Application of lean principles in the South African construction industry

by
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DECLARATION

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ABSTRACT

South Africa is a developing country that invests billions of rands annually in the construction industry. This industry consumes resources, and inevitably, waste is generated during the process. Although numerous approaches have been developed to improve quality, efficiency, and effectiveness in this industry, lean principles offer the ability to minimise and eliminate non-value adding work thus increasing value for the client. The research was carried out in three stages which are literature review, lean construction framework development and lean construction framework validation and verification through case studies.

In the literature review section the thesis discussed concepts of lean, lean thinking principles, lean production methods to reduce waste, lean construction, benefits of lean construction, lean construction tools currently used worldwide, barriers to lean construction, drivers of lean construction practice in the South African construction industry, waste classification in this industry and controllable waste in construction.

The research study then used the systematic literature review methodology to systematically analyze applications of lean principles in the construction industry, and identified tools that will be used to be implement lean construction in the South African construction industry (electrical and mechanical engineering services). The results of the systematic literature were used to develop a lean construction implementation framework. The framework was then implemented and refined using two local case studies focusing on electrical and mechanical engineering services in the South African construction industry. The refined lean implementation framework is made out of four segments which are focusing on culture and behaviour, implementing lean construction practices, lean construction drivers, and using lean project management strategies.

OPSOMMING

Suid-Afrika is 'n ontwikkelende land wat jaarliks miljarde rande in die konstruksiebedryf belê. Hierdie bedryf verbruik hulpbronne en onvermydelik word afval tydens die proses gegenereer. Alhoewel daar talle benaderings ontwikkel is om kwaliteit, doeltreffendheid en effektiwiteit in hierdie bedryf te verbeter, bied maer-beginsels die vermoë om nie-waardetoevoegende werk te minimaliseer en uit te skakel, wat die waarde vir die kliënt verhoog. Die navorsing is in drie fases uitgevoer, naamlik literatuuroorsig, ontwikkeling van ‘n maer-konstruksie-raamwerk en validering en verifikasie van die raamwerk deur gevallestudies.

In die literatuurstudiesegment bespreek die proefskrif konsepte van maer-denkbeginsels, maer-produksiemetodes om afval te verminder, maer-konstruksie, voordele van maer-konstruksie, maer-konstruksieinstrumente wat tans wêreldwyd gebruik word, hindernisse vir maer-konstruksie, drywers van maer-konstruksiepraktyk in die Suid-Afrikaanse konstruksiebedryf, afvalindeling in hierdie bedryf en beheerbare afval in konstruksie.

Die navorsingstudie het vervolgens die stelselmatige literatuuroorsigmetodologie gebruik om toepassings van maer-beginsels in die konstruksiebedryf stelselmatig te ontleed, en instrumente geïdentifiseer wat gebruik sal word om maer-konstruksie in die Suid-Afrikaanse konstruksiebedryf te implementeer (elektriese en meganiese ingenieursdienste). Die resultate van die sistematiese literatuur is gebruik om 'n skraal konstruksie-implementeringsraamwerk te ontwikkel. Die raamwerk is toe geïmplementeer en verfyn deur gebruik te maak van twee plaaslike gevallestudies wat fokus op elektriese en meganiese ingenieursdienste in die Suid-Afrikaanse konstruksiebedryf. Die verfynde raamwerk vir maer-implementering bestaan uit vier segmente wat fokus op kultuur en gedrag, die implementering van maer-konstruksiepraktyke, maer-konstruksie-drywers en die gebruik van strategieë vir maer-projekbestuur.

ACKNOWLEDGEMENTS

All glory and honor be to the Almighty God who created the heavens and the earth, for successful completion of this research study. May God increase in respect as I decrease forever and ever.

The author would like to thank all those who in their various ways made the writing of this research thesis a success. I would like to express my sincere gratitude to my academic supervisor, Prof Stephen Matope for his continued guidance, support, and advice throughout this research project. I am humbled to be part of your team; may the Lord richly bless you. I would like to thank my husband and pillar of strength, Engineer Richmore Aron Dondofema for his support, patience, guidance, and love throughout this master's journey; it was not an easy journey. I would like to acknowledge our daughter, Farirai Audrey Dondofema who is two weeks old at the time of submitting this thesis. Thank you for behaving in the womb so that your mother could focus and finish this thesis. Last but not least, special thanks to my parents and relatives for the prayers, guidance and support since I embarked this journey. To my friends, thank you all for your support and patience. I am blessed to have you all.

DEDICATION

Above all, I thank my God for making me successful in all my endeavours. To my family and friends, I am grateful for the moral and financial support during my studies.

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1 INTRODUCTORY CHAPTER

This is an introductory chapter of the research study. The chapter, among other things, presents the problem statement, aim and objectives of the study.

1.1 Introduction

South Africa is a developing country investing billions of Rands annually in the construction industry. The construction industry consumes resources, and inevitably, waste is generated during the process. Some of the construction wastes include building material, under-utilized labour, idle equipment and unutilized space (Banik, 1999). Profit margins are declining and competition is ever increasing in the construction sector. To remain operational and profitable, new ways of eliminating waste in the construction industry should be developed (Mastroianni and Abdelhamid, 2003). There are numerous approaches for continuous improvement that can be used to eliminate waste; however, lean manufacturing has been outstanding in production engineering (Womack, Jones and Roos, 1991; Dondofema, Matope and Akdogan, 2017).

Lean manufacturing methodology helps to identify and eliminate or reduce waste in any production processes. Waste can be defined as any non-value-adding activity in the production process (Bicheno and Holweg, 2016) (Koskal and Egitman, 1998). These non-value adding activities do not improve value, but only increase cost and also increase the overall production time (Hosseini *et al.*, 2011). However, non-value-adding activities can be grouped into essential non-value adding activities and non-essential, non-value adding activities (Liker, 2004). By planning adequately with proper supervision and correct decision making based on accurate information and procedures, lean manufacturing principles, if implemented in the South African construction industry, have the potential to eliminate waste. Elimination of waste is through the removal of non-essential, non-value adding activities leading to cost reduction and performance improvement (Liker and Meier, 2004). Eventually, this will improve overall construction time and facilitate the delivery of quality project outcomes in a timely manner (Paez *et al.*, 2005).

The construction industry has been lagging behind when compared with the manufacturing industry with regards to the implementation and improvement of lean manufacturing principles and methodologies (Ahmed and Forbes, 2011). This criticism has stimulated research on the application of lean manufacturing principles in the construction sector; hence the coinage of the term “lean construction” (Shang and Sui Pheng, 2013). Lean construction’s roots can be dated back to the late 1990s (Koskela and Howell, 2000). The lean construction philosophy originated from the lean manufacturing concept, and mainly from the Toyota Production System (Bajjou & Chafi, 2018; Sarhan, Xia, Fawzia, & Karim, 2017 ;Womack et al, 1990). Koskela and Howell in 2000 proposed analysing construction activities using production engineering analytical tools. This perspective assists in managing the design and building of complex physical structures (buildings) in dynamic environments within the targeted periods. To date, construction industry participants are exploring new techniques, practices and processes to make the industry less wasteful (Arbulu, 2002). Lean principles, when applied in the construction industry (which will be referred to as lean construction in this study), offers innovative ways to manage construction projects while reducing waste and improving quality, efficiency and performance. Key categories that differentiate production engineering and construction engineering are the nature of the operation, planning and activities execution (Paez *et al.*, 2005). With these contextual differences in key categories lean manufacturing principles developed for production engineering cannot be directly applied to construction engineering (Ballard and Howell, 2000).

The South African construction industry, to a large extent, contributes to the economy of the country, particularly the setting up of physical infrastructures (Takim and Akintoye, 2002). On the other hand, most activities of this industry have negative effects on the environment which can be improved through changes in the management of waste (Du Plessis, 2002). The successful implementation of lean principles in the manufacturing industry, and the benefits resulting from its adoption, is one of the key reasons for the adoption of lean thinking in construction (Egan, 1998). The term “lean construction” was introduced by the International Group for Lean Construction in the first conference on lean construction, which was organised in Finland in 1993 (Koskela *et al.*, 2002). Lean construction is “*a way to design production systems to minimize waste of materials, time and effort to generate the maximum possible amount of value*” (Koskela, Huovila and Leinonen, 2002). Implementation of lean construction principles is paramount in decreasing waste and enhancing the overall South African construction industry performance.

1.2 The rationale of the research

All over the world, construction projects suffer from waste being generated which affect the construction industry’s performance. Traditionally, waste was directly linked to material loss on construction sites, but this is no longer the case according to current statistics (Khanh and Kim, 2015a). According to a study done by Teo, Abdelnaser and Abdul, (2009), additional construction materials are generally procured due to wastage of materials which occurs during the construction phase.

Theory of constraints was not used in this research project because of the nature of construction projects. Construction projects are diversified; they differ from one project to another. Theory of constraints is best used in a production line where there is a uniform sequence such that bottlenecks would easily be identified and eliminated. There is a misconception that lean manufacturing tools cannot be implemented in construction management projects. The researcher's experience has exposed her to wastes in the construction industry. With her background as an industrial engineer, she sees it fit to implement lean construction in the South African Construction Industry to remove production wastes.

1.3 Problem statement

Waste in the construction industry represents a relatively large percentage of production costs (Babatunde, Emuze and Kumar, 2016) (Huovila and Koskela, 1998). The existence of various waste types has affected overall performance and productivity in the industry; thus, there is a need for the development and implementation of proven waste elimination techniques. The challenge in South Africa is that lean methodologies developed for other industrial sectors cannot be directly transferred to the construction industry due to contextual differences (as was discussed in section 3.4 below). These differences fall under three main key categories namely 1) nature of operation 2) planning and 3) activities execution (Paez *et al.*, 2005) that differentiate production engineering and construction engineering.

From the analysis of literature on lean construction in South Africa, it has been observed that there are limited frameworks for the implementation of lean construction for different construction projects in the South African construction industry (see section 3.4). The researcher observed that there is limited application of lean construction in the electrical installation services and mechanical installation services, that is, wet services, fire protection, heating ventilation and air conditioning (HVAC) projects which are also key components of the construction industry (see section 3.4). This study developed a framework for the implementation of lean construction that was in the construction industry (electrical and mechanical installation services).

1.4 Aim and objectives

This study aims to develop a lean implementation framework and implement it in the South Africa construction industry. To achieve this aim, the following objectives were pursued:

a) To understand the level of awareness of lean concepts in the construction industry in South Africa.
b) To categorize construction wastes according to groups of lean production wastes.
c) To classify barriers and difficulties that may be experienced in the implementation of lean concepts in South Africa and identify ways to overcome these barriers in literature.
d) To identify the principles and concepts used to implement lean manufacturing.
e) To develop a lean construction management framework that is applicable in the South African context.

1.5 Research questions

The research questions, which guide this project, are:

a) Are the key players in the South African construction industry aware of lean construction concepts, and to what level do they implement these concepts?
b) What are construction wastes and how can they be categorised into lean production wastes?
c) What are the challenges faced when implementing lean construction principles?
d) What are specific procedures and systems of lean construction that minimise waste and reduce project costs?
e) What is the connection between the application of lean construction techniques, controlling waste and improving performance?

1.6 Research contribution

The study aims to show that lean practices can be successfully applied in the South African construction industry (specifically mechanical and electrical services). The thesis provides an efficient method that facilitates project team-integration by using lean techniques. This integration will help contractors, architects, project managers and property developers to reduce waste and increase productivity. By successfully implementing the developed lean implementation framework in this study project, the author hopes this will open channels for the application of lean manufacturing techniques in public and private construction projects in South Africa. The developed framework will assist in sustainable implementation of lean techniques in the construction industry.

1.7 Limitations and assumptions of the study

The following limitations may affect the quality and depth of the study:

a) The results of implementing the lean implementation framework was limited to construction projects the student participated in. These were in Southdale in Gauteng Province and Promenade in the Western Cape Province. The student used these two sites due to resource and financial constraints and the COVID 19 pandemic that affected other construction projects countrywide.
b) The student did her postgraduate study as a part-time student.
c) The costs associated with carrying out the research. These include typing, printing and travelling expenses. To supplement the limited resources, the researcher relied on using work facilities.
d) The researcher focused on 1) Mechanical installations related to Heating, Ventilation and Air Conditioning (HVAC), Fire Protection and Wet Services; 2) Electrical installations construction projects.

1.8 Ethical implications of the research

a) The research complies with Stellenbosch University's guidelines on ethical scholarship and scientific research.
b) The research does not aim to harm or advertise any individual, company or organization.
c) Although no formal ethical clearance was applied for, the researcher sort for permission from the management of the company to conduct the study. The researcher was the Projects Engineer for the company on which this research was conducted. Hence, she did the research as a job enrichment exercise for the workers and herself.

1.9 Document structure

Figure 1-1 below shows the outline and sequence of this document. Chapter 1 is the introductory chapter and chapter 2 is the research design chapter. Chapter 3 is the literature review section, which focusses on lean manufacturing, lean application in construction, a review of lean applications in South Africa, and identification of lean implementation aspects. Chapter 4 discusses the development of the lean implementation framework and chapter 5 focusses on the verification and validation of the developed framework. Chapter 6 contains the findings and analysis, while Chapter 7 contains the study's conclusion and recommendations.

CHAPTER	RESEARCH OBJECTIVE(S) FULFILLED	DESCRIPTION
Chapter 1 Introduction		This chapter provides an introduction, rational of the research study, aims, objectives, problem statement, research questions, research contribution, limitations and delimitations.
Chapter 2 Research Design		This chapter provides an outline of the research study used in the thesis. The research was carried out in three stages which are literature review, conceptual framework and case studies. In this chapter, research philosophy, research approach, research method, strategies and techniques were discussed.
Chapter 3 Literature Review Lean Manufacturing in general Lean application in Construction Review of Lean Applications in South African Construction Industry Lean implementation conceptual aspects	a) To understand the level of awareness of lean concepts in the construction industry of South Africa. b) To categorize construction wastes according to groups of lean production wastes. c)To classify barriers and difficulties that may be experienced in the implementation of lean concepts in South Africa and identify ways to overcome these barriers in literature. d)To identify the principles and concepts used to implement lean manufacturing.	In this chapter focus was on lean manufacturing and the history of Toyota Production Systems was discussed. Lean wastes, lean applications in construction, lean thinking principles, benefits and barriers of lean construction were elaborated. Theoretical concepts were identified from the systematic literature review that was done.
Chapter 4 Developing Lean Construction Framework	e) To develop a lean construction management framework that is applicable in the South African context.	In this chapter lean construction principles identified in literature in Chapter 3 was used to develop lean construction framework. Lean implementation framework developed is made out of four categories namely Culture & Behaviour change, Lean Construction Practices implementation, Lean Construction Drivers and Lean Project Management
Chapter 5 Implementation and Evaluation of Lean principles in the South African Construction Industry		In this chapter the developed lean construction framework was successfully evaluated and implemented in the context of electrical and mechanical engineering services in the South African Construction Industry. The framework was implemented in two case studies to verify and validate its usefulness in this industry.
Chapter 6 Findings and Analysis		In this chapter, discuss findings of implementing lean construction practices in construction industry.
Chapter 7 Conclusion and Recommendations		This chapter presents the conclusions drawn based on the research findings and analysis. Recommendation further research was also discussed.

Figure 1-1: Thesis Overview

1.10 Chapter summary

This chapter introduced the research study. The reason for conducting the research was discussed and the problem statement was elaborated upon. It was noted that there are limited frameworks for the implementation of lean construction for different projects in the South African construction industry. The study's aims and objectives were discussed and the research contribution and research questions were formulated to guide the research. Also, the limitations, delimitations and assumptions of the study were indicated. The following chapter gives a detailed description of the research design followed in this study.

2 RESEARCH DESIGN

This chapter explains the research design in detail.

2.1 Chapter introduction

Research design gives a structure that guides how a researcher makes use of the research method and how to collect and analyse data. In this section, the researcher explains in detail the research design used for this study. To sufficiently explain the research design this study used the research onion as shown in Figure 2-1 was developed by (Saunders, Lewis and Thornhill, 2003). The research onion shown in Figure 2.1 shows various research philosophies, research approaches, strategies and techniques. In this chapter the research philosophy is discussed in section 2.2, the research approach is discussed in section 2.3, while the research method is discussed in section 2.4. The research strategy is discussed in section 2.5 and techniques and procedures are discussed in section 2.6.

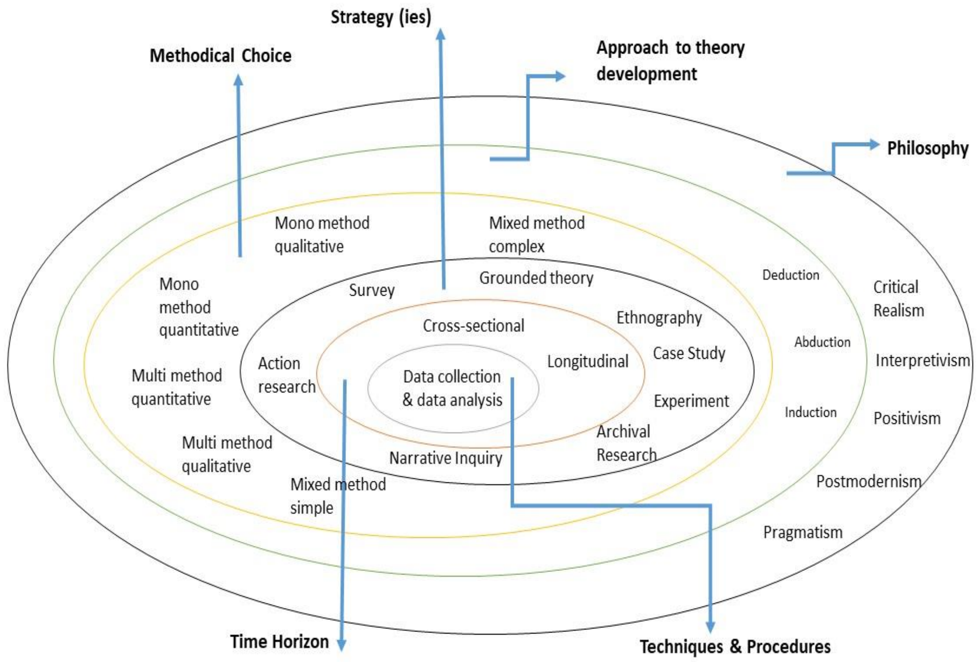

Figure 2-1: Research Onion

(Saunders, Lewis and Thornhill, 2003)

2.2 Research philosophy

This section discusses the research philosophy that shapes this study as indicated in section 2.1. Research philosophy refers to a set of beliefs and suppositions on the development of knowledge (Saunders, Lewis and Thornhill, 2003). When undertaking research, a researcher is developing knowledge in a specific discipline or field. There are three types of assumptions when carrying out a research study; these are ontological assumptions, epistemological assumptions and axiological assumptions (Burrel and Morgan, 2016). Ontological assumptions refer to those ideas that model how the researcher sees and studies research objects. It explains the nature of reality in the real world. Ontology directs how one sees the world of engineering, business and management; thus it influences the researcher's choice of research project (Thomas and Hardy, 2011).

Epistemological assumptions refer to knowledge, how one conveys/transmits knowledge effectively to others and what composes legitimate, well-grounded knowledge (Burrel and Morgan, 2016). In the business, engineering and management contexts, there are distinct types of knowledge which include numerical data, visual data and textual data ranging from stories, facts and opinions –which can be regarded as legitimate knowledge (Gabriel, Gray and Goregaokar, 2013).

Axiological assumptions describe the part played by ethics and values. As a researcher, one of the dilemmas one faces is how the research project will positively or negatively impact one's beliefs and values. You will be forced to decide on how to deal with your values and of the community within which you are carrying out the research (Heron, 1996). As a researcher, your research philosophy reflects on your values the same way as the choice of data gathering techniques.

In this research thesis, the researcher makes use of a research philosophy called Interpretivism. Interpretivism explains that humans are not the same as the physical phenomena – for the reason that humans create meanings. It supports the idea that we cannot study the social world and human beings comparatively as physical phenomena; this also explains why social sciences research is different from natural sciences research (Gubrium and Holstein, 1997; Suddaby, 2006). Since we have diverse cultural backgrounds, for different people under different situations at various times, they create different social classes. Interpretivism aims to develop understandings of social realities and contexts. From the business and management perspectives, researchers argue that CEOs, managers, board directors, shop assistants, customers, and cleaners see things differently in a big retail company such that they may be experiencing different workplace actualities because they are different groups of people. If one's research is to focus on the common experience of everyone, at all times then there will be a lot of differences between them and their situations that will be lost. Furthermore, cultural backgrounds and gender also contribute to people experiencing workplace, events and services in different ways. Interpretations of what may seem as clear and obvious can be different depending on geographical and historical contexts. Interpretivist researchers take all these complexities into consideration by gathering data that is meaningful and applicable to their research community or participants (Crotty, 1998).

2.3 Research approach to theory development

The research approach for this research project is deductive. The deductive approach is when one arrives at the conclusion using logic from theory-derived facts and when the conclusion is true and accurate and all the facts are true (Ketokivi and Mantere, 2010). If one's research begins with a theory that is developed through published academic literature, and one comes up with a research strategy to put the theory to test, such a process could be described as a deductive research approach. Deduction involves the advancement of a theory, which will undergo a meticulous test for all the propositions. (Blaikie, 2010) makes a list of six steps that can be followed when carrying out a deductive approach, these are as follows:

a) Come up with a provisional idea or an untested hypothesis that you wish to study in-depth to form a theory.
b) Through the use of existing literature, state the facts in which the theory will be anticipated to hold.
c) Scrutinize the logic of the facts, comparing these facts with existing theories to find out if there is value-addition to the existing body of knowledge. Continue with your research, if it does.
d) Collect data to select with care the concepts and analyse these concepts.
e) If the analysis results are not consistent with the logic of existing literature, then the test fails. If the theory is false, it can be rejected or adjusted and the process can start again.

f) If the analysis results are consistent with the logic of existing literature, then the theory is true (Saunders, Lewis and Thornhill, 2003).

2.4 Research methodical choice

In this thesis, the researcher uses the qualitative method. Qualitative research method focusses on words instead of quantification when collecting and analysing data. It mainly focusses on generating theories as compared to proving theories. Qualitative research method views the social world as continuously emergent and shifting (Crotty, 1998; Bryman *et al.*, 2017). For qualitative research, the selection of topic, data collection methods and research design are normally done as one begins the research project in the initial phases of a project; this is the first step. Search for the motive of why people do things in a certain way and why they believe in the way, they do. Formulate focused, achievable, specific, clear and relevant research questions (Gubrium and Holstein, 1997). The second step is to carry out a background literature assessment, this is of paramount importance because it will help the researcher to be well informed about the topic, to see how other researchers have dealt with the same research questions and where the gap is so that one can realign and focus the research questions appropriately.

The third step is to select which qualitative research design to use. There are different qualitative research designs, namely ethnography, phenomenological designs, grounded theory and case study research design. Ethnography is when one studies how human interaction is occurs within the community under study through direct observation and personal participation (Strauss and Corbin, 1998; Suddaby, 2006). A phenomenological design entails the researcher making use of the lived experiences of people to interpret and analyse their world. This design method suppresses the researcher's preconceptions so that the researcher will hold firmly to the experiences of the people being studied. The grounded theory is when the researcher makes use of specific data collected to develop a theory based on that information (Bryman *et al.*, 2017).

On the fifth step, there are different methods of collecting and analysing qualitative data; these include direct observation, participant observation, qualitative interviews, surveys, questionnaires, focus group discussions, language-based methods and content analysis. There are various techniques of analysing and interpreting data to get answers for one's research questions; these include coding, statistics, narrative analysis and content analysis. Qualitative researchers normally take counsel from the empirical literature and theoretical literature to interpret data. This is the seventh step (see Silverman, 1993). In this process, new theories may come into view, research questions might be reviewed, and additionally, more data might need to be gathered to tackle the reviewed questions upon writing the research project or thesis. There are eight main steps in qualitative research as discussed in this section and as shown in Figure 2-2 below.

