lead to waste generation. According to Nagapan et al. (2013), ineffective management such as inappropriate construction methods, poor information quality, resources problems, scarcity of equipment, rework, and lack of knowledge about construction can be factors of waste generation.

The study which focuses on construction efficiency by the National Institute of Standards and Technology in the UK, documents that 25% - 50% of construction waste is related to labour coordination and management, moving, and installing materials (Vilasini et al., 2011). Moreover, Formoso et al. (2002) suggest that management problems in the processes leading up to production are among the most important causes of waste.

2.4.4. Material Handling

Wahab and Lawal (2011) conducted research on the assessment of waste control measures in the construction industry in Nigeria. The work examines the forms, causes, and factors incidental to waste and measures to manage construction waste effectively. The inadequate handling of materials during different phases of construction generates waste and results in related environmental problems. Formoso et al. (2002) in Brazil studied the main causes of construction waste and prevention methods that can be used in waste minimisation. Material waste has been described as a major issue in the construction industry, with significant implications for both the efficiency of the industry and the environmental effects of construction projects. Three processes were evaluated, including masonry walls, timber frames and drywall panels (Formoso et al., 2002).

Formosa et al. (2002) examines the main cause of construction waste based on a model that generally explains the movement of solid waste at construction sites and provides a suggested classification of waste according to its source. The main cause of the waste found in the analysis in the United States of America (USA) was residual scrap resulting from uneconomical cutting of materials such as bricks, blocks, dimensional lumber, and sheet metal panels (Nagapan et al., 2012; Formoso et al., 2002). Material transportation can be another cause of waste, when the materials for construction get damaged during the delivery process (Eze et al., 2017). Additionally, poor site storage space and inappropriate storing methods can lead to damage and deterioration of the materials. Incorrect material handling might also lead to construction waste (Poon and Jaillon, 2009).

2.4.5. Site Conditions

Nagapan et al. (2012) and Al-Hajj and Hamani (2011) argue that poor site conditions, unforeseen ground conditions, leftover materials on site, waste resulting from packaging, congestion of the site, lighting problems, difficulties accessing construction site, and interference of other crews at the site are factors that can generate construction waste. The site must be in good condition so that waste generation can be avoided (Urio & Brent, 2006).

2.4.6. Workers

Construction workers may have an influence on the generation of waste at a construction site. Al-Hajj and Hamani (2011) and Nagapan et al. (2012) note that the factors contributing to the generation of waste caused by workers include: mistake by workers during construction; incompetent workers; poor attitudes of workers; damage caused by workers; lack of training for workers; lack of experience; shortage of skilled workers; poor workmanship; inventories of unregulated materials; and abnormal wear of equipment. Accidents caused by negligence, unused materials, inadequate craftsmanship and utilization of incorrect materials add to the generation of construction waste (Osmani et al., 2008).

Al-Hajj and Hamani (2011), conducted research on material waste in the United Arab Emirates (UAE) construction industry to find out the main causes of waste and minimization practices. In their study, they mention that UAE is encountering problems to achieve sustainable construction sites. The main challenge is the increase of waste generation from construction activities taking place on site and the waste that ends up dumped in landfills. The study examined the causes of waste happening in different construction sites in UAE. The survey centres on the perception of contractors regarding the problems and sources of material waste, steps to mitigate waste and its benefits. Research indicates that the key causes of the content are lack of awareness, unnecessary off cuts by workers arising from inadequate design, and rework and variations (Al-Hajj and Hamani, 2011).

2.4.7. External Factors

There are external factors which may lead to waste generation in construction projects. The weather can be a cause that contributes to construction waste, such as flooding or storms that can destroy the building and contribute to rebuilding (Nagapan et al., 2012). Pilfering, neglect of legislation enforcement, theft and unforeseeable circumstances may be identified as external causes that may lead to the production of waste (Nagapan et al., 2012).

Table 2.1: Summary for waste sources

Construction Waste						
Design	**Material Handling**	**Workers**	**Management**	**Procurement**	**Site Condition**	**External Factor**
Inexperienced designer	Wrong material storage	Workers mistakes during construction	Poor supervision	Wrong material delivery	Unforeseen ground condition	Pilferage
Last minute client requirements	Poor material handling	Incompetent workers	Lack of influence of contractors	Items not in compliance with specifications	Leftover materials on site	Effort of weather
Errors in contract documentation	Damage during handling	Poor attitudes of workers	Lack of knowledge about construction	Different method used for estimation	Lighting problem	Festival celebration
Interaction between various specialists	Poor quality of material	Damage caused by workers	Long project duration	Mistakes in quantity surveys	Difficulties accessing construction site	Accidents
Poor coordination of parties during design stage	Equipment failure	Insufficient training for workers	Non availability of equipment	Supplier error	Waste resulting packaging	Unpredictable local conditions
Frequent design changes	Delay during delivery	Lack of experience	Outdated equipment	Ordering errors	Poor site condition	Lack of legislative enforcement
Design errors	Tools not suitable used	Storage of skilled workers	Communication problems	Waiting for replacement	Congestion of the site	Vandalism
Lack of design information	Material supplied in loose form	Lack of awareness among workers	Waiting periods	Error in shipping	Interference of other crews at site	Damages caused by third parties

Construction Waste						
Design	**Material Handling**	**Workers**	**Management**	**Procurement**	**Site Condition**	**External Factor**
Poor design quality	Insufficient methods of unloading	Abnormal wear of equipment	Resource's problems	Frequent variation		
Slow drawing distribution		Inventory of material not well documented	Lack of waste management	Over allowances		
Incomplete contract		Worker's no enthusiasm	Scarcity of equipment			
Complicated design		Poor workmanship	Poor planning and controlling			
		Inappropriate use of materials	Poor site management			
		Too much overtime for workers	Lack of coordination among parties			
			Poor information quality			
			Late information flow among parties			
			Rework			
			Inappropriate construction methods			

Source: *Nagapan et al. (2012:331)*

2.5. Impacts of Construction Waste on the Environment

The problems of construction waste in environmental, social, and economic domains are forever increasing. Material waste is generally detrimental to the environment. Some of the material waste is disposed of on legal landfills, while some is disposed of illegally by dumping. Environmental concerns include: (1) decreasing the capacity of the landfill site due to the cumulative quantity of discarded waste; (2) depleted construction materials; (3) increased contamination from landfill sites leading to serious adverse health effects; (4) severe ecological damage to the environment; and (5) increased energy consumption for transport and processing of new materials instead of recycling and reuse (Marzouk and Azab, 2014).

Construction waste can also be dangerous to people's health and pose negative effects to society (Nagapan et al., 2012). Waste management in the construction industry involves methods such as waste prevention (reduction), minimization, reuse, recycling, and energy recovery (Esa et al., 2017). If there is effective planning of waste management, the waste problem to the environment can be minimised (Osmani et al., 2008). Van Wyk (2014) conducted a study in South Africa about construction waste as a challenge to the industry. The study highlights the effects of waste to the environment. The data collected on the study shows that most waste ends up in landfills. The DEA (2018) identified five aspects that can negatively be affected by waste generation in construction industry and other sectors. They are air quality, water quality, land contamination, land use and illegal dumping.

2.5.1. Air Quality

In terms of air quality, there are significant causes of air pollution that may possibly have a harmful effect on human health, as well as on the environment (DEA, 2018). Landfill gas is predominantly generated in landfills by decomposition of organic waste during anaerobic conditions (in the absence of oxygen) (DEA, 2018). These anaerobic environments are created by the distribution, compaction, and degradation of waste. Landfill sites have been listed as being one of the major contributing factors to greenhouse gases. In South Africa, landfills are estimated to generate about 43 million m^3 of methane per year or 595 550 tons of carbon dioxide equivalent (DEA, 2018). Tam et al. (2006); and Gupta and Malik, (2018) mentioned that construction wastes may cause dust at the construction site and landfills. This happens when waste materials, such as concrete and bricks, are demolished. Therefore, dust particles are formed, which have a negative impact on the environment.

2.5.2. Water Quality

The quality of natural water bodies above and below ground may be affected by the leachate resulting from the water content of the waste disposed of at the landfill site and by the rain that passes through the cover layers (DEA, 2018). As a result, landfills in wetter climatic conditions or with large quantities of waste with a high-water content create more leachate than in dry climates (DEA, 2018). As the leachate carries dissolved and suspended contamination from the waste, it may, if not managed properly, contaminate the soil and groundwater that poses a great risk to health and the environment (DEA, 2018).

2.5.3. Land Contamination

In South Africa, contaminated land means:

> *…the presence in or under any land, site, buildings or structures of a substance or micro-organism above the concertation that is normally present in or under that land, which substance or micro-organism directly or indirectly affects or may affect the quality of soil or the environment adversely (DEA, 2018).*

Some of the key causes of soil pollution include past and current industrial and commercial operations, the treatment and disposal of waste. There are two forms of soil pollution and dispersed soil degradation in broad regions (DEA, 2018). Local surface pollution arises as heavy construction operations, insufficient waste management and accidents have resulted in large quantities of contaminants. Figure 2.2 shows an example of landfill site in Pretoria. Although soils can absorb many of these pollutants, if this capacity is surpassed, the likelihood of water pollution, human interaction with contaminated soils and plants taking up pollutants rises (DEA, 2018).

Figure 2.2: New landfill site in Pretoria, Source: Pretoria Rekord (2019)

2.5.4. Land Use and Illegal dumping

The negative impacts associated with waste storage, treatment, and disposal facilities, mean that land usage in the region could be compromised. That covers possible effects, such as traffic, sound, dust, and odour (DEA, 2018). The usage of land surrounding landfill sites is limited because it cannot be used for residential, but rather for industrial or commercial land usage (DEA, 2018). Attributable to the vast volumes and the persistence of the waste, the effect of the related landfills persists even after the site has been closed and rehabilitated (DEADP, 2017).

Illegal disposal of waste, especially hazardous waste, creates a severe threat to the public and the environment (DEA, 2018). Mostly illegal dumping takes place in regions of the south and the north where the landfill sites are not nearby, or places have a lot of open space and dumping predominantly consists of housing debris and building industry waste. On average 4 500 tons of illegal dumping waste is gathered each week by Pikitup (Pikitup, 2017). Illegal dumping is relatively common in South Africa, especially in urban areas, as shown in Figure 2.3.

The City of Johannesburg's waste management unit, Pikitup (2017) indicates the following negative impacts of illegal dumping:

1. The environment – illegally dumping waste fills up land which otherwise could have been used for recreation or farming. At times, illicit waste contains toxic contaminants and pollutants that can cause environmental pollution, air contamination and freshwater loss. The result may be serious injuries or death of humans and animals.
2. Public Health – illegal disposal of waste may be the breeding ground for mosquitos and vermin such as mice and rats which might cause diseases to the people living in the area.
3. Community – The value of property drops, taxpayers' money is redirected to fund waste cleaning, and the environment which illegal dumping occurs becomes degraded.

Figure 2.3: Illegal dumping of construction waste in Sandton

Source: Sandton Chronicle (n.d)

2.6. Effects of Construction Waste to Project Cost and Time

Many construction projects face cost and time challenges due to various factors that might arise in the construction process. Studies show that material waste has a major impact on the cost of the project. Adewuyi and Otali (2013) state that material waste accounts for between 20 and 30% of project cost overruns. Most projects in the construction industry encounter a problem of cost overrun and time extension due to project delivery delays (Van Wyk, 2014). Construction waste can also contribute highly to cost overruns and delays in the progress of the project. Economic disadvantages of building waste include transportation costs into and out of the sites, waste handling expenses (labour costs), waste storage costs, waste disposal costs, loss of revenue from non-recovery of waste materials (Wortmann, 2014).

Furthermore, most projects encounter variation orders that create an increase in the project costs due to construction waste through re-work. However, if the project can be planned properly from the inception stage the variation orders can be avoided and the project can be completed within the initial budget (Osmani et al., 2008). Formosa et al. (2002; 320) describe waste using the formula which states that the difference between the quantity of materials effectively purchased by the client *(Mpurchased)* and the quantity of current inventories *(Inv)* in relation to the quantity of materials specified by the measurement of the work done *(Mdesigned)* is as follows: -

$$\boldsymbol{Waste}\ (\%) = \frac{(\boldsymbol{Mpurchased} - \boldsymbol{Inv}) - \boldsymbol{Mdesigned}}{\boldsymbol{Mdesigned}}$$

The above formula can be used to determine the percentage of waste generated. Therefore, this can be used to assess if the project is within budget or in cost overrun when there is an excess or underestimation of the materials (Formosa et al., 2002).

2.7. Waste Control Strategies

Many researchers have come up with waste control strategies that can be used for construction waste minimisation, as shown in Table 2.2. Materials control should be started from the design stage of the project and there should be an avoidance of late design variation (Al-Hajj and Hamani, 2011; Nagapan et al., 2012). In order to control waste, designers should be able to coordinate the dimensions between the materials defined during the design and those produced for use at the project (Wahab and Lawal, 2011). The construction manager needs to plan for material handling since poor material handling can lead to waste (Esa et al., 2017). The construction manager needs to create accurate scheduling of material for programmed delivery dates (Esa et al., 2017). It is important that when procuring materials, the individual in charge of procurement specifies the quality, quantity, delivery time and method, and packaging (Eze et al., 2017). Therefore, there should be effective communication between suppliers and recipient.

The construction manager must make sure that there are effective planning programmes including material storage from the start of site establishment and the procedures on how goods received should be put in their right designated place (Eze et al., 2017). Expensive materials should be held off-site up until when needed on site for usage to avoid breakage. The materials on site require an effective procedure when issuing to the site (Oladiran, 2009).

The management and other staff members should be trained in efficient ways to control waste to reduce and prevent waste deposited in landfills (Oladiran, 2009). The conclusion drawn by Formoso et al. (2002) is that there should be an increase in the management capability of organizations at the planning, procurement, supervision, and development levels. A DEA (2018) report states that the Gauteng Provincial strategies include waste awareness and cleaned up projects aimed at encouraging the separation of waste and eliminating illegal dumping by increasing consciousness within neighbourhoods, schools, and the construction industry. According to Al-Hajj and Hamani (2011), the most common measures in the UAE to reduce resource loss are staff training; enough storage; and just in time supply of materials. Research conducted in South Africa reveals the structure of waste management in which waste prevention, minimisation, re-use, recycling and recovery of resources and disposal are involved (Van Wyk, 2014).

Table 2.2: Methods to control and minimise construction waste from construction sites.

Waste Control Strategies	**References**
Planning and implementation of waste management and construction methods.	Esa et al., 2017
Enhancing awareness, awards, and regulations during the phase of procurement.	Esa et al., 2017
Efficient management during construction phases.	Esa et al., 2017
Lean principle application	Nikakhtar et al.,2015
Improving perceptions and behaviours in industry towards waste minimisation.	Udawata et al.,2015
Adequate monitoring of waste management operations and appropriate guidance.	Udawata et al.,2015
Understanding behaviours and attitudes towards waste management	Osmani et al.,2008
Effective care in handling the materials	Urio & Brent, 2006
Storage facilities and transport routes to the site planned properly.	Urio & Brent, 2006
High level of cooperation and risk-sharing	Osmani et al.,2008
Adequate selection of material	Poon and Jaillon, 2009
Effective site communication, management, and coordination	Udawattaa et al., 2015
Using knowledge communication technology services such as BIM for reliable quantity survey	Yuan, 2013
Policies and legislation implementation and compliance	Osmani et al., 2008
Adequate control and clear instructions on waste management procedures	Osmani et al., 2008
Adaptability design (design that is easily accessible to the environment or material)	Udawattaa et al., 2015
Simplification of designs	Ajayi et al., 2017

Waste Control Strategies	References
Contractual provisions stating waste minimization as part of key success factors	Ajayi et al., 2017
Whole lifecycle costing approach in construction projects	Udawattaa et al., 2015
Stakeholder training and education e.g., unskilled labours, and equipment operators	Osmani et al., 2008

Al-Hajj and Hamani (2011) recommend the following steps as the key strategies for the successful avoidance of material waste at building sites:

Logistics management: A study in UK has been reported in several publications addressing the value of introducing an on-site advanced Materials Logistics Program (MLP) to enhance waste avoidance (Al-Hajj and Hamani, 2011). The plan focuses on the utilization of waste and energy. Logistics administration has been seen to avoid replication of workmanship and to guarantee the correct handling of machinery such that material loss onsite is avoided (Al-Hajj and Hamani, 2011).

Supply Chain Management (SCM): This is focused on long-term loyalty to suppliers and subcontractors and win-win deals. Effective SCM may help to accomplish Just-in-Time distribution to reduce duplication due to lengthy storage or to the purchasing of unwanted materials (Al-Hajj and Hamani, 2011).

Modern Construction Methods: A study released by WRAP (2007) indicates that the replacement of traditional construction methods with certain modern construction strategies culminate in a significant decrease in the amount of waste (Al-Hajj and Hamani, 2011). In their review of waste minimization initiatives adopted in the UK, Dainty and Broke (2004) note the same results and suggest an expanded use of off-site prefabrication for waste and damage control on site.

Training and incentivisation: Many studies and government guidelines emphasize the training of workers as one of the first steps in reducing construction waste (Al-Hajj and Hamani, 2011). A growing awareness of the advantages and laws of waste minimisation can be accomplished by toolbox discussions or waste posters on-site. Incentives for successful operations can also lead to meeting waste targets (Al-Hajj and Hamani, 2011).

2.8. Drivers for Material Waste Minimisation

The waste minimization drivers can be classified into four major categories according to Osmani et al. (2006), namely environmental, industrial, economic, and legislative. The following may be regarded as the primary drivers:

Policy regulations and contractual terms: Many countries have been forced to enact legislation and policy on waste management because of their inability to introduce efficient waste management (Osmani et al, 2006). Policy regulation is regarded as the most significant element in the waste management of building in several cities (Lu and Yuan, 2010). In several countries throughout the world, the most important legislation is the landfill levy. Karavezyris (2007), for example, confirms that the government plays a crucial role in supporting the treatment of construction and demolition (C&D) waste by enforcing industry-wide regulations. At the moment, the laws and regulations of China are not yet flawless in terms of reduction, harmlessness and recycling of construction waste and the implementation of current policies are still minimal (Yunpeng, 2011). The government of South Africa has established waste management policies which play an important role in reducing waste (DOE, 2011). Therefore, policies and regulations significantly contribute to the reduction of waste (Lu and Yuan, 2010).

In addition to this, the contract document should define the required waste segregation and minimization rates and even certain "punitive for non-conformity steps" (Osmani et al, 2006). Yunpeng (2011), states that in Hong Kong, the architectural department responsible for construction contracts has suggested that contractors must submit waste management plan, and implementation records of waste management during the construction phase, and the officials from the department are tasked with carrying out supervision.

