A MECHANISM FOR WASTE REDUCTION IN STRUCTURAL DESIGN PROCESS IN SOUTH AFRICAN CONSTRUCTION

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DECLARATION OF ORIGINAL AUTHORSHIP

I, **ADEFEMI AKA** on this day July 2017 declare that:

The work in this thesis is through my personal effort. The sources used or referred to have been duly acknowledged, and the thesis has not previously been submitted in full or partial fulfilment of the requirements for an equivalent or higher qualification at any other recognized educational institution.

Signed…………………………………………

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DEDICATION

This research is dedicated to Almighty God for making this work possible.

LIST OF PUBLICATIONS

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ABSTRACT

The construction design process (CDP) is made up of five distinct phases. The phases include the inception design phase, the predesign phase, the detailed design phase, the construction phase (CP), and the close-out phase (COP). With the exception of the COP, the above-mentioned phases in the CDP are fraught with non-value-adding (NVA) activities that are otherwise called 'waste' in the lean terms. These wastes hinder the efficient delivery of projects in the construction industry. To overcome this dilemma, researchers worldwide have investigated how waste in the CP of a project can be eliminated through lean principles. However, the findings in the literature indicate that attention is focused mainly on the architectural process (AP) while the structural design process (SDP) is largely uncovered. In an attempt to bridge this gap, this research investigated the various waste that originate from the SDP, the causes of the waste, their impacts on projects, and how such waste can be eliminated. The study was executed through an action research design. Primary data were collected from five consulting engineering firms (CEFs) in Bloemfontein, South Africa. The engineers have extensive experience in the SDP, and are affiliated with the Consulting Engineers South Africa (CESA). To effectively identify, and confirm the various waste types in the SDP, a lean tool known as value stream mapping (VSM) was also deployed in the current flow of the activities in each phase of the SDP. That is, the VSM adopted in the study enabled the researcher and the study group in each firm to reaffirm the existence of the identified NVA activities in the SDP, and to explore more waste in the practice. Having compiled the various wastes in the system, the study proposes different strategies that can be adopted to reduce the identified waste. The proposed strategies were used to develop a lean or VSM mechanism that was used to execute a new project in one of the case study firms. The findings from the study reveal that waste exists in every phase of the SDP. Typical examples of these waste are waiting time, error, over-processing, excessive vigilance, motion, clarification, overproduction, work interruption, and rework. The findings in the study also indicate that some of the identified waste in the SDP, such as error and clarification, often lead to delay in the design phase, which consequently leads to delay in the start of the construction activities, and the completion time of a project. The identified waste in the SDP also contributes to poor project delivery and cost overrun. The study concludes that the lean concept can be extended to the SDP to eliminate waste in practice. This implies that the proposed mechanism in this study offers guiding information on how lean concept can be adopted to identify and reduce waste in the SDP. The mechanism also serves as a platform that allows structural designers to identify gaps in their implementation efforts, focus attention on areas for improvements and assess the benefits of the lean approach in the design and the construction phases of projects. The research recommends that VSM, and the five lean principles should be adopted by structural designers in every phase of the SDP for waste eradication.

Keywords: Construction, Design, Engineers, Lean, Value Stream Mapping, Waste

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ABBREVIATIONS

AAD	Appropriate architectural drawing/design
AP	Architectural process
AR	Action research
BBT	Black Belt Team
BIM	Building information modelling
CDP	Construction design process
CEFs	Consulting engineers firms
COP	Close-out phase
CP	Construction phase
DC	Design correctness
DDP	Detailed design phase
DDP-1	Attend design and consultants meetings
DDP-2	Review detail design document plans with other consultants
DDP-3	Selection of suitable structural elements computed at predesign phase
DDP-4	Incorporation of the comments in the predesign phase into the project
DDP-5	Incorporation of other consultants designs and requirements into work
DDP-6	Prepare the design development drawings (draft) and specifications
DDP-7	Review of the drawings by the senior engineer of the firm for corrections
DDP-8	Approval of the design by the senior engineer of the firm after corrections
DDP-9	Production of the construction drawings
DDP-10	Establish the detail design documents
DHMs	Daily huddle meetings

DOT	Design optimization technique
DP	Design phase
DTI	Department of trade and industry
DVSP	Design variability space policy
EC	Electronic communication
ECO	Engineering change order
GLDM	Generic lean design model
GP	Grace period
IC	Internet enabled communication
IDC	Industrial development corporation
IDP	Inception design process
IDP-1	Attend project initiation meetings so as to implement contract agreement
IDP-2	Brief review of the architectural drawings
IDP-3	Define the services and the scope of the project
IDP-4	Give favourable advice in term of project life cycle cost
IDP-5	Provide the information required to other consulting engineers
IDP-6	Schedule/inspect on the necessary land topographical survey
IDP-7	Schedule/inspect on the necessary soil tests
IDP-8	Oversee the compilation processes of site report
IDP-9	Sign inception design documents
IT	Information technology
JIT	Just-in-time
LAS	Look-ahead schedule
LC	Lean construction
LD	Lean design
LDM	Lean design model
LP	Lean production

LPT	Lean production theory
LT	Lead time
MOF	Management of an organization
NEF	National empowerment fund
NPO	Non-participatory observation
NVA	Non-value adding
PCP	Preconstruction phase
PDP	Predesign phase
PDP-1	Attend design and consultant meetings
PDP-2	Review the architectural drawings in detailed
PDP-3	Modification of the architectural drawings
PDP-4	Establish the necessary regulatory requirements and building codes and incorporate them into the project
PDP-5	Establish the structural predesign criteria
PDP-6	Ensure that the criteria established conform to the required building codes and regulatory authorities
PDP-7	Perform the necessary computations and preliminary sizing
PDP-8	Prepare the preliminary process designs and related documents suitable for costing
PDP-9	Review of the whole work by senior/chief engineer
PDP-10	Establish the preliminary design documents
PT	Process time
Q/S	Quantity surveyor
QA	Quality assurance
QMAR	Qualitative method in action research
RC	Reinforced concrete
RFIs	Requests for information
SDP	Structural design process
SDT	Structural design team
SLP	Sequential linear programming

TFV	Transformation-flow-value
TPS	Toyota production system
TQC	Total quality control
VAA	Values adding activities
VSM	Value stream mapping

DEFINITION OF TERMS

The following were used as the working definitions throughout this study:

Action research: Action research is any practical research undertaken by those involved in the practice area. It is a process of enquiry by a researcher into the effectiveness of a particular organization (Buchy & Ahmed, 2007: 358).

Client: A client is considered as the primary and secondary developers of a project (Morledge, 1987: 26).

Construction management: Construction management is the overall planning, coordination, and control of a project from beginning to completion. It main aim is to meet clients' requirement in order to produce a functionally and financially viable project (Strang, 2002: 3)

Construction planning: Construction planning is a fundamental and challenging activity in the management and execution of construction projects. It involves the choice of technology, the definition of work tasks, the estimation of the required resources and durations for individual tasks, and the identification of any interactions among the different work tasks (Paulson *et al.*, 1979: 89).

Defect: Defect is to do a particular aspect of work more than a time by an employee (Gatlin, 2013: 1).

Design management: Design management encompasses the ongoing processes, business decisions, and strategies that enable innovation and create effectively designed products, services, communications, environments, and brands that enhance quality of life, and provide organizational success (Kicherer, 1990: 1).

Lean Construction: Lean construction is a coherent synthesis of the most effective techniques for eliminating waste and enhancing values by delivering significant sustained improvement in cost, time, quality and safety (Ballard, 2000: 22).

Lean Design: Lean Design is the application of lean concepts to the design phase of a system (Ward 2009: 66).

Lean Production: Lean Production is a way of thinking that can promote understanding, and its main goal is to provide customers with precisely what they want, when they want it, while continuously thinking about how things can be done more efficiently (Womack & Jones, 2003: 92).

Motion: Motion is any unnecessary physical movement by construction actors during the progress of work (Womack & Jones, 2003: 82).

Over production: Overproduction is unnecessary production of materials before it is needed (Simms, 2007: 4).

Over-processing: Over-processing is working on one aspect of work more than required or to utilize resources more than necessary (Ohno, 1988: 18).

Participatory action research: Participatory action research is considered as a subset of action research, which is the "systematic collection and analysis of data for the purpose of taking action and making change" by generating practical knowledge (Gillis & Jackson, 2002: 264).

Project management: Project management is the discipline of initiating, planning, executing, controlling, and closing the work of a team to achieve specific goals that will meet specific success criteria (Nokes, 2007: 1).

Rework: Rework is a work that is required to be repeated due to inadequate/non-conformity with the specifications or standard at the time the work was initially conducted (Zhang, 2009: 8).

Structural design phase: The structural design phase of a construction project entails a systematic means of investigating the stability, strength, and rigidity of a structure (Lin & Gerwick, 1969: 693).

Waiting time: Waiting time is any form of delay experience in processing an item or component (Shingo, 1985: 6).

Waste: Waste is any activity or unnecessary work done and material loss that can increase production costs but add no value to the product itself (Koskela, 1992: 34).

1.0 ORIENTATION OF THE RESEARCH

1.1 Introduction

The structural design phase of a construction project entails a systematic means of investigating the stability, strength, and rigidity of a structure (Lin & Gerwick, 1969: 693; Galambos, 1998: 192; Al Nageim *et. al.,* 2010: 8). The main objective of this phase is to produce a structure that is capable of withstanding all imposed load without failure during its intended lifetime (Galambos, 1998: 192; Galambos & Surovek, 2008: 1). This objective is explicitly carried out by a structural design team (SDT) in the construction design process (CDP) (Nelson *et al.,* 1988: 14; Salmon & Johnson, 1996: 424; Galambos, 1998: 192).