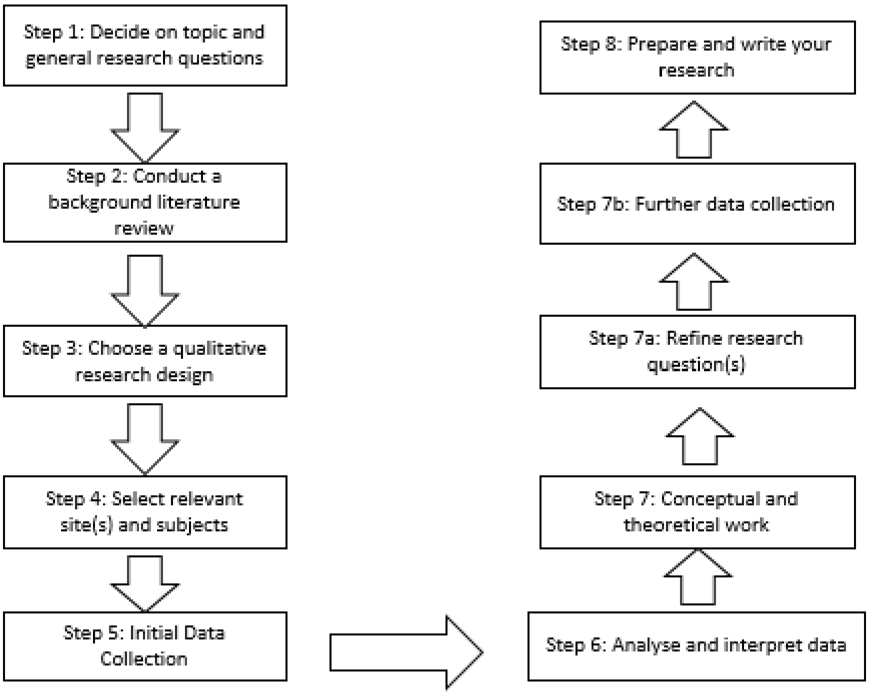

Figure 2-2: Main Steps in Qualitative Research
(Bryman *et al.*, 2017)

2.5 Research strategy

The research strategy used in this study is grounded theory approach. Grounded theory approach is defined as a method in which a concept originates from data that is systematically collected and analysed. In grounded theory, collection of data, its analysis and development of theory are in a close relationship with each other (Strauss and Corbin, 1998). Two distinct features of grounded theory are: it is centred on the evolution of theory from data collected, and the development of *concepts* is recursive and iterative.

Concepts are building elements of a theory; their value is determined by how useful they are. Concepts are regularly found in the data such that the community that will be studied can be able to acknowledge the concept and also correlate it with their experiences. Concepts are recorded on the concept cards, this is where incidents that occur during data collection are also recorded (Strauss and Corbin, 1998; Bryman *et al.*, 2017). Categories are various concepts which have been developed and detailed such that they are regarded as illustrating the real-world. A category could include more than two concepts. Categories are brief as compared to concepts; they could also be core categories where other categories revolve. Properties are elements of a category, while hypotheses are initial ideas about the relationship between concepts. A theory is a set of completely developed statements which are systematically arranged in connection to model a theoretical framework (Strauss and Corbin, 1998).

This study makes use of the Jabareen Conceptual Framework Development Methodology (Jabareen CFM). Jabareen CFM is a methodology within grounded theory and consists of various steps. These steps will be discussed in detail in the techniques and procedures section in this Chapter.

2.6 Techniques and procedures

The literature review was done to understand the level of lean construction in other countries and South Africa. A funnel approach was used, whereby the focus was on other continents, followed by Africa as a whole, then South Africa as a country. The understanding of lean manufacturing, lean construction and application of lean construction in extant literature was deeply researched through a systematic literature review. This research was carried out in three stages namely, literature review, conceptual framework study and case studies as shown in Figure 2-3 below.

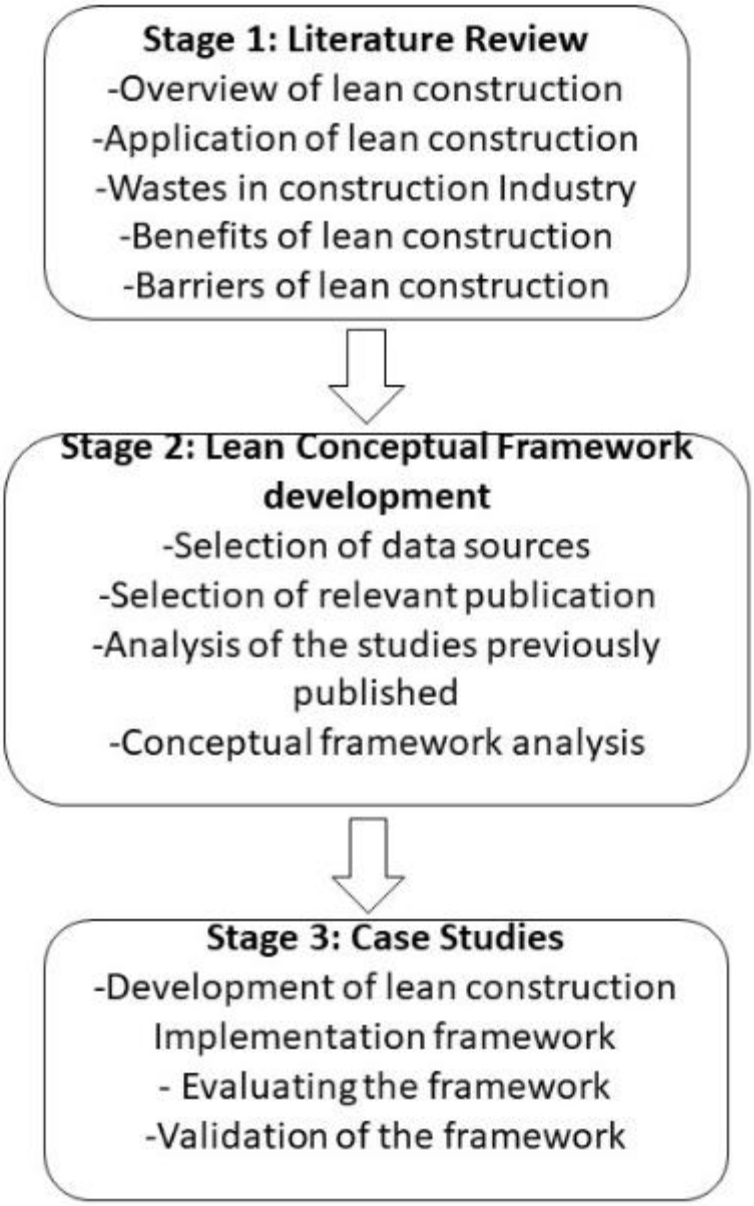

Figure 2-3: Research Strategy

The three steps of the systematic literature review process that was followed are shown in Figure 2-4 below. The systematic literature review is used to gather and study a huge amount of research studies and publications relating to a specific subject to answer-predefined questions by incorporating the useful evidence from all relevant studies. Through the systemic literature review, the researcher gained some insight into wastes and barriers in the construction industry as highlighted by other researchers; this helped the researcher to also be on the lookout for these wastes and barriers upon implementing the lean framework in South African construction industry. The outcomes of the systematic literature review were divided into two sections, which are descriptive statistics and conceptual aspects. Out of the 536 publications that were found on the internet, only 33 publications were relevant to this study. From the literature review that was done, it was evident that there are gaps of lean construction in the electrical installation and mechanical installation services in South Africa.

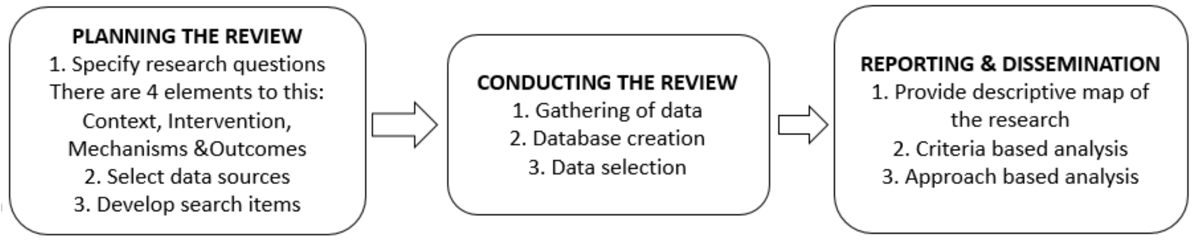

Figure 2-4: Systematic Literature Review Steps

The conceptual framework study was used to develop the framework as supported by Jabareen (2009). Conceptual framework study is a qualitative grounded theory analysis. Four different concepts were identified from the systematic literature review. These four categories of concepts were used to develop a lean construction implementation framework.

The framework was validated through two case studies: the first case study to be studied was of new construction for a bank branch in Promenade, Cape Town. The period and scope of work was noted. The researcher observed lean techniques, lean practice on the workers, wastes encountered in the project execution, number of workers per every stage and how the employees were doing work. From this first case study, the researcher came up with continuous improvement ideas/solutions on the developed lean construction framework to be implemented on the second case study. The second case study was a new construction site for a bank branch in Southdale, Gauteng Province. The improved or refined framework would be used on all the construction sites that this team was working on.

The researcher reviewed published journals and conference papers on lean construction by doing a systematic literature review to comprehensively understand the concepts of lean manufacturing and its applicability in the construction industry. She then identified construction wastes and barriers that may be encountered in the implementation of lean in the South African context. The researcher developed a framework to be used in South Africa. To verify the developed lean management tool, the researcher conducted an analysis of two case studies.

2.7 Reducing the Hawthorne effect

There is a tendency of workers acting differently when they are being observed. This change of behavior is called the Hawthorne effect (McCambridge *et al*, 2014). This tendency undermines the integrity of the conclusions drawn by researchers regarding relationships between variables (Salkind, 2010). To avoid this anomally, the author had to employ ethnographic research skills. Ethnography is a qualitative method where researchers observe or interact with a study's participants in their real life environment (McCambridge, Jim et al, 2014). Since the researcher was already employed as a project engineer in the company in which the study was conducted, she maintained the same working relationship with the workers and tried not to vividly show that she was observing the workers. Only the top management knew that the researcher was carrying out this study since permission was sort from them.

2.8 Chapter summary

The research study for this thesis used various research tools as shown in the chapter. The research was carried out in three stages, which are literature review, conceptual framework study and case studies. Chapter 3 below gives details of the literature review that was done.

3 LITERATURE REVIEW

This chapter outlines a systematic review of existing literature for the research study.

3.1 Chapter introduction

This chapter explores the applications of lean manufacturing principles in the construction industry. The chapter defines concepts of lean, lean thinking principles, lean production methods to reduce waste, lean construction, benefits of lean construction, barriers of lean construction, drivers of lean construction practice in South African construction industry, waste classification in this industry and controllable waste in construction. The goal of this chapter is to understand the application of lean principles in the construction industry and understand the level of awareness of lean concepts in the South African Construction Industry.

3.2 Lean manufacturing in general

Lean manufacturing methodology was used to examine the manufacturing activities exemplified by the Toyota Production System, it is an enhanced version of TPS (Womack, Jones and Roos, 1991). Implementing lean manufacturing helps in increasing efficiency and competitiveness, (Womack, Jones and Roos, 1991). Lean manufacturing can be defined as an organised reduction of waste. It is an organised procedure of continuously improving production activities and changing the organizational culture to embrace new production techniques, (Bicheno, 2004). In this section, the researcher will discuss Toyota Production System in section 3.2.1; The Toyota Way philosophy is discussed in section 3.2.2, the idea of lean wastes is explained in section 3.2.3 and lean thinking principles are examined in section 3.2.4.

3.2.1 Toyota Production System (TPS)

TPS was developed by Toyota, it is a combined socio-technical system that consists of management practices and management philosophy (Ohno, 1988). It is a continuous improvement tool that emphasizes investing in its employees and also promoting a culture of continuous improvement within the business (Ohno, 1988). Taiichi Ohno, founder of Toyota Production Systems stated that: “All we are doing is looking at the timeline from the moment the customer gives us an order to the point when we collect the cash. And we are reducing that timeline by removing the non-value-added wastes" (Ohno, 1988). The Toyota Production System entitles employees to prioritise quality by continuously improving procedures and eliminating unnecessary waste in the business. The root of lean manufacturing can be traced to Toyota Production System that was pioneered by Taiichi Ohno just after World War II in Toyota Motor Company (Womack and Jones, 2003). Due to resources and capital shortages, Toyota Motor Corporation had to develop ways of eliminating wastes and effectively use the little resources that they had (Womack and Jones, 1998; Piercy and Rich, 2009). To ensure high standards of work Toyota Production System (TPS) empowers employees with the autonomy to correct problems in their working environments. TPS focuses on *Just in time* (JIT) and *Process Automation* (Ohno, 1988).

JIT places emphasis on transportation of goods when it is required, and discourages to hoarding; this helps in avoiding inventory costs. The goal of JIT is that the correct quantity of the right material should be available at the right time (Ohno, 2013). *Process Automation* focuses on using automated machines to assist people to avoid human error and mistakes (Liker and Meier, 2004). When a problem occurs during the production process, process automation quickly ceases production and also highlights the cause of the problem (Lean Enterprise Institute, 2015). This is of paramount importance as it focusses on improving quality and eradicate root causes of wastes and defects (Lean Enterprise Institute, 2015). If the production line stops, an instant investigation to the reasons why the line has stopped are noted down and addressed to prevent this from recurring (Monden, 1993; Ohno, 2013).

The key theories of Toyota Production System are Levelling out production, Toyota Way Philosophy, Visual Administration and Standardization as shown in Figure 3-1 below.

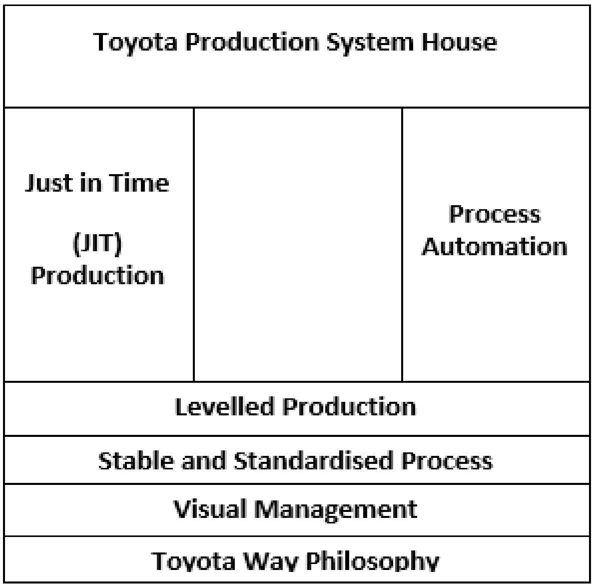

Figure 3-1: Toyota Production System
(Ohno, 1988)

Levelling out production is a basis for flow and pull methods and to minimise inventory. One of the major advantage of levelling out production is the speedy visualisation of the production process. This will enable short reaction time in case of variations within the production process and, hence lead to a smooth flow of production (Black, 2007; Ohno, 2013). The goals of levelling production are:

- To create flexibility for the customer and reduction of costs
- To ensure a smooth flow of production
- To be able to plan the workload for employees and machines
- To improve planning by creating continuous information and material flow
- To create a standard process for working
- To reduce throughput times by reducing inventory

(Rother, 2009) (Dickmann, 2015)

3.2.2 The Toyota Way incorporates the Toyota Production System.

The Toyota Way Philosophy is anchored on two ideas: respect for people and continuous improvement. People are the basis of continuous improvement because they are more significant than processes (Rother, 2009; Liker and Ogden, 2010; Liker and Convis, 2012). Every company should offer greater priority to the development of their employees and creating a conducive environment for them to work (Liker and Ogden, 2010). The principles for continuous improvement are teamwork, kaizen that is continuous improvement through continual innovation, long-term vision and going back to the source of the problem for one to make correct decisions. The principles connecting respect for people are teamwork and how to foster respect with each other (Rother, 2009; Liker and Ogden, 2010; Liker and Convis, 2012). The Toyota philosophy is summarized in Figure 3-2 below.

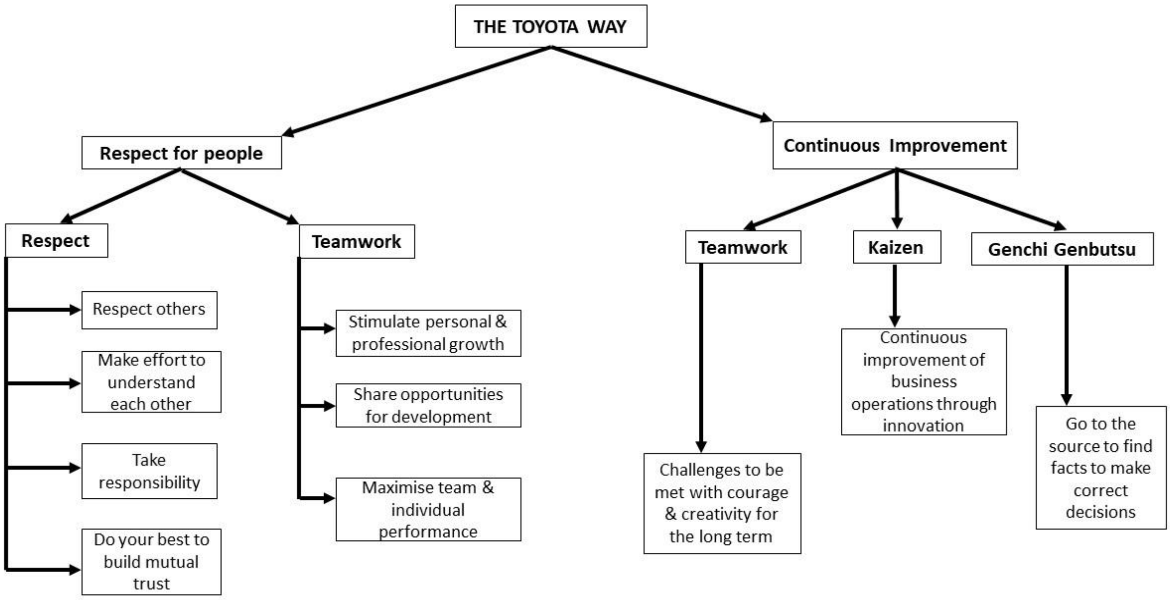

Figure 3-2: Toyota Way Philosophy

3.2.3 Lean wastes

Lean manufacturing can be applied in other contexts of production engineering. The methodology focusses on systematically eliminating process wastes within the production system (Dondofema, Matope and Akdogan, 2017). These wastes include overproduction, excess inventory, incorrect processing, delays, unnecessary transportation, excess motion and defects (Womack, Jones and Roos, 1991). They are briefly described below:

a) Overproduction occurs when organizations try to improve their equipment and employee effectiveness, and fail to strike a balance between demand and production. This leads a company to produce more than what is needed (Ohno, 1988; Liker and Meier, 2004; Bicheno and Holweg, 2009) (Womack and Jones, 2003)
b) Unnecessary transportation is when there is a pointless movement of raw materials and work in progress (Ohno, 1988; Womack and Jones, 2003; Liker and Meier, 2004; Bicheno and Holweg, 2009).

c) Incorrect processing is a situation whereby the product produced exceeds customer specifications. There are production costs incurred in doing this (Taiichi, 1988; Womack and Jones, 2003; Liker and Meier, 2004; Bicheno and Holweg, 2009).

d) Waiting wastes are processing delays, bottlenecks and equipment downtime that results in employee and equipment idle time. Waiting does not add value (Ohno, 1988; Womack and Jones, 2003; Liker and Meier, 2004; Bicheno and Holweg, 2009).

e) Unnecessary movement is an excessive motion of employees and other production equipment without any cause (Ohno, 1988; Womack and Jones, 2003; Liker and Meier, 2004; Bicheno and Holweg, 2009).

f) Defects wastes are when products are non-conforming to standards as well as customer specifications and requirements (Ohno, 1988; Womack and Jones, 2003; Liker and Meier, 2004; Bicheno and Holweg, 2009).

g) Excess inventory consists of additional work in progress, surplus finished goods and excess raw materials (Ohno, 1988; Womack and Jones, 2003; Liker and Meier, 2004; Bicheno and Holweg, 2009).

h) Non-utilized talent is the eighth lean waste. By not engaging employees, incorporating their ideas, providing training and growth opportunities; overall operational effectiveness is reduced. The elimination of this type of waste can improve all others (Gay, 2016 & Bach, 2017)

3.2.4 Lean thinking principles

To systematically eliminate waste, Womack and Jones (2003) developed a lean implementation methodology based on their longitudinal study of TPS. The methodology consists of five major steps that are shown in Table 3-1.

Table 3-1: Lean Methodology as developed by Womack and Jones (2003)

Step	Objective of Step	Tools
1) Specify Value	Understanding customer needs and product characteristics. Identification of production aspects that provide value to the customer.	• Process analysis • Value analysis
2) Identify value stream	To identify specific steps required to make the product.	• Value Stream Mapping • Process Flow Chart • Basic Activity Mapping
3) Establish flow of products	To eliminate process wastes and produce the product with value adding steps.	• 5 Why analysis • Visual Management • 5S (Sort, Set in Order, Shine, Standardize & Sustain) • Spaghetti diagrams • Standard work • Cellular Designs • Total Productive Maintenance (TPM) • Mistake Proofing
4) Pull Production	Enforce a pull system by synchronising production of other workstations to the pace maker workstation.	• Just in Time (JIT) • Pacemaker
5) Seeking Production	Facilitates the continuous improvement process by constantly repeating the cycle in search of a perfect production process.	

In the methodology above, five steps may be used to implement lean manufacturing and a brief description of the steps are as follows (Womack and Jones, 2003) :

(1) Specify value

Value specification should always be done from the customer's perspective and this is achieved when customers define their needs.

(2) Identify the value Stream

Value stream identification focusses on the production activities that the organization perform to meet customer needs at the required standard. This step helps in identifying value-adding activities and non-value adding activities in the production process.

(3) Flow

Establishing flow into the value stream is achieved when the production process is composed of value-adding activities.

(4) Pull

Pull production is done to synchronize workstations and is achieved when the focal work station produces only what is required by the succeeding work station.

(5) Perfection

Striving for perfection in the production process will cultivate the spirit of continuous improvement and this is achieved by repeating the cycle.

The Lean manufacturing methodology as developed by Womack and Jones needs to be contextualised. In the following section (Section 3.3), the student focused on how lean manufacturing has been applied in the construction industry.

3.3 Lean applications in construction

This section discusses wastes in the construction industry, the benefits of implementing lean construction principles and barriers to lean implementation. Lean construction is a waste management methodology focusing on the construction sector (Ballard and Howell, 2003b) and models a construction project as interlinked activities aimed at delivering specific value to the customer (Dos Santos *et al.*, 1998). The benefits of implementing this methodology results in improvements in safety in the working environment, increased productivity, cost reductions, improved employee morale which cultivates the spirit of teamwork and meeting project deadlines (Brookfield *et al.*, 2004; Nowotarski, Pasławski and Matyja, 2016; Bajjou *et al.*, 2017).

Lean applications in the construction industry refers to implementing lean concepts, principles, and tools through the phases of a project. This calls upon total transformation of the traditional way of construction (Nowotarski, Pasławski and Matyja, 2016). During construction, applying lean principles should focus on getting things right, in the right place, at the desired time and in desired quantity (Bertelsen, 2004; Brookfield *et al.*, 2004; Dondofema, Matope and Akdogan, 2017). Lean construction is the application of lean tools in a construction project to improve construction products (Diekmann *et al.*, 2003; Sacks and Goldin, 2007; Marhani *et al.*, 2013). When well implemented with the right resources, lean construction improves the construction process and delivers profit to the South African construction industry (Yahya and Mohamad, 2015). Previous studies by Common, Johansen and Greenwood, (2000) highlighted important areas that need to be changed for the implementation and application of lean construction in the construction industries. These four areas are planning, management, control, and procurement. In a lean environment, the management has two responsibilities namely sustaining and controlling existing systems and processes (Liker, 2004).