Environmental standards and Assessment tools: Environmental assessment methods during the design stage are most useful where deficiencies can be assessed and included in the conception development of the pre-design criteria (Ding, 2008). Many nations, such as the United Arab Emirates (UAE), have implemented ISO 14001 for the Environmental Management Program (EMP), which first emerged in 1996 (Osmani et al, 2006). ISO 14001 is a tool for organisations to reduce the environmental effects of their jobs. One of the ISO 14001's key criteria is to reduce waste and to establish a waste management strategy for an EMP (Poon et al, 2004).

Financial benefit: Al-Hajj and Hamani (2011) state that the actual expense of waste disposal equals the expense of charging the waste contractor with the removal of a skip from the construction site (for instance, Osmani et al. 2006; Tam et al. 2005). Hwang and Yeo (2011) say that other economic advantages are cost saving and maximizing profits which can lead to better results, such as cost saving by increasing focus on waste reduction, reuse, and recycling. In addition, the financial benefits for waste reduction according to Fujiwara and Weng, (2011) are saving on manpower cost for removing waste, dumping fees, collection, and transportation costs.

2.9. Lean Construction Theory

According to Ingle and Waghmare (2015), lean construction is the use of lean deduction to the design and development process making improved project delivery and improved profitability for contractors. Goetsch and Davis (2014) state that lean methodology was initially evolved as a manufacturing idea and in that capacity is frequently referred to as lean manufacturing. Lean construction is a philosophy that can be implemented within the construction industry, primarily to increase the level of productivity of the sector through the reduction of activities and acts deemed to generate waste during the construction process (Ingle and Waghmare, 2015). Nikakhtar et al. (2015) define lean construction as an aim to minimize waste. Most researchers have explored various methods and models of minimising waste in construction projects.

2.9.1. Application of Lean in Construction industry

Koskela et al. (2013) describe the application of concepts and principles of the Toyota Production System (TPS) to building. As with the TPS the main objective is to reduce waste, grow client satisfaction, and improve quality (Koskela et al. 2013). Lean construction has been used to monitor and improve building processes with reduced costs and considering client's requirements (Aziz and Hafez, 2013; Ingle and Waghmare, 2015; Pradeepkumar and Loganathan, 2015).

Wastes are the expenses, for example from rework, which should have been avoided, or expenses related to the longer duration of activity along the critical path (Howell and Ballard, 1998). Howell and Ballard (1998) claim that lean thinking in construction contributes to improved outcomes from the elimination of waste, that is the difference between the current situation and perfection, i.e., satisfying clients' demands with minimal duration. However, lean thinking applies mainly to the waste generated during the construction process, in contrast to other applications of lean thinking that explore the entire manufacturing process (Fitchett and Hartman, 2017).

Vilasini et al. (2011) conducted a study utilising a major construction project in New Zealand to find out if the adoption of lean principles can reduce waste. They found that waste and productivity depend on each other. The findings of this research (Vilasini et al. 2011) indicate that one third of the non-value-added activities are the result of management-controlled factors. The conclusion of the research is that the reduction of waste will occur through changing management practices through the implementation of the lean theory (Vilasini et al., 2011).

2.9.2. Types of Lean Waste

The lean philosophy focuses on waste reduction and recycling: the following are examples of lean waste theory (Goetsch and Davis 2014; Ingle and Waghmare, 2015; Nikakhtar et al., 2015):

1. Overproduction waste: this leads to creating more of a product or providing more of a service than is required or more than is presently expected. For example, in the building environment, this could involve the preparation of $10m^3$ of concrete when only $5m^3$ of concrete is required.
2. Inventory waste: this amounts to more inventory than is required at a given moment. The idea of just-in-time delivery has stock reduction as part of its wider purpose. For example, in the construction setting this could mean that more materials are trapped in the store than could be used for a given production cycle.
3. Motion waste: this means integrating excessive movement into the production process or the delivery of services. For example, when construction workers are returning to the office to pick up plans, tools or materials that are not available at the site.
4. Transport waste: this is the excess movement of the parts in a production environment. Usually, the excess movement of people is the product of a service climate. For example, in the construction setting, it occurs when transportation activity does not make any transformations to the project or add value.
5. Overprocessing waste: It exceeds client requirements so that when making a product, or doing more than clients want in operation, and does not generate additional value.

For example, it is when the contractor could do work that exceeds the specified requirement in the building environment.

6. Defects in waste: this refers to the creation of rejected work or to the creation of rework as a result of a mistake in manufacturing or processing error. For example, in the construction environment, this could be the case if the work performed is not created according to the design or specification when examined by the inspector. It can also include the building in of inferior materials that are deemed defective during an inspection.
7. Waiting waste: this leads to idling people, machines, or processes because something is not ready. For example, in construction, this might be when the plastering subcontractor has not plastered the wall on time causing delays to the painting subcontractor.
8. Underutilization waste: this is under-use of people's talent, expertise and innovation and technical capacity. For example, more likely is when a skilled person is doing unskilled work.

Management and subcontractors generally respond in a variety of ways to the lack of timely information. They could be 1. delay or slow down the progress of work until missing information and data has been obtained; 2. postponement of sections of the task plan, believing they would be returning to them at a later date; or 3. abandon the construction plan and continuation of other task packages that have detailed information (Sack et al., 2007).

From various authors, not all the mentioned lean waste types are considered as being important for construction. Roelandt (2019), in a study on implementing lean construction in South African companies, stated that the wastes which occur most frequently on sites are waiting, overprocessing, material movement, inventory, and motion. The study by Nikakhtar et al. (2015) shows that the wastes which were taken into consideration were waiting time and transportation time. Inge and Waghmare (2015) have said that waste in the construction sector may refer to waiting or idling time, wasted movement, over-processing, over-production, transport, inventory, and defects. Therefore, the literature agrees that the most common wastes are waiting time, motion, overprocessing, inventory and motion, with underutilization to a lesser extent.

2.9.3. Lean Tools

There are different types of tools and techniques that have been developed in the lean approach. They are as follows; value stream mapping, process mapping, poka-yoke, change management, just-in-time (JIT), kaizen (continuous improvement), and 5 Sigma process tools (Goetsch and Davis, 2014; Nikakhtar et al., 2015). Researchers have used some of these techniques to evaluate how to minimize building waste.

The value stream mapping tool, according to Goetsch and Davis (2014), is a tool which uses symbols to describe a value stream. The value stream can be applied in four ways as follows: (a) define the process groups (of the task), (b) create a map of the current state, (c) develop a map of the ideal future state, and (d) develop a plan for the future state system, as shown in Figure 2.4. The flow production in the lean concept is defined by the movement or transportation of materials, information, and equipment in the construction process (Nikakhtar et al., 2015; Aziz and Hafez, 2013). The process mapping tool is used to define the level of concern for waste reduction at the construction site (Vilasini et al., 2011). A poka-yoke method is designed in such a manner that it can be utilized while setting up a procedure and then seeking ways to detect and remove or mitigate possible errors (Goetsch and Davis, 2014). Just-in-time is a tool used to ensure that all goods are not shipped to their assigned locations before time (Goetsch and Davis, 2014).

The 5s process tool comes from five Japanese words that translate into English as sort, store, shine, standardize, and sustain. The 5s process is described as a method to ensure a safe and orderly workplace, which encourages high performance and continuous improvement (Goetsch and Davis, 2014). This has five stages of housekeeping that will help to reduce waste (Ingle and Waghmare, 2015).

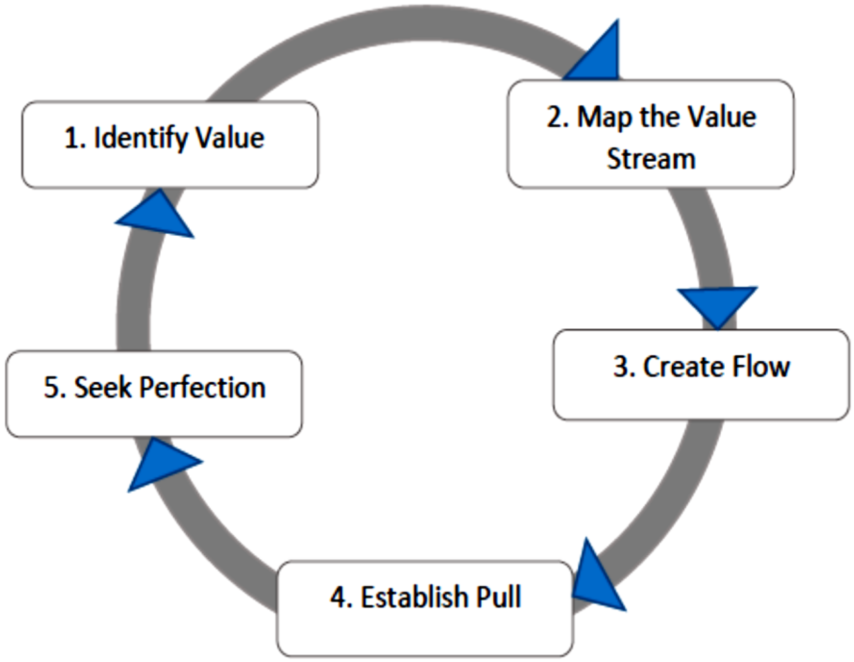

Figure 2.4: Lean construction principles

Source: *Marhani et al. 2012*

Furthermore, the lean waste generated on the construction site may be minimized or eliminated by using the above-mentioned lean tools. Nikakhtar et al. (2015); Aziz and Hafez, (2013); and Ingle and Waghmare, (2015) stated the lean tools to reduce waste, as summarized in Table 2.3. The use of lean tools like value stream mapping and process mapping can help reduce overproduction waste. The application of the just-in-time (JIT) tool can reduce inventory waste. Motion waste can be minimised by utilizing the 5S process tool. Transport waste also utilises value stream mapping and process mapping tools for waste minimisation. Overprocessing waste can be eliminated by using the 5S process tool. Defect waste can be reduced by applying poka-yoke (mistake proofing). Waiting waste can be reduced by kaizen (continuous improvement). Underutilization waste can be minimised by implementing kaizen (continuous improvement).

Table 2.3: Summary of lean waste and tools used

Lean waste	**Lean tools used to reduce waste**
Overproduction waste	Value stream mapping and process mapping
Inventory waste	Just-in-time (JIT)
Motion waste	5S process tool
Transport waste	Value stream mapping and process mapping
Overprocessing waste	5S process tool
Defect waste	Poka-yoke
Waiting waste	Kaizen (continuous improvement)
Underutilization waste	Kaizen (continuous improvement)

2.9.4. Lean Construction Model and Adapting Lean Tools to the Construction Industry

As the construction environment differs from the manufacturing industry, researchers have identified a set of lean tools from TPS (Bashir et al., 2013) appropriate for the construction environment. These include the duration, approaches, frequency, occurrence of unforeseen complications, stakeholder dependence, and the nature of the tasks to be performed (Bamana et al., 2019). The lean tools which have been used extensively in construction are poka-yoke (mistake proofing), 5S process, and just-in-time (Nikakhtar et al., 2015; Inge and Waghmare, 2015; Dos Santos and Powell, 1999; Aziz and Hazef, 2013) as shown in Table 2.5.

Lean construction models have been discussed in detail from different authors in the literature (Aziz and Hafez, 2013; Ingle and Waghmare, 2015; Vilasini et al., 2011). Sacks et al. (2007) discuss a lean management model which can also be used for waste minimisation. According to them, the production measure of cycle time, from the customer's point of view, is described as the period from their first meeting of design change with company representatives until the time when the building is ready for occupancy.

The lean management model suggested by Sacks et al. (2007) involves four important steps to enhance information and product flow stability, and thereby the work in progress (WIP) and cycle times:

1. Reduce the scale of the “batch” from full floors to single apartments. Traditionally, the fundamental "unit" of planning for high-rise buildings is the building floor.

2. During the final stage, the removal of a complex system of drawn apartments according to the client's complex design changes in the networking schedule defined. Finishing is carried out in each apartment in keeping with the sequence of design details.

3. Restructure work to reduce or eliminate the dependence of early activities on client design change information. Separating plumbing and electrical structures from structural or exterior construction is one example: transferring electrical ducts and water supply pipes to false ceilings and specialized racks instead of embedding them in concrete slabs, walls and columns ensure the structural concrete function is independent of the client's design. This alters the information limitations.

4. Restructure working packages to reduce their amount by focusing on the hands of less qualified subcontractors for more tasks.

Vilasini et al. (2011) developed a waste minimisation model by combining traditional industrial engineering methods (time study, activity sample, spaghetti diagrams and processes maps) with lean techniques (continuous improvement, error testing and standardization). This model has the greatest benefit of being simple and does not require profound training. Main success factors for this model adoption are the engagement of project members at all organizational levels and the development of a problem-solving mentality (Vilasini et al., 2011).

Ballard and Howell (1998) explored a modern theoretical paradigm for their study on the application of lean construction understanding and action. Lean-resolved issues, such as inefficient flow, have been described as building challenges, but common sense provides no remedies. Limited application of lean principles has been built and utilized in dynamic, unstable, and rapid programs, in particular on organizational or relational dimensions (Ballard and Howell, 1998). Changes at the stage of the mental model are special because they open up a new opportunity.

The first model focuses on reducing the cycle time, the second is a waste minimisation model, and the third is the mental model that deals with changing the mentality towards lean thinking to create change and better opportunities. Therefore, these models share the same main aim, which is to increase productivity and eliminate or minimise waste in the construction industry.

2.9.5. The application of 5 S in construction projects

Lean tools such as 5S, can be used to manage building sites more efficiently (Salem et al. 2006). Inge and Waghmare (2015), explain how the 5S process tool can be used for waste reduction in construction sites, described as follows:

1. Sort: used to eliminate unwanted objects from the area of the site.
2. Set in order: retaining essential materials close by to increase performance.
3. Shine: cleaning is a regular practice, equipment and building tools are cleaned.
4. Standardize: implement standardized strategies for increasing performance.
5. Sustain: they adopt the principle of reduction, recycle and restoration in the handling of materials.

2.9.6. The implementation of poka-yoke (mistake proofing) in construction

Building defects created by various types of building installations in a given project often constitute a major concern of the construction industry (Nikakhtar et al, 2015). When a defect occurs, efforts should be made to redress it, and the correction is referred to as a "rework." Research have shown that the rework cost is estimated at about 5% of the contract value for construction projects (Josephson and Hammarlund, 1999; Mills et al. 2009).

Areas at construction sites which are susceptible to mistakes should be marked for poka-yoke. Such errors may be quality concerns, production failures, protection problems, etc. The construction managers using poka-yoke will monitor where the issues are and focus their energy on analysing and fixing the problems and introduce the mistake proofing device to prevent potential problems from recurring, as shown in Table 2.4 (Nikakhtar et al, 2015; Dos Santos and Powell, 1999). Dos Santos and Powell (1999) note that poka-yoke devices are valuable for repetitive tasks or acts based on diligence or recollection, thereby allowing workers to do more innovative and value-adding activities. In conclusion, the poka-yoke (mistake proofing) can be implemented by measuring, finding, and eliminating the root cause of problems standardisation and installation of poka-yoke devices (Dos Santos and Powell, 1999; Koskela et al., 1992).

Table 2.4: Mistake-proofing (poke-yoke) tool

Response	Action
Eliminate	Eliminate the possibility of errors
Replacement	Substitute the process with improved one
Prevention	Re-engineer products or process
Facilitation	Employ techniques that reduce work difficulty
Detection	Identify errors before further processing
Mitigation	Minimizing the effect of errors

Source: Nikakhtar et al. (2015:467)

2.9.7. Implementing Just-in-Time in Construction

Just-in-time (JIT) tools consist of providing the appropriate materials in the right amount and quality as required to minimize waste and provide maximum value (Bamana et al., 2019). Bamana et al. (2019) indicate that JIT supplies could reduce amount of inventory on-site (buffer stock) and on-site building duration can decrease via prefabrication in the factory environment. Tommelein and Weissenberger (1999) and Pheng and Chuan (2001) argue that a buffer in practice is required, and the size of the buffer should be strategically established. Moreover, Pheng and Chuan (2001) have noted that the introduction of perfect JIT building deliveries is a little idealistic due to stakeholders' interdependence and to the harshness and complexity of building sites. The concept of a modified JIT in construction is therefore recommended in order to guarantee a minimum stock buffer level in order to alleviate the potential delays (Bamana et al, 2019). Table 2.5 shows the lean tools widely used on construction sites and the authors who recommended these lean tools.

Table 2.5: Summary of lean tools widely used in construction sites

Lean tools	Reference
1. 5S process	Marhani et al. (2012); Nikakhtar et al. (2015); Inge and Waghmare (2015)
2. Just-in-Time	Bamana et al. (2019); Nikakhtar et al. (2015); Peng and Chuan (2001); Ogunbiyi (2014)
3. Poka-yoke	Dos Santos and Powell. (1999); Nikakhtar et al. (2015); Koskela et al. (1992)

2.10. Factors Affecting the Implementation of Lean Principles in the Construction Industry

Bashir et al. (2010) said that studies have been undertaken in various countries to examine factors that could affect the implementation of lean construction success. These barriers were divided into six different categories on the basis of an in-depth and critical review of existing literature on lean principle (Bashir et al., 2010). The identified factors affecting the implementation of lean application are management, financial, educational, governmental, technical, and human attitude issues.

Management issues that have been identified as barriers in the implementation of lean principles involve delays in decision making, lack of support and commitments from top management, improper organizational structure, ineffective management, inadequate communication and planning (Forbes and Ahmed., 2004; Olatunji, 2008). Corruption, insufficient funding for projects, inflation, costs for implementation, poor worker wages, lack of incentives, motivation, and aversion to risk are the financial issues that could impede the success of lean construction techniques (Olatunji, 2008). The educational issues encountered were lack of understanding, lack of technical expertise, high-level illiteracy, inadequate training, poor understanding of lean concepts and insufficient exposures to lean application requirements (Bashir et al., 2010; Olatunji, 2008).

A comprehensive study of the results of Olatunji (2008), indicates government issues, including government bureaucracy, policy inconsistency, lack of social infrastructure and facilities, the unavailability of materials, and commodities price volatility. Technical issues include lack of construction design, incomplete concepts, and strategies for measuring poor performance (Koskela, 1999). Lack of agreed methodologies for implementing production process, lack of prefabrication, and uncertainty in the supply chain also a problem (Ballard and Howell, 1998). Howell (1999) found out that human attitude is one of the factors affecting the implementation of lean construction. Other issues identified for human attitudes include lack of transparency, change in culture, an inadequacy of the team spirit, lack of self-criticism, lack of cooperation, poor housekeeping, conflict of leadership, a misunderstanding of client information, a misconception of lean practices, and the fear of unfamiliar practices (Forbes and Ahmed., 2004).