The CDP is made up of five distinct phases, namely the inception design phase (IDP), where the design teams carry out a project feasibility study, the predesign phase (PDP), where the procedures needed to complete the detailed drawings are clearly laid out, the detailed design phase (DDP), where the complete plans of the project are carried out, the construction phase (CP), where the drawings and specifications are handed over to the construction contractors, and the close-out phase (COP), where final measurements, documentation and drawings (as-built drawings) are prepared and handed over to the clients and other construction stakeholders (Jensen & Tonies 1979: 22; Dupagene, 1991: 24; Melhado & Agopyan 1996: 502; Anderson *et al.*, 2006: 5; Soto, 2007: 19; Ko & Chung, 2014: 468).

Li *et al.* (2008: 915), Koskela *et al.* (2013: 3), and Ko and Chung (2014: 464) show that the above-mentioned phases in the CDP are fraught with activities and problems that constitute waste in construction. According to Koskela (1992: 34), waste is any form of unnecessary work done and material loss that can increase production costs but adds no value to the product itself. Such unnecessary work done and material loss include waiting time, quality costs, lack of safety, rework, unnecessary transportation trips, long distances, improper management procedures, and poor constructability (Koskela, 1992: 35). In studies conducted by Womack and Jones (2003: 89), Koskenvesa *et al.* (2010: 477), Zoya-Kpamma and Adjei-Kumi (2011: 102), Al-Aomar (2012: 105) and Koskela *et al.* (2013: 3), it was discovered that waste can also be defined as any activity that produces costs directly or indirectly and takes time, resources or requires storage, but does not add value or progress to a particular product.

The causes of waste in construction have been the subject of several studies (Li *et al.*, 2008: 915; Mossman, 2009: 13; Nagapan *et al.,* 2012: 22; Koskela *et al.*, 2013: 3). For instance, one study conducted in the United Kingdom (UK) reveals that poor design management and late approval of decisions by the client are the two major sources of waste in projects (El Reifi & Emmitt 2013: 195). The observations of El Reifi and Emmitt (2013: 195) juxtapose with the view espouse by Ndihokubwayo and Haupt (2008: 126), Osmani *et al.* (2008: 1147), Oladiran (2008: 1) and Abdelsalam *et al.* (2010: 749), regarding clients as the main source of waste through variation orders. Further, the Construction Industry Institute (CII) in the United States of America (USA) (2009: 3) opines that project actors that are involved in construction also contribute to waste. These project actors include those that specify and communicate concepts, and those that design materials, plant and building (CII, 2009: 3).

Li *et al.* (2008: 915), AbdelSalam *et al.* (2010: 749), and Ko and Chung (2014: 465) maintain that of all the processes in a project, the design phase (DP) is the most critical aspect. This phase is critical, as it is in this phase that values are explored and expressed, and when this phase is well managed, waste and associated problems can be minimized in the CP (Li *et al.*, 2008: 916; Ko & Chung 2014: 468). Despite its complexity, few researchers have investigated how construction waste can be reduced or eliminated (Marzouk *et al*., 2011: 42; Ko & Chung 2014: 468). Marzouk *et al.* (2011: 42) investigated how the five lean principles can be adopted in the DP of a project so as to aid decision-making in the early stages of construction. The researchers concluded that applying the five lean principles to the DP of projects helps in decision-making in the early stages of construction, which consequently leads to better resource utilization and reduces CP durations. Several other researchers have investigated how construction waste can be reduced through the DP of projects. However, the findings in the reviewed literature indicate that attention is focused mainly on the architectural process (AP); the aspect of the SDP is still largely unexplored.

It is essential to know that waste in construction can be categorized into: defects (corrections), overproduction, over-processing, waiting (delay), inventory, motion, transportation and unexplored creativity of employees (Koskela, 1999: 241; Womack & Jones, 2003: 83; Sommerville, 2007: 391; Love *et al.*, 2008: 234; Hwang *et al.*, 2009: 187; Zhanwen, 2009: 3; Lopez *et al.*, 2010: 399; Koskela *et al.*, 2013: 1). The aforementioned waste can be removed from the construction process through different lean concepts and tools (Hicks, 2007: 233; Matthias, 2007: 420; Arayici *et al.*, 2011: 189; Ko & Chen, 2012: 101; Ko & Tsai, 2013: 2409; Ko & Chung, 2014: 463). Manrodt *et al.* (2008: 1) define lean as a coherent approach of promoting value to the customer by identifying and eliminating waste related to time, effort and materials, which can be achieved through incessant improvement by moving the product at the pull of the customer in pursuit of perfection. Sacks *et al.* (2009: 1) say that lean construction is the adaptation of the concepts and principles originally developed from the Toyota Production System (TPS) in the 1950s to create a new way to manage construction projects.

According to Womack and Jones (2003: 89) and Matthias (2007: 420), lean thinking originates from production process, and can be viewed as a systemic method for the elimination of waste (Muda) within a manufacturing process. This means that lean takes into account waste created through overburden (Muri) and unevenness in workloads (Mura). Womack and Jones (2003: 92) accentuate that lean production (LP) is a way of thinking that can promote understanding, and its main goal is to provide customers with precisely what they want, when they want it, while continuously thinking about how things can be done more efficiently. Womack and Jones (2003: 92) further reveal that LP techniques are based on five main principles to guide management's actions toward success. These principles include:

- Precisely specify value in terms of a specific product;
- Identify the value stream for each product;
- Make value flow without interruptions;
- Let the customers pull value from the producers, and
- Pursue perfection.

These five lean principles have been adopted by the construction industry in terms of services to the clients (Velarde *et al.*, 2009: 77). However, the aspect of design where decisions have a major influence on the CP is still largely unaffected by these principles (Marzouk *et al.*, 2011: 43; Zimina *et al.*, 2012: 393).

Further studies are required to expand on the existing theories and knowledge in other aspects of the CDP such as the SDP. Premised on this requirement, an exploratory study was conducted in Bloemfontein, South Africa, to investigate the various types of process waste that originate from the SDP, and how such waste can be reduced so as to further enhance values in the design, and the construction phases of projects.

1.2 Problem Statement

Many structural engineers carry out design tasks without putting waste mentioned in section 1.1 into consideration. This has led to waste during construction activities with consequent decline in the industry productivity. In studies conducted by Song *et al.* (2009: 12) and Hwang (2009: 187), and Emuze (2011: 204), it was discovered that little interaction among the design and the construction teams is a major cause of errors in the DP of a project, and the consequences on site are excessive requests for information (RFIs), supervision, lack of constructability, inappropriate use of material, and a great number of change orders. Similarly, Mryyian and Tzortzopoulos (2013: 449), Ko and Chung (2014: 463) emphasise that improper drawings are often discovered in the construction phase. This makes the design to be returned to the architect for corrections. The continuous corrections by the architect also increase waste in project (Mendelsohn 1997: 17).

Simms (2007: 4) observes that over-processing is another form of waste that occurs in engineering drawings due to the creation of complex designs. Waste due to over-processing is applicable to the SDP as experience shows that most structural drawings, especially detailed drawing can be complicated and wrongly interpreted by construction workers. This also contributes to excessive RFIs, rework, and delays during site activities. Further, Shingo (1985: 5) and Ohno (1988: 18) contend that processing an order before it is needed or any processing that is done on a routine schedule regardless of its current demand is over production. In similar studies conducted by Ohno (1988: 18) and Muda the 7 deadly wastes, it was discovered that printing of drawings that may change over time due to correction or approval problem, and production of several drawings such as details and sections that are not necessary needed on site, but are produced by the designers in order to meet up with the approval standard or requirements are waste that can also be classified as over production. The preliminary investigation conducted by the researcher in some consulting engineer firms located in Bloemfontein, South Africa at the start of this study reveals that over production waste occurs in every phase of the SDP and is one of the major waste that is responsible for delay in the start of site activities. The literature shows that the certification process of construction designs also contributes to waste as it determines the starting and the finishing times of projects (Emuze, 2011: 204). Experience shows that a typical problem associated with the certification process of the structural design is the excessive time that is required for the approval of work. Waiting for the approval of work by the senior designers/the project directors before site activities commence takes longer time than expected. This also leads to the delay in the start of site activities, and the completion time of a project.

Presently, there is a consensus in the literature that the architect role is crucial in minimising the above-mentioned waste in projects (Oyedele & Tham 2007: 2090; Osmani *et al.* 2007: 1148). However, as at when this study was conducted, there was poor literature or understanding on the wastes that originate in projects due to structural design development. Therefore, the research problem statement states that *'lack of a mechanism for waste identification and reduction in the SDP promotes task conversion problems on construction sites'.*

Based on the above explanations and the postulated problem statement the submitted thesis sought responses to:

- What type of waste is synonymous with the SDP?
- What are the remote and immediate origins of such waste?
- What are the impacts of such waste on the construction projects?
- How should lean concept be used to remove waste in the SDP?
- What other mechanism should be used to remove waste in the SDP?
- How should lean thinking drive practice in the SDP in South Africa?