3.3.1 Wastes in the construction industry

In construction projects, waste is generated and the waste generated has an effect on efficiency and profits. Traditional methods in the construction industry acknowledged material wastes (Khanh and Kim, 2015a). With the application of lean manufacturing method in construction, various wastes are being unearthed. From the study carried out by Bajjou and Chafi (2019), twenty-two sources of waste were grouped into the typical seven categories of lean wastes as discussed in section 3.2.3. In over-processing wastes category, the study identified that there is excessive supervision of employees, complex working instructions and inefficient working methods. This study discovered that in the construction industry excessive time is spent transporting employees, materials and equipment; this falls under excessive conveyance also known as unnecessary transportation (Khanh and Kim, 2015a).

In the construction industry, there are defects just like in the manufacturing industry. There are quality defects whereby the quality is compromised. Design errors, re-work and work equipment failure all fall under defects wastes category. Over-storage of materials, broken materials, material waste, theft of equipment and materials from the construction site fall under excessive inventory. Material waste in the construction industry will be explained in detail in the section below. Under over-production waste on construction sites, there is solid waste generation and the utilization of more materials and labour than what is necessary. Under the delay category of waste, there are delayed instructions, activity start delays, delays caused by lack of equipment or materials in the inventory. There are also delays caused by work not completed by others, waiting for permission from the local authorities and unsystematic time breaks (Bajjou and Chafi, 2019). Figure 3-3 below shows a summary of wastes identified in the construction industry as discussed in this section.

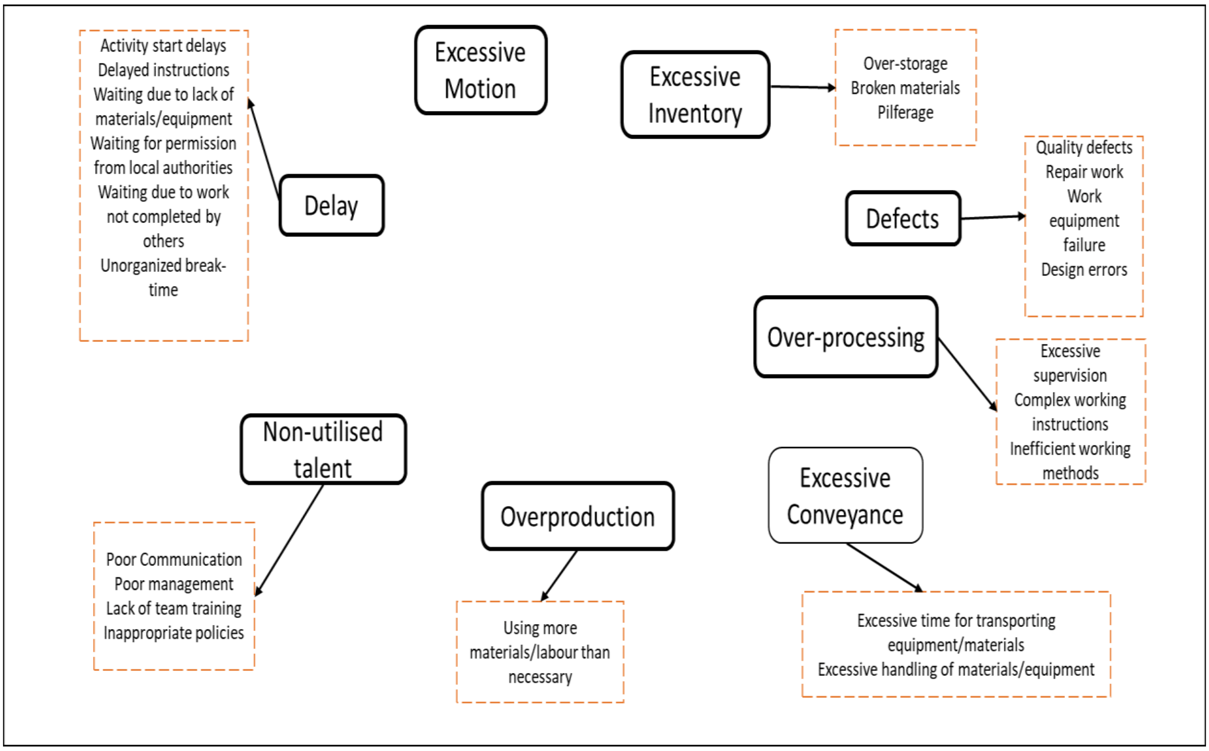

Figure 3-3: Sources of Wastes Classified into Seven Typical Waste Groups (Bajjou and Chafi, 2019)

In a survey conducted by John and Itodo, (2013), 21-30% of construction overruns in construction projects were incurred because of wastes. By implementing lean construction, organisations will have various ways to reduce wastes as shown in Figure 3.3. These wastes are linked to construction resources such as labour, equipment and time.

Waste may also be defined as any non-value-adding activity in the production process (Koskal and Egitman, 1998; Bicheno and Holweg, 2016). These non-value adding activities do not improve value but only increase cost and the overall production time (Hosseini *et al.*, 2011). However, in the construction industry it is critical to distinguish non-value-adding activities from essential non-value adding activities and non-essential value-adding activities (Liker, 2004). Some studies indicate that 68% of total project time is spent on non-value adding activities (Dupin 2014).

3.3.2 Material wastes in construction

Material wastes fall under excessive inventory in the seven categories of wastes that were discussed in section 3.3.1 above. According to a study done by Teo, Abdelnaser and Abdul, (2009), additional construction materials are generally procured due to wastage during the construction phase.

Studies that were done previously from different countries showed that material wastes in the construction industries represent a big percentage of the total project costs. A report that was done in the United Kingdom highlighted that there were 15% surplus costs to the overall project costs due to material wastage (Tam, Shen and Tam, 2007). In Hong Kong, a similar study was done and it concludes that wastage in material contributed to 11% of the total project costs (Tam, Shen and Tam, 2007). In the Netherlands, a study showed that 20% of project costs are due to material wastage (Bossink and Brouwers, 1996). In the Nigerian Construction Industry, 18% of the total project cost is due to building materials wastage (Akinkurolere and Franklin, 2005). Rogoff and Williams, (1994) explained that 15% of the total project cost is due to material wastage in the United States of America. Figure 3-4 below summarizes what has been discussed in this section.

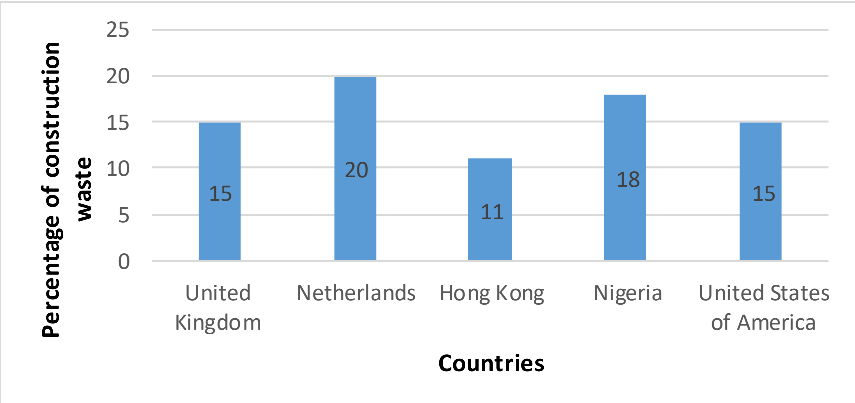

Figure 3-4: Percentage of Construction Waste Compared to Total Project Costs (Rogoff and Williams, 1994; Bossink and Brouwers, 1996; Akinkurolere and Franklin, 2005; Tam, Shen and Tam, 2007)

Material wastage as a percentage is directly proportional to the increase in total project cost. Teo, Abdelnaser and Abdul (2009) also noted that material wastage on a construction site contributes to cost overruns. This then means that if the construction industry aims to reduce material wastage, this would definitely lower the total project cost and save a lot of money.

An interesting perspective was presented by Hore *et al.*(1997) cited in Ajayi *et al.* (2008), they observed that for every one hundred houses that were built in the United Kingdom, there was more than enough waste material that could be used to build extra ten houses. In the UK construction industry, more than 70 million tons of waste was being generated each year (Guthrie and Mallet, 1995). From these discussions, it is evident that the nation was bleeding economically due to material wastage in the Construction Industry.

These findings could be used to help improve project efficiency in the South African construction industry. In the construction industry, lack of information and communication breakdown also results in cost increase, rework, and delays. All these are unwanted wastes are wasteful practises in the industry that makes it peculiar; thus, they are things to consider when developing lean construction principles. The overall implication is substandard products, unnecessary deadline extensions and cost increase which affect customer satisfaction negatively (Howel and Koskela, 2000).

3.3.3 Benefits of lean construction

Several authors attribute significant improvements in terms of the timely completion of construction projects to lean construction (Ahiakwo *et al.*, 2013). Benefits of implementing lean construction as identified in existing literature are shown in Table 3-2, (Lehman and Reiser, 2000; Koskela and Howell, 2000; Love, Zahir and David, 2003; Nahmens and Ikuma, 2009, 2012; Kristensson, 2011; Ikuma, Nahmens and James, 2011; Adamu and Howell, 2012; Tezel and Nielsen, 2012, 2013; Issa, 2013; Abbasian-Hosseini, Nikakhtar and Ghoddousi, 2014; Emuze and Ungerer, 2014; Carneiro *et al.*, 2015; Hamdar *et al.*, 2015; Monyane, Awuzie and Emuze, 2017; Erol, Dikmen and Birgonul, 2017; Akinradewo *et al.*, 2018).

Table 3-2: Lean Construction Benefits (Author's Analysis)

Benefits	**Project Type**	**Did the South African industry benefit from this benefit?**
Reducing total project duration	Industrial Project Residential Building Project Housing Estate Projects Units	According to(Akinradewo *et al.*, 2018) the South African construction industry is benefiting from this benefit.
Quick turnover and Low costs of construction projects	Construction & Civil Engineering Infrastructure Projects	In the collected literature, the researcher did not find any evidence on this benefit.

Improving the quality of work	Infrastructure projects Commercial buildings	In the collected literature, the researcher did not find any evidence on this benefit.
Improving the environmental performance	Housing Estate Projects Residential, institutional and commercial	In the collected literature, the researcher did not find any evidence on this benefit.
Improving the safety of workers	Residential, institutional and commercial	According to (Emuze and Ungerer, 2014; Akinradewo *et al.*, 2018), the South African Construction Industry is benefiting from this benefit.
Improved project delivery methods	Construction & Civil Engineering	In the collected literature, the researcher did not find any evidence on this benefit.
Managing uncertainties in supply	Hospital Construction Housing Estate Projects	In the collected literature, the researcher did not find any evidence on this benefit.
Supporting the development of teamwork and transfer the responsibility on the supply chain	Renovation Project	In the collected literature, the researcher did not find any evidence on this benefit.
Continuous improvement within projects	Residential Building Project	According to Monyane, Awuzie and Emuze (2017), lean construction implementation enhances continuous improvement within projects.
Minimisation of conflicts that can dramatically change budget and schedule	Housing Estate Projects Hospital Construction	In the collected literature, the researcher did not find any evidence on this benefit.
Delivery of custom products instantly without waste	Residential, institutional and commercial	In the collected literature, the researcher did not find any evidence on this benefit.
Delivery of products and services on time and within budget	Residential, institutional and commercial	In the collected literature, the researcher did not find any evidence on this benefit.
Reduction on direct cost and time in transportation and communication	Residential Building Project	In the collected literature, the researcher did not find any evidence on this benefit.
Reduced Waste	Road Construction Projects	According to Monyane, Awuzie and Emuze (2017) and Akinradewo *et al.*, (2018), lean construction implementation in South Africa reduces waste and increase productivity.
Improved Overall Equipment Effectiveness (OEE)	Residential, institutional and commercial	In the collected literature, the researcher did not find any evidence on this benefit.
Improved quality control	Housing Estate Projects	In the collected literature, the

and minimisation of risks	Hospital Construction	researcher did not find any evidence on this benefit.
Improved employee satisfaction and suppliers relationship	Residential Building Project	Yes, lean construction enhances motivation (Emuze and Ungerer, 2014).

As seen in Table 3-2, lean construction principles were applied to various construction projects. These include residential building projects, road construction, and commercial properties construction. Applications of lean construction principles in these projects have resulted in efficiency improvement of overall equipment effectiveness (OEE), as seen in Table 3-2. The main benefits of lean construction are reduction of wastes, customer satisfaction, and overall project cost reduction. Lean construction helps construction companies to identify and analyse wastes to improve productivity, reduce project duration, improve safety, improve quality, ensure customer satisfaction, and improve reliability.

3.3.4 Barriers to lean construction implementation

In as much as there are many benefits that come with lean construction implementation, there are also barriers and obstacles that hinder lean construction implementation. Based on some studies that previously explored lean construction barriers in the construction industry in developing and developed countries, this study compiled a list of barriers to lean implementation as shown in Table 3.3.

Aigbavboa, Oke and Momoti, (2016) identified lack of communication, resistance to change, shortage of technical skills, poor planning, inflation of construction material prices, waste believed as inevitable, extensive use of unskilled labour and customers not being interested in lean construction as some of the barriers that hinder lean construction implementation. In another study that was done by Sarhan and Fox, (2013) they investigated 140 construction professionals and realized that cultural issues and attitude was a major hindrance to implementation of lean principles. In another study by Bashir *et al.* (2015), the study identified that human-related matters of construction industry workers that include an unwillingness to change behaviour and the way they do things are some of the barriers of lean construction implementation. The study by Bashir *et al.* (2015) further highlights absence of long term commitment from management as a barrier to the implementation of lean in construction projects. This study identified in literature that inadequate training of employees is also a major barrier to lean construction implementation (Dulaimi and Tanamas, 2001). In a study by Shang and Pheng (2014), this study identified the following barriers: absence of long-term commitment, lack of lean culture in construction firms and extensive use of subcontractors.

Other barriers identified in this study by the student include government-related issues like strict requirements and authorizations, absence of organizational culture, shortage of technical skills and knowledge to back up the construction team players (Omran and Abdulrahim, 2015). Another study observed that absence of lean construction awareness and understanding as the major lean construction barriers (Adegbembo, Bamisaye and Aghimien, 2016). Lack of lean construction knowledge and unskilled workers are the most challenging barriers to the application and implementation of lean construction in the construction industry (Ciarniene and Vienazindiene, 2015; Ayalew, Dakhli and Lafhaj, 2016; Neeraj *et al.*, 2016).

Absence of lean awareness in top management and absence of management's long term commitment are also barriers to the adoption of the lean construction in the construction industry (see Dulaimi and Tanamas, 2001; Abdullah *et al.*, 2009; Sarhan and Fox, 2013; Devaki and Jayanthi, 2014; Shang and Pheng, 2014; Ciarniene and Vienazindiene, 2015; Adegbembo, Bamisaye and Aghimien, 2016; Aigbavboa, Oke and Momoti, 2016; Ayalew, Dakhli and Lafhaj, 2016; Neeraj *et al.*, 2016). This is also presented in Table 3-3 below.

Furthermore, in the construction industry, a lack of training and absence of lean specialists and professionals are barriers (Dulaimi and Tanamas, 2001; Alinaitwe, 2009; Ayarkwa, Agyekum and Adinyira, 2011; Al-Aomar, 2012; Sarhan and Fox, 2013; Shang and Pheng, 2014; Devaki and Jayanthi, 2014; Omran and Abdulrahim, 2015; Ayalew, Dakhli and Lafhaj, 2016; Oke, Aigbavboa and Momoti, 2016; Sarhan *et al.*, 2018).

Also, lack of lean culture and disinclination to adopt lean thinking are barriers to lean construction implementation (Dulaimi and Tanamas, 2001; Al-Aomar, 2012; Sarhan and Fox, 2013; Devaki and Jayanthi, 2014; Gao and Low, 2014; Ciarniene and Vienazindiene, 2015; Omran and Abdulrahim, 2015; Adegbembo, Bamisaye and Aghimien, 2016; Aigbavboa, Oke and Momoti, 2016; Ayalew, Dakhli and Lafhaj, 2016; Sarhan *et al.*, 2018).

In addition, studies that have been conducted show that lack of financial resources is a barrier in the construction industry (Alinaitwe, 2009; Ayarkwa, Agyekum and Adinyira, 2011; Al-

Aomar, 2012; Devaki and Jayanthi, 2014; Shang and Pheng, 2014; Ciarniene and Vienazindiene, 2015; Adegbembo, Bamisaye and Aghimien, 2016; Ayalew, Dakhli and Lafhaj, 2016; Sarhan *et al.*, 2018).According to (Devaki and Jayanthi, 2014), barriers to lean construction implementation are lack of lean culture and shortage of lean construction technical skills and expertise, refer to table 3.3.

Table 3-3: Global Lean Construction Barriers (Author's Analysis)

Lean Construction Barriers	(Sarhan and Fox, 2013)	(Neeraj *et al.*, 2016)	(Dulaimi and Tanamas, 2001)	(Aigbavboa, Oke and Momoti, 2016)	(Shang and Pheng, 2014)	(Abdullah *et al.*, 2009)	(Devaki and Jayanthi, 2014)	(Al-Aomar, 2012)	(Adegbembo, Bamisaye and Aghimien, 2016)	(Alinaitwe, 2009)	(Sarhan *et al.*, 2018)	(Ayalew, Dakhli and Lafhaj, 2016)	(Omran and Abdulrahim, 2015)	(Ayarkwa, Agyekum and Adinyira, 2011)	(Ciarniene and Vienazindiene, 2015)	Weightings
Lack of Lean Culture	**X**		**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**14**
Resistance to change	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**15**
Extensive use of unskilled labour	**X**		**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**		**13**
Lack of financial resources					**X**		**X**	**X**	**X**	**X**	**X**	**X**		**X**	**X**	**9**
Cultural issues & attitude	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**			**X**	**13**
Inadequate training ,expertise & shortage of technical skills	**X**		**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**14**
Absence of management long term commitment	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**			**X**	**13**

Government not in support					**X**		**X**		**X**	**X**	**X**	**X**				**6**
Extensive use of subcontractors	**X**		**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**		**13**

From the above discussion, the researcher went on to scale and weigh the barriers according to the number of times it was referenced in the literature. For each reference, a weight of 1 is given to each barrier. Table 3-4 shows the weighting and ranking:

Table 3-4: Lean Construction Barriers Weightings & Rankings (Author's Analysis)

Lean Construction Barriers	**Weighting**	**Ranking**
Resistance to change	15	1
Inadequate training, expertise & shortage of technical skills	14	2
Lack of Lean Culture	14	2
Extensive use of unskilled labour	13	4
Absence of management long term commitment	13	4
Extensive use of subcontractors	13	4
Cultural issues & attitude	13	4
Lack of financial resources	9	8
Government not in support	6	9

Table 3-4, above shows the most prevalent lean construction barriers affecting the industry worldwide as found in the systematic literature review. These barriers are hindering lean construction implementation; the top five are: resistance to change, inadequate training, expertise & shortage of technical skills, lack of lean culture, extensive use of unskilled labour, absence of management long-term commitment and extensive use of subcontractors. Resistance to change has been cited in fifteen studies, based on the results of the exercise and is considered as a key barrier. Lack of lean culture, inadequate training, expertise and shortage of technical skills have been cited in fourteen studies and these are key barriers in lean construction implementation. Extensive use of unskilled labour, absence of management long term commitment, extensive use of subcontractors, attitude problems and cultural issues have been cited in thirteen studies, while lack of financial resources has been cited in nine studies. Some governments do not support lean construction implementation in their countries; this has been shown in citations from six studies.

In this section, the researcher discusses solutions proffered for mitigating these barriers by researchers'. How other researchers found as the ways to mitigate these barriers.

According to a study done by Bashir *et al.*, (2015), the management in the construction industry should take full responsibility for staff training on lean construction at all levels and promoting lean construction concept to stakeholders and professional bodies thereby promoting lean culture. The workers in the construction industry should also be open and quick to adopt changes from traditional construction to lean construction as it is of major benefit in improving performance in organization and the whole industry (Ayarkwa, Agyekum and Adinyira, 2012).

Non-managerial workers including suppliers and sub-contractors should be conscious of lean construction; this will help ensure successful setting out of lean construction implementation in the industry (Gao and Low, 2014; Sarhan *et al.*, 2018). A lean culture should be much emphasised as it supports lean in the industry (Sarhan and Fox, 2013). This can be achieved by executing changes to the existing traditional culture to accommodate lean construction principles in the policy of the organisation. If done this way, everyone at the organisation would be obliged to embrace this lean construction culture. In order for the construction industry to succeed in lean construction implementation they should provide funding for hiring a lean consultant so as to give recommendations to employers and employees, particularly in the early stages of lean construction implementation (Bashir *et al.*, 2015). To ensure the effective implementation of lean construction, action plan has to be put in place to reduce or eliminate these barriers discussed.

3.4 A review of lean applications in construction industry

The objective of this section is to understand the applications of lean manufacturing principles in South African construction industry. In this section, a systematic literature review was conducted under the outlook of lean applications in the South African construction industry. Systematic literature review methodology was selected because it removes bias in the selection of the studies to review.

Some parts of this section were published in the South African Journal of Industrial Engineering Special Edition 2019 (SAJIE, Volume 30, issue 3, 2019).

3.4.1 Conducting the review

Systematic literature review is an important scientific research approach that can be used to appraise, summarise and communicate findings and implications of large quantity of research publications on a particular subject (Green, 2005). Secondly, evidence in the literature shows that previous authors (Emuze and Smallwood, 2013; Marhani *et al.*, 2013; Dondofema, Matope and Akdogan, 2017; Saieg *et al.*, 2018) had adopted similar approach in their respective lean manufacturing studies. Systematic literature review is used to gather and study a huge amount of research studies and publications relating to a specific subject to answer predefined questions by incorporating the practical evidence from all relevant studies (Bearman and Dawson, 2013).

A systematic literature review is a part of research in its peculiar right and by its nature, is able to discourse much wider questions than single empirical studies ever can. Without doubt, systematic review is at the top of the 'hierarchy of evidence' as compared to other research designs because it has the potential to deliver the most important practical implications (Bearman and Dawson, 2013). Thus, the systematic literature review focused on reviewing studies in construction industry available in different search engines. The study was conducted in six steps as shown in Table 3-5.

Table 3-5: Research Methodology Steps

Steps	**Reason for that step**	**Where it is presented**
1.Developing search terms	To develop appropriate terms that will assist to the required for analysis.	Section 3.4.1
2.Identifying data Sources	To identify the appropriate search engines and this study used Web of Science, Google Scholar, and Science Direct.	Section 3.4.2
3.Selection of relevant publication	The screening was done to see if the papers where relevant for the objective of study.	Section 3.4.2.1
4.Analysing studies	This step was important as it helps in understanding lean construction concepts in literature.	Section 3.4.5

3.4.2 Data sources and data collection

To identify studies on lean construction, the researcher used "lean in construction" and "lean construction" as search terms. The search fields used were Article title, Abstract and

Keywords. The search engines used were Web of Science, Google Scholar, and Science Direct. The initial search yield is displayed in Table 3-6.

Table 3-6: Initial Search Results

Search terms	Search Field	Web of Science	Google Scholar	Science Direct
Lean in construction industry and lean construction	Article tittle, Abstract, Keywords	312	134	90

3.4.2.1 Selection criteria

Out of 536 publications that were found on the initial primary search, an extensive review was done to establish if the publication was fit for the systematic literature review. The first screening criterion was to check if the publication was related or not related to the topic of lean construction implementation. The second vetting process was done to check if the publication was relevant to the scope of study or not. A total of 343 publications were found to be unrelated to the topic of study. From 193 publications that were related to the topic, only 33 papers were relevant to the current study. Of the 33 papers found, only 9 papers focussed on lean construction in the South African construction industry. Figure 3-5 shows document selection.