According to Senaratne and Wijesiri (2008), the construction sector is described as a slow-growing sector facing different problems like low efficiency, inadequate safety, time delays, cost overrun and poor quality. In addition to the above, the characteristics of the construction sector (such as uniqueness, site efficiency, complexity, speed) maximize instability and uncertainty, which exacerbate the challenges (Abbasian-Hosseini et al., 2014). Building works are also dangerous to the planet because they create gasses and generate waste (Pheng and Chuan, 2001). Wu et al. (2014), state that waste in the building process includes both materials (timber, metal, cement, stone, packing and mortar) and production waste. A move towards increasing the efficiency and profitability of the construction sector may be taken by eliminating waste during the construction stage (Alwan et al., 2016).

As sustainable development is increasingly recognized, various industry sectors including building and civil engineering, face growing constraints to enhance environmental efficiency (Jamil and Fathi, 2016). The implementation of lean building in the construction industry would boost efficiency and productivity, eliminate waste, and increase client satisfaction (Nikakhtar et al., 2015).

This said, there are many challenges with incorporating a lean philosophy into building projects and applying lean methods on real building sites. Therefore, information is required on how the construction companies adopt lean tools to identify the advantages and obstacles to the application of lean tools in construction. The following section describes the benefits of implementing lean principle.

2.11. Benefits of Implementing Lean Principles to the Construction Sector

The application of lean principles in the construction industry has benefited the industry positively according to previous studies, as summarised in Table 2.6. Lean construction can only be established through comprehensive changes to accomplish the social, economic, and environmental aspects of sustainability, the goals of creating value and reducing waste within the built environment (Ingle and Waghmare, 2015). Researchers (Ogunbiyi, 2014; Salem et al., 2014; Ingle and Waghmare, 2015) group lean application benefits into three major categories: environmental, economic, and social. These are addressed below.

2.11.1. Environmental benefits

Vilasini et al. (2011), Marhani et al. (2012) and Nikakhtar et al. (2015) have suggested that waste management, improvement of the efficiency of projects, health, and safety, and fulfilling client minimum requirements are the most sought-after benefits from lean construction. The main advantages of lean tools are reduced resource use, noise reduction, and lowered energy costs (Ogunbiyi, 2014). In fact, the sustainable advantages of lean construction in the building sector involve enhanced procedures by stronger manufacturer management and lowered inventories at the workplace (Nikakhtar et al. 2015).

2.11.2. Economic benefits

The greatest benefit of the lean approach in the construction industry is increasing productivity (Vilasini et al., 2011; Marhani et al., 2012). Building firms may reduce construction costs by utilizing more reliable materials and less waste, and thereby increase efficiency (Aziz and Hafez, 2013). Nikakhtar et al. (2015) have developed a computer simulation model to investigate the potential of lean building concepts to minimize building project waste through a case study by contrasting real-world and lean model outcomes. They note a decrease in rework, a reduction in the waiting time of materials, and a reduction in the amount of transport time. Vilasini et al. (2011), Marhani et al. (2012), Nikakhtar et al. (2015) and Aziz and Hafez (2013) add two other economic benefits: reduced uncertainty and increased consistency leading to fewer delivery orders to the site and an increase in the profitability of the construction project.

2.11.3. Social benefits

Vilasini et al. (2011) and Marhani et al. (2012) report that the most desirable social advantages from lean building are through improving the results. In addition, Marhani et al. (2012) identify the advantages of lean construction which are: consumer loyalty, enhanced supplier partnerships, expanded market share, staff wellbeing and work loyalty towards the company due to the engagement of all employees. Aziz and Hafez (2013) outline the social benefits of utilizing lean tools: improved coordination with the different partners of the initiative, and inspired decision-makers to make the project a success.

The analysis of lean social benefits in several studies has found that the most critical social benefits are strengthened brand identity, expanded communication and participation in the supply chain of companies, expanded staff productivity and involvement, improved creativity, cultural health, and clarity of knowledge (Marzouk et al., 2011). Table 2.6 summarizes the benefits of waste minimisation on construction sites.

Table 2.6: Summary of benefits on waste minimisation

Benefits of waste minimisation
1. Increased profit
2. Cleaner and safer site conditions
3. Saving cost of disposal and transport
4. Enhancing the image of the company as a green contractor
5. Protection of the environment

Source: Al-Hajj and Hamani, 2011

2.12. Conclusion to the Literature Review

There are nine themes, namely: experience; material waste; main causes of physical waste; methods and actions to minimise waste; strategies and benefits; cost and time implications; application of lean construction; waste management plan; and the most effective method to reduce waste as shown in Table 2.7.

From the survey of the literature, many studies state that construction waste has become a major problem across the world. Several surveys and studies have been carried out in different countries to identify the causes of waste and assess current practices. Most of the studies address ways that can be used to mitigate waste in construction projects, as summarised in Table 2.7. The factors which generate waste have been identified as poor planning, insufficient supervision, unsatisfactory design, ineffective material handling, inadequate management, poor site conditions and external factors like weather conditions.

The solutions of reducing physical waste and non-physical waste are effective management, applying lean principles, efficient material handling, effective planning and coordination, enhancing awareness and enforcing regulations, adequate monitoring of waste management, adequate selection of material, stakeholder training and simplification of designs. Lean principles can be applied to reduce waste during the construction process. There are few studies that address ways of reducing waste using lean applications in South Africa. This said, there are several papers published on the ways that can be used to minimise waste in the construction industry not only in Gauteng province but also in other parts of South Africa and across the world. This study aims to fill the gap of covering all the construction operations by finding out how waste can be reduced through the construction process in Gauteng through applying lean principles.

Table 2.7: Summary of construction waste across the world

Country	**Main Cause of Waste**	**Waste Control Strategy**	**Research Methods**	**Reference**
New Zealand	Poor management and coordination	Lean application approach	Qualitative method (Pilot Case Study)	Vilasini et al. (2011)
Brazil	Managerial problems	Managerial Improvement	Qualitative and Quantitative method	Formoso et al. (2002)
United Arab Emirates	Lack of government legislation and policies	Adequate storage of material	Qualitative method (Questionnaire survey)	Al-Hajj and Hamani (2011)
United States of America	Improper packaging and material handling	Appropriate packaging and material handling	Qualitative method	Formoso et al. (2002)
Nigeria	Improper control of materials	Proper control in the material storage	Qualitative method (Structured Questionnaires)	Wahab and Lawal (2011)
South Africa	Poor waste management	Effective waste management	Qualitative Method	Van Wyk (2014)

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Introduction

This chapter presents the research methodology adopted to achieve the aim and objectives of the study. It explains in depth the research strategy, the research method, the research approach, the data collection methods, sample selection, the type of data analysis, and the ethical concerns of the study.

3.2. Research Strategy

The study was restricted to construction companies in Gauteng province to determine the control and management of waste in construction sites. The limit to Gauteng province was motivated by the fact that this province has the greatest number of buildings construction projects. The research strategy implemented in this research is qualitative interviews.

3.3. Research Approach

This study about control of waste in building projects in Gauteng province used inductive approach using the qualitative method for data collection. This study used an emergent, exploratory, inductive qualitative approach (Williams, 2019). Due to this approach, the direction of the research cannot be predetermined or defined. It is particularly important to describe detailed phases of this research in the approach to research (Williams, 2019). The study uses structured interviews that consist of questions concerning waste control in construction projects. The questionnaire used for research is primarily focused on a comprehensive literature review (Yuan, 2013). A preliminary list of indicators resulting from the literature review was presented through structured interviews to the invited participants as shown in Annexure C.

3.4. Research Method

The study uses a qualitative method applying structured interviews that were conducted on construction site. The reason for using structured interview is that it offers clear details which can be matched between multiple respondents. The questions for the research interview were open-ended since these need more thought and provide more than a single word response.

Moreover, the qualitative method falls under inductive approach, which is a more flexible structure to permit changes as the research progresses.

Research framework

The research framework is shown in Figure 3.1.

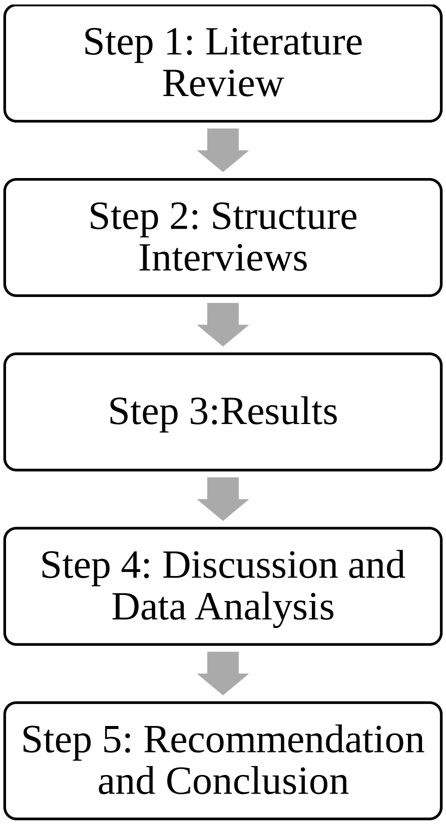

Figure 3.1: Research Framework

3.5. Data Collection Method and Tools

Structured interviews were used as a qualitative research methodology in this study. The aim of this strategy is to ensure that any interview is delivered in the same order on precisely the same questions (Williams, 2019). This means that answers can be aggregated accurately and that distinctions between sample populations can be made with assurance. Therefore, this ensures that answers can be reliably aggregated and that comparisons can be made with confidence between sample groups. An interview schedule was developed that lists the wording and sequencing of questions. Interview schedules are sometimes considered a means by which researchers can increase the reliability and credibility of research data (Williams, 2019)

Seventeen questions, which took 30 to 45 minutes, were asked during interviews with the ten respondents. The question wording was standardised and based on the findings of the Literature Review as shown in Annexure C. In addition, the data recording was conducted by paper-based (mail and face to face) and telephone interviews (Saunders et al., 2009). The advantages of interviews can be described as the opportunity for feedback, an opportunity for clarifications and probing complex answers (Williams, 2019).

3.6. Sample Selection and Participants

The study used a small sample size of ten respondents, the construction managers of which were participants in the study. The sampling criteria adopted for the study, ten projects were identified in Gauteng province, in which the construction companies executing the project should be a medium-sized company and they should be registered with CIDB. Sampling was applied for data collection to evade unrealistic involvement of huge amounts of time, cost and personnel required to interview every individual in a population (Udawatta, et al., 2015). Construction companies located in Gauteng Province, South Africa were selected from the sample set, as described below.

Construction activities are concentrated in Gauteng which accounted for 26% (R18 billion); Western Cape which accounted for 21% (R14 billion); KwaZulu Natal which accounted for 15% (R10 billion) and Eastern Cape which accounted for 15% (R10 billion) (CIDB, 2019).

Consequently, the province of Gauteng was selected as several buildings were being built. Also, Gauteng province has the largest population in South Africa and is the economic heart of the nation, which contributes to demand for building projects. The sampling technique that was used for the study was random sampling as it is accurate and easily accessible. The construction companies were selected using a non-probability sampling technique and the companies are on the Construction Industry Development Board (CIDB) list. The non-probability sampling applied was convenience sampling, simply includes the individuals who happen to be most accessible (Saunders et al., 2009). The CIDB grade for the projects was used for the study range from grade 6 to 7. The study focuses only on building construction (not civil engineering works) and medium-size commercial projects. The cost of the projects used ranged from R10 million to R40 million and the companies used for data collection consisted of medium-sized construction companies, as defined by the Construction Industry Development Board (CIDB).

3.7. Data Analysis

The collected data were analysed to answer the research question and to reach the research aim and objectives. The technique used for analysing data collected was the coding method, as shown in Figure 3.2. In qualitative research, coding is how you define what the data you are analysing (Gibbs, 2007; Saunders et al., 2009; Williams, 2019). Coding is the mechanism by which a text or other data elements is recorded (photograph, picture), ideas are checked and defined, and relationships are established. A spreadsheet was used for coding as in Annexure D. Two steps were taken: firstly, coding and categorization of transcripts into specific parent codes; and secondly, checking terms' frequency in the same order (Chileshe et al., 2016; Ose, 2016).

All the transcribed interviews were transferred from Microsoft Word to Microsoft Excel. Each and every transcribed interview was put on a separate sheet labelled from interview 1 to 10. The text was separated into two columns. The first one was for (interviewer I and respondent R) and the other column was for the quote. Thereafter, the coding in excel was executed on the third column using numbers. Another sheet was made for the codes, where each code represented a theme identified in the research interview response. The coded interviews were sorted accordingly. The sorting involved defining respondents and keeping track of the sequence in each interview. All the interviews were then combined into the same sheet. The information in the columns was then linked to the quotes and included the code list on the same sheet as the coded interviews. The quotes and references were transferred to Microsoft Word after Microsoft Excel coding and text was sorted into a logical structure based on codes.

<u>The steps of data analysis through coding implementation (O'Connor and Gibson, 2017):</u>

Step 1: Organizing the Data

↓

Step 2: Finding and organizing ideas and concepts

↓

Step 3: Building overarching themes in the data

↓

Step 4: Ensuring reliability and validity in the data analysis and in the findings

↓

Step 5: Finding possible and plausible explanations for finding, and an overview of the final step

Figure 3.2: Data analysis steps

3.8. Reliability and Validity

Reliability relates to the degree to which methods or procedures for data collection produce accurate results (Saunders et al., 2009). The validity of this study was determined through testing the quality of data, looking for ambiguity of direction and avoiding generalisation of the data. The coding method was employed in the analysis of data, to identify the patterns in the data. The same interview questions were conducted with all ten respondents, and the same data was analysed to test the validity (O'Connor and Gibson, 2003).

3.9. Ethical Considerations

Ethical concerns are crucial to the alignment between the possible risks of research as well as the likely advantages of research at all qualitative analysis phases (Arifin, 2018). There was consent approved by the participants, and the study was appropriately explained to them as shown in Annexure B. The participants gave explicit permission to be recorded during the interview sessions. However, they were assured that the information provided would remain confidential and anonymous. The ethical approval and access to participants was granted by the University of the Witwatersrand, Human Research Ethics Committee (Non-Medical). The ethics approval clearance number is H20/07/38 as shown in Annexure A of the ethic clearance certificate. In conclusion, the ethical consideration was taken into deliberation in this research project.

CHAPTER 4: RESULTS

4.1. Introduction

The purpose of this chapter is to report the results of the structured interviews of 10 construction managers from 10 building sites. The data analysis was conducted using a coding method utilising Microsoft Excel software as discussed under the methodology section.

4.2. Findings from Sites

Qualitative data was collected in 10 sampled projects across Gauteng province. Table 4.1 provides a summary of each of the sites sampled. Seven construction managers were interviewed face-to-face on site, while the other three interviews were conducted using a zoom meeting since the interviews were conducted during the Covid-19 pandemic period. Observations of how building managers treat on-site waste have been made at the sites to which access was granted. The years of experience for the construction managers interviewed was 10 years and above, which improved the reliability of the results as they answered questions centered on their experience in the building industry.

Table 4.1: Summary of each site, type of construction project, company CIDB grade, and project location

Name of Site	**Type of construction project**	**Construction Manager's Experience**	**Company CIDB Grade**	**Location**
Site 1	Retail Centre	27 years	7GB	Midrand
Site 2	Retail Centre	10 years	6GB	Centurion
Site 3	Health Facilities	18 years	7GB	Fochville
Site 4	Educational Institution	15 years	8GB	Braamfontein
Site 5	Retail Centre	24 years	7GB	Sandton
Site 6	Student Accommodation	13 years	7GB	Doornfontein
Site 7	Health Facilities	16 years	7GB	Katlehong
Site 8	Residential Apartments	18 years	6GB	Fochville
Site 9	Residential Apartments	10 years	6GB	Midrand
Site 10	Student Accommodation	22 years	7GB	Pretoria West

The construction managers were interviewed in 10 construction sites in Gauteng province. All of the participants had more than 10 years working experience in the construction industry. The most experienced construction manager has been in the industry for 27 years, the least experienced has 10 years. The range was therefore 17 years, and the average is 17.3 years, as shown in Figure 5.1. More than 10 years of professional experience has provided the research an advantage in extracting valid and reliable interview responses based on the experience of the construction manager, consistent with the literature (Begum et al., 2009; Nagapan et al., 2012).

Nagapan et al. (2012) state that the experience of the construction managers reflects their understanding about issues concerning identifying factors causing construction waste. Therefore, this supports the assertion that the data gathered is reliable and valid. In addition, the years of participants' experience shows that waste on site is effectively controlled, which is sustained by Begum et al. (2009) noting that the attitudes of construction managers towards waste management are more robust if construction managers have more construction job experience.

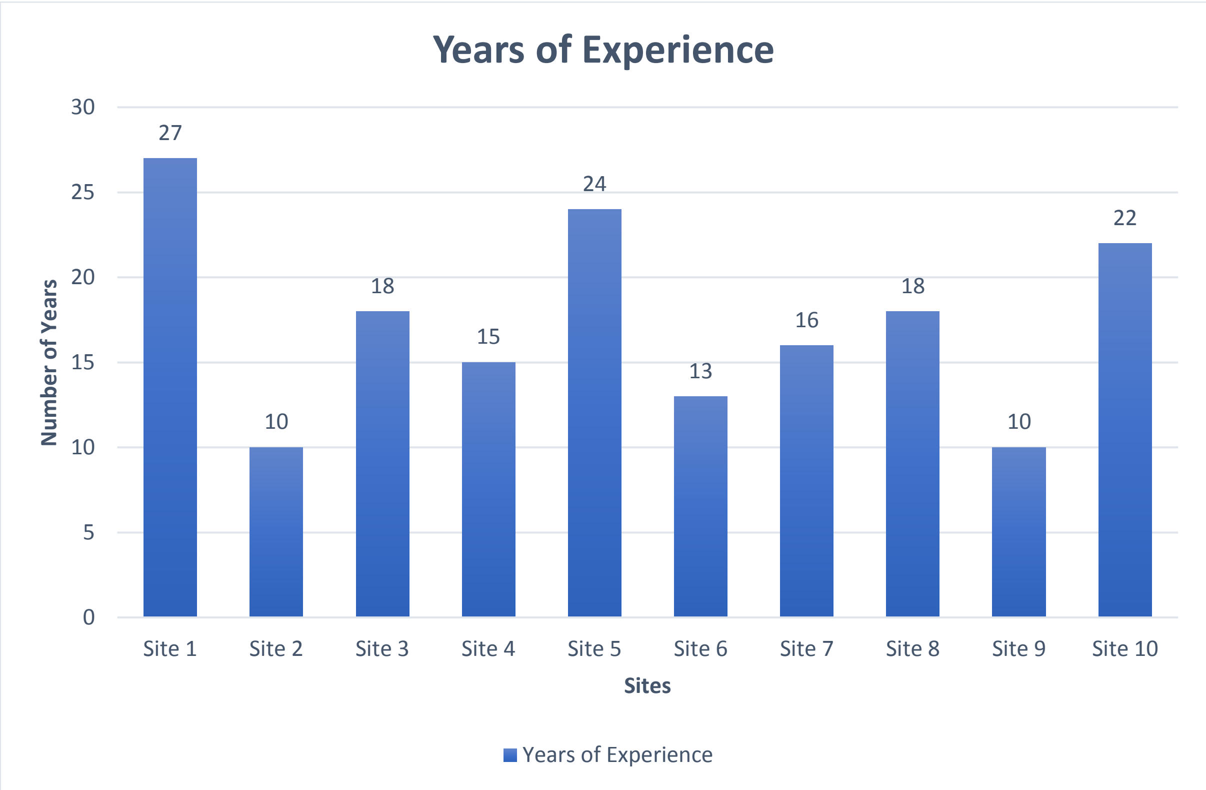

Figure 4.1: Construction manager's years of experience

The data analysis for this study used coding discussed. The entire texts are coded, and the codes in the final documents correspond to headings. The method creates a flexible Word document with interview data divided into logical chapters and subchapters (Ose, 2016; O'Connor and Gibson, 2017) as shown in Annexure D and E. The coding with the Microsoft Excel and Microsoft Word software was done using a guide published by Ose (2016).