The above questions are pertinent in an industry where production process is waste laden when compared with manufacturing. Globally, productivity has been hampered by waste in the design and the construction processes. Most lean construction researchers have addressed most of the essential areas in the construction process to include the ADP. However, no work has been exclusively focused on the SDP worldwide. This thesis has therefore, bridged such a big gap and it will be a forerunner to what will be uncovered in the years to come.

1.3 The Aim and Objectives of the Study

With South Africa as a geographic scope, this research developed a conceptual mechanism for waste reduction in the SDP by determining:

- the waste that is synonymous with the SDP;
- the remote and immediate origins of such waste;
- the impacts of such waste on construction project performance;
- the context specific lean concept tool/tools for the removal of waste in the SDP;
- a system for eliminating waste in the SDP, and
- a strategy for the promotion of lean in the SDP.

The aforementioned objectives of the study worked in union regarding the realization of the aim of the study, which is about *evolving a mechanism for waste elimination in the SDP to tackle task conversion problems on construction sites.'*

1.4 Research Methodology

In order to achieve the aim of this study stated in section 1.3 of this report, an action research study specifically, qualitative methods in action research (QMAR) proposes by Stringer (2014) was conducted in 2015 and 2016. Explicitly, the study was conducted with groups of consulting engineers in five different firms located in Bloemfontein. The selection of the firms was based on purposive sampling techniques (Ritchie & Lewis 2003). This implies that the selected firms in the study location are those that have designers with extensive work experience in the SDP, and are affiliated with Consulting Engineers South Africa (CESA). To be precise, five designers (a combination of both senior and junior engineers), and a technologist that have been working together as a team for not less than five years were selected and used for the study. It is essential to know that focus interviews served as the main technique for data collection in the QMAR study in all the firms. To facilitate the analysis of the anticipated data, the focus interview questions were focused on three different types of structures, namely residential, commercial and industrial buildings.

It is pertinent to know that the focus interviews were used to understand the current flow of activities in the SDP. Thereafter, VSM was depicted on the flow of the activities so as to identify NVA activities (waste) in the practice. After the depiction of the VSM, another focus interviews were conducted in each firm. The essence of these was to enable the researcher/the participants in all the groups to propose for different strategies that can be adopted to eliminate the identified waste in the SDP. For consistency reason, the focus interviews in the two main phases of the study (diagnosing/action planning) were conducted three times in each firm. Generally, each focus interview in all the firms was between 60 to 80 minutes (approximately 1 hour, 15 minutes) in duration. All the focus interviews discussions in each firm were fully recorded and transcribed accordingly (Arksey & Knight 1999). After transcription, the resultant information was analysed using content analysis (Krippendorff 2012). The resulting information from the analysed data (themes) were validated accordingly, after which conclusions and recommendations were drawn from the outcomes of the validated data.

1.5 Rationale of the Study

This research is needed in order to develop new ways of managing the DP in projects so that the required value for money in every construction project can be assured. More so, the results and the benefits of applying lean principles to projects in the developed countries are notable. In the USA, for instance, flow of communication and mutual coordination exist in the design and the construction phases of projects due to the adoption of the lean concept (Kim & Park, 2006: 381). Mossman (2009: 24) emphasizes that the adoption of the lean concept in the UK has greatly improved reliability, accountability, certainty and honesty within the project environment over the years. Application of lean thinking to the SDP may also be one of the benefiting areas of the lean concept in projects but this has to be investigated.

Therefore, this study is needed as it offers guiding information on how a lean tool known as value stream mapping (VSM) can be adopted to identify and reduce waste in the SDP. The study serves as a platform that allows structural engineers to identify gaps in their implementation efforts, focus attention on areas for improvement and assess the benefits of the lean process and its management. Hence, the consequences of not conducting the research over the years might have led to errors, excessive vigilance and delay in the design phase of projects, with consequent delay in the start of the construction activities (Kirby *et al.*, 1988: 69; Burati *et al.* 1992: 34; Oyedele & Tham, 2007: 2090; Mryyian & Tzortzopoulos, 2013: 449). Further, the consequence of not conducting the research over the years might have also triggered or engendered severe problems such as rework and delay in the construction phase of projects with consequent increase in the overall costs of projects (Ferguson, 1989: 175; Tzortzopoulus & Formoso, 1999: 335; Ko & Chung, 2014: 463).

1.6 Scope of the Investigation

Lean thinking is the basic approach that was adopted for waste identification and reduction in this study. Specifically, VSM is considered as the only suitable lean tool that can be used to identify problems in the structural design process (SDP). The strategies that were proposed for the reduction of the identified problems in the SDP are also limited to lean construction approaches in the literature, and on the information obtained from the study participants (structural engineers in the study context). Only consulting engineering firms that are located in Bloemfontein were considered for data collection in the study. The study is limited to five different firms that have at least five structural engineers with over 10 cognate years of work experience in the structural design practice, and are affiliated with Consulting Engineers South Africa (CESA).

1.7 Assumptions

i. Complete information is required from the architect before the start of the structural design activities?

ii. Complete information is required from the structural engineers before the start of tasks on the construction site?

iii. The approval time of the structural drawings influences the starting, and the finishing times of a construction?

iv. Continuous interaction is required between the designers, and the contractors from the start to the completion of a project?

1.8 Structure of the Thesis

As indicated in Figure 1.1, this thesis starts from Chapter 1 and ends at Chapter 7. Chapter 1 highlights the study background through the problem statement, the research questions, the aim and objectives, the rationale for the study, the scope of the investigations, and the main assumptions of the research. Chapter 2 of the thesis emphasizes mainly on waste in the design and the construction phases of projects. The chapter accentuates on the previous work on waste and its causes in the CDP, the impacts of the waste on projects, and how the waste can be addressed through a common philosophy know as lean thinking.

Chapter 3 of the thesis elucidates mainly the reasons while a lean tool known as the VSM is being adopted for waste identification and reduction in the SDP. Chapter 4 provides the methodological framework for this report. It also provides the methods, the philosophical assumptions, and the procedures adopted by the researcher for data collection and analysis. Chapter 5 presents the results of the action research conducted, while Chapter 6 shows the procedures used to develop and evaluate the proposed lean mechanism that was developed in the course of the research. Chapter 7 is the last section of this thesis and it points out the overall conclusions of the study conducted, the recommendations, areas for further studies and contribution to the knowledge.

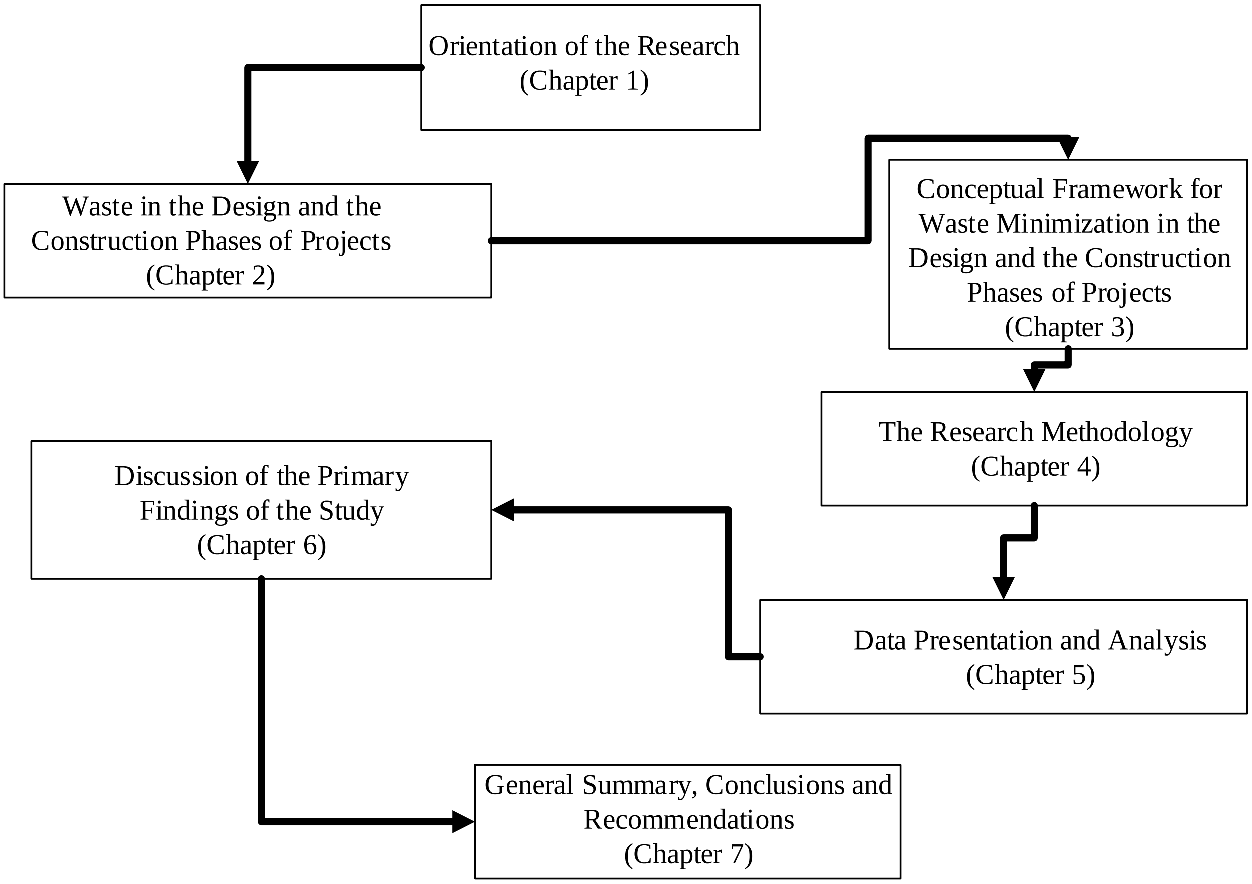

Figure 1.1: Structure of the thesis

1.9 Summary

This chapter has explicated the aim, objectives, and the research questions of this study. The rationale, as well as the consequences of not conducting the study over the years were also clarified in the chapter. Therefore, the chapter has provided the platform for the subsequent chapter of this study. In other words, the chapter concludes with an insight into the next part of the thesis: literatures that are relevant to the study area.