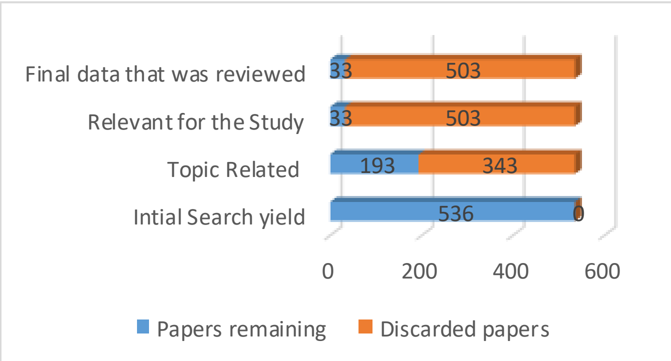

Figure 3-5: Document Selection (Author's Analysis)

This section is divided into two sub-sections, which are descriptive statistics and conceptual aspects.

3.4.3 Descriptive statistics

From the systematic literature review, it was found that documents related to lean construction were in the form of journal articles, conference papers, industry research reports, and book chapters. The review focused on lean implementation in the construction industry, thus the researcher selected materials with rich contents of empirical data on lean construction implementation. A total of 33 publications were relevant to the current study of lean construction implementation. These were published from year 2012 to 2019. From these publications 58% were journal articles, 39% conference papers, and 3% book chapters as shown in Figure 3-6. The next step taken by the researcher was to read the selected papers so as to understand the study objective, research approach used, key concepts and lean tools used for each paper (Maradzano, Dondofema and Matope, 2019).

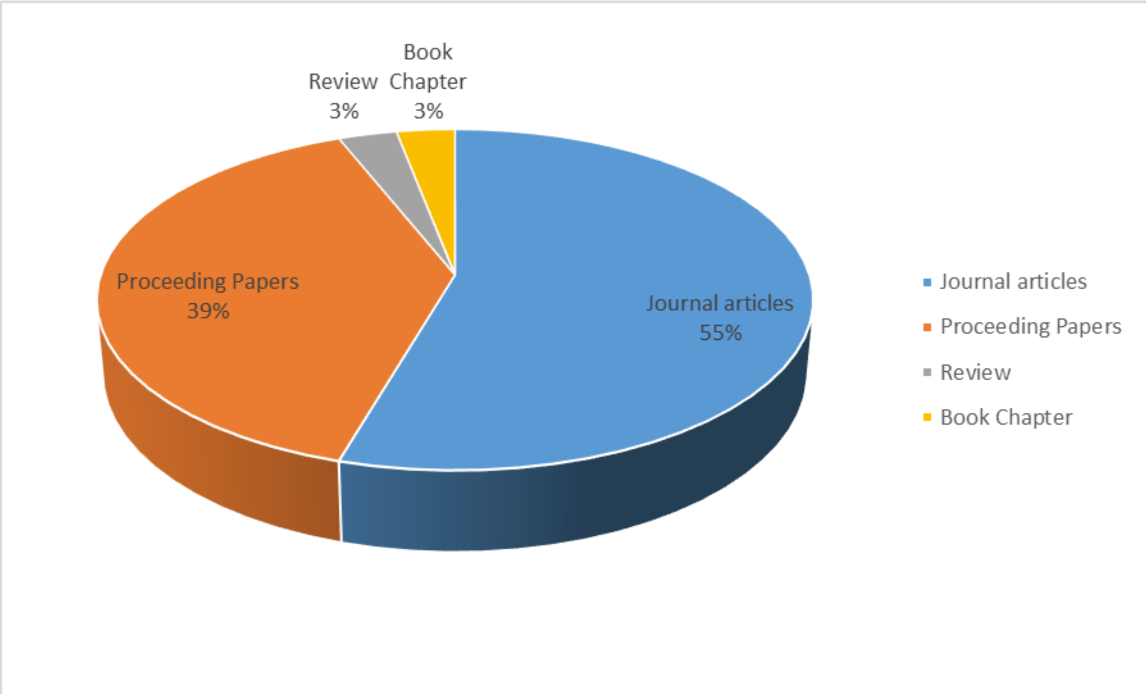

Figure 3-6: Paper Types (Author's Analysis)

Out of the 33 papers that were relevant to the current study, only 9 papers focussed on the South African construction industry. Figure 3-7 shows sub-sectors where lean construction has been applied in the South African construction industry. From these results, it is evident that there is limited application of lean construction particularly in the electrical and mechanical services (wet, fire, heating ventilation & air conditioning (HVAC)) in the South African construction industry (Maradzano, Dondofema and Matope, 2019). Construction and civil engineering projects involve management of infrastructures such as roads, tunnels, bridges, airports, railroads, dams, and sewerage. Commercial buildings are those construction projects that involve building projects that can be leased or sold in the private sector. These spaces can be anything from offices, retail shopping centres, and medical centres.

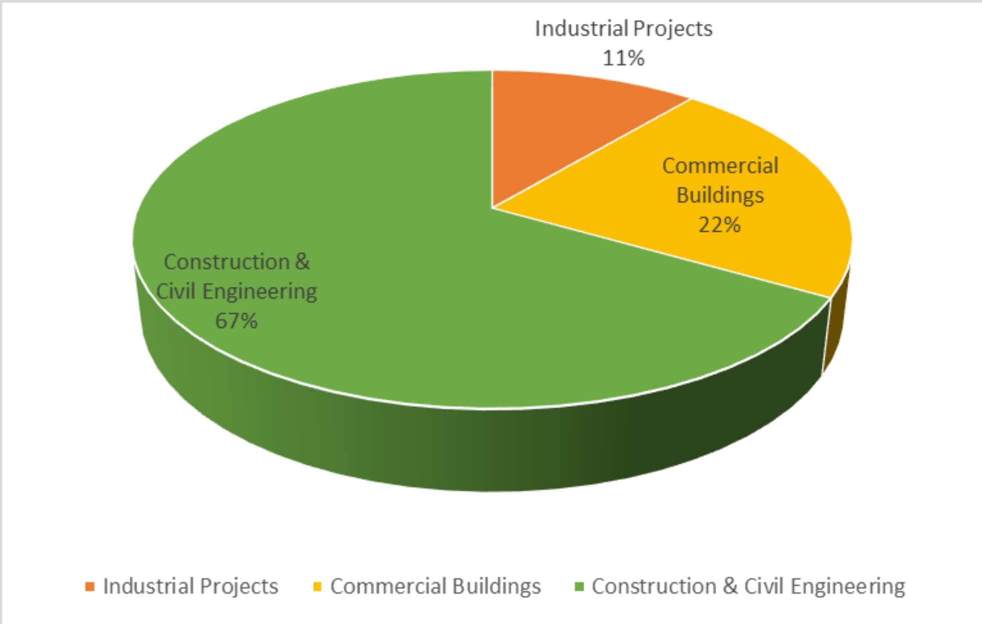

Figure 3-7: Project Types (Author's Analysis)

3.4.4 Identified gaps in South African construction industry

As the case with the global trend, the government of South Africa is actively encouraging the construction industry to be efficient in managing resources, reducing waste and also change the working environment so as to increase productivity (Shakantu *et al.*, 2007). The South African construction industry is having pressures to reform as it remains narrowed to its old methods of doing business as noted by Bowen, Pearl and Akintoye, (2007). A lot of industries in this country have gone through transformations in the last three decades but the South African construction industry is an exemption in this regard. This industry is well known for inefficiencies as well as participants' resistance to change and the adoption improvement strategies. The CIDB report highlights that each individual company executes a variety of non-value adding activities among its disciplines which generates inefficiencies causing delays and increase in costs (Construction Industry Development Board, 2004).

From the analysis of literature on lean construction in South Africa, it has been observed that there are limited frameworks for the implementation of lean construction for different construction projects in the South African construction industry. The researcher observed that there is limited application of lean construction in the electrical and mechanical services projects (wet, fire, heating ventilation and air conditioning (HVAC)) which are also key components of construction industry. Hence the aim of this study is to develop a lean construction implementation framework that can be used to implement lean principles in mechanical and electrical services projects (Maradzano, Dondofema and Matope, 2019).

3.4.5 Lean construction techniques identified

Many projects in South Africa experience time delays, cost overruns and the generation of substantial amounts of waste. Lean construction has been introduced to address these challenges in the South African construction industry; however, it is still in its infant stage. The construction industry is also characterised by poor quality, poor safety and negative effects on the environment (Bajjou, Chafi and En-Nadi, 2017). From available literature on lean construction implementation, the appropriateness of lean construction practices in the construction industry has remained subject to substantial discussions (Picchi and Granja, 2004; Gao and Low, 2015). This section discusses nineteen lean tools that are currently being used worldwide for lean construction implementation in this industry as identified in literature. From these nineteen lean tools, only four tools have been found in literature being used in the South African construction industry. The very basics of lean in construction have only been applied in the South African construction industry. Higher-level techniques such as Kanban and JIT are yet to be fully applied.

From the discussion below, the researcher observed that the lean tools used in the construction industry are Kanban system, value stream mapping, first run studies (plan-do-check-act), total quality management, poka-yoke, failure mode and effect analysis, five why's, just in time (JIT), increased visualisation, standardization, last planner system, waste elimination and continuous improvement. According to Salem *et al.* (2006), there are three characteristics that differentiate construction industry from manufacturing industry, these are 1) Unique Project 2) Complexity and 3) On-site production. These key differences make it difficult to simply transfer lean tools from manufacturing industry to construction industry.

3.4.5.1 Just-in-time (JIT)

The just-in-time method is a supply management tool driven by the customer's demand. Its aim is to maintain a construction material flow that matches the internal/external customer requirements to optimise inventory and work-in-progress (Ballard and Howell, 2003b; M. Bajjou and Chafi, 2018; Tezel, Koskela and Aziz, 2018). JIT production focusses on exceptionally tuned methods in the production line producing what is only required when it is needed and in the correct amount. It is a concept that explains that inventory is not valued and it should be considered as waste, therefore it should only be available when it is required only (Chaoiya et al, 2000). In the collected literature, the researcher did not find any evidence of the application of this tool in the South African construction industry.

3.4.5.2 The 5S process

The 5S process is a systematic housekeeping process that is performed by its five distinctive steps:

Sorting, straightening, shining, standardizing, and sustaining the facilities and processes used in construction. The 5S process increases productivity of the project as it reduces the time spent searching for supplies, tools and equipment (Umstot, 2013; Ansah and Sorooshian, 2017; Caldera, Desha and Dawes, 2018). The goal of 5S process is to build an orderly place of work with everything in place; this includes method, money, material, manpower and machinery also known as 5Ms in the construction industry. Sorting involves going through materials, tools and equipment to eliminate what is not necessary for one to complete the work. Straightening comprises of labelling and organizing the workplace so that it is clear where everything fits in. Shining involves cleaning up place of work so that it becomes an efficient workplace for people to be proud to work in. Standardizing involves using standardized work so as to keep the workplace organized (Salem and Zimmer, 2005; Bygballe, Endresen and Falun, 2018). In the collected literature, the researcher did not find any evidence on the application of this tool in the South African construction industry.

3.4.5.3 Five why analysis

It is a problem-solving technique used to identify the root causes of a targeted problem. Five why analysis is a question-asking technique that illuminates “cause-and-effect” mechanisms associated with a problem. The questions are usually specific to the project and are not limited to five questions. The five why are generally dependent on each project separately and are not restricted to five questions (Aziz and Hafez, 2013; Sarhan *et al.*, 2017; Bajjou and Chafi, 2019). This tool is currently used in the South African construction industry (Emuze and Ungerer, 2014).

3.4.5.4 Standardisation

Standardisation can be described as a set of methods, components, or processes in which there is repetition and regularity leading to successful practices; these practices are also called Standard Operating Procedures (SOP). This technique allows building in the shortest possible time and with the minimum of efforts (Howell, 1999; Tezel and Nielsen, 2012; Fitchett and Hartmann, 2017). In the literature reviewed, the researcher did not find any evidence on the application of this tool in the South African construction industry.

3.4.5.5 Prefabrication

This tool consists of using modularised and prefabricated construction components. The aim of this tool is to overcome the common production problems encountered during on-site construction (i.e. low output quality, low productivity, high variability, and poor safety) (see Alves, Milberg and Walsh, 2012; Nahmens and Ikuma, 2012; Alves *et al.*, 2016; Bajjou *et al.*, 2017; M. S. Bajjou and Chafi, 2018). In the collected literature, the researcher did not find any evidence on the application of this tool in the South African construction industry.

3.4.5.6 The Last Planner System (LPS)

Last Planner System offers an outline of how to control and plan construction project activities in an organised way. LPS is a method that forms workflow and deals with project variability. The advantage of LPS is that it allows transformation from expectant planning to accurate planning. This is achievable by firstly assessing employees' performance relative to their ability to constantly reach their attentions (Ballard and Howell, 1994; Lehman and Reiser, 2000; Watson, 2003; Salem and Zimmer, 2005).

Last Planner System embraces four levels, which are Master Pulling Schedule, Weekly Work Plan, Phase Schedule, and Look ahead plan. Master Pulling Schedule is a timetable for a complete project with milestones to be achieved. It is designed based on the client's project target standards, which are achieved by breaking down the project into smaller pieces (Antillon, 2010). It is a tool that helps in understanding project definition (Salem, Solomon and Luegring, 2005). Respective teams do phase schedule in each phase. This level is more practical as compared to the master pulling schedule. For a successful execution of the project, the phase schedule should be prepared before the project is started (Ballard and Howell, 2003a). Look-ahead planning is a level, which places flow of work into attainable order. The major advantage of look-ahead planning is that it helps managers to have control over backlog activities in a more malleable way. The activities are planned together by all involved trades, tasks that are depended on each other are grouped together, so as to design a work method for all the activities (Salem, Solomon and Luegring, 2005). The weekly work plan is important because it covers weekly schedules, material need, quality matters, safety concerns, construction methods, prepared work for the week and any challenges that might come up in the field. This helps in improving the way a project is executed, it also strengthens the bond among stakeholders since there will be clear communication of loads and or quantities requested by all task contractors participating within project execution. In the collected literature, the researcher did not find any evidence on the application of this tool in the South African construction industry.

3.4.5.7 Value Stream Mapping (VSM)

Value stream mapping is an information and material flow mapping tool which is used to graphically visualise the current value stream and design the future state of the construction process while reducing all sources of waste (overproduction, waiting, inventory, displacements, etc) (Yu *et al.*, 2009; Kristensson, 2011; Bajjou and Chafi, 2019). In the collected literature, the researcher did not find any evidence on the application of this tool in the South African construction industry.

3.4.5.8 Continuous Improvement (kaizen)

This technique supports the idea that every process can and should be continually measured, analysed, and improved in terms of resources used, the time required, quality demanded by customers and other performance criteria relevant to the construction. All lean techniques are established to push continuous improvement through problem solving and innovative thinking (Sarhan *et al.*, 2017; Caldera, Desha and Dawes, 2018). This tool is currently used in the South African construction industry (Emuze and Ungerer, 2014; Akinradewo *et al.*, 2018).

3.4.5.9 Total Productive Maintenance (TPM)

Total productive maintenance is a tool with an integrated approach to maintenance that focuses on proactive and preventative maintenance to maximise the operational time of equipment. TPM blurs the distinction between maintenance and production by placing a strong emphasis on empowering operators to help maintain their equipment (Ballard and Howell, 2003b; Al-Aomar, 2012). In the collected literature, the researcher did not find any evidence that this tool is being used in the South African construction industry.

3.4.5.10 Total Quality Management (TQM)

Most of the substantial tools used to address construction performance issues are based on the concept of plan-do-check-act. Functions involve identification and evaluation of the problem, developing, implementing solutions, evaluating and measuring the results (Koskela, 1992; Marosszeky *et al.*, 2002). Project quality is increased by the use of good quality material, improving observation and supervision on site. When planning a project, material availability should be closer to the workplace; this is an important factor to consider. The client's main goal in project execution is cost reduction using materials which are of good quality (Bicheno and Holweg, 2009; Charron *et al.*, 2015; Caiado *et al.*, 2018). In the literature reviewed, the researcher did not find any evidence that this tool is being applied in the South African construction industry.

3.4.5.11 Pareto analysis

The Pareto chart is a graph highlighting the most important causes having an effect on the analysed system and thus allows developing innovative actions to improve the current situation. Pareto charts are based on the Pareto principle, also known as 80-20 rule, which states that a small number of causes (20%) is responsible for a large percentage (80%) of the effect (Mandujano *et al.*, 2016; Tezel, Koskela and Aziz, 2018). In the collected literature, the researcher did not find any proof of the application of this tool in the South African construction industry.

3.4.5.12 Ishikawa diagram

This is an effective quality tool used to identify the causes of an inherent problem. The Ishikawa diagram is considered a powerful tool for Root Cause Analysis (RCA) approach (Ogunbiyi, 2014; Dakhli, Lafhaj and Benrard, 2016; Bajjou, Chafi and En-Nadi, 2017). This diagram is also known as fish bone diagram because of its fish bone like structure. It gives the relationship between quality characteristics and its factors. It focuses on causes and not the symptoms. The ishikawa diagram is usually created by a group of people who have knowledge of the process and understand the problems in the system being analysed; this assist in helping to find the root causes of a problem and generating improvement ideas. The effect (a specific problem or a quality characteristics) is considered to be the head, and the potential causes and sub-causes of the problem, or quality characteristics to be the bone structure of the fish as shown in Figure 3-8 below (Abdelhamid and Salem, 2015; Adamu and Howell, 2015).

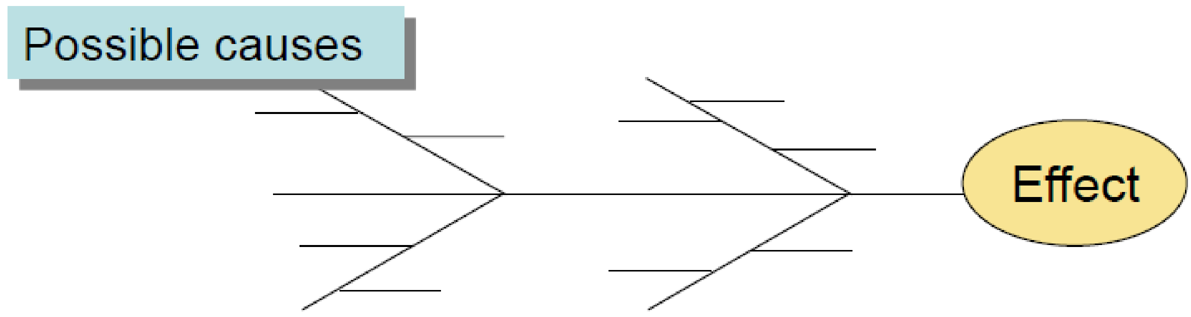

Figure 3-8: Ishikawa Diagram

In the collected literature, the researcher did not find any evidence on the application of this tool in the South African construction industry.

3.4.5.13 Waste elimination

This technique is the core of lean construction concept. It aims at spreading a culture of waste among the employees to eliminate various sources of waste such as overproduction, quality defects, unnecessary transportation, over-processing, waiting, inventory, displacements and unused employee creativity (Koskela, 1994; Khanh and Kim, 2015b; Zhang, Chen and Suo, 2017). This tool is currently used in the South African construction industry (Construction Industry Development Board, 2004; Monyane, Awuzie and Emuze, 2017).

3.4.5.14 Daily huddle meetings

Daily huddle meetings are meetings held to obtain the full involvement of employees in issues regarding the project and to encourage employees to solve problems together. These are short meetings generally fifteen minutes long and are conducted before start of the shift or day. The construction team discusses targets to be met, tasks for the day and any newsflash about the company. Two-way communication is key to daily huddle meeting process to achieve employee involvement (Salem and Zimmer, 2005; Adamu and Hamid, 2012; Ogunbiyi, 2014; Bygballe, Endresen and Falun, 2018). Table 3-7 below shows a comparison of daily huddle meetings with field huddle meetings.

Table 3-7: Daily Huddle Meeting vs Field Huddle Meeting

Daily Huddle Meeting	Field Huddle meeting
Daily huddle meetings involving everyone and are done on the construction site every day.	Field huddle meetings are done in field offices and only include management.
Daily huddle meetings are short, usually less than fifteen minutes.	Field office huddles generally takes more time. Trade crew leaders need to leave the place of work, travel to the field office and once the huddle is complete travel back to place of work for inducing correct way of approach in the construction.
Daily huddle meetings gives an opportunity for a walk-about after the meeting to have first-hand information.	Field office huddles limit the opportunity to see concerns first hand.
Daily huddle meeting make the daily planning and learning more visible to the team since everyone will be involved. It is important for people to see that workflow reliability is a concern and that leaders are engaged in supporting the work of the team. People cannot see that when the meetings are behind closed doors.	Field office huddles are done behind closed doors and they segregate the involvement of everyone in the team.

In the collected literature, the researcher did not find any evidence of the application of this tool in the South African construction industry.

3.4.5.15 Plan of conditions and work environment in the construction industry

This lean construction tool assures occupation safety and health management. It manages safety requirements through the risk management cycle consisting of continuous identification of risk, evaluation, and control (Aziz and Hafez, 2013; Ogunbiyi, 2014). In the collected literature, the researcher did not find any evidence on the application of this tool in the South African Construction Industry.

3.4.5.16 Pull ‘Kanban’ system

The pull system is a lean approach developed in the automotive industry as a mechanism to pull materials and parts throughout the value stream on a JIT basis. This system was initially adopted from the United States of American shops where goods would be restocked in exactly the same volumes they were taken by consumers (Ohno, 2013). Taiichi Ohno, an industrial engineer at Toyota introduced this system to automotive industry to improve and sustain highest level of production. The Productivity Press Development Team (2002) mentioned that the Japanese word "Kanban" means 'card' or 'sign' and is the name given to the inventory control card used in a pull system (Barlow, 1996; Arbulu, Ballard and Harper, 2003; Ferng and Price, 2005).

Kanban is an arrangement to control inventory; with Kanban, only the exact number of parts indicated on the kanban card will be produced. Kanban makes use of demand rate so as to control production rates, this is very important in that it helps in managing demand from the end client through the chain of all processes from other clients. It aligns levels of inventory with current consumption rate. When material is consumed then a signal is sent to the supplier so as to produce and deliver a new consignment (Monden, 1993).

In this system, the type and number of required units are noted down on a card called Kanban card. This card is used like a job card in that it is sent from one worker to the other worker of the next stage in the production process. A worker before starting on the production process should see the kanban card first, hence it can be used as an order card because it will indicate if all inventory is consumed during a production phase; then the upstream of the production phase is induced so as to get new inventory (Ohno, 2013). In the collected literature, the researcher did not find any evidence that this tool is being applied in the South African construction industry.

3.4.5.17 Error proofing (Poka- yoke)

Poka-yoke, a Japanese word, is a mechatronic device that works as an error proofing avoiding mistakes and defects from flowing through the process. It allows increasing the quality of the construction process and improving conditions safety for the workers (Abdelhamid and Salem, 2005; Conner, 2009; Ansah and Sorooshian, 2017; Bajjou, Chafi and En-Nadi, 2017).

Construction defects, which are produced during a construction phase, are a serious cause for concern in the construction industry. When a defect occurs, arrangements should be put in place to rectify it, this is known as rework. The definition of rework is the act of repetition for an activity which was executed for the first time incorrectly and this is common on construction sites (Love, 2002). According to studies done by Josephson and Hammarlund, 1999; Mills, Love and Williams, (2009), the probable cost of rework in the construction projects is in the region of five percent of the contract value. Lean construction ensures that mistakes are avoided through the process of error proofing also known as poka yoke. For the construction industry to achieve the concept of poka yoke, areas that are prone to errors need to be identified on construction sites. Project managers should then direct their efforts into investigating and solving these errors/mistakes, hence instigating error-proofing device so as to stop these problems from recurring in the future projects (Nikakhtar, Abbasian-Hosseini and Wong, 2015). In the collected literature, the researcher did not find any evidence of the application of this tool in the South African construction industry.