The method includes the following 10 steps:

1. Collect the data.
2. Transcribe the audio files.
3. Transfer the text from Word to Excel.
4. Prepare the Excel document for coding.
5. Code in Excel.
6. Prepare the coded interviews for sorting.
7. Sort the data.
8. Transfer quotes and references from Excel to Word.
9. Sort the text into a logical structure based on the coding.
10. Analyse the data.

4.2.1. Findings from Site 1

The respondent claimed that the material waste which mostly arises on the site was the debris of the construction, such as bricks, concrete, wood, and steel as shown in Table 4.2. Reasons for material waste to appear more often have been because there is often waste on building projects, such as brickwork and plasterwork. The interviewee responded by saying that the main cause of physical waste at the building site was subcontractors, whose bricklayers do not use all materials, such as half bricks, which end up in the skip waste and then is carted away. The methods used to minimize construction waste at the site include the proper handling of the material, e.g., the unloading of bricks using a crane to prevent the breakage of the bricks and to ensure, for instance, that the concrete surface is as clean as possible when taking off the formwork. The weekly toolbox meeting for all subcontractors on-site to inform them about all waste materials was the action taken on the waste arising on-site, and so far, there is a decrease in the volume of waste generated on-site from using the mechanism of the toolbox meeting.

The respondent indicated that the waste management strategy used at this site is to appoint waste firms to collect waste using skips and classify waste according to content streams for recycling purposes. The main benefit of implementing these strategies was its prevention of soil contamination on site, e.g., from chemical waste. Construction waste may have a negative impact on the costs, as the respondent claimed that the waste could result in a late practical completion of the project causing high cost through penalty clauses. The participant explained that the lean wastes that happen most often at their site were overproduction and defect wastes.

According to the respondent, the project does not apply lean construction to reduce waste, but the organization plans to incorporate lean construction for its future projects. Therefore, this will then require training of construction personnel. The interviewee mentioned that in the contract for this project, a waste management plan was not required. However, the construction manager stated that the company has a waste management plan which sets out to ensure the use of skips to contain waste on site in a designated area so that chemical waste does not penetrate the land, which may impact groundwater. Introducing lean construction and training on waste management was the most effective method preferred by the respondent.

4.2.2. Findings from Site 2

The interviewee indicated that the most commonly found material waste was bricks at his site. When the bricklayers cut the bricks in half, they leave some of them unused contributing to material waste, which is discarded and ends up in in the landfills as presented in Table 4.2.

According to the respondent, the main reason for the more frequent occurrence of half bricks was that of unskilled bricklayers and negligence. The participant claimed that the main cause of physical waste at the building site was the nature of the site attributable, for example, to the bad site condition in that the site is brown-field condition. On this site, the method used to reduce waste was by the re-use of waste on site. He said that the strategy used in site control waste was to purchase materials as and when they were required to avoid waste. The strategy's implementation has benefits that save resources and increase profits for the construction firm. In this project, impact on cost and time was anticipated to the degree that the cost of extracting the debris and waste affects the working area, resulting in project delays when activities associated to waste arise such as cleaning and removal of waste on site.

In addition, defects were the most frequent type of lean waste found at this site. However, lean construction is said to be implemented in this project and the primary lean tool used is just-in-time (JIT). No difficulty has been faced since adapting the lean approach to this project. That being said, this project contract did not require a waste management plan in place, although the contractor has its own waste management plan in place. The construction manager at this site said that the most effective method of controlling construction waste was the efficient planning and reuse of waste materials.

4.2.3. Findings from Site 3

The participant stated that material waste which occurs most regularly at this site is cement which was most often caused by unskilled workers. Poor supervision was the main cause of the physical waste found in this construction site by the construction manager. Quantification of material was the method used to minimize construction waste and actions taken with regard to the waste arising on site was disposing waste in the bin as shown in Table 4.2. One of the strategies mentioned by the respondent to manage waste at this site was to ensure that the design of the engineered mix should be precise. The benefits of using the aforementioned strategy are that waste is minimized. As far as the interviewee is concerned, the construction waste generated at the site has an impact on the cost and time of the project, and the effect on each of them was when the project cost increases as a result of waste, there is also an increase in the duration of the project.

Overproduction was the lean waste type that happens most often in this site and lean construction was applied in this project to minimise waste. The lean tool used in this project was 5S process but there was a challenge experienced when applying lean construction, which was poor supervisory skills. Waste management plan was not required in this project's contract. The most effective method to control waste according to the construction manager interviewed from this site was the execution of lean construction.

4.2.4. Findings from Site 4

According to the respondent, concrete, and bricks (wet trades) were waste materials that occur most regularly on this site. The skill level of the subcontractors and the speed of execution were the main reasons for larger occurrence of such material waste. Incorrect work which led to rework and drawing revisions were cited as the main causes of physical waste. Quality control of work, management of subcontractors on a microlevel and ordering just enough materials were the methods used in the project to minimise waste. Issuing of non-conformance notifications and charging subcontractors for excessive waste were the actions taken for the waste that arises on site. Hands on control and forcing subcontractors to follow revision drawings were the strategies implemented on site to control waste. Increasing profitability for the main contractor and subcontractor, and speed execution were the benefits of the strategies implemented. Construction waste that arose on site had the impact on the cost of the project. The impacts were namely additional costs, wasteful expenditure and the rework on site might put the practical competition date at risk leading to time overrun as shown in Table 4.2.

Overproduction, motion, overprocessing and defects were the lean wastes which occur frequently in this site. This project did apply lean to minimise waste and the lean tools used were process mapping method, just-in-time and 5S process. Skill level of the subcontractors and the cultural diversity were some of the difficulties faced in applying lean thinking. The contract for this project did require a waste management plan, which states that rubble disposed of should be taken to legal dumping site by waste specialist subcontractor. The respondent stated that continuous improvement, skills upliftment (training employees) and sharing accountability were the most effective methods to control waste in a construction site.

4.2.5. Findings from Site 5

The respondent mentioned that wet trades (bricks, plaster, and concrete), plastics and boxes were material wastes occurring frequently in this site. Lack of skills was the reason for them to occur more frequently. Rework done due to variation and design changes, and accelerated working pace were the main cause of physical waste in this site. Reuse of bricks from demolition, plaster and mortar rubble for filling where possible, and recycling were the methods applied in minimising construction waste. The actions to manage the waste arising were using skips as per waste management plan, and for every subcontractor that uses a skip get charged for waste removal from site as presented in Table 4.2.

Issuing of non-conformance notifications, fining of subcontractors, and stopping payment for subcontractors were the strategies used to control waste. A cleaner site, recovery of payment for skips and reduced wastage were the benefits of implementing those strategies. Construction waste had an impact on the cost and time of the project. The participant from this site said that costs for supervision, cleaning, skips, transport to dump waste and waste itself caused project delays affecting the practical completion (PC).

Defect was the lean waste type occurring most often in this site. This project did apply lean construction for waste minimisation, and the lean tools used were value stream mapping and just-in-time (JIT). Late issue of information was the challenge experienced when applying a lean approach. No waste management plan was required for this project's contract. The most effective methods that were used to control waste were well managed waste, implementation of waste management, using recycling companies and employing skilled workforce.

4.2.6. Findings from Site 6

Concrete was the material waste that most commonly happens on this site. The reason the respondent stated was that it was because of poor supervision that concrete waste occurred more often. The main causes of the waste found on this site were the following: (a) unforeseen ground beams during demolition stage, not casting (columns, beams, and shear walls) to correct level, which then results in breaking concrete to the required level, and (b) not ordering the correct amount (quantity) of concrete from the ready-mix concrete supplier.

The participant stated that ready mix concrete will minimise waste on site, if the concrete is ordered as when needed. Staff personnel measures concrete physically on the plan and allow for minimal wastage of 5-10%. The respondent said that making sure cut off levels are correct when casting concrete to structural elements such as columns, slabs, and beams, to avoid concrete breakage. The quality assurance forms, and pre-and post-concrete checklists are applied to help minimise waste on site as presented in Table 4.2. The foremen were told of the financial effects of the concrete waste with the expected future profit margins, thereby impacting the project or paying annual bonuses. A subcontractor for removal of waste collects and dumps the scrap at a nearby designated landfill site.

The waste management strategies used at this site were to identify a specific area where rubble would be stockpiled and removed regularly, continuous housekeeping was conducted on site and quality assurance was applied daily. The contractor benefits from the introduction of these strategies, as concrete waste is greatly minimized, and a clean site and environment provides the impression that all is in order. Cost and time have been impacted by waste that arises on this site. The time was impacted when the work force was allocated to break concrete not foreseen in the schedule of the project and to delegate the plant to extract waste. Project costs are affected by waste collection, when removing TLB / skid steers from productive operations to load the rubble truck, and by spending more time producing unrelated activities.

The types of lean waste encountered on this site include overproduction, transport, and defects. However, lean construction is not used in the project to minimize waste. No waste management plan was required by the contract for this project. The approach used to manage waste in this building project, that is, recycling waste, has been reported to be most effective; waste concrete can be carried back to the suppliers for reuse in two ways: (a) ready mixing suppliers to crush and reuse concrete as fines and aggregates are removed from the crush machine for batching b) A quarry for crushing and supply or use of the concrete with a grade of a G (G4, G5, G6), used for re-filling or for roads or earthworks as shown in Table 4.2.

4.2.7. Findings from Site 7

The interviewee said that the material wastes commonly occurring on this site were formwork, concrete, bricks, and sand. The reasons for waste were the lack of supervision, poor management, and planning. The main causes of waste in this project were inexperienced labours and poor communications. The methods used to minimize waste were daily meetings with all staff, cost reports and safety toolbox meetings. The strategies used to control waste on site were site walk about, photographic reports and encouraging good workmanship. These strategies benefit the team working in the project by good turnaround time on the project deadline, good profit, and incentives.

The interviewee stated that the building waste generated had an impact on project cost and time. Impacts that occur were practical completion date not met and the project running at a loss. Overproduction, defect, waiting, and underutilization were types of lean waste in this site. This project did implement lean thinking to minimise waste and the lean tools applied were value stream mapping, change management and just-in-time (JIT). The challenges facing the use of a lean strategy were time management and communication. This contract did not require any waste management plan.

The most effective methods used in this site were to make everyone in the project to be accountable for the waste generated and duration to when should the project be completed, daily meeting with staff and once off monthly meeting with labour force creating an awareness on site regarding the waste with posters and safety toolbox meeting as shown in Table 4.2. These strategies are intended to educate those involved in the project about waste and how production, future activities and income can be impacted.

4.2.8. Findings from Site 8

Bricks and mortar (wet trades) were the most common material waste in this project. Unskilled subcontractors have often been the reason for these material waste. The main cause of physical waste was inadequate planning on this site and the reuse of the material waste was the method used for minimizing waste. The main contractor took an action of issuing a non-conformance notice to the subcontractor for the waste arising repeatedly on site. This site's waste control strategy was to train subcontractors on waste management. The advantages of this strategy were saving on waste disposal costs, preventing waste from being dumped into landfills, and reducing pollution. The project cost and time were affected by the waste in the project, which caused a delay in the project and additional expenses as presented in Table 4.2.

Overproduction and defects were the lean waste types that frequently occur at this site. Lean principles were used in this project to minimize waste, using the tools of process mapping and just-in-time (JIT). Challenges mentioned by the participant were cultural and unskilled subcontractors. No waste management plan was required for this project contract. In conclusion, lean construction was the most effective method stated by the construction manager.

4.2.9. Findings from Site 9

Cement bags, construction waste in general and mortar were more common material wastes at this site. The reason for this material waste is the building process and unskilled subcontractors. The method used to eliminate waste was to appoint a subcontractor to remove and recycle waste from the site. The action taken to prevent waste occurring on site was by doing the job once and avoiding reworks. The strategy used for waste management was charging for waste generated by sub-contractors as shown in Table 4.2.

The waste generated on site impacted the cost and time of the project, which might cause project delays and increase the cost to remove waste. Lean waste on this site was defects and the lean principle was used to reduce waste. The lean thinking tool used to reduce waste was value stream mapping. Unforeseen circumstances, equipment breakdown and shortage of materials were the challenges of adopting a lean approach. This project's contract did not include a waste management plan. Recycling was said to be the most effective method for controlling the building waste, to do the work correctly first time, and avoiding re-work.

4.2.10. Findings from Site 10

The material wastes were bricks and mortar that are prevalent on this site. The reason for the waste being generated frequently was due to unskilled subcontractors. The causes of physical waste at this site have been design changes and variations. The method used by the contractor to reduce waste on site was to reuse and recycle waste materials. The actions taken in conjunction with the waste arising from the site were to charge the subcontractor the cost to remove waste. The strategy for waste management consisted of the use of waste management plans, which define on-site waste control procedures. The benefits of adopting this strategy, decreased expenses, and maximizing profit as presented in Table 4.2. Practical completion (PC) of the project is put at risk and further delays may result in the project’s contract penalty clause.

The lean wastes that often happens on this site were defects and over-production. This project did not apply lean approach to minimise waste. In this project contract, no waste management plan was required. The application of lean construction and training subcontractors were suggested to be the most effective methods to controlling waste on site

Table 4.2: Synthesis of the results of the interviews

INTERVIEW QUESTIONS AND ANSWERS	**CONSTRUCTION SITES**									
	Site 1	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**	**Site 7**	**Site 8**	**Site 9**	**Site 10**
	1. How many years of experience do you have as a construction manager?									
	27 years	10 years	18 Years	15 years	24 years	13 years	16 years	18 years	10 years	22 years
	2. Which material wastes occur frequently on your site?									
	Builders' rubble	Half bricks	Cement bags	Concrete and bricks	Concrete and wet trades	Concrete	Formwork, concrete, bricks, sands	Bricks and mortar	Mortar	Concrete and bricks
	3. What could be the reason for them to occur more frequently?									
	Normal waste arising	Unskilled labours and negligence	Unskilled workforce	Skill level and excessive speed of execution	Lack of skills and design changes	Poor Supervision	Lack of supervision, poor management, and planning	Unskilled subcontractors and labour	Work process, and unskilled subcontractors	Unskilled subcontractor
	4. What are the main causes of physical waste on the construction site you are working on?									
	Poor Material handling	Poor Site condition	Poor supervision	Incorrect work and drawing revisions	Accelerated working pace	Incorrect works	Incompetence and poor communication	Poor planning	Construction process	Changes of design and variations
	5. What are the methods used on your project to minimize construction waste?									
	Proper material handling	Reduction of off cuts	Proper quantification of material to be used	Adequate quality control	Reuse and recycling of waste	Proper planning	Toolbox meeting	Reuse waste materials	Reuse and recycling of waste	Reuse and recycle some materials
	6. Which actions do you take with regard to the construction waste that arises on your site?									
	Weekly toolbox meeting	Reuse waste	Waste are disposed in a waste bin	Issuing of non-conformance	Using waste skips	Removal of rubbles	Cost report figures and cash flow	Issuing of non-conformance	Avoiding reworks	Charging subcontractor

	7. Which strategies are you using to control construction waste on site?									
	Waste material put into streams	Buying materials when needed	Following the engineer’s mix design	Hands on control	Stop payment for subcontractors	Continuous housekeeping	Encourage good workmanship	Waste awareness	Penalise subcontractors	Applying waste management plan
	8. What are the benefits of implementing those strategies?									
	Prevent pollution	Saving money and increase in profit	The wastage is reduced	Increase profitability of main contractor	Overall cleaner site, recover losses from skips and wastage	A clean site/ environment	Good turnaround time and good profit	Save on cost of waste removal, and reduce pollution	Reduce land pollution	Reduce cost and maximise the profits
	9. Does waste that arises on your construction site have an impact on the cost and time of the project?									
	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	10. What are the impacts on those two variables of time and cost?									
	Late PC and extra cost	Time delay and additional cost	Increase cost and project duration	Wasteful expenditure and time overrun	Additional cost and project delays	Increase in project duration and extra cost	Target date is not met, and the project runs on a lose	Project delays and additional costs	Cause delays due to waste and extra cost for waste removal	Late PC and extra cost
	11. What are the types of lean wastes which happens frequently on your construction project?									
	Over-production and defects	Defects	Over-production	Over-production, motion, over-processing, and defects	Defects	Over-production, transport, and defect	Over-production, defects, waiting and underutilization	Over-production and defects	Defects	Over-production and defects
	12. Do you apply lean construction to minimise waste?									
	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No

	13. If yes, which lean tools do you use the most to reduce or eliminate the waste?									
	None	Just-in-time (JIT)	5S process tools	Process mapping method, just-in-time (JIT) and 5S process tool	Value stream mapping and just-in-time (JIT)	None	Value stream mapping, change management and just-in-time (JIT)	Process mapping method and just-in-time (JIT)	Value stream mapping	None
	14. Which are the challenges experienced when applying lean approaches in your projects?									
	None	None	Poor supervisory skills	Skills level and cultural diversity	Late issue of information	None	Time and communication	The culture and unskilled subcontractors	Unforeseen circumstances, breakdown, and shortage of materials	None
	15. Does the contract for this project require a waste management plan?									
	Yes	No	No	Yes	No	No	No	No	No	No
	16. If so, briefly describe the waste management plan.									
	Skips to waste that controls waste and plant on site	None	None	Rubble disposed in legal dumping site, and specialist subcontractor	None	None	None	None	None	None
	17. Which method do you think is the most effective for construction waste control?									
	Educating the team on lean construction and training labours	Accurate planning and Reuse of materials	Applying lean thinking	Continuous improvement	Training labours	Recycling waste	Waste awareness	Applying lean construction	Recycling and avoiding reworks	Applying lean and training labours

CHAPTER 5: DATA ANALYSIS AND DISCUSSION

5.1. Introduction

The objective of this chapter is to discuss and analyse the results in relation to the aims and objectives of the study. The themes included in the interview questions have been derived from the literature review and the discussion evaluates the outcomes of the interviews with this literature.