2.0 WASTE IN THE DESIGN AND THE CONSTRUCTION PHASES OF PROJECTS

2.1 Introduction

The design stage of every project offers a potential for improvement in terms of waste reduction and elimination (Reifiet *et al.*, 2013: 329). To attain this improvement, there is need for project actors to take into cognizance the activities that add value, and those that are non-value adding (waste) (Reifiet *et al.*, 2013: 329). Therefore, this chapter explores the significant waste that are synonymous with construction design process (CDP), the origin of the waste, and their impacts on projects.

2.2 An Overview of a Typical Construction Design Process

The activities within the flow of the construction design are in different segments and each section is handled by different specialists (Alarcon & Mardones, 1998: 2). In building projects, for instance, the first stage is the selection of the architect (Alarcon & Mardones, 1998: 2). The architect selected by the client prepares the architectural designs as well as the specifications, after which the structural and other specialty designs will be developed by the structural engineers, and other professionals (Alarcon & Mardones, 1998: 2). The next phase is the certification process where the drawings are judged standard or not by the appropriate authority (Murdoch & Hughes, 2007: 1). The implementation stage is the responsibility of a contractor selected by the owner (Alarcon & Mardones, 1998: 2).

2.3 Phases in the Construction Design Process

As stated in Chapter 1 of this study, five main phases exist in the CDP. These include the inception, the predesign, the detailed design, the construction, and the post construction or close-out phases (Jensen & Tonies 1979: 22; Dupagene, 1991: 24; Melhado & Agopyan 1996: 502; Anderson *et al*, 2006: 5; Soto, 2007: 19; Ko & Chung, 2014: 468). The activities in each phase are explained in detail in the following sections:

2.3.1 The inception design phase

The inception design phase (IDP) is the planning and budgeting process where several feasibility studies of the proposed project or development reports are carried out by the various actors (Dupagene, 1991: 24; Melhado & Agopyan 1996: 502; Anderson *et al.*, 2006: 5). Anderson *et al.* (2006: 5) accentuate that in the planning and the budgeting process of the IDP, the project actors are expected to investigate all the site constraints that may dramatically affect the usefulness or the cost of the project, and perform an accurate cost estimate to include the contingency fund of the proposed project. Premised on the above-stated requirements in this phase, Anderson *et al.* (2006: 5) contend that in most projects, the planning and the budgeting process may take time that may exceed the actual design and the construction process. In spite of the lead time often experienced in the planning/budgeting process in the IDP, Anderson *et al.* (2006: 5) point out that it would be imprudent and uneconomical for the client or project actors to proceed to the architectural drawings without a conceptual plan and budget of the proposed project.

After the planning and the budgeting, the next stages are the topographical survey and the geotechnical investigations of the proposed site (Kent, 2005: 1). It is essential to know that the surveying of a proposed site creates accurate, details topographic and utility location maps that serve as the basis for the critical design decisions of the proposed structure (Kent, 2005: 1). Kent (2005: 1) is of the view that an aesthetically pleasing site plan, a drainage system that handles storm water efficiently, and the logical placement of site utilities, and other improvements depend to a great extends on the topographic information recorded by a surveyor. Accordingly, accurate boundary information is also necessary as it enables the design professionals to locate buildings, other site amenities, and ascertain whether they meet the regulatory as well as jurisdictional requirements (Kent, 2005: 1).

According to Aladejana *et al.* (2015: 3), a geotechnical site investigation is the process of collecting information and evaluating the conditions of a site for the purpose of designing and constructing the foundation of the proposed structure. It should be noted that adequate assessments of site geologic and geotechnical conditions of a new site is one of the most important aspects of the proposed structure evaluation (Aladejana *et al.*, 2015: 3). Therefore, all efforts around the details of the geotechnical site investigation are to obtain sufficient and correct site information that will enable the designers to select and design a foundation for the proposed building or structure (Aladejana *et al.*, 2015: 3). Ko and Chung (2014: 468) contend that in most projects, the overall activities in the inception phase of the CDP are often led by the architect in close consultation with the client.

2.3.2 The predesign phase

The predesign phase (PDP) is a major factor in a project's success and it takes place once the project's design criteria have been established in the inception phase (Anderson *et al.*, 2006: 6; Soto, 2007: 20). The PDP describes the project's purpose, architectural goals, applicable codes, and other special requirements such as the structural designers, as well as other specialties or professionals such as mechanical and electrical engineers (Anderson *et al.*, 2006: 7; Soto, 2007: 20; Ko & Chung, 2014: 468). The PDP also governs the architect and the engineers in their project design and often determine the final project budget (Anderson *et al.*, 2006: 7). Succinctly put, the PDP of the CDP focuses mainly on the detailed analysis of the building plan model for a design competition's winning entry, to include planning for the required structural reinforcements, structural strength, load analysis, water pipe, electrical layout, and emergency evacuation routes (Ko & Chung, 2014: 468).

2.3.3 The detailed design phase

The purpose of the detailed design phase (DDP) of the CDP is to compile all documentation following every necessary inspection to reduce design errors (Ko & Chung, 2014: 468). Ko and Chung (2014: 468) aver that once the proposed project design (sketch plan) has been approved by the owner in the PDP, the design actors formalize the sketch drawings into plans and specifications that are suitable for construction in the detailed phase. Upon the completion of the detailed drawings, the designers will develop the construction drawings and the final specifications (Ko & Chung, 2014: 468). Hence, the final specification of the proposed project contains the details of the materials, the inspections, and the level of workmanship of the proposed project (Ko & Chung, 2014: 468).

2.3.4 The construction phase

After the completion of the construction drawings, the construction phase (CP) is the next aspect of the CDP. Soto (2007: 19) emphasizes that the CP of a project is the process of identifying all the activities and resources that are required to make a design a physical reality. That is, the implementation of the design envisioned by the architect and the engineers (Soto, 2007: 19). It is also a phase where the owner selects a suitable contractor so as to be assured of a successful project (Alarcon & Mardones, 1998: 2; Anderson *et al.*, 2006: 13). It should be noted that the contractor selection process varies as it depends on the type and nature of the project, as well as the environmental legislative constraints (Anderson *et al.*, 2006: 13).

2.3.5 The close-out phase

As stated in Chapter 1 of this thesis, the main purpose of this phase in the CDP is to hand over to the clients, and other construction stakeholders the final measurements, documentation and drawings (as-built drawings) of the newly executed project. Based on these explanations on CDP, Figure 2.1 indicates the flow of work in the CDP.

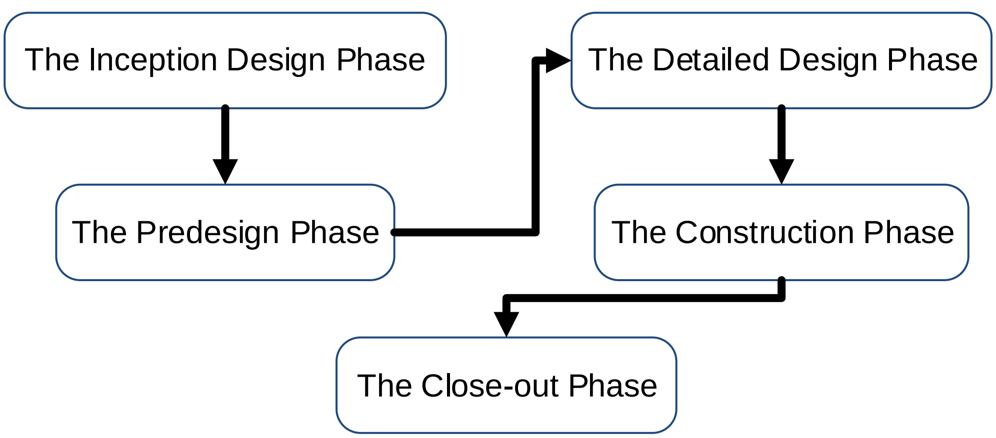

Figure 2.1: Flow chart of activities in construction design process

2.4 Requirements of the Structural Design Process

In order to capture the requirements of a client in every project, a holistic definition of a client is needed in this thesis. There are various definitions of what client is by different authors. Morledge (1987: 26) considers clients as primary and secondary developers, whilst Flanagan and Norman (1993: 145) classify clients as public and private 'bodies'. Similarly, Kamara *et al.* (2002: 1) emphasize that a client is considered as a 'body' that "incorporates the interests of a buyer of construction services, the prospective users and other group interests". A client may also be the owner, users and other identified persons, groups or organizations that influence, and are affected by, the acquisition, use, operation and demolition of the proposed facility (Lee & Egbu, 2005: 867). Latham (1994: 1) stresses that client requirements constitute the primary sources of information in the planning, the design and the construction phases of a project, and are therefore of vital importance to the successful planning and implementation of a project.