3.4.5.18 Target Value Design (TVD)

TVD approach applies methods for the design to be developed in accordance with the constraints, especially cost (i.e. design-to-cost or design-to-targets). Target value design considers customers' vision to define restrictions and deliver the required target values (Bertelsen, 2004). In the collected literature, the researcher did not find any evidence that shows that this tool is being used in the South African construction industry.

3.4.5.19 FMECA

Risk analysis is an essential step in construction project management. It is a method of qualitative analysis of the reliability which makes it possible to assess the risks of the appearance of failures, to evaluate their consequences and to identify their root causes (Ferng and Price, 2005; Ansah and Sorooshian, 2017). This tool is currently used in the South African construction industry. (Construction Industry Development Board, 2004; Emuze and Smallwood, 2011).

Out of nineteen lean tools that are currently being used worldwide for lean construction implementation, only four lean tools have been found in literature being used in the South African construction industry. These four tools are 5-why-analysis, continuous improvement, waste elimination, failure mode, effects and criticality analysis (FMECA).

3.5 Conceptual aspects

Different concepts were identified from systematic literature review and the researcher grouped these concepts into 4 categories as shown in Table 3-8. Category 1 consists of the following concepts: understanding customer needs, identifying value stream, identifying value adding and non-value adding activities (Alves *et al.*, 2016; Akinradewo *et al.*, 2018; M. Bajjou and Chafi, 2018). Category 2 focuses on investigating the current state of lean construction, identifying lean construction barriers, identifying lean construction implementation drivers and implementing lean construction tools (Picchi and Granja, 2004; Abdelhamid and Salem, 2005; Adamu and Howell, 2015). Lean implementing barriers include cultural barriers, resistance to change and lack of knowledge about lean construction philosophy. Category 3 highlights managerial support for successful implementation of lean construction, government support, mind-set change and change management of organisational culture and perception (Aziz and Hafez, 2013; Aziz and Abdel-Hakam, 2016; Babalola, Ibem and Ezema, 2019). When paradigm shifts, everything changes (Marhani *et al.*, 2013). Training programs should be made available to workforces from different levels so as to spread the required skills and techniques for minimising waste such as cost and time control, scheduling and risk analysis (Nahmens and Ikuma, 2012; Marhani *et al.*, 2013; Umstot, 2013). Category 4 consists of performance management, lean construction plan, lean project delivery system, project planning, and continuous improvement. There are nine lean construction key performance indicators. These are time, costs, quality, client satisfaction, environmental impact, waste, speed, value, health and safety (Hosseini *et al.*, 2011; Erol, Dikmen and Birgonul, 2017; Li *et al.*, 2017).

Table 3-8: Concepts Identified (Author's Analysis)

Category 1	**Category 2**
*Understand customer needs *Identify value stream *Identify value adding processes *Identify non-value adding processes *Identify wastes and sources of wastes	*Investigate current state of lean construction or other waste reduction processes *Identify lean construction barriers *Lean implementation drivers *Implement lean construction tools
Category 3	**Category 4**
*Managerial support for successful implementation *Mind-set change *Change management of organisation culture and preparation *Transparency *People involvement & training	*Performance management *Lean construction plan *Lean project delivery system *Project planning *Focus on continuous improvement * Supply planning and scheduling * Standardization * Quality

The main aim of customer focus and customer needs is to introduce the customer to the production processes so as to identify value, guarantee flexibility of resources and also maintain a good relationship with the customer (Alves *et al.*, 2016; Akinradewo *et al.*, 2018). This helps in gaining customer's confidence and will allow accomplishing tasks with minimum waste as the customer will be involved in all decisions and steps to be taken (Hosseini *et al.*, 2011; Issa, 2013; M. S. Bajjou and Chafi, 2018). Supply aims at maintaining what is necessary on site; this helps to avoid inventory wastes. Much emphasis is on ordering just in time and ordering what is enough for the construction process (Salem *et al.*, 2006; Tezel and Nielsen, 2012; Shang and Pheng, 2014; Nesensohn, Bryde and Pasquire, 2016). The aim of continuous improvement is to permanently improve the way construction companies operate and also moving from traditional construction ways to more efficient ways so as to reduce waste and maximise on profit (Johansen and Walter, 2007; Marhani *et al.*, 2013; Oguz *et al.*, 2015).

People involvement: the main difference between traditional construction and lean construction is that the latter contemplates workers as the main advocate of change and improvement in the company. For improvement to be effective in the organization, everyone from top management to lower management should take part (Diekmann *et al.*, 2003; Harris, McCaffer and Fotwe, 2013; Marhani *et al.*, 2013). The objective of planning and scheduling in lean construction system is to ensure that all stakeholders participate in construction projects so as to guard against high cost and delays overrun which are the key sources of traditional construction planning (Tezel and Nielsen, 2012; Hallman, 2013). Quality management is a participative, organised approach to plan and implement an organisational improvement procedure. Its methodology is focused on surpassing customers' expectations, identifying problems and establishing commitment whilst encouraging workers to be open decision-makers (Kristensson, 2011; Tezel and Nielsen, 2012; Nesensohn, Bryde and Pasquire, 2016).

Standardisation in lean construction projects refers to the process of implementing and developing Standard Operating Procedures (SOP). The SOP give details to the practices of each task covered by the operator. They play an important role in the construction industry. Standard Operating Procedures are a set of standards, rules and procedures every organisation needs in the management and operations of the entire organisation to ensure success (Diekmann *et al.*, 2003; Tezel and Nielsen, 2012). The aim of transparency is to preserve a perfect and flexible workflow throughout the project. 5S technique aims to improve and safeguard the reliability of communication among all stakeholders on project site (Sacks, Treckmann and Rozenfeld, 2009).

3.6 Chapter summary

In this chapter, lean manufacturing in general and the history of Toyota Production System was discussed. Lean wastes, lean applications in construction and lean thinking principles were discussed in detail. Twenty-two sources of wastes in the construction industry were identified from literature search and these were grouped into seven typical categories of lean waste. It was evident from the literature found on the internet that material wastage is directly proportional to the increase in total project cost as seen in many countries on different projects. A systematic literature review was conducted on the outlook of lean applications in the South African construction industry. The benefits of adopting lean construction as highlighted in this chapter are immense, and will make the industry more resource-efficient. Inasmuch as there are benefits of lean construction implementation, studies previously done show that there are lean construction barriers in the construction industry. The top ten barriers as found in literature were resistance to change, inadequate training, shortage of technical skills, lack of lean culture, extensive use of unskilled labor, absence of management long term commitment, extensive use of subcontractors, cultural issues, attitude, lack of financial resources and government not in support. Lean construction techniques that were being used worldwide were discussed and from these, the researcher did a literature survey to find out which lean construction techniques were being used in the South African construction industry. Theoretical concepts were identified from the systematic literature done, it was evident that lean construction techniques have not been practiced and implemented in the mechanical (HVAC) and electrical construction services. The study contributes to covering that gap by developing a lean construction framework in the next chapter.

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4 DEVELOPING A LEAN CONSTRUCTION FRAMEWORK

This chapter explains in detail a developed lean construction management framework.

4.1 Introduction

In this chapter, the researcher develops a lean construction management framework. From the systematic literature review done in the previous chapter, the researcher developed a lean construction implementation framework that was used in the mechanical and electrical services industry.

4.2 Towards a conceptual framework

From the concepts identified in Chapter 3, the researcher went on to weigh identified concepts according to the number of times it was used in literature systematically collected in section 3.4. When the concept is used in a study, a weight of 1 is given to that concept. The discussion below shows the weightings and rankings as shown in Table 4-1.

Table 4-1: Principles of Lean Construction and Studies they were used in (Author's Analysis)

Category	**Concepts**	(Alves *et al.*, 2016)	(Akinradewo *et al.*, 2018)	(M. S. Bajjou and Chafi, 2018)	(Picchi and Granja, 2004)	(Abdelhamid and Salem, 2005)	(Adamu and Howell, 2015)	(Aziz and Hafez, 2013)	(Aziz and Abdel-Hakam, 2016)	(Babalola, Ibem and Ezema, 2019)	(Marhani *et al.*, 2013)	(Hosseini *et al.*, 2011)	(Erol, Dikmen and Birgonul, 2017)	(Johansen and Walter, 2007)	(Tezel and Nielsen, 2012)	(Nesensohn, Bryde and Pasquire, 2016)	Diekmann et al., 2003	Salem et al., 2006)	Weightings
Category 1 Concepts	Understand customer needs	X	**X**	**X**										**X**	**X**	**X**	**X**	**X**	**8**
	Identify value stream	**X**	**X**	**X**														X	**4**
	Identify value adding processes	**X**	**X**	**X**														**X**	**4**
	Identify non-value adding processes	**X**	**X**	**X**														**X**	**4**
	Identify wastes and sources of wastes				**X**	**X**	**X**										**X**		**4**
Category 2 Concepts	Investigate current state of lean construction or other waste reduction processes				**X**	**X**	**X**												**3**
	Identify Lean Construction barriers			**X**	**X**	**X**	**X**												**4**
	Lean implementation drivers				**X**	**X**	**X**												**3**
	Implement lean construction tools				**X**	**X**	**X**												**3**
Category 3	Managerial support for successful implementation							**X**	**X**	**X**	**X**						**X**		**5**

	People Involvement & Training										X			X	X	X	X	X	6
	Mind-set change							X	X	X	X						X		5
	Transparency														X	X	X	X	4
	Change management of organisation culture and preparation							X	X	X	X						X		5
Category 4 Concepts	Performance management										X	X	X				X		4
	Lean Construction Plan					X					X	X	X				X		5
	Lean Project delivery system										X	X	X				X		4
	Project Planning										X	X	X				X		4
	Focus on continuous improvement										X	X	X		X	X	X	X	7
	Supply Planning & Scheduling													X	X	X	X	X	5
	Standardization															X	X	X	3
	Quality															X	X	X	3

Colour coding was used to highlight the frequency of a concept's usage. The weighting and ranking are as follows, **dark green** shows that the concept was "most frequently" used as it would have been used in 7 or more studies. **Light green** shows that the concept was "frequently" used as it would have been used in studies between 4 to 6. **Colour yellow** shows that the concept was "less frequently" used as it would have been used in studies between 1 to 3.

Table 4-2: Lean Construction Practices Category

Understand customer needs	8
Identify the value stream	4
Identify value adding process	4
Identify non-value adding process	4
Identify wastes and sources of wastes	4

The first category focused on implementing lean practices as shown in Table 4-2. The category objective was to meet customer's needs and expectations in the best possible time, quality, speed and cost. In the construction industry, all phases ought to be managed properly to avoid wastes on site and to deliver value to the customer (Howel and Koskela, 2000). In this study this category is named lean construction practices. As discussed in section 3.5 in Table 3-8 the category consist of the following concepts: understanding customer needs, identifying the value stream, identifying value-adding process and identifying wastes and sources of wastes. As shown in Table 4-2 understanding of customer needs concept has been referenced in eight studies, identifying the value stream, identifying value adding process and non-value process, and identify wastes and sources of wastes concepts were referenced by four studies. Results of this exercise in this category shows that understanding customer needs concept is most frequently used. Identifying value stream, identifying value-adding process, identifying non-value adding process and identifying wastes concepts are frequently used in applying lean construction principles.

Table 4-3: Lean Construction Drivers Category

Identify Lean Construction barriers	4
Investigate the current state of lean construction or other waste reduction processes	3
Implement lean construction tools	3

Table 4-3 was extracted from Table 4-1 and shows lean construction drivers category. The second category focused on lean drivers in the construction industry. The category objective was to investigate the current state of lean construction waste reduction processes to identify and eliminate lean construction barriers. Identifying lean construction barriers concept has been referenced in four studies. This concept is frequently used in implementation of lean construction drivers, as shown in Table 4-3. Investigation of the current state of lean construction and implementation of lean construction tools were referenced in three studies and are less frequently used in the construction industry.

Table 4-4: Culture and Behaviour Category

Managerial support for successful implementation	5
People Involvement & Training	6
Mind-set change	5
Transparency	4
Change management of organisation culture and preparation	5

Table 4-4 was extracted from Table 4-1**;** the third category focused on culture and behaviour. The category objective was to involve all practices that permit the sharing of a culture to improve production in the construction industry whilst ensuring an ideal use of employee talents and skills. The concept of people involvement and training was referenced in six studies. Managerial support, mind-set change and change management of the organization were referenced in five studies. Transparency concept was referenced in four studies. Concepts in this category are frequently used in applying lean construction principles in the construction industry.

Table 4-5: Lean Project Management Strategy Category

Focus on continuous improvement	7
Supply chain planning	5
Performance management	4
Lean Construction Plan	5
Lean Project delivery system	4
Project Planning	4
Planning & Scheduling	3
Standardization	3

Table 4-5 was extracted from Table 4-1; this fourth category focused on lean project management strategies. The category objective is to deal with operational approach that focuses on performance optimisation for the project. Focus on continuous improvement concept was referenced in seven studies and this concept is most frequently used. Supply chain planning and lean construction plan were referenced in five studies, whilst performance management, lean project delivery system and project planning were referenced in four studies and these concepts are frequently used. Planning, scheduling and standardization concepts were referenced in three studies and these two concepts are less frequently used in the construction industry.

The diagram shown in Figure 4-1 below shows how concept categories are connected. When implementing lean, one should first focus on concepts that change culture and behaviour at the site. This is important to prepare contractors, project managers and employees for a mindset change towards lean construction practices as shown in Figure 4-1. Lean construction practices, once implemented, are sustained by lean drivers. The adoption of lean construction tools enhances project delivery and how a project is handled from conception to finish of the project. Lean project management strategies facilitates the integration of different teams and tasks at the construction site.

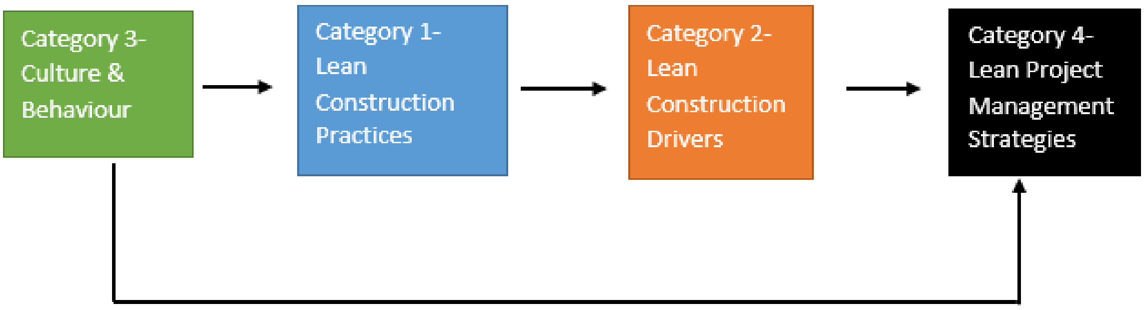


Figure 4-1: Towards a Conceptual Framework

4.3 Interlinks between categories and concepts

Linkages of lean construction concepts and their categories are shown in Figure 4-2. Culture and behaviour category is of paramount importance and provides a solid foundation for sustainable implementation of lean construction principles. Change management of organisational culture will lead to the understanding of customer needs and help in identifying value stream, hence delivering value to the customer; consequently, the implementation of lean construction practices will be easy. If culture and behaviour are changed this will lead to the implementation of lean project management strategies whereby much focus will be on continuous improvement, performance management and project planning to benefit from lean construction in the construction industry.

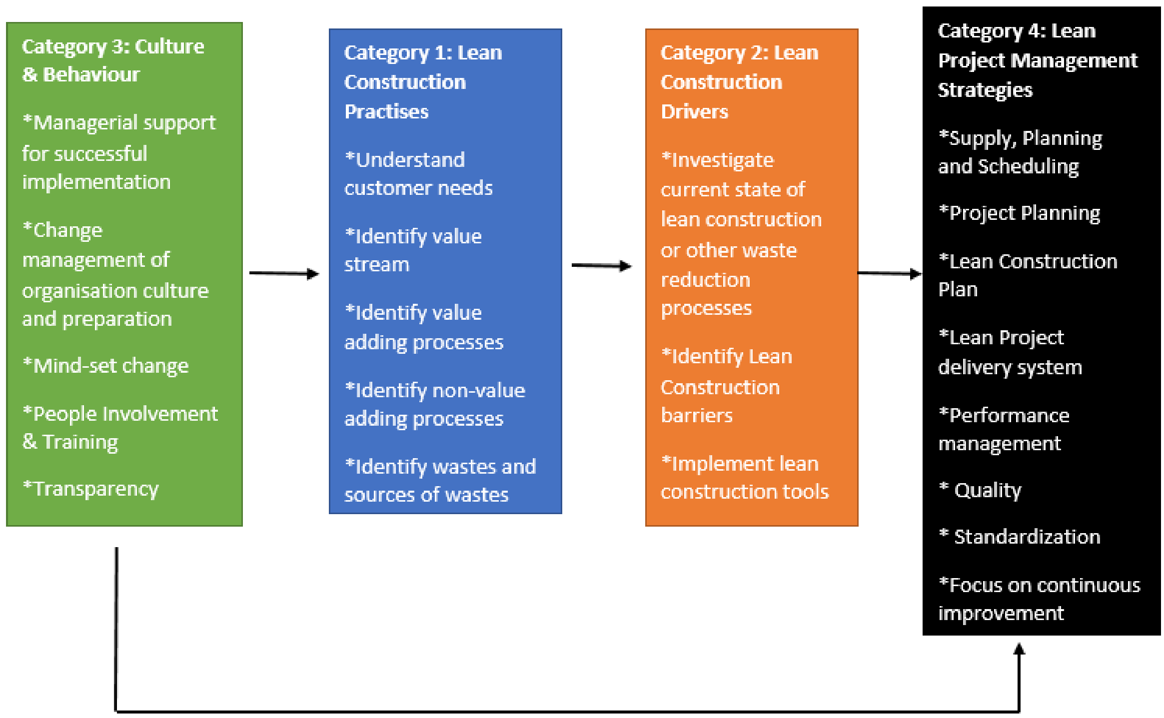


Figure 4-2: Concept Category Connection

Value stream identification focuses on production activities that the organisation performs to meet customer needs at the required standard. This step helps in identifying value adding activities and non-value adding ones in the construction project progression. Every organisation should offer greater priority to the development of their employees and the creation of a conducive environment for them to work (Liker and Ogden, 2010). The benefits of implementing lean construction results in improvements in safety at the working environment, productivity increase, cost reductions, improved employee morale which cultivates the spirit of teamwork and meeting project deadlines. Lean applications in the construction industry mean implementing lean concepts, principles and tools through the phases of a project. This calls upon total transformation of the traditional way of construction (Nowotarski, Pasławski and Matyja, 2016). During construction, applying lean principles focuses on getting things right, in the right place, at the desired time and in the desired quantity. The processed involved in Last Planner system are:

1. Master schedule
2. Phase schedule
3. Look ahead schedule
4. Weekly work plan

4.4 Developing a lean construction implementation framework

The researcher grouped and mixed the categories and concepts. Concepts with color blue are in lean construction practices category, concepts with color orange are in lean construction drivers, concepts with color pink are in lean project management and concepts with color green are in culture and behaviour category.

On the development of this framework, the researcher met with other project partners to understand and plan the project time frames and critical path. Much emphasis was on how best the critical path can be reduced as to meet customer's deadline and handover date. Managerial support was of high importance to achieve successful lean construction implementation in every project. Lean construction plan and implementation drivers were discussed and shared with top players of project execution and implementation so that everyone was on the same page in terms of the goals of the project.

The researcher educated contractors and everyone on site during morning toolbox talks and daily huddle meetings about the importance of mindset change. A good or bad thought starts in the mind therefore, it was important to change the mindset so that it becomes easy to identify value adding and non-value adding processes in the lean construction implementation process. To maintain quality, the researcher saw it fit to train and involve everyone on site in lean construction implementation. Supply of material, use of material on site and restocking of material was a bottleneck. There were a lot of waste that was generated onsite because of poor management of material. The researcher pointed out this loophole to the responsible authorities to address it to minimise and mitigate these wastes. After understanding customer needs the next step was to investigate the current state of lean construction to identify wastes and the sources of wastes, the developed framework is shown in figure 4.4 below.

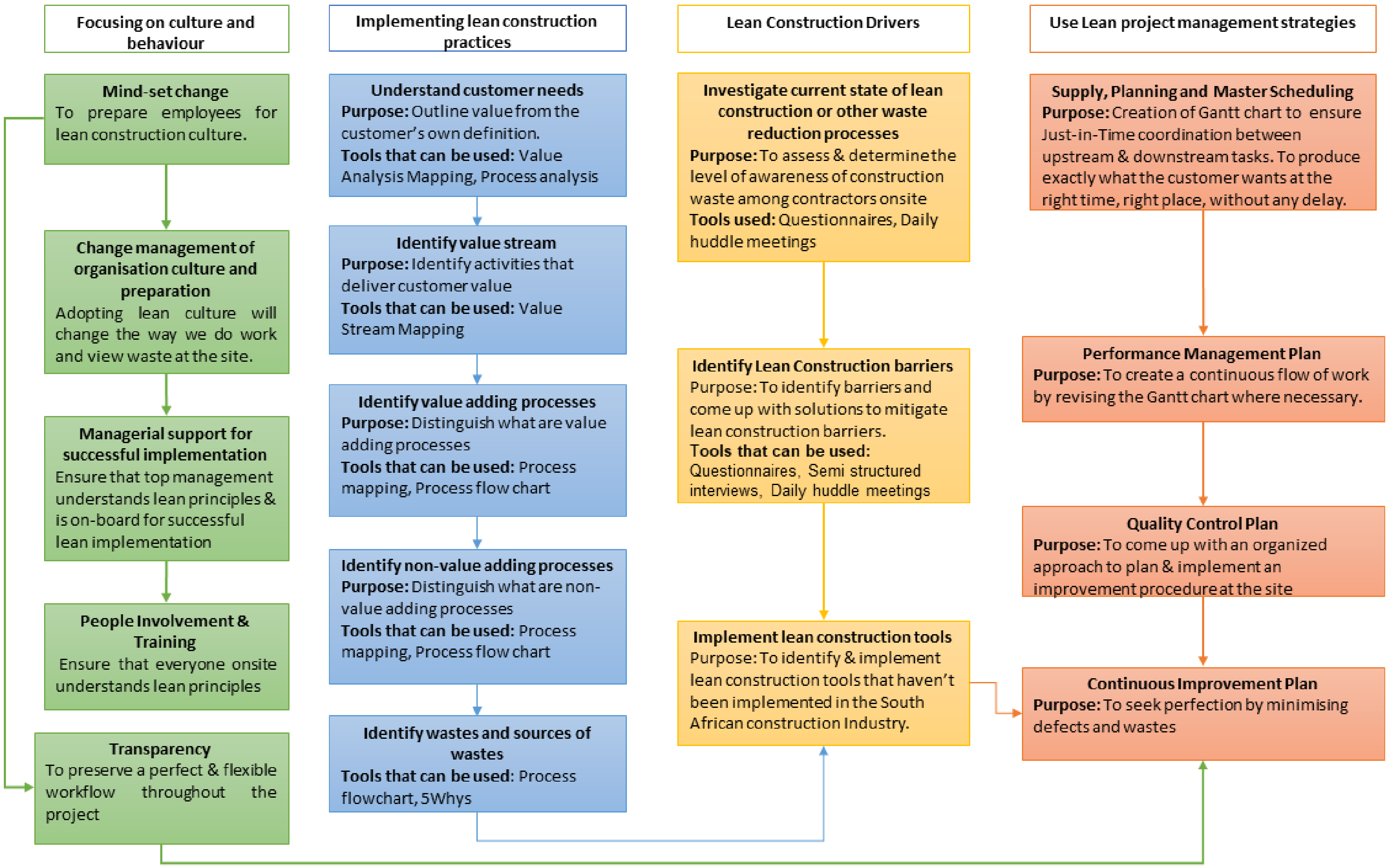


Figure 4-3: Developed Lean Construction Implementation Framework

4.5 Chapter summary

In this chapter, concepts from the previous chapter were grouped into four categories. These groups are Culture and Behaviour, Lean Construction Practices, Lean Construction Drivers and Lean Project Management Strategies. The concepts and categories were connected, interlinked and a lean construction implementation framework was developed. Implementation of this framework is discussed in detail in the next chapter.