In this section data is analysed using the Microsoft excel coding method. The data has been coded and arranged according to the themes derived from the literature review, which formed the structure and content of the interviews. The data obtained from 10 sites, as described in the previous chapter, reveals that there is quite a variety of waste control strategies used at construction projects in Gauteng.

5.2. Material Waste

Table 5.1: Most common material waste on site - A comparison of 10 sites

Material Waste	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**	**Site 7**	**Site 8**	**Site 9**	**Site 10**	**Total**
Concrete				X	X	X	X			X	5
Bricks		X		X	X		X	X		X	6
Formwork							X				1
Cement			X								1
Mortar								X	X		2
Builder’s rubbles	X										1
Sand							X				1
Plaster					X						1
General waste									X		1

Material Waste	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Total
Plastics and boxes (from supplier)					X						1
Cement bags (from the supplier)	X								X		2

Rubble, half bricks, concrete, and brick work (wet trades), formwork, mortar and general waste were the types of material waste mentioned by the participants that arise on sites. Moreover, cement bags, plastics and boxes were sources of material waste emanating from the suppliers. Most common waste materials cited in the data gathered from the construction managers were concrete and bricks. Concrete was the material waste that occurred at 5 sites and bricks at 6 sites, as shown in Table 5.1. While the material wastes that arose at 2 sites examined were mortar and cement bags originating from the suppliers. The material waste that was not common on the sites were formwork, builders' rubbles, sand, general waste, plaster, and plastics, as well as boxes coming from the suppliers. Participants clarified that concrete waste happens when it is poured at a wrong level that induces breakage and rework, and ordering more than the needed concrete, which results in the discarded concrete being wasted. In addition, brick waste in the building sites that are part of the study happens as bricklayers break the brick in half and do not use the remaining half.

Furthermore, it can be inferred that, according to the data gathered, the types of material waste that occur most frequently in Gauteng building projects are concrete and brick waste. One of the respondents mentioned that the reasons for these types of material waste to appear more often have been because there is often waste on building projects, such as brickwork and plasterwork. The respondent simply means that waste is inevitable in construction and just part of doing the job. The management and workers believe that waste is unavoidable due to the complexity of the project (Ajayi et al., 2015; Osmani et al., 2008).

Nagapan et al. (2012) divide waste types into two categories, namely physical and non-physical waste, where physical waste includes rubble, demolished debris, scrap metal and others. In addition, non-physical waste involves the project cost and time. According to Nagapan et al. (2012), the non-physical waste occurring on site are caused by poor financial management, wrong construction specifications, lack of supervision and project delays. The respondents claimed that the lack of supervision on their construction sites contributed to reworks, which resulted in additional costs and prolonged duration of the project.

However, most of the sources from the literature focus on material waste rather than non-physical. For example, Yuan et al. (2013) define waste as any material arising from construction work, e.g., concrete, bricks, mortar, and others. Tam et al. (2007) describe waste as a by-product of building waste, which includes concrete, rubble, plastics, bricks, and others. The types of materials waste that occurred in the projects within examination, namely concrete, wood, brick, and steel, are listed by Hajj and Hamani (2011). The comparison of the material waste from the collected data and the literature is similar. In conclusion, it can be deduced that construction managers see concrete and brick waste as the most prevalent on-site waste when comparing literature and data obtained.

5.3. Main Cause of Physical Waste

Reasons for material waste to appear more often include poor material handling, unskilled subcontractors and workers, incompetence and inexperience, poor communications, speed of execution, change of design, poor supervision, poor management and planning, and the working process in general. Poor material handling is said to be the major source of waste at one of the sites. The respondent clarified that materials were not kept in a convenient location and the method of unloading materials is poor, which can lead to a breakage causing material waste. This is consistent with Poon and Jaillon (2009), who assert that improper handling of materials can contribute to building waste. Moreover, Eze et al. (2017) note that poor handling of materials could result in waste during the delivery process. Nagapan et al. (2012) and Formoso et al. (2002) claim that uneconomical material cutting could create waste on site. Therefore, by comparing gathered data and literature, poor handling of materials is consistently said to be the main cause of waste.

Unskilled subcontractors and workers have been mentioned as a significant obstacle in the construction industry in the province of Gauteng. Construction workers are unskilled and do incorrect work, so rework needs to be performed in order to repair the same work leaving the waste after the incorrect work is demolished. Many of the construction workers are incompetent and inexperienced in carrying out building projects, which is a problem that needs to be addressed in order to produce a successful job, and for waste to be avoided in order to keep the project within budget. Al-Hajj and Hamani (2011) and Nagapan et al. (2012) report that shortage of skilled labours, lack of training for staff, incompetent and inexperienced staff are factors leading to the generation of waste. It can therefore be inferred that unskilled workers, inefficient and inexperienced workforce are the key causes of waste, as the literature is consistent with the findings of the interviews.

Poor communication at one of the sites was seen as a factor leading to waste, for example, whenever there is no instruction given to workers to proceed to the site resulting in schedule delays affecting the project duration. This can also arise because the building manager cannot supply the foreman with information on time, for example, whenever there are design changes and the foremen use the outdated drawing, this leads to wastage in that the work needs to be demolished. Osmani et al., (2008) also concur that the main causes of waste on site are poor coordination, communication, and the late distribution of updated drawings. Moreover, Wahab and Lawal (2011) find that last-minute changes in client requirements contribute to design variation resulting in waste.

The excessive speed of execution can also play a part in building waste by attempting to get work completed rapidly and neglecting quality and precision, which leads to rework in most cases. Eastham (2002) points out that one of the major risks associated with fast-tracking in construction is the enormous amount of waste generated. Kasim et al. (2005) mentioned that the fast-tracking of a project can result in poor material handling when the fast-tracking method is not managed properly. This occurs when receiving materials before they are required, causing more inventory cost and chances of deterioration in quality. Park (2002) also stated that the ineffective handling of fast-tracking on a project might lead to reworks. Therefore, the fast-tracking on site can be effective when there is adequate material handling (Kasim et al., 2005). Nagapan et al (2013), mentioned that inappropriate construction methods, poor information quality, rework, and lack of knowledge about construction can be factors of waste generation.

Change of the design adds considerably to the building waste, which occurred on most sites as updated plans were issued, meaning that the waste might result in changes to the project, either increase or decrease construction works. Esa et al. (2017) emphasised that frequent design changes may also lead to the generation of waste in construction projects. The other design factor is when the architect or engineer specifies an element that is not a standard size, that contributes to construction waste on site. Bossink and Brouwersz (1996) stated that the design factors involve, among other things, include insufficient considerations of the dimensions (size) of building materials. If there is extra work as per the revised drawings, additional material will have to be procured with variation orders, whilst the reduction of work as per drawings will result in surplus materials bought on site. Al-hajj and Hamani (2011), stated that frequent variation orders also contribute to construction waste generation in the literature above. Consequently, variation orders create extra costs by purchasing additional project materials.

The other main causes of the reported waste fall under the management category, namely poor supervision, inadequate management, and poor planning. Poor supervision is the key factor found in the construction projects in Gauteng, which occurs when the construction manager does not supervise the work such that it is carried out correctly by the construction workers. Inadequate management arises whenever the building manager cannot manage the personnel and site workers adequately to produce a successful project. Bad planning is also a contributing factor that requires consideration, ensuring that the planned activities are carried out according to the schedule. Lack of management and supervision are some of the management problems that cause waste reported by Osmani et al. (2008). The factor mostly emphasized by the respondents was unskilled subcontractors resulting in poor supervision.

It is of the highest significance that the construction manager considers the main reasons for eliminating the continuation of construction waste on site. Hwang and Yeo (2011); Nagapan et al. (2012) state that the reasons for reducing waste are cost saving, profit maximization, and reduced demand for landfill space. Construction waste reduction creates productivity and quality improvement, improved resource management, and image improvement (Hwang and Yeo, 2011).

As per Table 5.2, unskilled labour or subcontractors was the main cause that occurred prevalent at 7 sites. While poor supervision and design changes were the major causes of waste happened at 3 sites. Poor planning and management, excessive speed of execution or accelerated working pace, and incorrect work were main causes identified at 2 sites. Poor site condition, negligence, normal waste arising, incompetence, poor material handling, and frequent variations were the uncommon causes of waste, each happens in 1 site, respectively. Therefore, the most common cause of the comparison is unskilled labours.

Table 5.2: Comparison of main causes of physical waste

Site	**Main causes of waste**
Site 1	Poor material handling and normal waste arising
Site 2	Unskilled labours, negligence, and poor site condition
Site 3	Unskilled workforce and poor supervision
Site 4	Skill level, excessive speed of execution, incorrect work and drawing revisions
Site 5	Lack of skills, design changes, and accelerated working pace
Site 6	Poor supervision, and incorrect works
Site 7	Lack of supervision, poor management and planning, incompetence, and poor communication
Site 8	Unskilled subcontractors and labour, and poor planning
Site 9	Construction process and unskilled subcontractors
Site 10	Unskilled subcontractor, changes of design and frequent variations

5.4. Methods, Actions, and Strategies Used to Minimise Waste

Construction managers from the 10 sites interviewed mentioned various methods for waste reduction. Methods for adequate handling of the materials include: the unloading of bricks by means of a crane to prevent breakage; the storing of cement in a protected storage area; and the proper stacking of materials. Urio and Brent (2006) state that effective care should be taken in handling the materials on site. The second method described by the respondents is reduction in off cutting as another way to reduce waste.

The respondent at one of the sites said that off cutting is the approach used to reduce waste. The off cutting occurs when elements delivered to site are of incorrect size or workers selecting an element that is too long and cutting it down to size. Nagapan et al. (2012) mentioned that design errors such as incorrect size have to be avoided to minimise construction waste. On one of the sites, cost reports and cash flow estimates were prepared to assess whether there were any extra expenses generated at the project. Delivery of quality work eliminates waste, as there will be no errors that need to be reworked. Eze et al. (2017) mention that to minimise waste, when procuring materials, the individual in charge of procurement specifies the quality, accurate quantity, delivery time and method, and packaging method.

It is essential that the material procured must be ordered in the correct quantity in order to avoid the procurement of more materials. Osmani et al. (2008) said that the ordering errors can be avoided through ordering the correct materials as per the design specifications, and an adequate quantity of the materials. Nagapan et al. (2011) mentioned that proper material ordering plays an important part and helps to reduce material losses and damage for construction projects.

The efficient management of subcontractors at the micro level on the project minimizes waste. Managing subcontractors at the micro level is when the construction manager closely observes or controls the work of the subcontractors. Therefore, to minimise waste there should be efficient management during the construction phase (Esa et al., 2017). Adequate planning and supervision are the methods in which the management of the site can be used to reduce waste at the site. Site walkabout, photographic reports and encouraging good workmanship were strategies stated by one of the participants.

Another approach used by the construction managers interviewed, which is seen to be effective in Gauteng, is the re-use of material waste arising on sites and effective planning. Formoso et al. (2002) state that there should be an increase in the management capability of organizations at the planning, procurement, supervision, and development levels to minimise waste on site. The strategy used by the respondents are ensuring that the design of the engineering mix is implemented and obliging subcontractors to follow the revision drawings. Nagapan et al. (2012) said that the contractor and subcontractors are required to follow the designs to avoid building waste from occurring and to prevent reworks.

The actions taken by the construction managers on waste arising on site were weekly toolbox meetings with all the subcontractors on site to educate them on all the material waste and charging subcontractors for excessive waste. Osmani et al. (2008), state that unskilled labourers should be educated and trained in order to minimise construction waste. Moreover, Sertyesilisik et al. (2012) state that there should be agreements between contractors and sub-contractors to determine who is responsible for waste on-site. Therefore, if the subcontractor is accountable for waste arising, it means that the subcontractor should be charged for the waste (Sertyesilisik et al. 2012).

The disposal in a waste bin or skip and then dumping waste on legal landfills site was another action taken by construction manager. The strategies used by the construction personnel interviewed is to hire skips from waste firms, to employ waste disposal companies and to separate waste according to material streams for recycling purposes. In addition, issuing of non-conformance certificates and informing foremen of the financial implications that concrete waste has on projected possible profit margins were methods cited by one of the respondents. Tam et al. (2006) mention that if subcontractors are not complying to waste management plan, a non-conformance certificate should be issued. Correspondingly, a dedicated collection area should be established at the site where the debris can be stacked up and disposed of on a regular basis, continuous housekeeping should be carried out on site on a daily basis and quality assurance systems should be applied. Urio & Brent (2006) state that storage facilities and transport routes at the site must be planned properly. Thus, the responses from the Gauteng construction managers is largely consistent with the literature on the topic of appropriate storage and disposal of construction waste.

The key point most highlighted by the participants is the training and educating of site workers on waste control and prevention. The most focused strategy of the participants in Gauteng was to promote quality practice to eliminate waste. Therefore, the objective of identifying the strategies used in construction sites in Gauteng has been reached. If the above methods are incorporated, the waste can be significantly reduced in the Gauteng province.

Table 5.3 represents the main cause of physical waste, actions taken, and methods used to minimise waste on site as per the sites that participated in the study.

Table 5.3: Methods, actions, and strategies used to minimise waste

Sites	**Methods**	**Actions**	**Strategies**
Site 1	Proper material handling	Weekly toolbox meeting	Waste material sorted in streams
Site 2	Reduction of off cuts	Reuse waste	Buying materials when needed
Site 3	Proper quantification of material used	Waste are disposed in bins	Following the engineer's mix design
Site 4	Adequate quality control	Issuing of non-conformance	Hands on Control
Site 5	Reuse and recycling of waste	Using waste skips	Stop payment for subcontractor
Site 6	Proper planning	Removal of rubbles	Continuous house keeping

Sites	Methods	Actions	Strategies
Site 7	Toolbox meeting	Cost reports figures and cash flow	Encourage good workmanship
Site 8	Reuse material waste	Issuing of non-conformance	Waste awareness
Site 9	Reuse and recycling of waste	Avoid reworks	Penalise subcontractors
Site 10	Reuse and recycle some materials	Charging subcontractors	Apply waste management plan

5.5. Benefits of Waste Reduction

The advantages of the use of the above methods and strategies are cited by the respondents to be to prevent land pollution, to minimize costs and to save resources as shown in Table 5.4.

Table 5.4: Benefits of implementing waste minimization strategies

Site	Benefits
Site 1	Prevent pollution
Site 2	Saving money and increase in profit
Site 3	The wastage is reduced
Site 4	Increase profitability
Site 5	Overall cleaner site, recover losses from skips and wastage
Site 6	A clean site or environment
Site 7	Good turnaround time and good profit
Site 8	Save on cost of waste removal and reduce pollution
Site 9	Reduce land pollution
Site 10	Reduce cost and maximise the profits

Waste reduction provides overall cleaner site. Vilasini et al. (2011) and Marhani et al. (2012) mention that less pollution would occur in the natural environment by minimizing waste generation. Improving the main contractor and subcontractor's profitability, and speed of execution were the benefits experienced on the assessed sites. Benefits for waste reduction are a good turnaround period for the project deadline and incentives for the team involved.

According to Nikakhtar et al. (2015) and Aziz and Hafez (2013), waste management at the site benefits the construction firm by increasing profits and that the project can be executed in accordance with the schedule planned. The advantage most participants claimed was maximizing the construction company's profitability.

5.6. Cost and Time

All the construction managers interviewed reported that the waste had an impact on the cost and time of the project, as presented in Table 5.5. The impacts that occur for time are late practical completion date because waste takes up workspace that results in building work being delayed until it is cleared, which then increases project duration. According to Van Wyk (2014), most building projects face delays caused by waste related activities due to loss of workspace. Nagapan et al. (2012) stated that construction waste can lead to time overrun when more critical construction works are stopped to clean the space with the generated wasted.

Table 5.5: Impacts on cost and time

Site	Cost	Time
Site 1	Extra costs	Late practical completion
Site 2	Additional cost	Time delay
Site 3	Increase in cost	Increase on project duration
Site 4	Wasteful expenditure	Time overrun
Site 5	Additional cost	Project delays
Site 6	Increase in project cost	Increase in project duration
Site 7	The project runs on a lose	Target date not met
Site 8	Additional costs	Project delays
Site 9	Extra costs	Project delays
Site 10	Extra costs	Late practical completion

Costs are affected when there are waste expenses like extra supervision costs, cleaning costs, penalty clause for reaching practical completion late, skip and transportation cost for dumping waste, according to the construction managers who were interviewed. This waste expenses thereby contribute to a drastic spike in project costs. Wortmann (2014) states that economic disadvantages of building waste include transportation costs into and out of the sites, waste handling expenses (labour costs), waste storage costs, waste disposal costs, loss of revenue from non-recovery of waste materials (Wortmann, 2014).

Bossink et al. (2017) mentioned that construction waste does have consequences to the project finances. The consequences that happen when waste is created to the project are additional costs. The additional costs are from the purchase losses, collection costs, transport cost, recycling costs and dumping costs (Bossink et al., 2017). According to Bossink et al. (2017) minimization of the amount of construction waste will lead to substantial savings. Adewuyi and Otali (2013) state that material waste accounts for between 20 and 30% of project cost overruns. Wortmann (2014), Adewuyi and Otali (2013), and Bossink et al. (2017) concluded that construction waste can lead to cost overrun. The respondents also mentioned that construction waste generated on site can lead to cost overrun.

In the words of the construction manager from site 6:

> *Time: allocating labour force to break concrete which was not planned for in the program. Allocating plant to remove rubble. Cost: waste collection/rubble removal is done more frequently than what was originally allowed for. TLB/Skid steer is removed from actual production driven activities to load the rubble truck. Cost will go up due to more time spent on production unrelated activities.*

The most discussed effect of waste on cost and time results is an increase in the cost of the project and an increase in the duration of the contract, placing the practical completion date at risk. The increase in the project cost arises as waste is produced on site, which contributes to increased expenses incurred to the activities associated with wastes, whereas the increase in duration occurs when labours take time to remove and clean waste, in which this time is not allowed for on the project programme. All of the respondents shared these views, consistent with many of the sources in the literature.