In a study conducted by Huovila and Seren (1998: 225), it was discovered that the structural design team (SDT) usually consists of a group of engineers that design and oversee the supervision of the building projects, so as to ensure that the projects are unyielding or stable when subjected to the intended loads. It can thus be concluded that the main objectives or requirements of the SDT in building projects is to identify the needs of the client, and to translate these needs into requirements, so as to be able to effectively manage all form of technicalities in the design, and the construction phases of a project (Huovila & Seren, 1998: 225).

2.5 Waste in the Construction Design Process

Based on literature, it can be debated that value has several meanings. For instance, Koskela (2000: 1) refers it to the fulfilment of customer requirements. While Garcia (2003: 105) viewed it as a relation established between subject and object. In a study conducted by Menger (2007: 18), it was further discovered that value is not inherent in goods, but certain importance that goods can acquire for the users. This implies that 'value is the importance that we first attribute to the satisfaction of our needs, and that we transfer to economic goods' (Feijo, 2001: 389). NVA activities in a process are the events that constitute waste, and can be classified into seven categories (Koskela 1999: 241; Womack & Jones, 2003: 82; Simms, 2007: 2; El-Kourd, 2009: 28; Abdelsalam *et al.*, 2010:

750). The seven categories have been briefly discussed in Chapter 1. For better understanding, the various classes of waste are discussed in detail in the following sections:

- **Transportation**

Transportation in the production process occurs due to the movement of people, paperwork, multiple hands-offs of electronic data, approvals, excessive email attachments and unnecessary distribution of the attachment copies (Shingo, 1985: 5; Ohno, 1988: 18; Simms, 2007: 3; Muda The 7 deadly wastes). Typical examples of this form of waste in the CDP are movement of the junior designer to the superior office for correction or approval of engineering drawings, paper trail of an engineering change order (ECO), the approval processes for new or changed products that often take longer than the engineering time itself, and distributing unnecessary copies of work to those that do not really need it (Alarcon, 1997: 365; Simms, 2007: 3; Bolviken *et al.*, 2014: 820). Simms (2007: 3) asserts that these activities in the CDP are often called transportation waste as they consistently stop the design process, and also increase the design time and delay the overall design cycle.

- **Defects**

This is another form of waste that is applicable to both the production and the engineering processes. In a study conducted by Li *et al.* (2008: 915), AbdelSalam *et al.* (2010: 749), Gatlin (2013: 1), Ko and Chung (2014: 463), it was discovered that defect or correction in the production process is to the performing of an activity or aspect of work by an employee more than once. Typical examples of defects or corrections in engineering designs are improper information on a drawing, missing views, and any error that is being returned for correction and clarifications after it has passed through the downstream (Simms, 2007: 2; Song *et al.*, 2008: 12; Hwang, 2009: 187).

- **Inventory**

Inventory is excessive or unnecessary high level of raw materials, work-in-progress and finished products in an organization (Koskela, 1992: 242; Womack & Jones, 2003: 83; AbdelSalam *et al.*, 2010: 751). Inventory is also the common result of multi-tasking or unbalanced workloads (AbdelSalam *et al.*, 2010: 752). Typical examples of inventories in engineering designs are drawings, models or information that are not yet needed by the designers but are developed or created, and stored in a hard drive for later use (Ohno, 1988: 45; Simms, 2007: 3). This means that if a designer completes a drawing before it is actually needed, the designer is adding to the work on ground, thereby incurring waste (Ohno, 1988: 45; Simms, 2007: 3; Muda The 7 deadly wastes). Ohno (1988: 45) opines that the time it takes for a manufacturer (designer in the case of the SDP) to design a work that is not yet needed, that same time could have been used for urgent work, which might enable the designer to reduce the workload at hand.

- **Waiting time**

Waiting time is any form of delay experience in processing an item or component (Shingo, 1985: 6; Ohno, 1988: 45; Koskela 1999: 242; Simms, 2007: 3; Bolviken *et al.,* 2014: 820). Such waiting time in production and engineering design may include waiting for parts, waiting for decisions or direction, waiting for data or information, waiting for recommendation, and waiting for the approval of work (Ohno, 1988: 45; Simms, 2007: 3; Forbes & Ahmed, 2011: 64).

- **Motion**

Motion is any unnecessary physical movement by construction actors during the progress of work (Womack & Jones, 2003: 82; Forbes & Ahmed, 2011: 64). Such movement may divert the attention of the actor(s) from the actual processing work (Womack & Jones, 2003: 82). Simms (2007: 4) argues that in engineering drawings, motion is a form of waste that can be equated with the efficiency of the software in use. Simms (2007: 4) further points that motion in engineering designs can be compared to the number of the clicks of a mouse button, or the number of routines it takes by a designer to complete an engineering drawing before taking it for an approval.

- **Over-processing**

Over-processing is working on one aspect of work more than required or utilizing resources more than necessary (Ohno, 1988: 18; Alarcon, 1997: 365; Womack & Jones, 2003: 83; Forbes & Ahmed, 2011: 65; Koskela, 2013: 7). Womack and Jones (2003: 83), Forbes and Ahmed (2011: 65), Koskela (2013: 7) and Bolviken *et al.* (2014: 821) emphasize that over-processing might only keep an actor busy during the production process but adds no value to the work and the output. Typical examples of over-processing in engineering drawings are writing comprehensive design specifications when a simple and less complex one would be adequate, and spending extra time more than necessary to carry out design analysis (El-Kourd, 2009: 29; Hickethier *et al.,* 2012: 1; Ko & Chung, 2014: 463).

Simms (2007: 4) declares that over-processing may also occur in engineering drawings when a designer rely on inspections, rather than to design the process to eliminate errors/mistakes. Further, Simms (2007: 4) emphasizes that over-processing is liable to emerge in a design or from the software in use by the designers. For instance, common among the designers is to come up with a design that is too complex to interpret on the site or to produce a complex design with a sophisticated software or equipment while a simple one would be sufficient for the same drawing (Simms, 2007: 4).

- **Overproduction**

In the engineering department, overproduction is the unnecessary documentation of engineering drawing (Ohno, 1988: 19; Simms, 2007: 3; El-Kourd, 2009: 29). Simms (2007: 4) argues that virtually all designers and draftsmen are habitually guilty of this waste in projects. This implies that in most projects, designers and draftsmen repeatedly design some aspects of work based on a routine schedule regardless of its demand, i.e. not necessary/needed. A typical example of this waste as observed by Simms (2007: 3) is making extra copies of drawings that are not needed by the designers or by the contractors, and printing paperwork that may eventually change before being needed.

In a study conducted by Sutherland and Bennett (2007: 27), it is notable that overproduction could be the worst waste among the classic wastes in product design, as it means resources were spent to manufacture unnecessary products, and therefore contributing to the other six classic earlier discussed waste. Contrary to the opinion of Stherland and Bennett (2007: 27), Koskela *et al.* (2013: 7) contend that overproduction is not a dominant waste in construction, rather making-do is prevalent in the process (2013: 7). Koskela (2004: 2) explains that making-do occurs when a task has been started before all the preconditions for such an activity have been met. Koskela (2004: 2) contends that making-do occurs to keep capacity busy, which has detrimental side-effects such as an increase in work in process, a need for rework, and creation of Health and safety hazards in projects. Therefore, making-do is the prevalent waste in construction.

2.6 Causes of Waste in the Construction Process

Overproduction is the primary source of waste in the mass production process (Ohno, 1988: 55). That is, a NVA activity that is responsible for most of the problems experienced in the production process (Ohno, 1988: 55). Similar to overproduction, Koskela (2004: 2) identifies making-do as waste that is responsible for most of the NVA activities in the CP of projects. Koskela (2004: 2) refers making-do as a waste that arises when a contractor starts a task before all preconditions are ready (lead waste).

In similar studies by Chang *et al.* (2007: 1), Oyedele and Tham (2007: 2090), Li *et al.* (2008: 915), Osmani, (2008: 1147), Song *et al.* (2008: 12), AbdelSalam *et al.* (2010: 749), and Ko and Chung (2014: 463), it was discovered that deficient projects have always been allotted to the clients due to design errors/mistakes and omissions. In another study by Hwang *et al.* (2009: 197), it was observed that design errors/mistakes and omissions are the root causes of rework and delay in the design and the construction phases of projects. Several other studies that include Andi and Minato (2003: 541), Nagapan, *et al.* (2012: 23), Halwatura and Ranasinghe (2013: 1), have identified design errors/mistakes and omissions as the main contributors of projects variations/modifications. Further, Hicketheir *et al.* (2012: 1) and Nagapan *et al.* (2012: 22) aver that complexities in design lead to iteration which can be value adding or wasteful. Hicketheir *et al.* (2012: 1) and Nagapan *et al.* (2012: 22) are of the view that the wasteful iterations known as rework are the main cause of delays and unnecessary waiting time in the design and the construction phases of projects.