5 IMPLEMENTATION AND EVALUATION OF LEAN PRINCIPLES IN THE SOUTH AFRICAN CONSTRUCTION INDUSTRY

This chapter highlights the implementation and evaluation of the lean implementation framework in construction industry. Evaluation of the lean implementation framework was conducted through the use of two cases. The first case was the construction of a new branch of a bank in Promenade, Western Cape Province; the size of the branch was 860 square meters. The second case study was the construction of a branch in Southdale, Gauteng Province; the size of the branch was 1300 square meters. The researcher was involved as the project engineer in the two construction projects. As indicated in section 1.7 this study focus was on mechanical and electrical building installations.

5.1 First Case study

The developed framework is shown in Figure 4-3 and was first implemented on the construction of a branch in Cape Town. The project span was 45 days, from the 15th of July to 16th of September 2019. This branch was 860 square meters.

Lean tools and techniques implemented in the construction project are shown in Figure 5-1. As shown in Figure 4-3 the implementation framework is made out of four categories. During the implementation of the framework, the researcher focused on each category and documented tools and techniques as shown in Figure 5-1. Section 5.1.1 focused on culture and behaviour change category techniques that were implemented. Section 5.1.2 focused on lean construction implementation drivers' category techniques. Section 5.1.3 focused on lean project management strategies and section 5.1.4 focused on lean construction practices implemented.

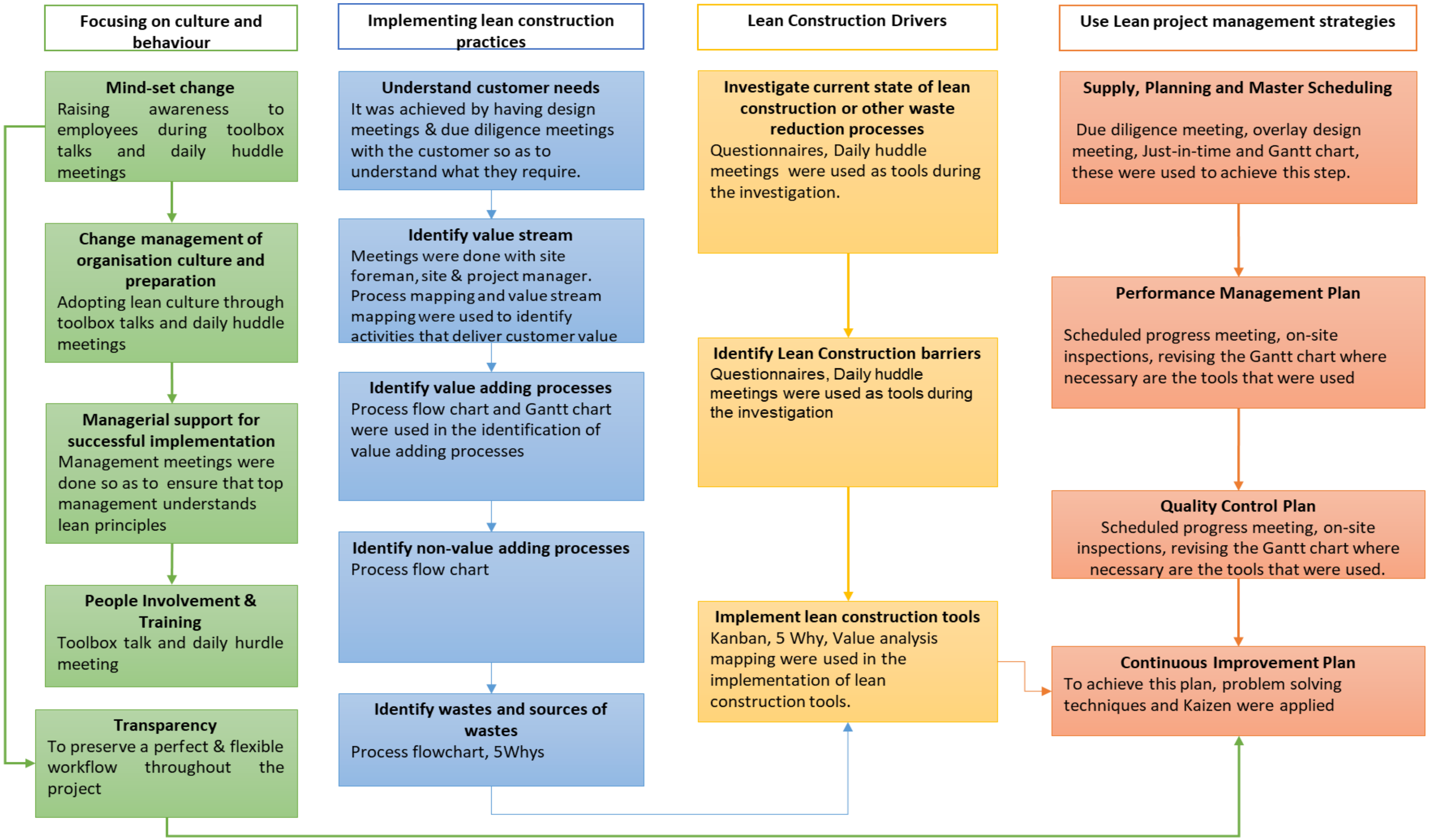


Figure 5-1: Lean Construction Implementation Framework Showing Tools used for 1st Case Study

5.1.1 Focusing on culture and behaviour

This section focuses on how mind-set change, change management, managerial support, people involvement, training, and transparency were achieved in the first case.

5.1.1.1 Mind-set change

During the construction phase at this site, all employees on site were educated about lean construction. Toolbox talks and daily huddle meetings were conducted on a daily basis and were conducted fifteen minutes before commencing work and fifteen minutes before knock-off time. The purposes of these meetings were to equip each and every employee on the daily targets and also to raise awareness to employees about our goal of lean construction culture on this project. The project manager used these meetings to encourage employees to solve problems together. These meetings proved to be a communication channel and an arena to achieve employee involvement.

5.1.1.2 Change management of organization culture and preparation

This step is directly linked to mind-set change. The organisation changed how it operated to adopt the lean construction culture during construction at this site. Traditionally, there was no accountability in terms of not meeting daily targets and production of material wastes. These were the first two issues to be resolved on this project so that it was easy to adopt lean construction culture and implement lean construction successfully.

5.1.1.3 Managerial support for successful implementation

The objective of this step was to ensure that top management understands lean principles and is on-board for successful lean implementation. When paradigm shifts, everything changes. Construction sites consist of different organisations and sub-contractors. However, this step is focused on project managers (engineers) that are responsible for the day-to-day operations at the site.

5.1.1.4 People involvement and training

People involvement and training is important for a successful implementation of lean construction. Training programs were made available to workforces at different levels to spread the required skills and techniques for minimizing waste, such as cost control, time control, risk analysis and scheduling. This was accomplished through toolbox talks and daily huddle meetings, where different topics were presented to everyone so as to equip everyone with information concerning lean construction. Posters were pasted on-site to raise awareness and remind everyone of our goal to implement and adopt lean construction culture on this site. The objective of this step was to ensure that everyone on-site understands lean construction principles and is on board for successful implementation.

5.1.1.5 Transparency

Displaying posters and placards on-site helped to a larger extent since everyone had an opportunity to see all actions performed, when they were performed, what was required to happen, how and when these actions should be achieved. The best approach to finish a construction project on time, within everyone's anticipations, within the stipulated budget is by devising a commitment to transparency from project start to handover. Transparency simply means effective communication to everyone who is involved in the project – these include owners, clients, tenants, facility managers, suppliers, vendors, contractors, sub-contractors and employees. During this project, consultants were making follow-ups to the contractors and sub-contractors to check if they were adhering to what had been designed. They also ensured that South African National Standard (SANS) regulations were being followed; this helped in preserving a perfect and flexible workflow throughout this project. Transparency in lean construction ensures quality in the construction industry.

5.1.2 Focusing on lean construction drivers

This category focused on how lean construction drivers were implemented. This section also focused on the following concepts: investigation of current state of lean construction, identify lean construction barriers and implementation of lean construction tools.

5.1.2.1 Investigation of current state of lean construction, other waste reduction process and lean construction barriers

This step was accomplished by use of short semi-structured questionnaires that were distributed to mechanical site supervisor, electrical site foreman, site manager and project manager to pinpoint wastes and lean construction barriers that they were encountering from the previous projects executed. The aim of this was to gather as much information as possible on the wastes and barriers in the South African construction industry and to understand if the responsible authorities at a construction project site are aware of any waste reduction processes and solutions to mitigate lean construction barriers. The researcher had meetings with foremen, site manager and project manager so as to find out what waste reduction processes they use from their previous experience in handling construction projects.

5.1.2.2 Implementation of lean construction tools

The researcher did a literature survey of the lean construction tools that were currently being used in the South African construction industry. The results from this survey show that a small percentage of lean construction tools used globally were implemented in the South African construction industry. The very basics of lean in construction have only been applied in the South African construction industry. Based on the results of the analysis in this study the research used Kanban, 5 why analysis, and value analysis mapping lean construction tools.

5.1.3 Using lean project management strategies

This category focused on how lean construction project management was achieved. This section discusses the implementation of supply, planning and master scheduling, performance management plan, quality control plan and continuous improvement plan.

5.1.3.1 Performance management plan and quality control plan

Scheduled progress meetings were done during project execution. These meetings were done three times on-site. Safety Health Environment and Quality Officers, property management delegate, mechanical engineers, civil engineers, electrical engineers, architect, project managers, site manager, contractors and quantity surveyors were among the people present in each project site meetings. These meetings were very important because they would ensure that every task is done according to what was designed by different professionals and to maintain quality in the overall job done. After every meeting, professionals would send a snag-list to site manager, and project managers, so that they address outstanding and pressing issues that would have been raised from this site inspection. Table 5-1 below is a mechanical snag-list. This snag-list was from an inspection meeting that was done on site on the 2nd of August 2019; the project had started on the 15th of July 2019. During the progress meeting, the mechanical engineer noted down these seven snags that the contractors were supposed to correct.

Table 5-1: Mechanical Snaglist

DATE OF INSPECTION	02 August 2019	
REASON FOR VISIT	Site Inspection	
PROGRESS STATUS	In construction	
WORK IN PROGRESS	In construction	
ITEM	**PARTICULARS**	**ACTION BY**
1	To install a second or backup Air Conditioning Unit in the Server Room, as shown on the revised drawing.	HVAC CONTRACTOR
2	To clean refrigerant cable tray in the covered walkway (coming from kitchen to the condensers)	HVAC CONTRACTOR
3	Install midwall Air Conditioning Units in each of the cashier rooms as shown on the drawing. These are currently not installed.	HVAC CONTRACTOR
4	To install fresh air disc valves in all offices as indicated on the drawing.	HVAC CONTRACTOR
5	To send the following documents to the Professional team , 3 days before PC Meeting for review :Manuals, Commissioning documents, As built drawings, Training registers and one year maintenance schedule	PROJECT MANAGER
6	To Install Fire Hose Reels and Fire Extinguishers as shown on the Fire Protection Layout Drawing.	FIRE CONTRACTOR
7	Ensure that all drainage pipes are checked for leaks especially at the joints.	HVAC CONTRACTOR
Inspection by .... **PROJECT ENGINEER**	Follow Up by .... **PROJECT ENGINEER**	

Table 5-2 below is an electrical snag-list. This snag-list was from an inspection meeting that was done on the 2nd of August 2019 on site. During the progress meeting, the Electrical Engineer noted down these ten snags that the contractors were supposed to correct.

Table 5-2: Electrical Snaglist

DATE OF INSPECTION	02 August 2019
REASON FOR VISIT	Practical completion
PROGRESS STATUS	Practical completion
WORK IN PROGRESS	Snags

ITEM	**PARTICULARS**	**ACTION BY**
1	Light fittings to be cleaned (remove dust).	ELECTRICAL CONTRACTOR
2	Labeling of the plugs to be completed.	ELECTRICAL CONTRACTOR
3	Ensure that all emergency lights as per the design are operational.	ELECTRICAL CONTRACTOR
4	Final decision regarding the existing generator to be finalized by the client.	CLIENT
5	Distribution to be mechanically earthed.	ELECTRICAL CONTRACTOR
6	All occupancy sensors to be installed as per design.	ELECTRICAL CONTRACTOR
7	All occupancy sensors to be set to maximum sensitivity and time.	ELECTRICAL CONTRACTOR
8	All (Certificate of Conformity) CoC's to be issued.	ELECTRICAL CONTRACTOR
9	O&M manuals to be submitted.	ELECTRICAL CONTRACTOR
10	All copper pipes to be bonded.	ELECTRICAL CONTRACTOR

5.1.3.2 Continuous improvement plan

Continuous improvement plan also known as kaizen, supports the idea that every process can and should be continually measured, analysed and improved in terms of resources used, the time required, quality demanded by customers and other performance criteria relevant to construction. All lean techniques are established to push continuous improvement through problem solving and innovative thinking (Sarhan et al., 2017; Caldera, Desha and Dawes, 2018). The purpose of this improvement plan was to seek perfection by minimising defects and waste. The project deadline was met and the client's needs were satisfied, hence saving on project costs.

5.1.4 Implementing lean construction practices

This category focused on how understanding customer needs and the identification of value stream, value adding processes, non-value adding processes, wastes, and sources of wastes were achieved.

5.1.4.1 Understanding of customer needs, supply planning and master scheduling

The researcher organised a due diligence meeting on-site before design commenced. This meeting was attended by mechanical engineer, electrical engineer, civil engineer and architects. The purpose of this meeting from the mechanical engineer's side was to check the following:

1. Are toilets extraction and kitchen extraction mechanically or naturally ventilated? If mechanically ventilated what system was available and was it enough, (Calculations required in this regard). If the toilets are naturally ventilated, were the openings available as per South African National Standards regulations?
2. All internal spaces must have fresh air supply systems and fresh air must be as per regulations. Calculations required comparing with regulations. The engineer also checked for any fresh air contamination like nearby bin area, toilet vents, gas area etc.
3. For air conditioning units, what system was being used for air conditioning and what refrigerant gases were being used? General noise levels max 45dB (A) for residential areas and 50dB (A) for commercial areas.
4. The engineer checked if there were any ducts that were passing through firewalls, so that upon the design and construction phase, fire dampers must be installed.
5. For fire protection, the engineer checked if the building has sprinklers. If yes, were they installed as per regulations. Void space was checked and to see if void sprinklers were required on this site.
6. Are the sprinklers regularly tested and maintained as per regulations, checked when they were last serviced and when were they due for service.
7. Are there smoke detectors? Was there a local smoke detection panel in this branch, if yes, was it linked to any other system (e.g. the fire department or a central management system)? Are these detectors regularly serviced and tested? The engineer checked to see when they were last serviced and tested.
8. Do we have manual call points and if yes, the engineer marked all the positions.

9. Are all escape doors having the recommended locking mechanisms? Checked signage for compliance with regulations, and these must be adequately installed.
10. The engineer marked the positions of hose reels and checked if they reached all the areas and have enough pressure. Checked if the hose reels were regularly serviced as per regulations, taken note of the service provider.
11. The engineer checked if all fire extinguishers were hanged as per regulations, checked if they were regularly serviced and must have signage. Escape routes to be checked for obstructions as per regulations.

After the due diligence meeting, the next phase was the design phase. In this phase, the customer's requirements were then implemented and also taking into consideration the South African National Standards regulation that was to be followed in all the design criteria. When all designs were finished, an overlay design meeting was done. This design meeting was attended by client's engineers, consultant engineers, contractor's project manager, client's architect, consultant/ contractor's architect, client quantity surveyor, contractor's quantity surveyor, client's finance representative, SHEQ Officers and client's security representative. The purpose of this overlay design meeting was to go through the designs as a team of professionals so as to check if the designs were done according to the client's requirements. Among what was discussed in this meeting were the following issues:

1. Project planning and construction programme were finalised and everyone who was in the meeting discussed the Gantt chart, and took note of the project milestones, completion date, and handover dates.
2. Rules on how to operate whilst onsite were outlined. It was highlighted that no access to the site was to be allowed without an approved Occupational Health Safety file. All SHEQ issues were discussed and taken note of.
3. Furniture drawings, mechanical engineering design drawings, electrical engineering design drawings and architecture drawings, were all approved and were to be sent to the suppliers for material quotation.

The just-in-time method is a supply management tool driven by the customer's demand. Its aim is to maintain a construction material flow that matches the internal/external customer requirements to optimise inventory and work-in-progress (Ballard and Howell, 2003b; M. Bajjou and Chafi, 2018; Tezel, Koskela and Aziz, 2018).

5.1.4.2 Identifying value stream, value adding process and non-value adding process

A summary of the tasks that were followed on this construction site are shown in Figure 5-2 below.

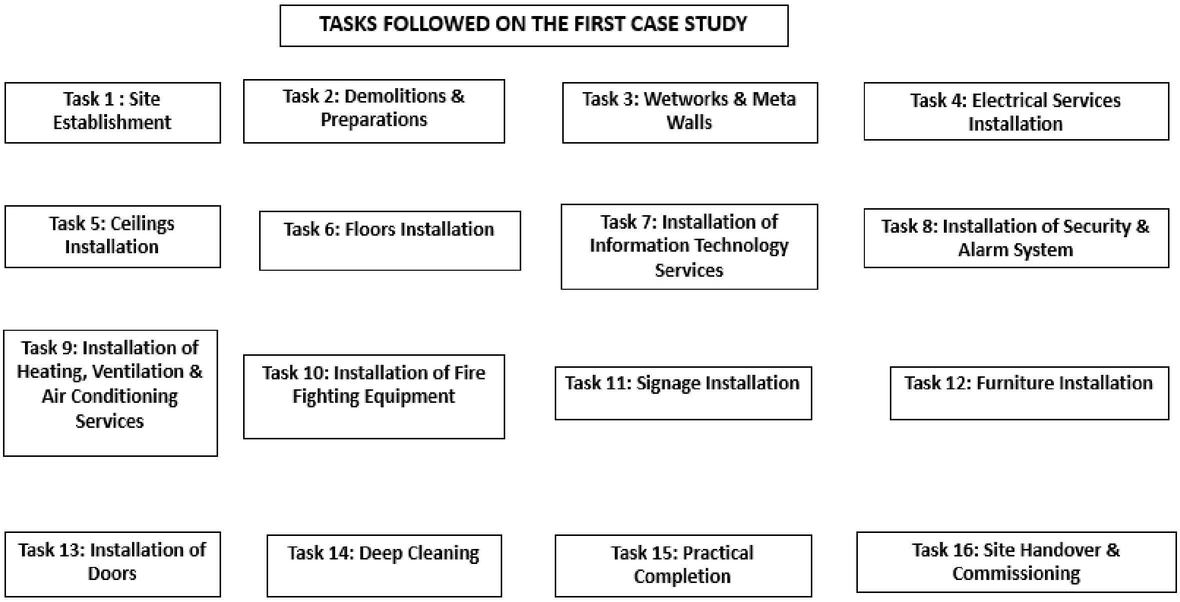


Figure 5-2: Summary of Tasks Followed in Case Study 1

The detailed tasks that were followed on this construction site are as follows:

Site Establishment includes site handover from the developer or landlord to the construction company so that construction can commence. The construction company is given a letter of appointment, all drawings and designs.

At the *Demolitions and Preparations* stage, the construction company installed a hoarding area on the construction site where they are based. Fire sprinklers were blocked off from the main (mall) source, electrical contractor made sure temporary power points were available, provided temporary lighting for this construction site and made the area safe to work on. Demolition was done, according to the demolition plan and removing all that was not shown on the drawings.

Wetworks and Meta Walls involves brickwork for the toilets inside the branch and all metawalls was done. *Electrical Services Installation* comprises of electrical first fix, cable trays, chasing and conduits were installed. Electrical second fix and commissioning was done. *Ceiling Installation* involves installation of new ceiling grids including hangers was done. Installation of new ceiling tiles was done. *Floor Installation* involves installation of floor screed, coverings was done, tiling of floor area, and carpets were installed in some of the offices.

Information Technology installation this involves Installation of global access, voice and interconnection of all IT services was done. *Security/Alarm/CCTV* this includes installation and commissioning of alarm system, CCTV, access control and visual verification was done. *Heating Ventilation and Air Conditioning (HVAC)* involves installation of HVAC ducts and air conditioning units. Installation of building management system (BMS) was done. The two pictures below show HVAC ducts installation.

The picture shown in Figure 5-3 below shows installation of heating ventilation and air conditioning units suspended in the ceiling. Drainage pipes are connected as shown in the picture below.

Figure 5-3: Heating Ventilation and Air Conditioning Duct Installation

The picture shown in Figure 5-4 shows installation of heating ventilation and air conditioning spigots.

Figure 5-4: Heating Ventilation and Air Conditioning Duct Installation

Firefighting equipment Installation involves installation of smoke detection, sprinklers and hose reels. *Signage installation* involves installation of internal signage, external signage and shopfronts for offices. *Furniture installation* involves furniture-fixing, tellers and office furniture was done. Installation of doors, safes, printers and computers was done. Deep cleaning, practical completion inspection and site handover to the client were done.

The professional team was on-site for the Practical Completion Inspection that was done on the 9th of September. practical completion affirms the completion of a construction project. At this point, construction work is complete except for minor defects that will be finished and finalised before handing over the project to the client. Table 5-3 below shows a screenshot of the Practical Completion snag list that the engineer gave the mechanical contractor to address before handover.

Table 5-3: Practical Completion Snaglist

DATE OF INSPECTION	09 September 2019
REASON FOR VISIT	Practical completion
PROGRESS STATUS	Practical completion
WORK IN PROGRESS	Finalizing snags

ITEM	PARTICULARS	ACTION BY
1	Training for staff on both HVAC and Fire system to be done.	Fire & HVAC Contractor
2	Pressure testing and commissioning of the systems to be done.	HVAC Contractor
3	Interface between HVAC and smoke detection to be tested.	HVAC Contractor
4	Ensure that all drainage pipes are checked for leaks especially at the joints.	HVAC Contractor
5	All Test certificates to be issued.	HVAC Contractor
6	Operation & Maintenance manuals to be submitted.	HVAC Contractor
7	Interface of the BMS with the HVAC and fire to be tested.	HVAC Contractor
8	All copper pipes to be bonded.	HVAC Contractor
9	Ensure that all refrigerant piping exposed to the elements are covered in galvanized trunking.	HVAC Contractor
10	Mounting brackets for condensers and fans to be checked for stability.	HVAC Contractor
11	Fire signage to be installed properly.	Fire Contractor

Inspection by	Follow Up by
....	....
PROJECT ENGINEER	**PROJECT ENGINEER**

During handover stage, the engineer inspected if all the snags that were highlighted to the mechanical contractor at the Practical Meeting Inspection were attended to and addressed. Upon satisfaction, the engineer issued a Completion Certificate. Table 5-4 below shows a screenshot of a Practical Completion Certificate.