5.7. Lean Construction

According to the respondents from the construction companies interviewed, seven adopted a lean approach, while three replied that they did not apply lean construction to their sites. For sites that do not use lean, they allege that their construction companies are going to start using lean because it has good benefits. Therefore, it is clear that there is widespread knowledge about lean construction and its benefits. The forms of lean waste encountered at these sites are shown in the Table 5.6. As seen in the table 5.6, overproduction and defects were the most prevalent lean categories of waste in the sampled sites. Seven of the sites identified overproduction as occurring and the occurrence of defects has been identified at nine sites, suggesting that defects have a huge impact on the cost or duration of the project.

The construction managers who applied lean philosophy, mentioned the lean tools implemented at their sites being just-in-time (JIT), 5S process tool, process mapping, value stream mapping, and change management. Common lean tools used in the construction industry in Gauteng province according to the data collected are just-in-time, 5S process tools, process mapping, value stream mapping and change management. The lean tools seen in the following Table 5.6 had to suggest that just-in-time (JIT) is Gauteng's most widely used tool, being used at five of the sites. Bamana et al. (2019) mentioned that just-in-time (JIT) tool consist of providing the appropriate materials in the right amount and quality as required to minimize waste and provide maximum value. Just-in-time is the most popular because it prevents overproduction, minimising waiting times and transport costs, and dispensing with the need for inventory operations. Just-in-time has the benefit of reducing inventory and waste coming from poor storage and potentially overhandling.

The value stream mapping (VSM) tool is utilized at three of the sites as shown in Table 5.2. The value stream mapping tool, according to Goetsch and Davis (2014), is a tool which uses symbols to describe a value stream. The most important goal of value stream mapping tool is identifying opportunities for improvement for future periods (Pradeepkumar and Loganathan, 2015).

The process mapping tool is used at two of the sites as presented in Table 5.2. The process mapping tool is used to define the level of concern for waste reduction at the construction site (Vilasini et al., 2011). The process mapping tool is significant in the construction industry, it shows the sequence of activities of the project and activities can be grouped into two, namely value-adding and non-value adding activities (Nikakhtar et al., 2015). The benefits of using process mapping are communication improvement amongst the project’s team, improves the understanding of the process, and present the project plan.

The 5S process tool is used at two of the sites as shown in Table 5.2. The 5s process is described as a method to ensure a safe and orderly workplace, which encourages high performance and constant improvement (Goetsch and Davis, 2014). The importance of 5S process tool is creating more storage space, quicker access for materials, less in-site transportation, and improvement of health and safety (Nikakhtar et al., 2015; Sarhan et al., 2017).

According to Nikakhtar et al. (2015); Inge and Waghmare, (2015); Dos Santos and Powell, (1999); Aziz and Hazef, (2013) the lean tools which have been used extensively in construction are poka-yoke (mistake proofing), 5S process, and just-in-time. Most of the construction projects are applying just-in-time method tool, as there is no cost, and can be applied by the construction managers (Bamana et al., 2019). While value stream mapping and process mapping tools require specialized expertise and staff to map on site (Pradeepkumar and Loganathan, 2015). The 5S process tool is a management initiative, cost effective and easier to implement on a construction site (Sarhan et al., 2017). Therefore, value stream mapping and process mapping can be used together, as both of them use maps for the project activities. The common lean tools from the literature and the collected data are just-in-time and 5S process tools in most countries.

The data collected as in Table 5.6 shows that 7 sites do apply lean construction to reduce construction waste whereas 3 sites do not use lean tools, as they still make use of the traditional construction technique. The 3 sites which do not apply lean tools, still utilise traditional management systems which are extremely characterised by a high level of waste in the construction industry, leading to low performance, cost, and time overruns. While the 7 sites that do apply lean tools have shown an improvement in waste elimination resulting to cost saving, the project meeting practical completion date, and adequate production on site.

Table 5.6: Types of lean waste experienced at the sites interviewed

Sites	**Types of Lean Waste**	**Lean Tools**
Site 1	Overproduction and defects	None
Site 2	Defects	Just-in-time (JIT)
Site 3	Overproduction	5S process tools
Site 4	Overproduction, motion, overprocessing and defects	Process mapping method, just-in-time (JIT) and 5S process tool
Site 5	Defects	Value stream mapping and just-in-time (JIT)
Site 6	Overproduction, transport, and defects	None

Sites	Types of Lean Waste	Lean Tools
Site 7	Overproduction, defects, waiting and underutilization	Value stream mapping, change management and just-in-time (JIT)
Site 8	Overproduction and defects	Process mapping method and just-in-time (JIT)
Site 9	Defects	Value stream mapping
Site 10	Overproduction and defects	None

Bajjou et al. (2017) did a comparison of traditional construction and traditional construction. The comparison shows that traditional construction focuses only on the activities of conversion or transformation; neglects the non-value-added activities, lacks a waste elimination culture, and uses a push strategy (Bajjou et al., 2017). Push strategy is closely tied to material requirement planning (MRP), where production schedules for each workstation in a production chain are developed centrally (Kalsaas et al., 2015; Bajjou et., 2017; Nikakhtar et al., 2015). Whereas the lean construction its mastery of the entire construction process (flows, steps of conversion); take into consideration the value-added activities and activities with non-value-added; identification and elimination of all forms of waste throughout the project life cycle (design, construction, and demolition) and applies to pull strategy (Bajjou et al., 2017). Pull strategy is defined as a downstream work process that pulls materials from an upstream process (Kalsaas et al., 2015; Bajjou et., 2017; Nikakhtar et al., 2015).

From the construction firms applying lean construction, challenges faced were poor supervisory skills, skills level of the people working for subcontractors, cultural diversity, late issue of information, time and communication, unforeseen circumstances, equipment breakdown, and shortage of materials. The cultural differences in the interviews include production, the construction site, and the techniques of construction, which some use traditional and modern building methods. The implementation of lean approach from the collected data aligns with one of the objectives of this study, which is to identify main types of construction waste from the lean construction perspective. The types of lean waste found from data include overproduction, defects, motion, overprocessing, transportation, waiting and underutilization.

5.8. Waste Management Plan

Just two of the respondents said that the waste management plan (WMP) was required by the contract. The two participants required by contract elaborated on the waste management plan, which included waste management skips, onsite work in some places to prevent contaminants from infiltration into the soil, rubble waste disposal at a legal dumping site and the recruitment of specialist subcontractors for waste disposal. However, the remaining eight respondents said the waste management plan was put in place by the construction company but not required in the contract. The eight participants indicated that the purpose of the waste-management plan drawn up is to ensure the management, reuse, recycling, or disposal of waste in site that is in accordance with regulations and waste management acts. There is a difference between those who have a waste management plan required by a contract and those that the contract does not require a waste management plan. The contract that requires a waste management plan, ensures that the implementation of WMP is applied and that the contractor full compliance accordingly to the WMP drafted. In contrast, the contract that does not require WMP gives the contractor the impression that WMP does not have to be enforced, even though it is in place, it is not contractually binding. Therefore, the waste management plans for eight sites consist of methods to be used for the material waste arising, strategies for material waste minimization, record keeping of the quantity of waste, and waste awareness to the construction workers.

According to Hwang and Yeo (2011), the waste management plan is explained as a "strategic document drawn up for achieving the objectives of waste management and waste prevention and recovery", adding a limitation of the environmental impact of waste on human health and the environment. Wilson et al. (1998) stated that the project's examined had the designated areas for storage of goods and waste bins. The contractor drafted a waste management plan explaining the company policy, staff responsibilities, and procedures to be adopted and designed to meet and exceed the company's current obligations under the Environmental Protection Act 1994 (Wilson et al., 1998). In general, to be effective, CDW management plans must be accompanied by regulation and enforcement practices, or economic drivers, such as taxes, levies, etc (Gálvez-Martos et al., 2018). When the waste management plan is in place and assigned execution responsibilities to designated people, it assists to an effective management of construction waste in construction projects (Poon, 2007). Osmani et al. (2008), mentioned that if there is effective planning of waste management, the waste problem to the environment can be minimised. When comparing the waste management plan for the participants and the authors from various literature, methods, and strategies used are similar such as recycling, reuse, and disposing of waste.

5.9. Effective Methods to Minimise Waste

The participants described the approaches most efficient for controlling building waste as proper planning, training, use of the waste firms specializing in waste, correct material handling and re-use, as show in Table 5.7.

Table 5.7: Most effective methods for construction waste control

Site	Most effective methods
Site 1	Educating the team on lean construction and training labours
Site 2	Accurate planning and reuse waste materials
Site 3	Applying lean thinking
Site 4	Continuous improvement
Site 5	Training labours
Site 6	Recycling waste
Site 7	Construction waste awareness
Site 8	Applying lean principle
Site 9	Recycling and avoiding reworks
Site 10	Apply lean approach and training labours

Furthermore, lean construction, continuous development, skills enhancement (training staff), sharing the duties, well managed and implemented waste management plans, using recycling companies and doing work right first time to avoid rework are also effective methods. Nikakhtar et al. (2015) say that the most effective method of reducing waste is the lean principle implementation. It has been noted by Esa et al. (2017) that effective approaches often include proper planning, waste management execution, efficient management during construction and appropriate construction methods. Urio & Brent (2006) assert that the materials should be handled appropriately, while Osmani et al. (2008) conclude that educating and training of stakeholders are the most efficient methods of waste control on site.

The construction manager on site 6 asserted the following:

> *Recycling waste. Waste concrete can be taken to the following suppliers for reuse: a) Ready mix suppliers so that they crush the concrete and reuse for batching once the fines and aggregates are separated from the crushing machine. b) A quarry so that the concrete can be crushed and supplied/used as a G grading (G4, G5, G6 material) used for backfilling or on roads/earthworks projects.*

In line with many of the sources in the literature, as discussed above, the respondent from site 7 made the following comment:

> *Make everyone involved on the project* [understand] *the value of the presence on the project and duration when should the project be completed, daily meeting with staff and once off monthly meeting with labour force creating an awareness on site regarding the waste with posters and safety toolbox talk meeting. Educating everyone involved on the project about the wastage and how it can impact the production, future work, and income.*

In conclusion, training subcontractors, labourers and other staff for waste handling and implementation of lean construction are the methods most stated by the participants.

5.10. Concluding Remarks

This research aims to achieve a greater understanding of how waste can be minimized or eliminated by lean strategies from construction projects in the province of Gauteng. Lean construction is not utilized by all construction firms in the Gauteng province. This demonstrates that in Gauteng province there still is an opportunity to incorporate lean building principles and practices in the operations of construction companies. This can be achieved by lean construction training, although some of the construction managers consulted have little understanding or knowledge as to what the meaning of lean construction is. The types of lean waste that occur regularly at the Gauteng sites are overproduction and defects. The lean tool used most often to minimize the amount of waste found in the projects that participated was just-in-time.

This then gives the impression that there is still a lack of lean knowledge in Gauteng. It is crucial that lean should be more widely considered in the South African construction industry in order to minimize waste. The literature indicates that, through evaluating studies undertaken in other foreign construction firms, lean shows promising results. That being said, there are stated challenges in the implementation of lean construction in Gauteng Province, which include weak supervisory abilities, the level of skills of people (especially subcontractors), cultural diversity (quality of workmanship), late delivery of information, communication, unexpected circumstances, equipment breakdown and scarcity of materials.

From the data collected, waste material that happens most frequently in Gauteng construction projects is concrete and brick waste. Unskilled labour and subcontractors are attributed to be the main source of physical waste in Gauteng province. The main method that has been used to reduce waste by the participants of this study is the training of site staff on waste management. The most mentioned strategy by the participants was to promote the quality practice of the construction work. The benefit mentioned by most participants is to increase the profitability of the construction company. The most reported impact of waste was an increase in the cost of the project and a rise in the duration of the contract, putting the practical completion date at risk. The waste management plan as demanded in the construction contract was in place at two of the sites which interviews were done, although respondents of the eight sites said that their contracts does not require waste management plan, the WMP document was drafted by the construction company to internally be applied by the site workers.

CHAPTER 6: CONCLUSION AND RECOMMEDATIONS

6.1. Introduction

The purpose of this chapter is to present the conclusions drawn from the results of the qualitative analysis of the structured interviews and then make recommendations for further research. The study findings from 10 sites are related to the aim and objective of the study. They also address the problem statement of the study and answer the research question set out in chapter 1. Extensive literature was consulted to provide a background on waste control in building sector within Gauteng province and internationally. Pertaining to the aim of the study, the research design has the following main features: structured interviews, divided into themes, and coding as a data analysis method. These research results can help to understand the current situation regarding the control of construction waste in Gauteng and can therefore help to improve the control of construction waste on site.

6.2. Conclusion

All ten construction managers interviewed for the study have more than 10 years of experience. The results of the research answered the question of how construction managers control on-site waste and limit waste generated on-site that ends up in landfills. The interviewees explained the methods used to control waste at their respective sites. The aim of the study was to establish a better understanding of how to reduce or eliminate waste in building construction projects in the Gauteng province through the application of lean techniques. The aim of the study has been achieved. Lean waste types, lean tools and challenges faced towards the implementation of lean approach have been identified. The results indicate that few lean tools are used in construction sites at Gauteng province.

In addition, the first objective set out in Chapter 1 was to define the causes of construction waste and the strategies used by construction managers to manage the generation of waste during the construction process. As can be seen in the results presented in Chapter 4, the common causes of waste are poor materials handling, unskilled subcontractors/workers, incompetence and inexperience, poor communication, excessive speed of execution, change of design, poor supervision, poor management and planning, and the working process in general. The methods utilized by construction managers to manage waste generation during construction process are effective material handling, avoiding offcuts, proper quantification of the material used, ensuring quality of work, effective management of subcontractors on a micro level, minimization of waste by doing the task once, ordering just enough material, adequate planning and supervision, reuse and recycle of waste. Most of the respondents stated that the re-use and recycling of waste material would significantly reduce waste disposal in landfills. The construction managers mentioned that the re-use of waste materials creates savings of the project cost while some of the waste materials are sold for recycling, generating income for the construction firm while reducing the volume of waste sent to landfills. Consequently, these main causes of waste and waste control methods are similar to the literature by authors such as Nagapan et al. (2012), Formoso et al. 2002 and Osmani et al. (2008).

The second objective, which is to determine sustainable methods which can be implemented in waste control through the construction stages and site management measures which can create efficient waste on construction projects, has been accomplished. Sustainable methods and site management initiatives that are determined in this study are the use of waste management firms on site, use of waste firms that separate waste based on material sources and use of a waste management plan. According to Yunpeng (2011), a waste management plan should be prepared and submitted to government officials by the contractors to supervise them in compliance with the approved waste management plan. Therefore, the most effective method answers the research question in chapter one in which the answer can be stated to be training staff and implementation of lean thinking.

The third objective is to explore how top management in construction can play a role in minimization of waste. This study reveals that top management plays a role in reducing waste through adequate planning, efficient management, and effective supervision. Formoso et al. (2002), Nagapan et al. (2012) and Udawattaa et al. (2015) mention that there should be an effective planning, adequate procurement, proper supervision, and efficient management to minimise on site. However, lean thinking also deals with leadership challenges on the management aspect. The lean tool which can resolve management problems is last planning system (LPS) tool. According to Paez et al. (2005), the last planner system has been demonstrated to be a very useful tool for the management of construction process and continuous monitoring of the planning efficiency. Zhang and Chen (2016) define LPS as a tool to level out workload and improve the workflow reliability through engaging all members of the project team.

The fourth objective is to determine the main types and the volume of construction material waste in building projects in Gauteng province. The material waste which occurs more frequently during construction as per the findings are rubble, half bricks, cement, concrete and brick work (wet trades), formwork, mortar, and general waste. Cement bags, plastics and boxes are the material wastes from the supplier. The most common material waste identified by the respondents is concrete and bricks, and the generation of such material waste is high in volume. Nagapan et al. (2012) show that concrete and bricks are the most prevalent waste material that occurs on site.

The fifth objective is to determine main types of construction waste from a lean perspective in the building projects in Gauteng province and recommend lean techniques to improve waste management. Overproduction and defects were the most common types of waste identified by the respondents, and only seven out of ten sites use a lean approach for waste reduction. Just-in-time (JIT) and value stream mapping are most commonly used Lean tools in construction projects in Gauteng province as per the results. When applying a lean approach, there are challenges faced by the construction managers, which are poor supervisory skills, skills level of workers and subcontractors, cultural diversity (precise work), late issue of information, timeousness of communication, unforeseen circumstances, breakdown, and shortage of materials.

Additionally, all participants said that waste arising in their sites do have an impact on cost and scheduling of the project. These impacts are increase in expense of the waste related activities and the time to clean and remove waste from site result in project duration extension, then leaving the practical completion at risk. Respondents therefore note the benefits of minimizing or eliminating waste. The benefits from the findings are prevention of land pollution, the reduction of costs and savings of resources, the improvement in profitability of the main contractor and subcontractor, the speed of execution, an overall cleaner site, recovery of losses from skips and wastage, the elimination of waste, a good turnaround period for the project deadline, and incentives for the team concerned. The above-mentioned advantages include the prevention of land pollution, which addresses the research question of reducing the dumping of waste in landfill sites. The respondent stated that waste is inventible in construction projects and construction waste is part of construction works. Authors such as Ajayi et al. (2015) and Osmani et al. (2008) have backed these arguments in the literature, claiming that the management and staff believe waste to be inevitable because of the project complexity. Based on the qualitative analysis of construction waste, it can be concluded that there should skill upliftment for labours to prevent construction waste.

6.3. Recommendations

The main causes of waste emphasised are poorly skilled labours, poor planning, and inadequate supervision. Centered on the qualitative analysis of construction waste, it can be recommended that there should be skill upliftment for labour to prevent construction waste. Poor planning and lack of supervision should be handled by the management of the company to the degree that the party responsible for the project ought to be liable for any waste produced on site. When it comes to poor material handling on site, labour need to be charged for creating waste. Comprehensive consideration should be given to concrete and bricks, as they are cited as the most common waste materials at sites in this study.

As per the findings, not all construction managers seem to have the knowledge of what lean construction means: three sites do not use lean approaches at all. This is not surprising, as Monyane et al. (2019) indicate that the lean approach in the South African construction industry has remained scarce in the last two decades. The recommendation for on-site lean application would be for construction managers to take lean construction training. Lean construction has advantages in reducing waste on site and increasing the productivity of the project, as discussed in the literature by numerous researchers. The most effective methods that can be recommended for managing on-site waste is the implementation of a lean principle.

The lean tools to be recommend are value stream mapping and 5S process for construction managers to incorporate. Value stream mapping is recommended because it is a visual tool illustrating project activities and procedures, while the identification of waste is easier, process cycle times are minimized, and process changes are initiated. Furthermore, 5S process tool aims to clean and organize the workspace on site, while enhancing the standard for doing things onsite.