Based on the findings in the literature, it can be concluded that making-do, design errors/mistakes and omissions are the main causes of waste in the design and the construction phases of projects. It can also be debated that design errors/mistakes and omissions are the fundamental causes of construction rework that often lead to unnecessary waiting time, project delays, and the consequent cost overrun. Therefore, while deliberating on the causes of waste in the design and the construction phases of projects, it is essential for all project actors to understand or put into cognizance the origin and the root causes, and impacts of design errors/mistakes and omissions, rework, and unnecessary delays that are responsible for other forms of waste. These are essential as adequate understanding of the root causes of the waste and their impacts on projects can assist designers and contractors to develop the strategies that can be adopted to curb or eliminate the occurrence of such waste (Simpeh, 2012: 84; Simpeh *et al.*, 2012: 1; Mryyian & Tzortzopoulos, 2013: 451; Najafabadi & Pimplikar, 2013: 80). Hence, the origin, the root causes, and the impacts of design errors/mistakes and omission, rework, and delays are considered in the following sections.

2.6.1 Causes of design errors/mistakes and omissions

A design is said to have been defected if it fails to meet the professional standards; was not prepared in accordance to the required or applicable building codes; if a designer fails to carry it out in accordance to the prepared plans and specifications, and if the design contains too many unclear or missing items of information (Li *et al.*, 2008: 915; AbdelSalam *et al.*, 2010: 749; Gatlin, 2013: 1; Ko & Chung, 2014: 463). In a study conducted by Ko and Chung (2014: 463) and Li *et al*. (2008: 915), it was observed that design error is a mistake in which the design element is over- or under-constructed due to wrong calculation, and needs to be replaced. While design omission is an aspect of work that is either missed or overlooked by the designer (Li *et al*., 2008: 915; Osmani, 2008: 1147; Gatlin, 2013: 1; Ko & Chung, 2014: 463).

Studies by Mohammad (2012: 22), Nagapan *et al* (2012: 22), Al-Hajj and Hamani (2011: 221), Wasfy (2010: 28), EL-Kourd (2009: 25), Nazech *et al* (2008: 19), and Osmani *et al* (2008: 1148) show that omissions and all forms of errors or mistakes in the design phase (DP) of a project occur due to lack of or poor design coordination and integration; poor interaction among the design and the construction teams; designers with little knowledge; lack of design standards, and lack of or poor design documentations.

2.6.2 Impacts of design errors/mistakes and omissions on projects

The problems of design errors/mistakes and omissions are not only widespread, but continue to get worse in spite of the negative influences they are having on the construction industry (Ndihokubwayo & Haupt, 2008: 127; Hwang, 2009: 187; Mryyian & Tzortzopoulos, 2013: 450). Gatlin (2013: 1) emphasizes that omission in a design may later be discovered by the designer before the CP, and may be added to the design. In such a scenario, the oversight might not actually constitute waste or negative impacts during site activities (Gatlin, 2013: 1). However, when the omission is not discovered before the CP, several iteration or negative impacts are likely to be experienced during site activities (Gatlin, 2013: 1; Ko & Chung, 2014: 463). Correlating with the views espouses by Gatlin (2013: 1) on design omissions, Ndihokubwayo and Haupt (2008: 127), Hwang *et al.* (2009: 187), Mryyian and Tzortzopoulos (2013: 450) contend that the negative impacts of design omissions, errors or mistakes might not only affect the CP of a project but also adversely influence the DP itself. Such negative impacts in the DP are poor quality, redesign, excessive changes, rework, and erratic decision making by the client and the designers (Sommerville, 2007: 391; Zoya Kpamma & Adjei-kumi, 2011: 102; Mryyian & Tzortzopoulos, 2013: 450).

Whilst in the CP, the negative impacts are suboptimal solutions, lack of constructability, unbalanced resource allocation, poor or inadequate communication among the construction specialists, excessive RFIs, unnecessary delay, mistakes, and rework (Chang *et al.,* 2007: 2; Li *et al.*, 2008: 915; Song *et al.*, 2008: 12; AbdelSalam *et al.*, 2010: 749; Ko & Chung, 2014: 463). Further, Sommerville (2007: 393), Ndihokubwayo and Haupt (2008: 127), Hwang *et al.* (2009: 196), Zoya Kpamma and Adjei-kumi (2011: 102), Hickethier *et al* (2012: 22), and Nagapan *et al* (2012: 22) establish that design mistakes/errors or omissions are the major factors that reduce the overall performance and efficiency of a project and as such, directly responsible for many projects that are being plagued with rework, excessive RFIs, variations, change orders, dispute, cost overrun and slow progress of projects.

This opinion is supported by Ndihokubwayo and Haupt's (2008: 127) point of view that design mistakes/errors or omissions have a significant impact on speed. That is, it prolongs the completion time of projects. In addition, Abdulrahman and Salim (2013: 1) reveal that errors that are not detected in the DP of a project are the main causes of building failures. Failures such as structural cracks and foundation problems that can lead to high cost of maintenance with the consequent low returns on investments have been identified in their study.

Based on the above discussions, the main impacts of design errors/mistakes or omissions on projects can be summarized as:

- Delay in the completion time of projects;
- Projects disputes;
- Propagate unwanted iterations known as reworks;
- Increase the overall costs of project;
- Inefficient and poor projects performance;
- Slow speed and progression of projects;
- Building failures such as cracks and foundation problems;
- High maintenance cost, and
- Low returns on building investment.

2.6.3 Causes of rework in construction

Rework is any activity that is required to be repeated due to inadequate or non-conformity with the specifications or standard at the time the activity was initially conducted (Zhang, 2009: 8; Hwang *et al.*, 2009: 187). McDonald (2013: 1) redefines rework as efforts carried out inform of corrections so as to conform an aspect of work or whole to the original requirements or specifications. Wasfy (2010: 28) opines that rework in projects is caused by factors that can be classified as either direct or indirect. The direct factors according to the author are incompetent or insufficient supervisors, poor workmanship, wrong materials specifications, deviation from the recommended standard, design errors and omissions. While the indirect factors are a selection of improper subcontractors, improper work protection, lack of coordination and improper work sequences. Going by the above definitions and explanations, it can be debated that rework occurs not only in the CP of a project, but also in the DP. To be precise, Table 2.1 shows some of the main causes of rework in the design and the construction phases of projects.

Table 2.1: Main causes of rework in construction

Causes	Description
Construction change	Changes in the methods of construction: usually to enhance constructability
Construction error	Results of erroneous construction methods
Construction omission	Omission of some construction activities or tasks
Design error	Error made during design
Design omission	Omission made during design
Design changes	Changes made in design at the request of construction professionals
Design changes/field	Changes made due to field conditions; a deviation could not have been seen by the designer
Design changes/owner	Design changes initiated by the owner (scope determination)
Design changes/process	Design changes in the process initiated by the owner and engineers
Design changes/fabrication	Design changes initiated or requested by fabricator or supplier
Design changes/improvement	Design changes due to revisions, modifications and necessary improvements
Design changes/unknown	Redesign due to errors

(Adapted from Burati *et al*., 1992 cited in Zhang, 2009: 10)

2.6.4 Effects of rework in construction

Common impacts of a rework in the design and the construction phases of a project are time wastage, schedule overrun, additional hiring of resources such as labors and plant workers, reduction in project scope and quality, reduction in project profits, loss of market shares, damage to reputation, low productivity, and higher costs (Wasfy, 2010: 29; Mastenbroek, 2010: 27). The above-stated impacts of rework on projects are in agreement with the findings of Al-Hajj and Hamani (2011: 223) regarding the impacts of rework in the design and the construction phases of a project. Al-Hajj and Hamani (2011: 223) accentuate that reworks are NVA activities that consume time and efforts in the design and the construction phases of projects, and as such, lead to loss of materials and delay in meeting the stipulated time for the execution of a task. The overall impacts of rework on projects are:

- Projects delay;
- Extra labour and construction materials, and
- Cost overrun.

2.6.5 Causes of delay in construction

A project is delayed if it is still under construction as at the time stipulated that completion period has elapsed (Sambasivan & Soon 2007: 517; Enshassi *et al.*, 2009: 126; Kaliba *et al.*, 2009: 522). Divya and Ramya (2015: 47) redefine project delay as the time overrun either beyond the completion date specified in a contract, or beyond the date that the parties involved agreed upon for delivery of the project. Divya and Ramya (2015: 47) contend that a project delay may be due to certain challenges that may come up in the design or in the construction phase of a project, and may even occur due to unexpected problems in the two phases. It is essential to know that delays in projects occur frequently in developing countries such as South Africa, Thailand, Pakistan, Saudi Arabia, Nigeria and Vietnam respectively (Toor & Ogunlana, 2008: 395; Pourrostam, *et al.*, 2011: 2189). This means that projects delay is one of the main challenges to construction industry in the above-mentioned developing countries (Enshassi *et al.*, 2009: 126). Succinctly put, Table 2.2 indicates the factors that are responsible for delay in the DP of a project specifically in the developing countries.