Table 5-4: Practical Completion Certificate

We certify herewith that the above sub-contract has been completed in accordance with the sub-contract document subject to the following:			
1) None			
PORTION	**PRACTICAL COMPLETION**	**GUARANTEE COMMENCE**	**GUARANTEE TERMINATE**
	16/09/2019	16/09/2019	16/09/2020
The following documents are attached: **None**			
PRACTICAL COMPLETION .... **PROJECT ENGINEER**		For Sub-Contractor .... **SUB-CONTRACTOR**	

5.1.4.3 Identifying wastes and sources of wastes

This section discusses wastes and potential sources of wastes that were identified at the construction site. A process flowchart was used to identify wastes at this site. Wastes were identified and listed for each task. The 5 why analysis was used for each and every task so as to find the root cause of waste and the sources of waste. Figure 5-5 below shows wastes that were identified upon project execution. On the first task: site establishment, there were activity start delays that were caused by taking a long time to prepare the site and handing it over to the contractor. This was caused by the client. Instructions from the landlord to the contractor were not communicated in time. On demolition and preparation, the electrical contractor was delayed in providing temporary power points and lighting to this construction site because the main contractor had not finished installing the hoarding area on site. During wetworks and meta-walls, the researcher noticed that there was excessive supervision of employees by the site supervisors on brickwork for the toilets. Upon installation of electrical services, there were design errors that were picked up on site on the electrical drawings that were submitted by the electrical engineering consultant; this delayed the start of electrical services installation. There was excessive handling of ceiling tiles, which led to a quite number of ceiling tiles breakages; this then contributed to solid waste generation during ceiling installation task.

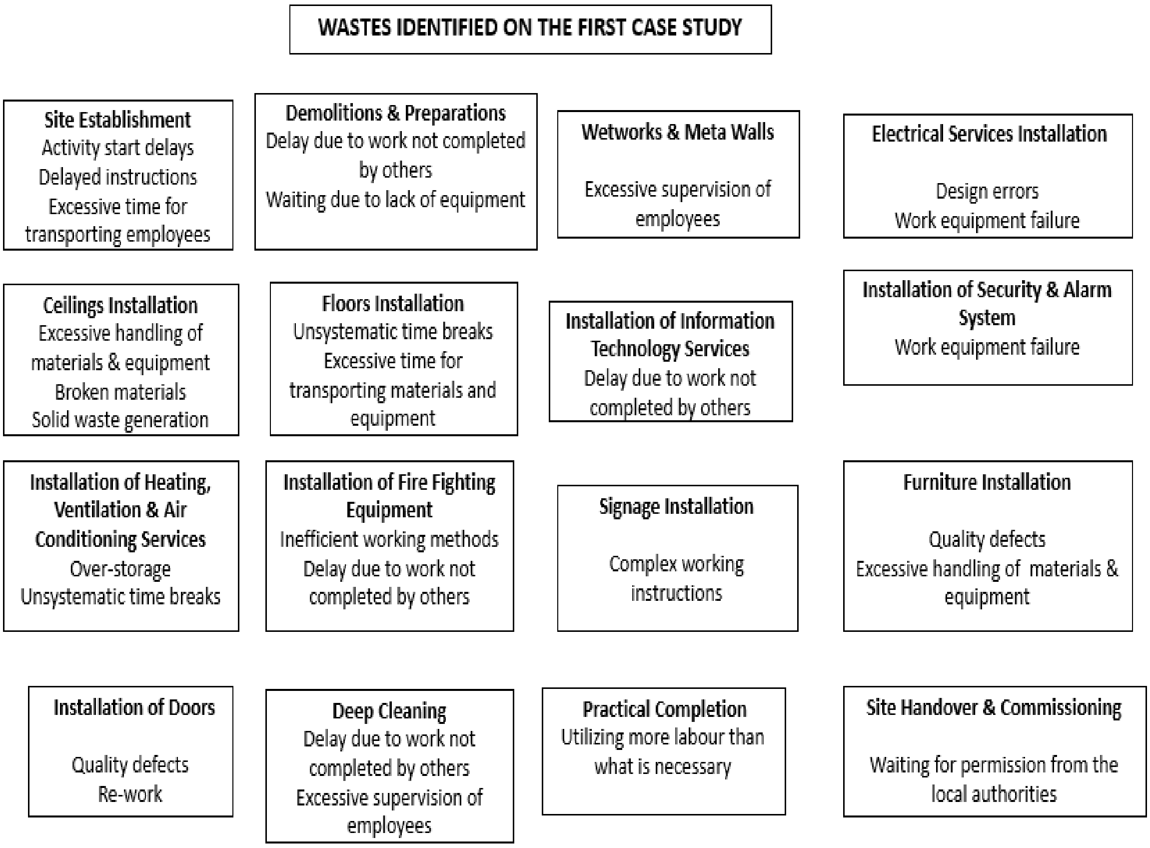


Figure 5-5: Wastes Identified in the First Case Study

On installation of floor screed and floor covering, there was excessive time that was used in transporting carpets, floor tiles, and cement. There were unsystematic break times during floor installation; this led to a delay on the installation of information technology services since this task succeed and depends on floor installation. There was equipment failure upon installation of security and alarm system. On the installation of HVAC services, there was over-storage of air conditioning ducts on site and unsystematic time breaks. On installation of smoke detection, sprinklers, and hose reels there were delays due to work not completed by others and inefficient working methods that was done by the fire contractor. The client had issued complex working instructions to the signage contractor, hence the contractor delayed finishing this task on the scheduled time – as he had to continuously call and confirm with the client. On furniture installation, quality defects were noticed on the furniture that was supposed to be installed on this site; this was as a result of excessive handling of furniture on site. The furniture was scratched and dented. During installation of doors, there were quality defects. A lot of rework was done to correct these defects. The researcher noted that there was excessive supervision of employees upon deep cleaning. This was not necessary.. There was delay due to wok not completed by others, some contractors did not meet the deadline, and this delayed the process of deep cleaning. On practical completion, there was utilisation of more labour than what was necessary. During this process, only critical professionals were required to come for a meeting to do the final inspection. On site handover and commissioning, there was waiting time due to permission from local authorities. The fire chief took time to sign off this project and to give a go-ahead for the client to occupy the building.

After completion of this first case study, the researcher refined the lean implementation framework based on insights gained in implementing the first version of the framework in mechanical and electrical construction services industry. The refined lean implementation framework was then used to implement lean construction in the second case study. The refined lean implementation framework is shown in Figure 5-6.

5.2 Second case study: evaluating the framework

This section further verifies the lean implementation framework that was resynthesised after the case study. The implementation framework in Figure 5-6 was implemented in a second case study. The second case study was a new construction site for a branch in Gauteng Province. The project span was 57 days, from 16th of September to 11th of November 2019. This branch was 1300 square meters. The researcher used the improved framework from the first case study, as shown in Figure 5-6. The reasoning behind testing this framework was to strengthen the lean tools with the construction contractors and setting up a platform for continuous improvement in the organisation.

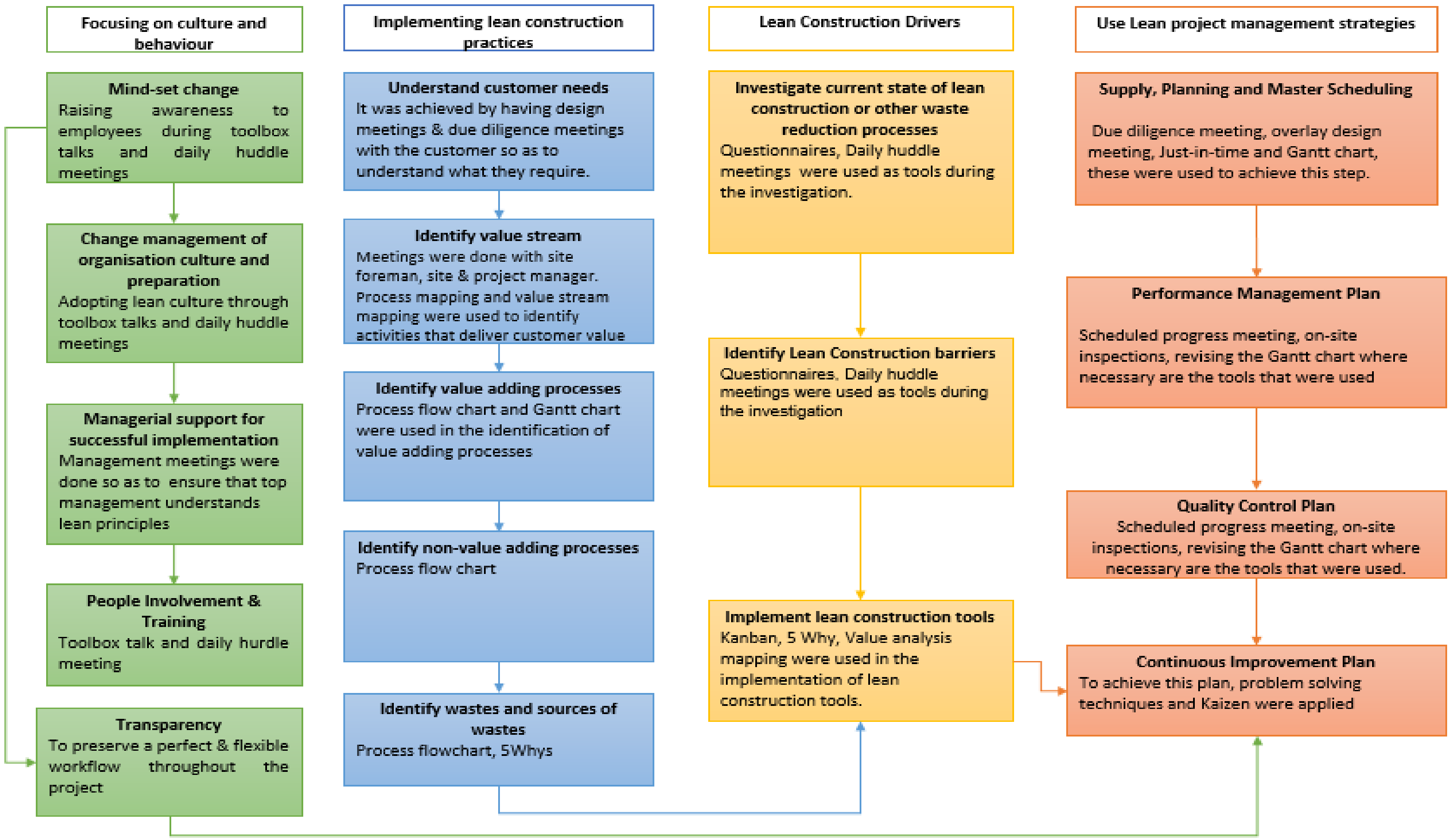


Figure 5-6: Lean Implementation Framework Used in the Second Case Study

The construction team that worked on the first case study was the same group of people that worked on the second case study. This team had an idea of what lean construction is and how to implement the framework that was used on the first case study. The first step was to identify waste practices on this site. This helped to enable the responsible people tasked with implementing lean construction to determine the level of comprehension of construction wastes amongst contractors involved in the project. Contractors at the project site were trained on how to assess awareness of wastes and how it can be eliminated amongst team members and supervisors, this was done during daily toolbox talks and daily huddle meetings. Project managers and team leaders were educated about lean construction and its benefits. This step was crucial to get support from all teams that were involved in the project. Identification of value from the customers' perspective and identification of value stream which was made out of all activities that creates customer's value and satisfy the demands and expectations of the customer, this was done through value analysis mapping and process mapping.

The next step was to establish flow by minimising the following wastes: unnecessary waiting time, storage of material, unnecessary processes, unnecessary transportation of material, movement of labour workforces etc; and focusing on value adding activities only. Different lean tools like the plan-do-check-act were used to maintain continuous flow of work on-site, whereby everything was documented and taken responsibility for each action. Contractors identified possible sources of wastes when they were doing their risk assessment on site. Wastes likely to be encountered were shared with other workmates on site and how to reduce these wastes so that everyone on-site was aware of lean construction. This helped to cultivate continuous learning within the construction site. The last step was to seek and provide a perfect solution without defects or mistakes and this was achieved by repeating all the above steps and stages. It is through repeating these steps that Kaizen (continuous improvement) was achieved.

5.2.1.1 Identifying of value stream, value adding process and non-value adding process

A summary of the tasks that were followed on this construction site are shown in Figure 5-7 below.

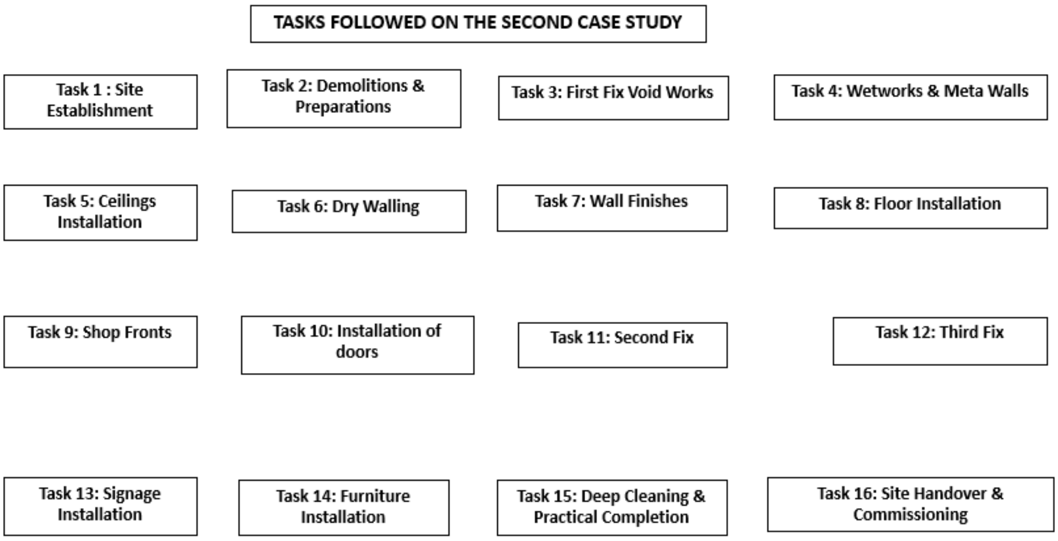


Figure 5-7: Summary of Tasks Followed in Case Study 2

The detailed tasks that were followed on this construction site are as follows:

Site Establishment: this includes site handover from the developer or landlord to the construction company so that construction can commence. The construction company was given a letter of appointment, all drawings and designs. Mobilisation to site was done.

Preparations: at this point the construction company installed a hoarding area at the construction site where they were based. There was verification of floor levels, preparation of existing brick walls and floors, and setting out of construction activities.

First fix void works: this involves electrical services first fix, including wire trays, cable trays, cable baskets and wire runs. It also involves air conditioning services first fix, which includes installation of air conditioning units, ducting and flexible connectors; and security first fix, which includes CCTV, access control, camera and alarms. There is also Information Technology services first fix, which includes the installation of voice and data cables. Building management systems installation first fix. Fire detection first fix. Plumbing first fix.

Figure 5-8 below is a picture that shows electrical services and air conditioning services first fix for this site.

Figure 5-8: Electrical Services and Air Conditioning Services First Fix

Wet Works and Meta walls includes brick works and plaster works It also involves *ceiling installation* includes plaster ceiling grid work, plaster ceiling boards' installation, plaster ceiling joint and skimming. Ceiling hangers were installed, grid installation, ceiling cut boards and complete ceiling installation was done.

Dry walling includes wall frame installation. Boarding was done; this involves installation of boards. *Wall finishes* including painting of walls, wallpaper installation and wall tile installation was done. Skimming, a finishing plastering method done to smoothen the surface area, was carried out. Installation of door frames was done.

Flooring involves self-leveling and floor tile installation. Grouting was done to fill in the spaces, which were in between the tiles, this gave a finished look on the floor and wall. Carpet tile installation and covering of carpets was done. Installation of vinyl floors was done.

Shop Fronts installation encompasses internal shopfronts installation, external shopfronts installation and installation of glass. *Doors installation:* this includes installation of security doors and installation of office doors.

Second Fix involves electrical services second fix, this includes conduits installation, plug points and wiring. Air conditioning second fix included the installation of diffusers, outdoor condensers and refrigerant piping. Telkom second fix and commissioning. Interconnect IT installation and commissioning was done. Alarm system /CCTV /Cameras /Access Control installation checks and commissioning as well as smoke detection second fix, and plumbing second fix were executed.

Figure 5-9 below shows electrical services and air conditioning services second fix for the site.

Figure 5-9: Electrical Services and Air Conditioning Services Second fix

Figure 5-10 below shows electrical services and air conditioning services third fix for the site.

Figure 5-10: Electrical Services and Air Conditioning Services Third Fix

Third fix comprises of electrical services third fix; this includes commissioning, fire protection system commissioning and testing as well as HVAC system commissioning and testing.

Figure 5-11 below is a picture that shows electrical services and air conditioning services third fix for this site.

Figure 5-11: Electrical Services and Air Conditioning Services Third Fix

Signage installation involved internal signage installation and external signage installation. Furniture installation and safes installation was done. Kitchen cupboards installation, Intel cab installation, ATM installation and ATM alarm installation was done. Visual verification alarm system test and printer installation was done.

Construction Final Phase this involves finalising of snag lists, quality assurance inspection, deep cleaning, practical completion and issuing of completion certificates.
Handover the branch to the client.

5.2.2 Understanding current waste reduction practises at the targeted construction site

Semi-structured interviews were conducted to determine the level of understanding of lean construction from the site supervisors, site manager, and project manager. Each interviewee was briefed about lean thinking and different waste types based on the work of Womack and Jones, (1998) and Liker and Meier, (2004). During the interviews, these team leaders were requested to provide examples of waste from their experience.

5.2.3 Educating all contractors taking part in project about lean construction and its benefits

The researcher presented to all contractors on site during daily toolbox talks about lean construction and its benefits. The objective was to ensure that everyone on site understands lean construction principles and is on-board for successful implementation of lean.

5.2.4 Specify value

Value stands for what the customer accepts to pay in return. Value in this construction project was to achieve heating, cooling, fresh air supply, ventilation, fire detection systems, fire protection systems, lighting, and power supply.

5.2.5 Identify value stream

A Gantt chart was used to help identify value stream. Activities on the Gantt chart were shared on notice boards on site so that everyone can get a chance to appreciate the value stream. The importance of finishing the project on time and religiously following the Gantt chart was emphasised to everyone. Identification of sources of wastes and potential sources of wastes was done on site. Demonstration of value-adding, non-value adding and unnecessary activities for each construction process was done. Value-adding activities were defined as those activities that directly affect the construction process final product, increase economic worth of the process and valued by the customer.

5.2.6 Establish flow of products

A continuous flow of work was created by revising the Gantt chart where necessary. Waste in construction is assumed to be physical, for example, waste of materials in the construction process but in reality, there are multiple activities that are not adding any value and should be considered as waste in this industry. Flow of products was defined as movement of materials, information, and equipment through a system. This step was necessary as it enhances flow of materials and information in a construction process.

5.2.7 Pull production

Pull production aims to ensure just in time coordination between upstream and downstream tasks. The researcher was on site twice a week to ensure that everything was delivered just in time to avoid any delays. Materials and information was delivered to the next station at the right time, at the right place, without delay and unnecessary storages. Architectural drawings and design drawings were delivered in time by the designing team to the contractor. Kanban system was also used to achieve pull production. This helps in controlling and balancing the resources required in order to achieve project completion.

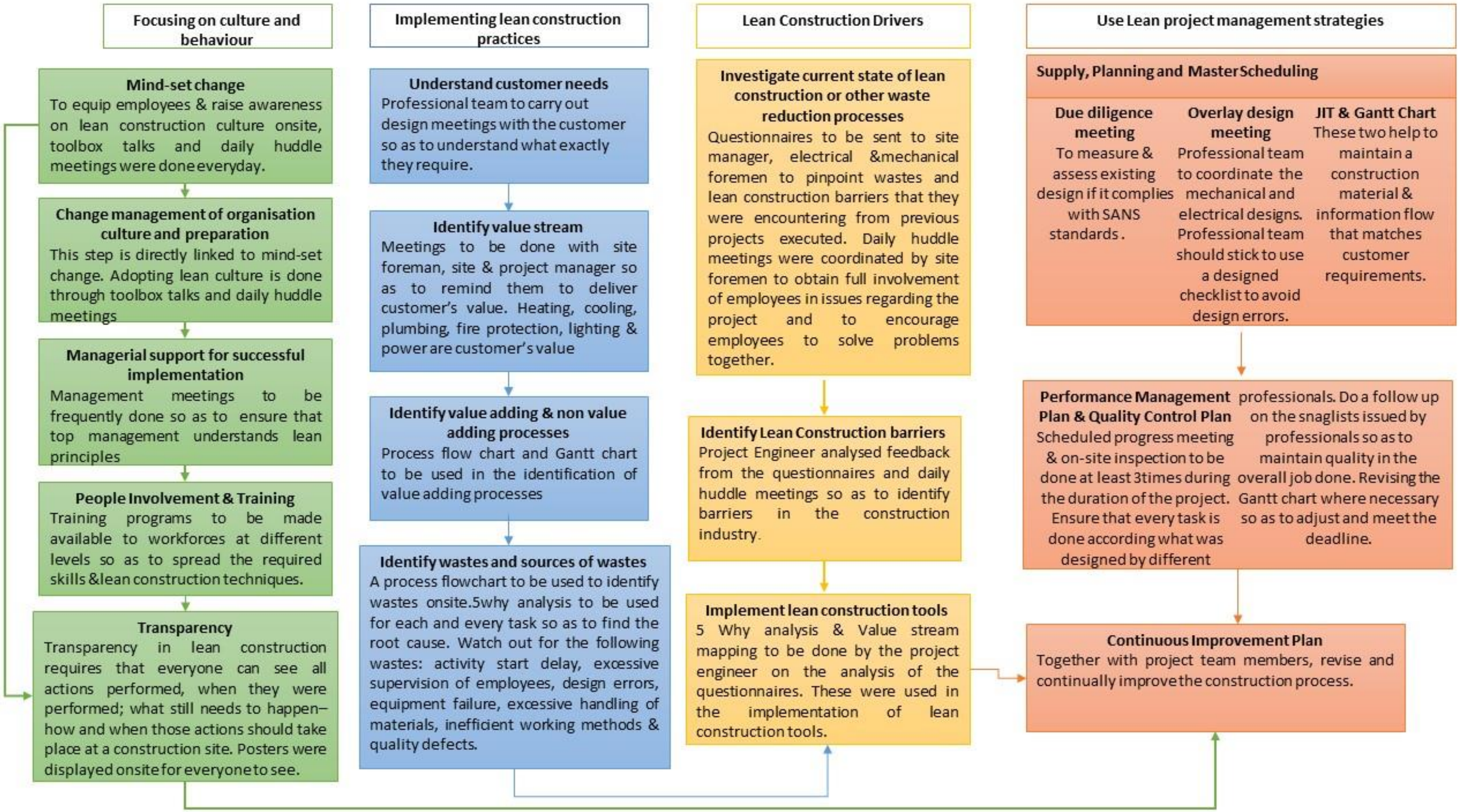
5.2.8 Seeking perfection

Continuous improvement (Kaizen) was done to provide a perfect solution without mistakes. Project deadline should be met, and the client’s needs satisfied hence saving on the project costs and reducing project duration.

5.2.9 Improved lean implementation framework

Table 5-5 below shows a final and improved lean construction implementation framework to be used in the construction industry. The framework is discussed in detail in Chapter 6, section 6.1.

Table 5-5: Improved Lean Construction Implementation Framework



5.3 Chapter summary

In this chapter, a lean implementation framework was developed and evaluated in the context of electrical and mechanical engineering services in the construction industry in South Africa. The developed framework was implemented in the construction industry. Two cases were studied, one in the Western Cape Province and the second one in Gauteng Province. During the implementation of this framework, the researcher went on site to educate the construction team about the benefits of adopting lean construction in the industry.

6 FINDINGS AND ANALYSIS

This chapter focusses on the findings of applications of lean construction principles in electrical and mechanical building services construction.