6.4. Limitation of the Study

The study had major limitations, which are as follows:

1. The limitation of non-probability sampling is that it's impossible to know how well you are representing the population, i.e., lack of representation of the entire population.
2. The limitation of lower level of generalization of research findings compared to probability sampling, difficulties in estimating sampling variability and identifying possible bias.
3. This study is the small sample size; there was difficulty in convincing a larger number of companies to participate where only 10 respondents were interviewed.
4. This study focused on lean tools implementation only in building's projects only.
5. The lack of practical application of the lean principle in Gauteng project construction projects

6.5. Areas for Further Study

The study has successfully identified the aims and objectives of the research on the methods and strategies used to control construction waste in Gauteng province. The methods and strategies identified are compatible with the current literature. As described above, the most common approaches have been defined as adequate planning, supervision and management, proper handling of materials and the implementation of a lean approach. However, lean construction also needs more focus in Gauteng province, to the point that construction personnel have to be trained on the lean concept. The recommendation for further studies will be on how small and large companies apply lean principle in the construction projects in within Gauteng province. This would include discussing the lean tools and their advantages at a level where construction managers have extensive knowledge of applying the lean concept for small and large construction projects. The study should also be expanded to other parts of the country and region.

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ANNEXURE A: ETHICS CLEARANCE CERTIFICATE

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R14/49 Rambuwani

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER: H20/07/38**
PROJECT TITLE	Waste Control in Construction Projects within the Gauteng Province
INVESTIGATOR(S)	Mr P Rambuwani
SCHOOL/DEPARTMENT	Civil Engineering and Environmental School/
DATE CONSIDERED	24 July 2020
DECISION OF THE COMMITTEE	Approved Risk Level: Minimal
EXPIRY DATE	19 August 2023

DATE 20 August 2020 **CHAIRPERSON** ____________________
(Professor J Knight)

cc: Supervisor : Professor A Fitchett

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University. Unreported changes to the application may invalidate the clearance given by the HREC (Non-Medical)

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to completion of a yearly progress report.**

____________________ **Signature** **Date** ______/______/______

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES

ANNEXURE B: PARTICIPANT CONSENT FORM

Title of project: Waste Control in Construction Projects within the Gauteng Province

Name of researcher: Phuluphedziso Rambuwani

I, …………………………………………………………., agree to participate in this research project. The research has been explained to me and I understand what my participation will involve. I agree to the following:

(Please circle the relevant options below).

I agree that my participation will remain anonymous	YES	NO
I agree that the researcher may use anonymous quotes in his / her research report	YES	NO
I agree that the interview may be audio recorded	YES	NO
I agree that the information I provide may be used anonymously after this project has ended, for academic purposes by other researchers, subject to their own ethics clearance being obtained.	YES	NO

……………………………………. (signature)
……………………………………. (name of participant)
……………………………………. (date)

……………………………………. (signature)
……………………………………. (name of person seeking consent)
……………………………………. (date)

ANNEXURE C: INTERVIEW QUESTIONS

1. How many years of experience do you have as a construction manager?

2. Which material wastes occur frequently on your site?

3. What could be the reason for them to occur more frequently?

4. What are the main causes of physical waste on the construction site you are working on?

5. What are the methods used on your project to minimize construction waste?

6. Which actions do you take with regard to the construction waste that arises on your site?

7. Which strategies are you using to control construction waste on site?

8. What are the benefits of implementing those strategies?

9. Does waste that arises on your construction site have an impact on the cost and time of the project?

10. What are the impacts on those two variables of time and cost?

11. What are the types of lean wastes which happens frequently on your construction project?

    a. overproduction,

    b. motion,

    c. transport,

    d. overprocessing,

    e. defects,

    f. waiting and

    g. underutilization waste.

12. Do you apply lean construction to minimise waste?

13. If yes, which lean tools do you use the most to reduce or eliminate the waste?

    a. value stream mapping,

    b. process mapping method,

c. poka-yoke,

d. change management,

e. just-in-time (JIT), and

f. 5 S process tools.

14. Which are the challenges experienced when applying lean approaches in your projects?

15. Does the contract for this project require a waste management plan?

16. If so, briefly describe the waste management plan.

17. Which method do you think is the most effective for construction waste control?

ANNEXURE D: MICROSOFT EXCEL DATA CODING

	A	B	C	F	G	H	I	J	K
1				Experience years	1	0			
2	Site 1	Construction Manager 1	1	**How many years of experience do you have as a construction manager?(Site 1_Construction Manager 1_1)**	1	1			
3	Site 1	Construction Manager 1	2	27 years(Site 1_Construction Manager 1_2)	1	1		CODES	
4	Site 10	Construction Manager 10	307	**How many years of experience do you have as a construction manager?(Site 10_Construction Manager 10_307)**	1	1		**Themes**	
5	Site 10	Construction Manager 10	308	22 years(Site 10_Construction Manager 10_308)	1	1			
6	Site 2	Construction Manager 2	35	**How many years of experience do you have as a construction manager?(Site 2_Construction Manager 2_35)**	1	1		Experience years	1
7	Site 2	Construction Manager 2	36	10 years(Site 2_Construction Manager 2_36)	1	1		Material waste	2
8	Site 3	Construction Manager 3	69	**How many years of experience do you have as a construction manager?(Site 3_Construction Manager 3_69)**	1	1		Main causes of waste	3
9	Site 3	Construction Manager 3	70	18 Years(Site 3_Construction Manager 3_70)	1	1		Method to minimise waste	4
10	Site 4	Construction Manager 4	103	**How many years of experience do you have as a construction manager?(Site 4_Construction Manager 4_103)**	1	1		Strategies and benefits	5
11	Site 4	Construction Manager 4	104	15 years(Site 4_Construction Manager 4_104)	1	1		Cost and time	6
12	Site 5	Construction Manager 5	137	**How many years of experience do you have as a construction manager?(Site 5_Construction Manager 5_137)**	1	1		Lean	7
13	Site 5	Construction Manager 5	138	24 years(Site 5_Construction Manager 5_138)	1	1		Waste management plan	8
14	Site 6	Construction Manager 6	171	**How many years of experience do you have as a construction manager?(Site 6_Construction Manager 6_171)**	1	1		Most Effective method	9
15	Site 6	Construction Manager 6	172	13 years(Site 6_Construction Manager 6_172)	1	1			
16	Site 7	Construction Manager 7	205	**How many years of experience do you have as a construction manager?(Site 7_Construction Manager 7_205)**	1	1			
17	Site 7	Construction Manager 7	206	16 years (Site 7_Construction Manager 7_206)	1	1			
18	Site 8	Construction Manager 8	239	**How many years of experience do you have as a construction manager?(Site 8_Construction Manager 8_239)**	1	1			
19	Site 8	Construction Manager 8	240	18 years(Site 8_Construction Manager 8_240)	1	1			
20	Site 9	Construction Manager 9	273	**How many years of experience do you have as a construction manager?(Site 9_Construction Manager 9_273)**	1	1			
21	Site 9	Construction Manager 9	274	10 years(Site 9_Construction Manager 9_274)	1	1			
22				Material waste	2	0			
23	Site 1	Construction Manager 1	3	**Which material wastes occur frequently on your site?(Site 1_Construction Manager 1_3)**	2	1			

Interview 1 | Interview 2 | Interview 3 | Interview 4 | Interview 5 | Interview 6 | Interview 7 | Interview 8 | Interview 9 | Interview 10 | CODES | Combine

ANNEXURE E: MICROSOFT WORD CODED DATA

Experience years

How many years of experience do you have as a construction manager? (Site 1_Construction Manager 1_1)
27 years (Site 1_Construction Manager 1_2)
How many years of experience do you have as a construction manager? (Site 10_Construction Manager 10_307)
22 years (Site 10_Construction Manager 10_308)
How many years of experience do you have as a construction manager? (Site 2_Construction Manager 2_35)
10 years (Site 2_Construction Manager 2_36)
How many years of experience do you have as a construction manager? (Site 3_Construction Manager 3_69)
18 Years (Site 3_Construction Manager 3_70)
How many years of experience do you have as a construction manager? (Site 4_Construction Manager 4_103)
15 years (Site 4_Construction Manager 4_104)
How many years of experience do you have as a construction manager? (Site 5_Construction Manager 5_137)
24 years (Site 5_Construction Manager 5_138)
How many years of experience do you have as a construction manager? (Site 6_Construction Manager 6_171)
13 years (Site 6_Construction Manager 6_172)
How many years of experience do you have as a construction manager? (Site 7_Construction Manager 7_205)
16 years (Site 7_Construction Manager 7_206)
How many years of experience do you have as a construction manager? (Site 8_Construction Manager 8_239)
18 years (Site 8_Construction Manager 8_240)
How many years of experience do you have as a construction manager? (Site 9_Construction Manager 9_273)
10 years (Site 9_Construction Manager 9_274)

Material waste

Which material wastes occur frequently on your site? (Site 1_Construction Manager 1_3)
Builders rubble and cement bags (Site 1_Construction Manager 1_4)
What could be the reason for them to occur more frequently? (Site 1_Construction Manager 1_5)
There is always waste that occur on construction work for instance brick work and plaster works (Site 1_Construction Manager 1_6)
Which material wastes occur frequently on your site? (Site 10_Construction Manager 10_309)
Concrete and Bricks (Site 10_Construction Manager 10_310)

What could be the reason for them to occur more frequently? (Site 10_Construction Manager 10_311)

Unskilled subcontractors (Site 10_Construction Manager 10_312)

Which material wastes occur frequently on your site? (Site 2_Construction Manager 2_37)

Half brick cutting (Site 2_Construction Manager 2_38)

What could be the reason for them to occur more frequently? (Site 2_Construction Manager 2_39)

Unskilled labours and negligence (Site 2_Construction Manager 2_40)

Which material wastes occur frequently on your site? (Site 3_Construction Manager 3_71)

Cement (Site 3_Construction Manager 3_72)

What could be the reason for them to occur more frequently? (Site 3_Construction Manager 3_73)

Unskilled workforce (Site 3_Construction Manager 3_74)

Which material wastes occur frequently on your site? (Site 4_Construction Manager 4_105)

Concrete and brickwork (Wet trades) (Site 4_Construction Manager 4_106)

What could be the reason for them to occur more frequently? (Site 4_Construction Manager 4_107)

1. Skill level of the employees/subcontractors, 2. Speed of execution (Site 4_Construction Manager 4_108)

Which material wastes occur frequently on your site? (Site 5_Construction Manager 5_139)

Concrete, Wet trades (Bricks and Plaster), Plastics and boxes (Site 5_Construction Manager 5_140)

What could be the reason for them to occur more frequently? (Site 5_Construction Manager 5_141)

Excessive waste, Rework done due to variation and design changes, and lack of skills (Site 5_Construction Manager 5_142)

Which material wastes occur frequently on your site? (Site 6_Construction Manager 6_173)

Concrete (Site 6_Construction Manager 6_174)

What could be the reason for them to occur more frequently? (Site 6_Construction Manager 6_175)

Poor Supervision (Site 6_Construction Manager 6_176)

Which material wastes occur frequently on your site? (Site 7_Construction Manager 7_207)

Formwork, concrete, bricks, sands, time overstaff and labour (Site 7_Construction Manager 7_208)

What could be the reason for them to occur more frequently? (Site 7_Construction Manager 7_209)

Lack of supervision, poor management, and planning (Site 7_Construction Manager 7_210)

Which material wastes occur frequently on your site? (Site 8_Construction Manager 8_241)

Wet trades e.g. Bricks and Mortar (Site 8_Construction Manager 8_242)

What could be the reason for them to occur more frequently? (Site 8_Construction Manager 8_243)
Unskilled subcontractors labour (Site 8_Construction Manager 8_244)
Which material wastes occur frequently on your site? (Site 9_Construction Manager 9_275)
Cement bags, General waste, and Mortar (Site 9_Construction Manager 9_276)
What could be the reason for them to occur more frequently? (Site 9_Construction Manager 9_277)
Work process, and Unskilled subcontractors (Site 9_Construction Manager 9_278)

Main causes of physical waste

What are the main causes of physical waste on the construction site you are working on? (Site 1_Construction Manager 1_7)
Subcontractors, bricklayer do not use all material such as half bricks end up in waste hip and then cart away. (Site 1_Construction Manager 1_8)
What are the main causes of physical waste on the construction site you are working on? (Site 10_Construction Manager 10_313)
Changes of design and variations (Site 10_Construction Manager 10_314)
What are the main causes of physical waste on the construction site you are working on? (Site 2_Construction Manager 2_41)
Site Condition (Site 2_Construction Manager 2_42)
What are the main causes of physical waste on the construction site you are working on? (Site 3_Construction Manager 3_75)
Poor Supervision (Site 3_Construction Manager 3_76)
What are the main causes of physical waste on the construction site you are working on? (Site 4_Construction Manager 4_109)
1. Incorrect work/ Rework, 2. Drawing revisions (Site 4_Construction Manager 4_110)
What are the main causes of physical waste on the construction site you are working on? (Site 5_Construction Manager 5_143)
Accelerated working pace (Site 5_Construction Manager 5_144)
What are the main causes of physical waste on the construction site you are working on? (Site 6_Construction Manager 6_177)
Unforeseen ground beams during demolition stage, Not casting concrete (columns, beams, shear walls) to the correct level. Which then results in breaking concrete to the required level. Not ordering the correct amount (quantity) of concrete from the ready-mix concrete supplier. Unused concrete will be discharged on site and once cured after a few days, a rubble truck will be called to cart away the concrete and any other debris on site. (Site 6_Construction Manager 6_178)
What are the main causes of physical waste on the construction site you are working on? (Site 7_Construction Manager 7_211)
Inexperience and poor communication (Site 7_Construction Manager 7_212)
What are the main causes of physical waste on the construction site you are working on? (Site 8_Construction Manager 8_245)
Poor planning (Site 8_Construction Manager 8_246)

What are the main causes of physical waste on the construction site you are working on? (Site 9_Construction Manager 9_279)
Construction process (Site 9_Construction Manager 9_280)

<u>Method to minimise waste</u>

What are the methods used on your project to minimize construction waste? (Site 1_Construction Manager 1_9)
1. Brickwork, offloading of bricks using crane to avoid bricks breakage, 2. Formwork, making sure that the stripping is nice as possible (Site 1_Construction Manager 1_10)
Which actions do you take with regard to the construction waste that arises on your site? (Site 1_Construction Manager 1_11)
Weekly toolbox with all the subcontractors on site to educate them on all the material waste, so far there is difference on waste arising on site. (Site 1_Construction Manager 1_12)
What are the methods used on your project to minimize construction waste? (Site 10_Construction Manager 10_315)
Reuse and recycle some materials (Site 10_Construction Manager 10_316)
Which actions do you take with regard to the construction waste that arises on your site? (Site 10_Construction Manager 10_317)
Charge subcontractors for causing waste on site, for dumping them (Site 10_Construction Manager 10_318)
What are the methods used on your project to minimize construction waste? (Site 2_Construction Manager 2_43)
Lot of off cuts (Site 2_Construction Manager 2_44)
Which actions do you take with regard to the construction waste that arises on your site? (Site 2_Construction Manager 2_45)
Reuse waste (Site 2_Construction Manager 2_46)
What are the methods used on your project to minimize construction waste? (Site 3_Construction Manager 3_77)
Quantification of material to be used (Site 3_Construction Manager 3_78)
Which actions do you take with regard to the construction waste that arises on your site? (Site 3_Construction Manager 3_79)
Waste are disposed in a waste bin (Site 3_Construction Manager 3_80)
What are the methods used on your project to minimize construction waste? (Site 4_Construction Manager 4_111)
1. Quality control of work, 2. Management of subcontractors on Microlevel and 3. Ordering just enough materials (Site 4_Construction Manager 4_112)
Which actions do you take with regard to the construction waste that arises on your site? (Site 4_Construction Manager 4_113)
1. Issuing of non-conformance, 2. Contractor charging excessive waste (Site 4_Construction Manager 4_114)
What are the methods used on your project to minimize construction waste? (Site 5_Construction Manager 5_145)
Reuse of bricks from demolition, plaster, and mortar rubble (used for filling where possible), and landfill and recycling (Site 5_Construction Manager 5_146)

Which actions do you take with regard to the construction waste that arises on your site? (Site 5_Construction Manager 5_147)

Skips as per the waste management plan, for every subcontractor that uses a skip the is a charge for the waste the put in the skip. Subcontractors reuse the plastics and boxes inhouse. (Site 5_Construction Manager 5_148)

What are the methods used on your project to minimize construction waste? (Site 6_Construction Manager 6_179)

Ready mix concrete, site personnel to measure concrete physically on plan and allow for minimal wastage (usually 5-10%), Structural elements (columns, walls, beams) to be cast to the correct cut off level to avoid concrete braking post casting. QA checks/forms are incorporated to avoid such. Pre and Post concrete checklists are crucial in such instances. (Site 6_Construction Manager 6_180)

Which actions do you take with regard to the construction waste that arises on your site? (Site 6_Construction Manager 6_181)

Foremen on site are informed of the financial implications the concrete waste has on projected possible profit margins, which then has a knock-on effect on project or annual bonuses being paid out. So, with that being said, the foremen are ought to be mindful of such going forward, Rubble removal subcontractor collects the rubble and dumps it at the nearest approved dumping site. (Site 6_Construction Manager 6_182)

What are the methods used on your project to minimize construction waste? (Site 7_Construction Manager 7_213)

Daily meetings to all staff, cost reports and safety toolbox talk as one of the highlights in waste management and environment (Site 7_Construction Manager 7_214)

Which actions do you take with regard to the construction waste that arises on your site? (Site 7_Construction Manager 7_215)

Cost report figures and cash flow (Site 7_Construction Manager 7_216)

What are the methods used on your project to minimize construction waste? (Site 8_Construction Manager 8_247)

Reuse waste materials (Site 8_Construction Manager 8_248)

Which actions do you take with regard to the construction waste that arises on your site? (Site 8_Construction Manager 8_249)

Issue non-conformance to subcontractor (Site 8_Construction Manager 8_250)

What are the methods used on your project to minimize construction waste? (Site 9_Construction Manager 9_281)

Subcontractor to remove waste from site and also recycle (Site 9_Construction Manager 9_282)

Which actions do you take with regard to the construction waste that arises on your site? (Site 9_Construction Manager 9_283)

Minimise waste by doing the job once (Site 9_Construction Manager 9_284)

<u>Strategies and benefits</u>

Which strategies are you using to control construction waste on site? (Site 1_Construction Manager 1_13)

Skips from waste companies, waste companies collect and separate waste according to the material streams (Site 1_Construction Manager 1_14)

What are the benefits of implementing those strategies? (Site 1_Construction Manager 1_15)

Prevent pollution, e.g. Chemical waste can harm the ground (Soil) (Site 1_Construction Manager 1_16)