Table 2.2: Causes of delay in the design phase of projects

Design-related issues	Descriptions
Insufficient funding	Funds are not adequately released during the design phase of projects. It may be due to designer or client breach of contract agreement
Design interference	Top management staff of the designer's establishment may interfere in the design process because of vested interest. For instance, some scope could be introduced without due authorization. This happens mostly, if the management staff were instrumental in the appointment of the designer.
Wrong choice of designers	Clients select the designers and contractors as their vendors. If the selection process is faulty, unqualified designers will be engaged. This can lead to faulty design, frequent rework and delay in the design phase of projects
Slow decision making	Clients are the project owners. When they do not make decisions on time regarding project matters, they slow down activities in the design and the construction phases of project. The slow decision making may be due to wrong channels of communication
Design alterations or change orders	Change in specifications and scope which were not considered originally or changes of design to address some omissions that were vital to project functionality. Alterations may require temporary stoppages that delay overall project completion
Inappropriate design methods	Design activities are required to be carried out using best practices and techniques. When the appropriate procedures are not followed, errors occur, leading to rework and delays
Inadequate design planning	A faulty plan will lead to delay in design completion. Most local designers rarely have practicable work programmes in the initial stage of work. This lack impairs monitoring of design progress against the stipulated time

Inadequate experience	A designer who does not possess requisite experience usually makes design errors. These errors can lead to rework, and delays in the progress of activities
Mistakes	Inexperienced designers usually make errors during the progress of work. Sometimes designers employ low skilled staff (draft men) in order to make more profit by paying them lower salaries. Tendencies of errors are, thus, higher. Rework of an already designed aspect of a scope slows down work progress. This has serious impact if it involves design of critical tasks
Late identification and resolution of drawings and specification errors/omissions	Projects are required to be completed on schedule, within budget and according to specification. If designers do not identify errors and omissions in the construction drawings early enough, already completed activities may require alterations when construction supposed to have started
Late preparation of other design contract documents	Drawings and other contract documents such as Bill of Engineering Measurement and Evaluation (BEME) are required for a smooth execution of any project. Therefore, delay in their release can hinder the start of the construction activities
Over-inspection	Inspectors are required to track performance of a project through periodical monitoring. Too frequent inspection becomes a distraction to the designers, and hence could impede designers progress

(Adapted from Sunjka & Jacob, 2013: 644)

2.6.6 Impact of delays on projects

Project delay either in the design or in the CP will generally lead to three main effects, which are time overrun; budget (cost) overrun, and dispute or claims (Sunjka & Jacob, 2013: 649). In a study conducted by Divya and Ramya (2015: 49), it was discovered that delays due to late submission of drawings and specifications, frequent change orders, and inadequate site information are caused either by the designer or the client, and can lead to claims from both the main contractor and the subcontractor (Divya & Ramya, 2015: 50), while the delays triggered by the contractors can generally lead to the downfall of the actors (Divya & Ramya, 2015: 50). In summary, Sambasivan and Soon (2007: 518), Sunjka and Jacob (2013: 649), Divya and Ramya (2015: 49) establish the following as the main impacts of delays on projects: time overrun; cost overrun; dispute; arbitrations; total abandonment; litigation, and poor quality of work.

2.7 Summary

This chapter shows that the concerned waste types such as delay, design error or mistakes in the CDP may not only emanate from AP, but also from the SDP. This implies that waste such as design errors or mistakes that constitute rework and delay during construction activities also arise from the SDP. The chapter further indicates that design error/mistakes and omission are the main causes of problems such as excessive requests for information, rework and delay in the CP of projects. The chapter concludes that time overrun, cost overrun, projects dispute, arbitrations, total abandonment, litigation, inefficient/poor projects performance, high maintenance cost; building failures such as cracks and foundation problems, and low returns on building investment are the major impacts of design errors/mistakes and rework on projects.

Based on these observations, further insights are required on how lean concepts can be implemented in the SDP. The next chapter thus provide the framework that would allow the exploration of the ways in which the SDP can be made lean in construction.

3.0 THE CONCEPTUAL FRAMEWORK FOR WASTE MINIMIZATION IN THE DESIGN AND THE CONSTRUCTION PHASES OF PROJECTS

3.1 Introduction

This chapter discusses the theoretical perspectives compiled based on the need to eliminate waste in the SDP. The chapter also explains the conceptual framework, which illustrates the thinking behind the proposed ways of eradicating waste in the SDP.

3.2 Production Theories

The construction industry is susceptible to multiple waste such as overruns, delays, errors, and inefficiency or poor project performance (Al-Aomar, 2012: 106). Several advanced technologies such as Computer Aided Design (CAD) have been applied to construction so as to weed out the afore-mentioned waste in the process (Koushki *et al.*, 2005: 285; Sacks & Goldin, 2007: 374). However, the performance and efficiency of the industry has remained low (Koushki *et al.*, 2005: 285; Sacks & Goldin, 2007: 374). To provide the client with the lowest possible cost, and high quality project, the design and the construction actors have to devise both the new technology and contemporary management concepts to reduce the activities that do not add value to the projects (Li & Love, 1998: 187; Green, 1999: 133; Love *et al.*, 2000: 567; Chase *et al.*, 2006: 1). Among these strategies are the adoption of the constraints theory (CT), the business process reengineering (BPR), and the lean production philosophy (LPP) (Green, 1999: 133; Nave, 2002: 75; Forbes & Ahmed, 2014: 45).

The CT focuses on system improvement by concentrating on the process that slows down the speed of product in the system (Goldratt, 1993: 18; Nave, 2002: 75; Boyd & Gupta, 2004: 350). Through the CT, manager can adopts five basic steps to improve the process of an organization (Goldratt, 1993: 18; Nave, 2002: 75). These steps are to: identify the constraint; exploit the constraint; subordinate other processes to the constraint; elevate the constraint, and repeat the cycle (Goldratt, 1993: 18; Nave, 2002: 75). Literature shows that appropriate adoption of the CT in an organization process can result in increased output while decreasing both the inventory and the cycle time (Aggarwal, 1985: 8; Johnson, 1986: 22; Koziol, 1988: 44).

In spite of the benefits of the CT observed in the literature, it application in many organizations is limited due to the fact that the technique produces results that are feasible, but are not always optimal (Cook, 1994: 73; Chakravorty & Atwater, 1996: 91; Gupta *et al.,* 2002: 907; Lea & Min, 2003: 29; Watson *et al.*, 2006: 388).

The BPR is the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service and speed (Hammer & Champy, 1993: 32). According to Davenport (1993: 35), Simon (1994: 14), effective adoption of BPR with information technology (which is an enabler for BPR) in an organization process will lead to significant gains in speed, productivity, service, quality and innovation. Indeed, BPR has to some extent pointed out the way towards more effective approach to information technology (Betts & Wood-Harper, 1994: 551; Ibbs 1994: 27). However, literature shows that organizations cannot be fully satisfied with BPR as a foundation due to the fact that the concept lacks an explicit theory and it takes into consideration only a part of all process improvement/redesign principles and methods (Betts & Wood-Harper, 1994: 553; Ibbs 1994: 30). In a study conducted by Davenport and Short (1990: 11), Hammer (1990: 104), Sobek and Ward (1996: 9), and Prasad (1996: 478), it was discovered that several factors are responsible for BPR failure in organizations. Among these is lack of detailed guidance and support for its implementation (Davenport and Short, 1990: 12; Hammer, 1990: 105; Sobek and Ward, 1996: 9; Prasad, 1996: 479). Sobek and Ward (1996: 10) and Prasad (1996: 479) contend that one main reason for failure of BPR in organizations is the fact that the approach retains faith in information technology as a dominant support. Therefore, many organizations rarely adopt the concept in their practices.

The lean production philosophy also known as the Toyota production system has emerged since 1950s (Aziz & Hafez, 2013: 679). Its principles have been successfully implemented by Toyota Motor Company mainly for waste identification and reduction in practice. Initially, the theory had limited application in construction due to the perception that construction is completely different from manufacturing production (Forbes & Ahmed, 2014: 45). However, in the evolution of lean construction, Koskela in 1992 applied the concept to construction with a research work titled: '*Application of the New Production Philosophy to Construction'*. The production theory has developed into what is now known as the transformation-flow-value (TFV) (Koskela, 1992: 1). Since the discovery of this theory in 1992, the philosophy has been applied to remove and eliminate waste in projects with minor challenges. However, as at the time this study was conducted, the concept has not been adequately adopted in the design phase of projects. Therefore, this study seeks to investigate how the concept can be adopted for waste elimination in the design phase of a project specifically the SDP.

3.2.1 Lean concepts in the construction design process

It is important to understand how lean philosophy/thinking can be applied to projects environment so as to have insights of how it can be adopted to eliminate waste in the process (Ahmed & Forbes, 2011: 45). Lean thinking is a business methodology that aims to provide a new way to contemplate on how to organize human activities so as to deliver more benefits and value to the society/individuals while eliminating waste (Womack et al., 1990: 2). Hence, lean thinking can be viewed mainly in three perspectives to include lean production (LP), lean construction (LC), and lean design (LD). Each of these concepts is fully explained in the following sub-sections.

- **Lean production**

Womack *et al.* (1990: 2) originally define LP as means of requiring half of human effort in the factory, manufacturing space and engineering hours to develop a product within a short time. This infers that LP requires keeping far less than half the needed inventory on site that results in fewer defects, and produces a greater and ever growing variety of products (Womack *et al.*, 1990: 2). Womack and Jones (1996: 76) later improved on lean philosophy by proposing value, value stream, flow, pull and perfection as the five basic principles of LP (see section 2.7.4 of this thesis).

It is essential to know that the idea of LP originates from the Japanese manufacturing industry, and it entails a set of concepts and tools that assist in the identification and steady elimination of waste in a process (Krafcik, 1988: 41). As waste is eliminated, the quality of the process improves while production time and cost are reduced (Krafcik, 1988: 41). Typical examples of the LP tools and techniques for waste identification and reduction in a process are VSM, 5 Whys, Kanban (pull systems), A3 problem solving report, Kaizen, daily huddle meetings (DHMs), look-ahead schedule

(LAS), quality assurance (QA), total quality control (TQC), and just-in-time (JIT) (Koskela, 1997: 4; Holweg, 2007: 420; Liker & Michael, 2008: 3). Koskela (1997: 5) reveals that QA, TQC and Kanban have been implemented by a growing number of organizations. For instance, QA, TQC and Kanban were first adopted in material and component manufacturing, and later in the design and the construction phases of projects (Koskela, 1997: 5). Also, JIT concept has found a great application by component manufacturers, specifically in window fabrication and prefabricated housing (Koskela, 1997: 5).