6.1 Discussion on the lean implementation framework

The framework as shown in Table 5-5 is made out of four key categories that one should focus on when implementing lean principles in the construction industry. These categories are culture and behaviour change, implementing lean construction practices, implementing lean construction drivers and using lean project management strategies. This section discusses the categories in depth.

As shown in Table 5-5 culture and behaviour change category focuses on the following concepts:

- Changing the mindset of contractors, sub-contractors and construction employees
- Changing management culture of the organization (project management firm) to embrace lean culture in its project management style
- Managerial support refers to support from the various professionals (architects, electrical and mechanical engineers)
- People involvement and training focus on empowering construction employee and their supervisors with the necessary skills for lean construction principles
- Transparency focuses on effective communication and evaluation of project management performance metrics to all construction stakeholders at that particular project.

In the culture and behaviour change category, the discussed concepts were implemented as documented in Section 5.1 and Section 5.2. During the implementation of these concepts, the researcher noted various benefits in these two construction projects. The benefits included improvement in safety on construction sites, increased productivity, reduction in project costs, improved employee morale, which cultivated the spirit of teamwork and meeting project deadlines.

Preservation of lean culture on construction sites was fulfilled during daily huddle meetings and toolbox talks. Daily huddle meetings are meetings held to obtain the full involvement of employees in issues regarding the project and to encourage employees to solve problems together. These are short meetings generally fifteen minutes long and conducted before start of the shift or day. As indicated in section 3.3.4, a lack of communication among employees was identified as one of the major reasons for failure of lean construction implementation. Daily huddle meetings and toolbox talks offered a great opportunity to communicate to construction employees about lean culture. For transparency on the construction site, posters and placards were displayed for everyone to see all actions performed, when they were performed, what was required to happen, how and when these actions should be achieved. Effective transparency means communication to everyone involved in the project – these include clients, owners, tenants, facility managers, contractors, sub-contractors and employees. Design meetings, overlay meetings and inspections needed to be carried out frequently to design as per client’s requirements.

The nature of construction projects is that in different construction projects you work with different contractors and sub-contractors. However, this study observed that contractors and sub-contractors that were involved in the first case easily adopted implementation of lean construction practices in the second case. These contractors knew how the project execution duration could be reduced after implementing lean construction. This includes the design teams; they also adopted lean construction culture during the implementation of lean construction.

On implementing lean construction practices category as shown in Table 5-5, focus is on the following:

- Understanding customer needs and this refers to the requirements of the client and how it is captured by the design professionals and how it is translated into a physical product (building and its services),
- Identifying value stream is conducted by the projects engineer and site supervisors and will help to identify all the activities, contractors and sub-contractors that will deliver the required value,
- Identifying value adding, non-value adding process, wastes and sources of wastes will help to improve the efficiency and effectiveness of the value stream.

Upon implementing lean construction practices category, during project execution the professional team should keep an eye or watch out for any non-value adding processes; these should be eliminated by all means as they contribute to wastes. One easy way to identify wastes on a construction site is to use a lean construction tool called Five Why analysis. Five why analysis asks questions to get to the actual root cause of the problem. It is a problem-solving technique used to identify the root causes of a targeted problem. This analysis is a question-asking technique that illuminates "cause-and-effect" mechanisms associated with a problem. The questions are usually specific to the project and are not limited to five questions. The Five Whys are generally dependent on each project separately and are not restricted to five questions (Aziz and Hafez, 2013; Sarhan *et al.*, 2017; Bajjou and Chafi, 2019). The researcher found the following wastes on these two construction sites:

- Excessive time for transporting materials and equipment
- Design errors
- Theft of equipment and materials
- Solid waste generation
- Activity start delays
- Excessive supervision of employees
- Just late
- Quality defects
- Broken materials
- Utilizing more materials and labour than what was necessary
- Delayed instructions
- Complex working instructions
- Re-work
- Over-storage of materials
- Delay due to lack of equipment
- Inefficient working methods
- Work equipment failure
- Delay due to work not completed by others
- Waiting for permission from the local authorities
- Unsystematic time breaks
- Material shortages

On implementing construction drivers as shown in Table 5-5, focus is on the following:

- Investigate current state of lean construction practices or other waste reduction processes. This will be done to all stakeholders involved in that particular construction project.
- Identifying barriers to lean construction implementation at the site
- Implementing lean construction tools

On lean construction drivers' category: questionnaires to be sent to site manager, electrical foremen, and mechanical foremen so that they pinpoint wastes and lean construction barriers that they were encountering from previous projects executed. According to published literature, the researcher found the top ten barriers in the construction industry; these include resistance to change, inadequate training, expertise and shortage of technical skills, lack of lean culture, extensive use of unskilled labour, absence of management long term commitment, extensive use of subcontractors, cultural issues and attitude, lack of financial resources and lack of governmental support. Project team members on site should watch out for these barriers when implementing lean construction. Management meetings should be frequently organised to ensure that top management understands lean principles. Employee involvement and training should be made available to employees of different levels so that skills and lean construction expertise are spread throughout the organization.

As shown in Table 5-5 the use of lean project management strategies will help the project engineer to coordinate the numerous construction activities. The category focuses on supply planning and masters scheduling, performance management plan and quality control plan and continuous improvement plan. On lean project management strategies, project quality is very important at the construction site; it is increased by the use of good quality material, improving observation and supervision on site. When handling material at the construction site, JIT principles help in avoiding raw material wastes. Upright customer relation amongst contractors and sub-contractors contributes to lean construction effectiveness. Just in time (JIT) principle and Gantt chart are the tools used to help maintain construction material and information flow that matches customer requirements. Scheduled progress meetings and on-site inspection should be done frequently during project execution. Quality control plan to be in place to monitor and check if every task is done according to what was designed by a team of professional.

6.2 Lean principles applied in carrying out projects on sites

Lean Construction is all about involving everyone that comprises the project team from the design phase through to construction phase. From lean principles that were explained in detail in the last chapter, all contractors on site were encouraged to use the last planner system to display their schedule. This helped in that all contractors would see how their schedules affected the overall completion date for that site. The researcher also introduced a 3-week look-ahead schedule. The contractors were not familiar with this schedule or plan, so it faced some resistance when it was first introduced. The 3-week look-ahead plan, helped in the project execution because it provided a clear picture of the steps to be taken to implement the project.

6.3 Reduction in project execution time frame

The researcher saw a reduction in project execution time frame when lean framework was being implemented on these two sites. According to Salem *et al.,* (2006), there are three characteristics that differentiate construction industry from manufacturing industry; these are 1) unique project 2) complexity and 3) on-site production. These key differences make it difficult to directly transfer lean tools from manufacturing industry to construction industry; hence, it is difficult to measure how effective lean implementation in the construction industry is as compared to lean implementation in the manufacturing industry. Before implementing lean construction framework, on average it took us forty-five days to complete a project of 500 square meters, which gives an average of 11.11 square meters per day. In the first case study, it took us forty-five days to complete a project of 860 square meters, which gives an average of 19.11 square meters per day. In the second case study, it took us fifty-seven days to complete a project of 1300 square meters, which gives an average of 22.80 square meters per day. This is 19% improvement in project execution, comparing case study 1 and case study 2. These differences in values before and after the framework implementation is a measurement of how effective this framework was in reducing the project execution time.

Table 6-1 below shows the number of professionals that worked on the two case studies. in case study 1 there was a higher number of high-level professionals as compared to case study

2. In case study 2 there was a higher number of low-level professionals than case study 1, hence case study 2 had lower labour rates as compared to case study 1.

Table 6-1: Professionals Involved in the Case Studies

Profession	Case Study 1	Case Study 2
Electrical Engineer	2	1
Structural Engineer	2	1
Mechanical Engineer	2	1
Quantity Surveyor	1	1
Electrical Foreman	1	1
Mechanical Foreman	1	1
Architect	2	2
Draughts person	1	1
Artisans	7	9
General hand workers	10	14

For these two case studies, the same type of machinery was used. Daily maintenance, weekly maintenance, monthly maintenance and quarterly maintenance was carried out on these machines. Daily maintenance was scheduled for 30 minutes prior to using the machine.

6.3.1.1 Increased visualisation on site

Upon communication to every employee on site about lean construction and how it will improve customer satisfaction and waste reduction in the construction industry, they all signed commitment cards or pledges. They committed to doing everything in their best ability to follow lean construction techniques on site. These commitment pledges were pasted around the construction site to remind everyone on site of their pledges.

6.4 Chapter summary

This chapter discussed the findings of this research project. The researcher discussed the final and improved lean construction implementation framework that is to be used in the construction industry, specifically in mechanical and electrical services.

7 CONCLUSIONS AND RECOMMENDATIONS

This final chapter summarises the findings of each chapter and the conclusions drawn based on the research findings. Thereafter, recommendations for implementation and further research are stated.

7.1 Research summary

The South African construction industry, to a larger extent, contributes to the economy of the country, particularly in the setting up of physical infrastructures (Takim and Akintoye, 2002). The rationale of the research study, problem statement, research aim, objectives, research questions and research contribution were presented in Chapter 1. The background of the study was also detailed in the chapter.

The researcher explained in detail the research design used for this study in chapter 2. The research was carried out in three stages which are literature review, implementation framework development and validation of the implementation through case studies. To sufficiently explain the research design in this study, a research onion was used. The research onion shows various research philosophies, research approaches, strategies and techniques. The research philosophy was discussed in section 2.2; the research approach was discussed in section 2.3, research method was discussed in section 2.4, research strategy was discussed in section 2.5, whilst the techniques and procedures were discussed in section 2.6.

Chapter 3 explored the applications of lean manufacturing principles in the construction industry. Objectives 1 to 4 were achieved in this chapter. The chapter defined concepts of lean, lean thinking principles, lean production methods to reduce waste, lean construction, benefits of lean construction, barriers of lean construction, drivers of lean construction practice in the South African construction industry, waste classification in this industry and controllable waste in construction. The goal of chapter 3 was to understand the application of lean principles in the construction industry and understand the level of awareness of lean concepts in the South African construction industry. From the analysis of literature on lean construction in South Africa, it has been observed that there are limited frameworks for the implementation of lean construction in the South African construction industry. The researcher also observed that there are limited applications of lean construction principles in the electrical installation services and mechanical installation services.

A systematic literature review was conducted under the outlook of lean applications in the South African construction industry. The benefits of adopting lean construction as highlighted in this research project are immense and will make the industry more resource efficient. Inasmuch as there are benefits of lean construction implementation, studies previously done shows that there are lean construction barriers in the construction industry. The study also highlighted lean construction tools that are being used worldwide as discovered in existing literature. In the literature review, this study discovered that nineteen lean construction tools were used in various construction projects worldwide. Based on the evidence gathered in literature only four tools were implemented in the South African construction industry.

Objective number 5 was achieved in Chapter 4, and a lean construction implementation management framework was developed in section 4.4. The researcher developed a lean construction implementation framework that was used in the mechanical and electrical services industry. In the lean implementation framework, core concepts were grouped into 4 categories namely culture and behaviour, lean construction practices, lean construction drivers and lean project management strategies. The implementation framework was verified and validated in Chapter 5. The verification and validation of the implementation framework was done in the South African construction industry. Evaluation of the framework was conducted using two cases, where the developed framework was refined and improved.

7.2 Recommendations

The scope of this study was to implement lean construction principles successfully in electrical and mechanical building services in construction industry. The developed framework was evaluated and tested in this context. For sustainability, the company should focus on mindset change, continuous improvement (Kaizen) on upcoming construction projects and managerial support. This study recommends the application of lean manufacturing principles in other branches of the South African construction industry that include road and dam construction.

7.3 Research papers written out of this study

The researcher has contributed in both the academia and industry; from this research, she has produced one research paper, which is a journal article. At the time of submitting this thesis, the journal article had been published by the South African Journal of Industrial Engineering (SAJIE) Special Edition 2019 (SAJIE, Volume 30, Issue 3). The article is entitled "Application of Lean Principles in the South African Construction Industry".

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9 APPENDICES

APPENDIX A: Research timeline schedule

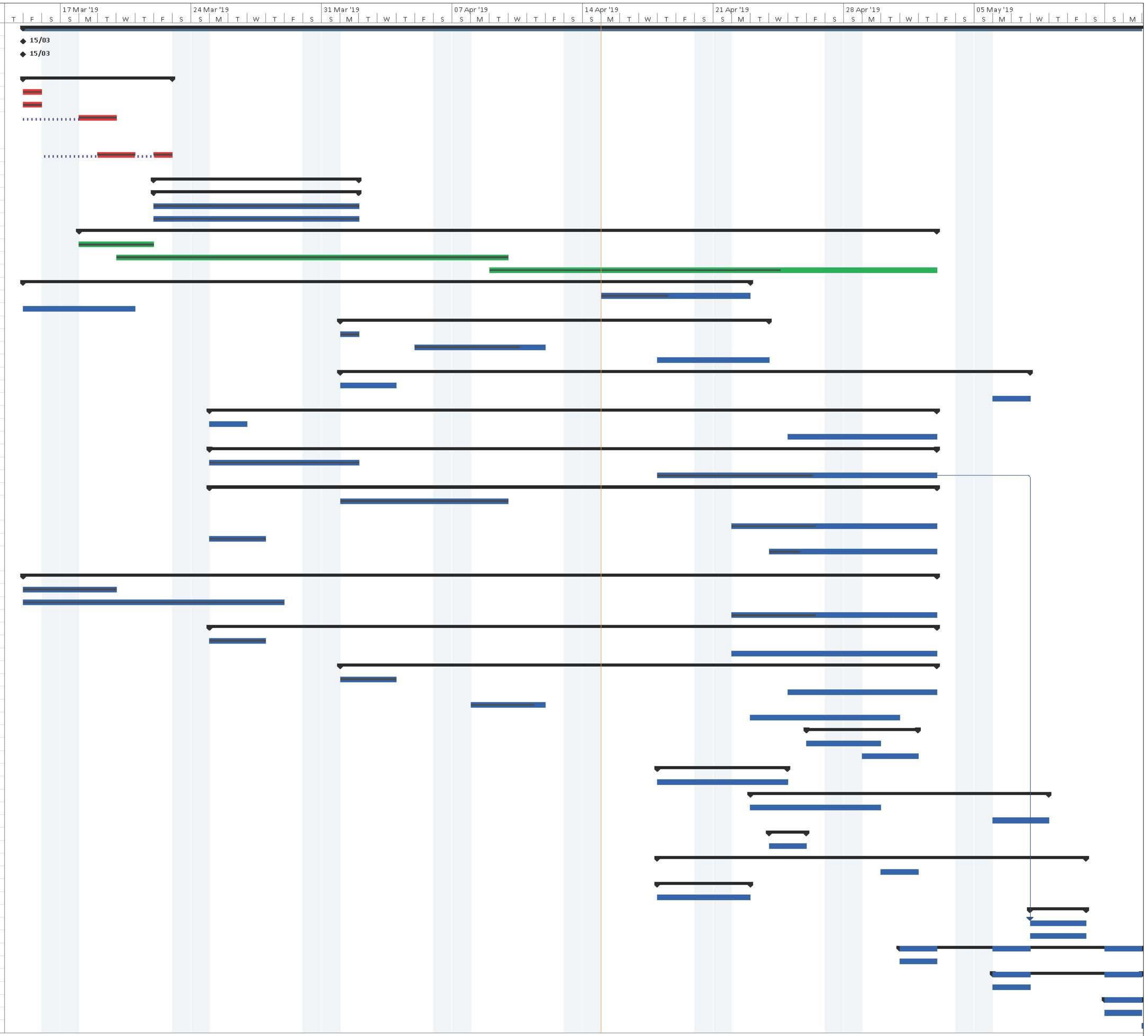
Table 9-1 below shows the Gantt chart that the student followed:

Table 9-1: Study Progression

Activity	**2019**				**2020**			
	Q1	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**
Research Proposal	■	■	■					
Systematic Literature Review			■	■				
Lean Construction Theoretical Framework				■	■	■		
Case Studies					■	■	■	
Thesis Write-up			■	■	■	■	■	■

APPENDIX B: Case Study 2 Gantt Chart

ID	Task Name	Duration	Start	Finish	% Complete	Predecessors
1	**Absa Promenade**	**45 days**	**Fri 15/03/19**	**Tue 14/05/19**	**51%**	
2	**Site Establishment**	**0 days**	**Fri 15/03/19**	**Fri 15/03/19**	**100%**	
3	Site Handover which will include:Letter of Appointment; Keys; Three sets of drawings;	0 days	Fri 15/03/19	Fri 15/03/19	100%	
4	**Demolitions and Preparations**	**6 days**	**Fri 15/03/19**	**Fri 22/03/19**	**100%**	
5	Install hoarding	1 day	Fri 15/03/19	Fri 15/03/19	100%	
6	Sprinklers to be blocked off	1 day	Fri 15/03/19	Fri 15/03/19	100%	
7	Electrical contractor to make area safe and provide temporary power points and provide temporary lighting	2 days	Fri 15/03/19	Tue 19/03/19	100%	
8	Demolitions	3 days	Sat 16/03/19	Fri 22/03/19	100%	
9						
10	**Wetworks and Meta walls**	**7 days**	**Fri 22/03/19**	**Mon 01/04/19**	**100%**	
11	**Brickwork**	**7 days**	**Fri 22/03/19**	**Mon 01/04/19**	**100%**	
12	Toilets	7 days	Fri 22/03/19	Mon 01/04/19	100%	
13	Metawalls	7 days	Fri 22/03/19	Mon 01/04/19	100%	
14	**Electrical**	**34 days**	**Mon 18/03/19**	**Thu 02/05/19**	**83%**	
15	Electrical first fix, cable trays	4 days	Mon 18/03/19	Thu 21/03/19	100%	
16	Electrical first fix ,chasing and conduits	15 days	Wed 20/03/19	Tue 09/04/19	100%	
17	Electrical second fix and commisiong	18 days	Tue 09/04/19	Thu 02/05/19	65%	
18	**Ceilings**	**27 days**	**Fri 15/03/19**	**Mon 22/04/19**	**36%**	
19	Install new ceiling grid including hangers	6 days	Mon 15/04/19	Mon 22/04/19	60%	
20	Install new ceiling tiles	4 days	Fri 15/03/19	Wed 20/03/19	0%	
21	**Floors**	**17 days**	**Mon 01/04/19**	**Tue 23/04/19**	**48%**	
22	Install floor screed & coverings	1 day	Mon 01/04/19	Mon 01/04/19	100%	
23	Tiling floor area	5 days	Fri 05/04/19	Thu 11/04/19	75%	
24	Install carpets	4 days	Thu 18/04/19	Tue 23/04/19	0%	
25	**Global Access**	**27 days**	**Mon 01/04/19**	**Tue 07/05/19**	**0%**	
26	First Fix	3 days	Mon 01/04/19	Wed 03/04/19	0%	
27	Second Fix and commisioning	2 days	Mon 06/05/19	Tue 07/05/19	0%	
28	**Voice**	**29 days**	**Mon 25/03/19**	**Thu 02/05/19**	**0%**	
29	First Fix	2 days	Mon 25/03/19	Tue 26/03/19	0%	
30	Second Fix/commissioning	6 days	Thu 25/04/19	Thu 02/05/19	0%	
31	**First Fix Interconnect IT**	**29 days**	**Mon 25/03/19**	**Thu 02/05/19**	**71%**	
32	First fix	6 days	Mon 25/03/19	Mon 01/04/19	100%	
33	Second Fix Interconnect IT/commissioning	11 days	Thu 18/04/19	Thu 02/05/19	55%	
34	**Security/Alarm/CCTV**	**29 days**	**Mon 25/03/19**	**Thu 02/05/19**	**63%**	
35	First fix Alarm system , CCTV & Access control installation	7 days	Mon 01/04/19	Tue 09/04/19	100%	
36	Second fix and commision	9 days	Mon 22/04/19	Thu 02/05/19	50%	
37	Install Visual Verification alarm system first fix	3 days	Mon 25/03/19	Wed 27/03/19	100%	
38	Install Visual Verification alarm system 2nd fix commision	7 days	Wed 24/04/19	Thu 02/05/19	25%	
39	**HVAC**	**35 days**	**Fri 15/03/19**	**Thu 02/05/19**	**60%**	
40	Removing Hvac ducts and equipment	3 days	Fri 15/03/19	Tue 19/03/19	100%	
41	First fix	10 days	Fri 15/03/19	Thu 28/03/19	100%	
42	Second fix & commissioning	9 days	Mon 22/04/19	Thu 02/05/19	50%	
43	**BMS**	**29 days**	**Mon 25/03/19**	**Thu 02/05/19**	**25%**	
44	First fix	3 days	Mon 25/03/19	Wed 27/03/19	100%	
45	Second fix & commissioning	9 days	Mon 22/04/19	Thu 02/05/19	0%	
46	**Fire Installation**	**24 days**	**Mon 01/04/19**	**Thu 02/05/19**	**33%**	
47	First Fix -fire detection	3 days	Mon 01/04/19	Wed 03/04/19	100%	
48	Second fix and commisioning	6 days	Thu 25/04/19	Thu 02/05/19	0%	
49	First Fix -first fix sprinkler repositioning	4 days	Mon 08/04/19	Thu 11/04/19	80%	
50	Second fix sprinkler positioing and commisioning	6 days	Tue 23/04/19	Tue 30/04/19	0%	
51	**Signage**	**4 days**	**Fri 26/04/19**	**Wed 01/05/19**	**0%**	
52	External signage	2 days	Fri 26/04/19	Mon 29/04/19	0%	
53	Internal signage	3 days	Mon 29/04/19	Wed 01/05/19	0%	
54	**Shopfronts**	**5 days**	**Thu 18/04/19**	**Wed 24/04/19**	**0%**	
55	Install shopfronts for offices including glazing	5 days	Thu 18/04/19	Wed 24/04/19	0%	
56	**Furniture**	**12 days**	**Tue 23/04/19**	**Wed 08/05/19**	**0%**	
57	Furniture Installation, Tellers and office furniture	5 days	Tue 23/04/19	Mon 29/04/19	0%	
58	Chairs/Equipment	3 days	Mon 06/05/19	Wed 08/05/19	0%	
59	**Install doors**	**2 days**	**Wed 24/04/19**	**Thu 25/04/19**	**0%**	
60	Universal doors and Mantrap	2 days	Wed 24/04/19	Thu 25/04/19	0%	
61	**Install Safes**	**17 days**	**Thu 18/04/19**	**Fri 10/05/19**	**0%**	
62	Safes	2 days	Tue 30/04/19	Wed 01/05/19	0%	
63	**Intell Cab Installation**	**3 days**	**Thu 18/04/19**	**Mon 22/04/19**	**0%**	
64	Intel Cab installation including hvac units	3 days	Thu 18/04/19	Mon 22/04/19	0%	
65	**Install computers**	**3 days**	**Wed 08/05/19**	**Fri 10/05/19**	**0%**	
66	Install Printers	3 days	Wed 08/05/19	Fri 10/05/19	0%	33
67	Install computers	3 days	Wed 08/05/19	Fri 10/05/19	0%	
68	**Small Foot Mantrap**	**11 days**	**Wed 01/05/19**	**Mon 13/05/19**	**0%**	
69	Small Foot Mantrap	2 days	Wed 01/05/19	Thu 02/05/19	0%	
70	**Hygiene Installation**	**8 days**	**Mon 06/05/19**	**Mon 13/05/19**	**0%**	
71	Install hygiene items	2 days	Mon 06/05/19	Tue 07/05/19	0%	
72	**Deep Clean**	**2 days**	**Sun 12/05/19**	**Mon 13/05/19**	**0%**	
73	Deep Clean	2 days	Sun 12/05/19	Mon 13/05/19	0%	
74	**Practical Completion**	1 day	Tue 14/05/19	Tue 14/05/19	0%	



Project: Westgate ABSA PROJECT
Date: Mon 15/04/19

Task | Split | Milestone | Summary | Project Summary | External Tasks | External Milestone | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | Deadline | Progress

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Figure 9-1: Case study 2 Gantt chart

THANK YOU