Which strategies are you using to control construction waste on site? (Site 10_Construction Manager 10_319)

Waste management plan, which stipulates the process to control waste on site (Site 10_Construction Manager 10_320)

What are the benefits of implementing those strategies? (Site 10_Construction Manager 10_321)

Reduce cost and maximise the profits (Site 10_Construction Manager 10_322)

Which strategies are you using to control construction waste on site? (Site 2_Construction Manager 2_47)

Buy as when materials are needed on site (Site 2_Construction Manager 2_48)

What are the benefits of implementing those strategies? (Site 2_Construction Manager 2_49)

Saving money and increase in profit (Site 2_Construction Manager 2_50)

Which strategies are you using to control construction waste on site? (Site 3_Construction Manager 3_81)

Ensure Engineer mix design are followed (Site 3_Construction Manager 3_82)

What are the benefits of implementing those strategies? (Site 3_Construction Manager 3_83)

The wastage is reduced (Site 3_Construction Manager 3_84)

Which strategies are you using to control construction waste on site? (Site 4_Construction Manager 4_115)

1. Hands on control, 2. Forcing subcontractors to follow revision drawings (Site 4_Construction Manager 4_116)

What are the benefits of implementing those strategies? (Site 4_Construction Manager 4_117)

1. Increase profitability of main contractor and subcontractor, 2. Speed of execution and time (Site 4_Construction Manager 4_118)

Which strategies are you using to control construction waste on site? (Site 5_Construction Manager 5_149)

Issuing non- conformance (NCR) and fine subcontractors, stop payment and production for subcontractors (Site 5_Construction Manager 5_150)

What are the benefits of implementing those strategies? (Site 5_Construction Manager 5_151)

Overall cleaner site, Recover losses from skips and wastage (Site 5_Construction Manager 5_152)

Which strategies are you using to control construction waste on site? (Site 6_Construction Manager 6_183)

A designated stockpile area should be identified on site where rubble will be stock piled and removed regularly, Continuous housekeeping to be done daily on site, Implementing quality assurance system(s) (Site 6_Construction Manager 6_184)

What are the benefits of implementing those strategies? (Site 6_Construction Manager 6_185)

Concrete wastage will be reduced drastically, A clean site/environment gives off an impression that all is in order (even when things/activities are really not going according to programme) (Site 6_Construction Manager 6_186)

Which strategies are you using to control construction waste on site? (Site 7_Construction Manager 7_217)

Site walk about, photo graphic reports and encourage good workmanship (Site 7_Construction Manager 7_218)

What are the benefits of implementing those strategies? (Site 7_Construction Manager 7_219)

Good turnaround time on the project deadline, good profit and incentives to the team involved on the project (Site 7_Construction Manager 7_220)

Which strategies are you using to control construction waste on site? (Site 8_Construction Manager 8_251)

Educate subcontractors on waste management (Site 8_Construction Manager 8_252)

What are the benefits of implementing those strategies? (Site 8_Construction Manager 8_253)

Save on cost of waste removal, prevent waste to be dumped in landfills and reduce pollution (Site 8_Construction Manager 8_254)

Which strategies are you using to control construction waste on site? (Site 9_Construction Manager 9_285)

Charges to the subcontractor's waste (Site 9_Construction Manager 9_286)

What are the benefits of implementing those strategies? (Site 9_Construction Manager 9_287)

Reduce land pollution (Site 9_Construction Manager 9_288)

Cost and time

Does waste that arises on your construction site have an impact on the cost and time of the project? (Site 1_Construction Manager 1_17)

Yes (Site 1_Construction Manager 1_18)

What are the impacts on those two variables of time and cost? (Site 1_Construction Manager 1_19)

Late practical completion time, leading to penalties which is a great cost (Site 1_Construction Manager 1_20)

Does waste that arises on your construction site have an impact on the cost and time of the project? (Site 10_Construction Manager 10_323)

Yes (Site 10_Construction Manager 10_324)

What are the impacts on those two variables of time and cost? (Site 10_Construction Manager 10_325)

Put Practical Completion at Risk and result to penalties by the client. (Site 10_Construction Manager 10_326)

Does waste that arises on your construction site have an impact on the cost and time of the project? (Site 2_Construction Manager 2_51)

Yes (Site 2_Construction Manager 2_52)

What are the impacts on those two variables of time and cost? (Site 2_Construction Manager 2_53)

Rubble costs money to remove and they occupy the working space which will need delay the construction works when removed (time delays) (Site 2_Construction Manager 2_54)

Does waste that arises on your construction site have an impact on the cost and time of the project? (Site 3_Construction Manager 3_85)

Yes (Site 3_Construction Manager 3_86)

What are the impacts on those two variables of time and cost? (Site 3_Construction Manager 3_87)

Increase cost on the project and increase duration on the project (Site 3_Construction Manager 3_88)

Does waste that arises on your construction site have an impact on the cost and time of the project? (Site 4_Construction Manager 4_119)

Yes (Site 4_Construction Manager 4_120)

What are the impacts on those two variables of time and cost? (Site 4_Construction Manager 4_121)

1. Additional /Wasteful expenditure, 2. Putting completion date at risk (time overrun) (Site 4_Construction Manager 4_122)

Does waste that arises on your construction site have an impact on the cost and time of the project? (Site 5_Construction Manager 5_153)

Yes (Site 5_Construction Manager 5_154)

What are the impacts on those two variables of time and cost? (Site 5_Construction Manager 5_155)

It causes delays to the project, the cost for supervision, cleaning and, skip and transport for cart away. (Site 5_Construction Manager 5_156)

Does waste that arises on your construction site have an impact on the cost and time of the project? (Site 6_Construction Manager 6_187)

Yes (Site 6_Construction Manager 6_188)

What are the impacts on those two variables of time and cost? (Site 6_Construction Manager 6_189)

Time: allocating labour force to break concrete which was not planned for in the program. Allocating plant to remove rubble. Cost: waste collection/rubble removal is done more frequently than what was originally allowed for. TLB/Skid steer is removed from actual production driven activities to load the rubble truck. Cost will go up due to more time spent on production unrelated activities. (Site 6_Construction Manager 6_190)

Does waste that arises on your construction site have an impact on the cost and time of the project? (Site 7_Construction Manager 7_221)

Yes (Site 7_Construction Manager 7_222)

What are the impacts on those two variables of time and cost? (Site 7_Construction Manager 7_223)

Target date are not met, and the project runs on a lose (Site 7_Construction Manager 7_224)

Does waste that arises on your construction site have an impact on the cost and time of the project? (Site 8_Construction Manager 8_255)

Yes (Site 8_Construction Manager 8_256)

What are the impacts on those two variables of time and cost? (Site 8_Construction Manager 8_257)

Project delays and Additional costs (Site 8_Construction Manager 8_258)

Does waste that arises on your construction site have an impact on the cost and time of the project? (Site 9_Construction Manager 9_289)
Yes (Site 9_Construction Manager 9_290)
What are the impacts on those two variables of time and cost? (Site 9_Construction Manager 9_291)
Cause delays due to waste and extra cost for waste removal (Site 9_Construction Manager 9_292)

<u>Lean</u>

What are the types of lean wastes which happens frequently on your construction project? (Site 1_Construction Manager 1_21)
Overproduction and Defects (Site 1_Construction Manager 1_22)
Do you apply lean construction to minimise waste? (Site 1_Construction Manager 1_23)
No (Site 1_Construction Manager 1_24)
If yes, which lean tools do you use the most to reduce or eliminate the waste? (Site 1_Construction Manager 1_25)
N/A (Site 1_Construction Manager 1_26)
Which are the challenges experienced when applying lean approaches in your projects? (Site 1_Construction Manager 1_27)
N/A (Site 1_Construction Manager 1_28)
What are the types of lean wastes which happens frequently on your construction project? (Site 10_Construction Manager 10_327)
Overproduction and Defects (Site 10_Construction Manager 10_328)
Do you apply lean construction to minimise waste? (Site 10_Construction Manager 10_329)
No (Site 10_Construction Manager 10_330)
If yes, which lean tools do you use the most to reduce or eliminate the waste? (Site 10_Construction Manager 10_331)
N/A (Site 10_Construction Manager 10_332)
Which are the challenges experienced when applying lean approaches in your projects? (Site 10_Construction Manager 10_333)
N/A (Site 10_Construction Manager 10_334)
What are the types of lean wastes which happens frequently on your construction project? (Site 2_Construction Manager 2_55)
Defects, (Site 2_Construction Manager 2_56)
Do you apply lean construction to minimise waste? (Site 2_Construction Manager 2_57)
Yes (Site 2_Construction Manager 2_58)
If yes, which lean tools do you use the most to reduce or eliminate the waste? (Site 2_Construction Manager 2_59)
Just-in-time (JIT) (Site 2_Construction Manager 2_60)
Which are the challenges experienced when applying lean approaches in your projects? (Site 2_Construction Manager 2_61)
None (Site 2_Construction Manager 2_62)
What are the types of lean wastes which happens frequently on your construction project? (Site 3_Construction Manager 3_89)

Overproduction (Site 3_Construction Manager 3_90)
Do you apply lean construction to minimise waste? (Site 3_Construction Manager 3_91)
Yes (Site 3_Construction Manager 3_92)
If yes, which lean tools do you use the most to reduce or eliminate the waste? (Site 3_Construction Manager 3_93)
5S process tool (Site 3_Construction Manager 3_94)
Which are the challenges experienced when applying lean approaches in your projects? (Site 3_Construction Manager 3_95)
Poor supervisory skills (Site 3_Construction Manager 3_96)
What are the types of lean wastes which happens frequently on your construction project? (Site 4_Construction Manager 4_123)
Overproduction, motion, overprocessing and defect (Site 4_Construction Manager 4_124)
Do you apply lean construction to minimise waste? (Site 4_Construction Manager 4_125)
Yes (Site 4_Construction Manager 4_126)
If yes, which lean tools do you use the most to reduce or eliminate the waste? (Site 4_Construction Manager 4_127)
Process mapping method, Just-in-time (JIT) and 5S process tool (Site 4_Construction Manager 4_128)
Which are the challenges experienced when applying lean approaches in your projects? (Site 4_Construction Manager 4_129)
1. Skills level of the people working with (Subcontractors), 2. Cultural diversity (precise work) (Site 4_Construction Manager 4_130)
What are the types of lean wastes which happens frequently on your construction project? (Site 5_Construction Manager 5_157)
Defects (Site 5_Construction Manager 5_158)
Do you apply lean construction to minimise waste? (Site 5_Construction Manager 5_159)
Yes (Site 5_Construction Manager 5_160)
If yes, which lean tools do you use the most to reduce or eliminate the waste? (Site 5_Construction Manager 5_161)
Value stream mapping and Just-in-time (JIT) (Site 5_Construction Manager 5_162)
Which are the challenges experienced when applying lean approaches in your projects? (Site 5_Construction Manager 5_163)
Late issue of information (Site 5_Construction Manager 5_164)
What are the types of lean wastes which happens frequently on your construction project? (Site 6_Construction Manager 6_191)
Overproduction, transport, and defects (Site 6_Construction Manager 6_192)
Do you apply lean construction to minimise waste? (Site 6_Construction Manager 6_193)
No (Site 6_Construction Manager 6_194)
If yes, which lean tools do you use the most to reduce or eliminate the waste? (Site 6_Construction Manager 6_195)
N/A (Site 6_Construction Manager 6_196)
Which are the challenges experienced when applying lean approaches in your projects? (Site 6_Construction Manager 6_197)
N/A (Site 6_Construction Manager 6_198)
What are the types of lean wastes which happens frequently on your construction project? (Site 7_Construction Manager 7_225)

Overproduction, defects, waiting and underutilization (Site 7_Construction Manager 7_226)
Do you apply lean construction to minimise waste? (Site 7_Construction Manager 7_227)
Yes (Site 7_Construction Manager 7_228)
If yes, which lean tools do you use the most to reduce or eliminate the waste? (Site 7_Construction Manager 7_229)
Value stream mapping, change management and Just-in-time (JIT) (Site 7_Construction Manager 7_230)
Which are the challenges experienced when applying lean approaches in your projects? (Site 7_Construction Manager 7_231)
Time and communication (Site 7_Construction Manager 7_232)
What are the types of lean wastes which happens frequently on your construction project? (Site 8_Construction Manager 8_259)
Overproduction and Defects (Site 8_Construction Manager 8_260)
Do you apply lean construction to minimise waste? (Site 8_Construction Manager 8_261)
Yes (Site 8_Construction Manager 8_262)
If yes, which lean tools do you use the most to reduce or eliminate the waste? (Site 8_Construction Manager 8_263)
Process mapping method and Just-in-Time (JIT) (Site 8_Construction Manager 8_264)
Which are the challenges experienced when applying lean approaches in your projects? (Site 8_Construction Manager 8_265)
The culture and unskilled subcontractors (Site 8_Construction Manager 8_266)
What are the types of lean wastes which happens frequently on your construction project? (Site 9_Construction Manager 9_293)
Defects (Site 9_Construction Manager 9_294)
Do you apply lean construction to minimise waste? (Site 9_Construction Manager 9_295)
Yes (Site 9_Construction Manager 9_296)
If yes, which lean tools do you use the most to reduce or eliminate the waste? (Site 9_Construction Manager 9_297)
Value Stream Mapping (Site 9_Construction Manager 9_298)
Which are the challenges experienced when applying lean approaches in your projects? (Site 9_Construction Manager 9_299)
Unforeseen circumstances, Breakdown, and shortage of materials (Site 9_Construction Manager 9_300)

Waste management plan

Does the contract for this project require a waste management plan? (Site 1_Construction Manager 1_29)
Yes (Site 1_Construction Manager 1_30)
If so, briefly describe the waste management plan. (Site 1_Construction Manager 1_31)
1. Skips to waste that controls waste, 2. Plant on site, work on certain areas to avoid the chemical from penetrating the soil (Site 1_Construction Manager 1_32)
Does the contract for this project require a waste management plan? (Site 10_Construction Manager 10_335)
N/A (Site 10_Construction Manager 10_336)

If so, briefly describe the waste management plan. (Site 10_Construction Manager 10_337)
N/A (Site 10_Construction Manager 10_338)
Does the contract for this project require a waste management plan? (Site 2_Construction Manager 2_63)
N/A (Site 2_Construction Manager 2_64)
If so, briefly describe the waste management plan. (Site 2_Construction Manager 2_65)
N/A (Site 2_Construction Manager 2_66)
Does the contract for this project require a waste management plan? (Site 3_Construction Manager 3_97)
No (Site 3_Construction Manager 3_98)
If so, briefly describe the waste management plan. (Site 3_Construction Manager 3_99)
N/A (Site 3_Construction Manager 3_100)
Does the contract for this project require a waste management plan? (Site 4_Construction Manager 4_131)
Yes (Site 4_Construction Manager 4_132)
If so, briefly describe the waste management plan. (Site 4_Construction Manager 4_133)
1. Rubble disposed of must be done in legal dumping site, 2. Specialist subcontractors for waste removal (Site 4_Construction Manager 4_134)
Does the contract for this project require a waste management plan? (Site 5_Construction Manager 5_165)
No (Site 5_Construction Manager 5_166)
If so, briefly describe the waste management plan. (Site 5_Construction Manager 5_167)
N/A (Site 5_Construction Manager 5_168)
Does the contract for this project require a waste management plan? (Site 6_Construction Manager 6_199)
N/A (Site 6_Construction Manager 6_200)
If so, briefly describe the waste management plan. (Site 6_Construction Manager 6_201)
N/A (Site 6_Construction Manager 6_202)
Does the contract for this project require a waste management plan? (Site 7_Construction Manager 7_233)
No (Site 7_Construction Manager 7_234)
If so, briefly describe the waste management plan. (Site 7_Construction Manager 7_235)
N/A (Site 7_Construction Manager 7_236)
Does the contract for this project require a waste management plan? (Site 8_Construction Manager 8_267)
No (Site 8_Construction Manager 8_268)
If so, briefly describe the waste management plan. (Site 8_Construction Manager 8_269)
N/A (Site 8_Construction Manager 8_270)
Does the contract for this project require a waste management plan? (Site 9_Construction Manager 9_301)
No (Site 9_Construction Manager 9_302)
If so, briefly describe the waste management plan. (Site 9_Construction Manager 9_303)
N/A (Site 9_Construction Manager 9_304)

<u>Most Effective method</u>

Which method do you think is the most effective for construction waste control? (Site 1_Construction Manager 1_33)

Educating the team on lean construction and Training labours, make use of waste company that specialise in waste, they should have a method statement (Site 1_Construction Manager 1_34)

Which method do you think is the most effective for construction waste control? (Site 10_Construction Manager 10_339)

The application of lean construction and training subcontractors on waste control (Site 10_Construction Manager 10_340)

Which method do you think is the most effective for construction waste control? (Site 2_Construction Manager 2_67)

Accurate planning and reuse of materials (Site 2_Construction Manager 2_68)

Which method do you think is the most effective for construction waste control? (Site 3_Construction Manager 3_101)

Lean Construction (Site 3_Construction Manager 3_102)

Which method do you think is the most effective for construction waste control? (Site 4_Construction Manager 4_135)

1. Continuous improvement ,2. Skills upliftment (Training employees) ,3. Share the accountability (Cause and effect, and there should be either reward or penalty) (Site 4_Construction Manager 4_136)

Which method do you think is the most effective for construction waste control? (Site 5_Construction Manager 5_169)

Well managed and implement waste management. Using recycling companies Skilled people for subcontractors (Site 5_Construction Manager 5_170)

Which method do you think is the most effective for construction waste control? (Site 6_Construction Manager 6_203)

Recycling waste. Waste concrete can be taken to the following suppliers for reuse: a) Ready mix suppliers so that they crush the concrete and reuse for batching once the fines and aggregates are separated from the crushing machine. b) A quarry so that the concrete can be crushed and supplied/used as a G grading (G4, G5, G6 material) used for backfilling or on roads/earthworks projects. (Site 6_Construction Manager 6_204)

Which method do you think is the most effective for construction waste control? (Site 7_Construction Manager 7_237)

Make very one involved on the project the value of the presence on the project and duration when should the project be completed, daily meeting with staff and once off monthly meeting with labour force creating an awareness on site regarding the waste with posters and safety toolbox talk meeting. Educating everyone involved on the project about the wastage and how it can impact the production, future work, and income. (Site 7_Construction Manager 7_238)

Which method do you think is the most effective for construction waste control? (Site 8_Construction Manager 8_271)

Applying lean construction (Site 8_Construction Manager 8_272)

Which method do you think is the most effective for construction waste control? (Site 9_Construction Manager 9_305)

Recycling and do right work at first and avoid rework (Site 9_Construction Manager 9_306)