- **Lean construction**

LP focuses attention on the removal of waste in a product or service (Koskela, 1992: 34). Ballard (2000: 22) improved on the theory to develop the last planner system (LPS) in construction. According to Ballard (2000: 22), LC presents a coherent synthesis of the most effective techniques for eliminating waste and delivering significant sustained improvement in cost, time, quality and safety. This indicates that LC can be viewed as a concept that adds value to a process by eliminating waste to create quality and responsive changes that will enhance the effectiveness of the workforce (Ballard, 2004: 67; Ballard & Howell, 2004: 119).

It is important to know that LC adopts the principles of LP to create a new way to manage construction projects (Womack & Jones, 2003: 87). This denotes that LC has the same goal as LP, which is to meet customer needs in a better way while using less of every available resources (Gleeson & Townend, 2007: 1; LCI, 2012: 1). Therefore, LC can be referred to as the application of LP principles and practices in the design and the construction phases of projects to maximize value and to reduce waste (Koskela, 1997: 4; Howell & Ballard, 1998: 1). From a research perspective, one of the typical examples of successful experience of the application of lean tools in projects can be observed in Brazilian construction industry (Conte & Gransberg, 2001: 1). Conte and Gransberg (2001: 1) implemented the five LP principles to over 20 construction companies in Brazil. The researchers concluded that application of lean thinking in construction will lead to waste reduction, and reduce the duration and the overall cost of projects. Similarly, Thomas *et al.* (2003: 144; 251) in their study proposed on how projects variability can be reduced so as to improve performance, and labour flow reliability for better productivity through the knowledge of the five lean principles and tools.

- **Lean design**

LD is the application of lean concepts to the DP of a system (Czap, 2013: 1; Stouffer 2013: 1; Ward 2009: 66). The system may be complex product or process (Czap, 2013: 1; Stouffer 2013: 1; Ward 2009: 66). It is a way of designing production systems to minimize waste of materials, time, and effort to create the maximum possible value (Czap, 2013: 1; Stouffer 2013: 1; Ward 2009: 66). Czap (2013: 1), Stouffer (2013: 1) and Ward (2009: 66) emphasize that one major goal of LD is to reduce waste and maximize value. Other goals are to improve the quality of the design and reduce the time to achieve the final solution. LD concept has been used in architecture, healthcare, product development, processes design, information technology systems, and even in modern businesses to create lean business models (Czap, 2013: 1; Stouffer 2013: 1; Ries 2011: 1; Ward 2009: 66).

LD application is used in the form of principles and methods for managing the processes and the development of the CDP (Jorgensen & Emmitt, 2009: 7). According to Czap (2013: 2) and Stouffer (2013: 2), conventional mass-production design focuses primarily on product functions and manufacturing costs; whereas LD systematically widens the design equations to include all factors that determine a product's success across its entire value stream and life-cycle. Study by Ward (2009: 66) reveals that the most important determinants of projects are supposed to be workflow reliability and labour flow, but LD has changed the traditional view of construction as transformation, and embraces the concept of flow and value generation.

It should be remembered that LD also shares the same objectives of LP and LC, e.g., cycle time reduction, elimination of waste, and variability reduction. To this end, continuous improvement, pull production control, and continuous flow have been the direction for the implementation of LD (Ries, 2011: 1; Ward, 2009: 67). This implies that LD is also using the same LP principles, and techniques that are originally developed by Womack *et al.* (1990: 2) to reduce waste, increase productivity and effectiveness in the DP of a project. These principles are succinctly described in the next sub-sections of this thesis.

3.2.2 Benefits of lean design

Generally, the outcomes of lean application are mainly waste elimination, cycle time reduction, redesigning of better working environment, modification or change in the sequence of processes, and quality improvement (Vidal, 2007: 247; Hasle *et al.*, 2012: 829; Wickramasinghe & Wickramasinghe, 2012: 157; Culliane *et al.*, 2013: 41). This denotes that lean can change working methods and working environments that may affect beliefs, values, and working practices of employees if properly adopted (Vidal, 2007: 247). Further, Hook *et al.* (2008: 20) studied the organizational culture of the industrialized housing industry and realized that after the depiction of lean principles and techniques to the work floor order and visibility, workers' attitude and cultures completely changed.

According to Hook *et al.* (2008: 20), the implementation of lean can result in employees learning redesigned processes that is more effective and in turn, positively impacted company's culture and job satisfaction. This implies that application of lean principles and techniques in the DP of a project can improve employees' job satisfaction in terms of behaviours and passions to learn new and improved processes that may leads to positive impacts. Therefore, lean techniques and principles may have the potential to transform the culture, thinking and the behaviours of structural designers to the one that is more proactively efficient, that can result into a higher level of job satisfaction in their organizations (Hook *et al.*, 2008: 20).

3.2.3 Strategic perspective of the five core lean principles and the design process

The five lean principles instigate by Womack and Jones (2003: 82) can be strategically applied to the three phases of the project design (initiation, core design, and finalization) to eliminate all sources of waste (Marzouk *et al.*, 2011: 50; Velarde *et al.*, 2009: 77). These are explained as follows:

- **Specifying value**

Lean thinking starts with a conscious attempt to precisely define value in terms of specific products with specific capabilities offered at specific prices through a dialogue with specific customers (Womack & Jones, 2003: 82). This means that the first lean principle predominantly deals with precise definition of value from the perspective of the end-customer (client) to proffer solution to the client problem by reducing the numbers of decisions need to be taken in the process of solving the problems (Barber & Tietje, 2008: 155). To convert value principle into practical action and integrate it into the first phase of design so that designers will be able to recognize values in practice, Emmit *et al.* (2005: 57) suggest a four-stage workshop procedure, as shown in Figure 2.1.

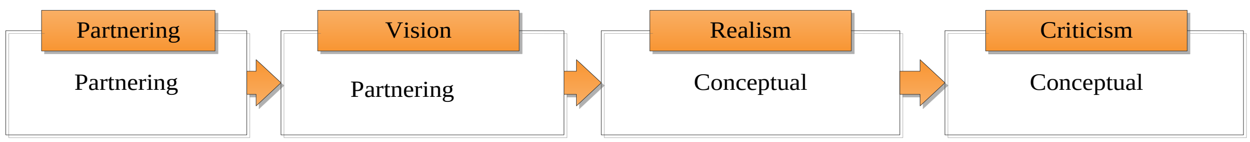

Figure 3.1: A four-stage workshop procedure for value identification in the initiation phase of project design (Emmit *et al.*, 2005: 57)

In each stage of the workshop (partnering, vision, realism and criticism), value and NVA activities in the initiation phase of a project can be identified by designers through adequate discussions and interactions with various project actors. However, Marzouk *et al.* (2011: 50) argue that attending this workshop for value identification takes time and therefore, suggest a model for more accurate value identification process that reduces the lengthy workshop procedures. According to Marzouk *et al.* (2011: 50), the model uses an operational block to represent an assumed or predicted time of the workshops, and identifies value and the required changes in the DP of a project based on the improvements expected if the workshop has actually taken place.

- **Identifying the value stream:**

Value stream is the second aspect of the five lean principles and it consists of all specific actions required to realize a product from the very first ideation to final market launch (National Research Council Canada (NRCC), 2004: 1). It is a set of all specific actions that are required to bring a specific product or service to a client (Womack & Jones, 2003: 82). Womack and Jones (2003: 82), Marzouk *et al.* (2011: 51) emphasize that the specific actions are three types and they occur simultaneously in the initiation phase of the design. These include steps that will be found to be clearly creating value; steps that will be found to create no value, but to be unavoidable due to the current technologies and production knowledge and lastly, some additional steps that will be found to create no value, and can be immediately avoided.

Marzouk *et al.* (2011: 52) recommend that once all the activities in a system have been classified according to the above-listed three classes, the next action is to remove the NVA activities and reduce the value supporting through the application of flow, pull and perfection techniques that are to be subsequently discussed in this thesis.

- **Achieve Flow**

Womack and Jones (2003: 82) emphasize that after the NVA activities that hinder the effective delivery of values to the client have been removed in the stream, the remaining value adding activities are treated to make the system flow freely without any interruption. This means that the achieving flow principle enables an organization to work continuously on every aspect of work such as the design, order and production without any unnecessary waiting, downtime or waste within or between the steps of value creation (Belfrage & Hedberg, 2006: 1). Practical application of this principle in the design process can be realized in the area of information and data handling activities (Belfrage & Hedberg, 2006: 1). This means that the achieving flow principle can be applied to reduce or minimize the duplication of information, and the volume of out-of-date or unnecessary data within and across the various departments during the design process in an organization (Belfrage & Hedberg, 2006: 1).

Hicks (2007: 233) identifies several barriers to data and information flow that influence design processes. Application of the achieving flow principle to remove these barriers by producing a details and clearer map of the design process will enable values to be delivered to the client, and consequently leads to smoother and faster flow of the system (Marzouk *et al.*, 2011: 52).

- **Apply Pull**

The ‘applying pull’ concept means that no activity should produce a good or service until the next customer downstream asks for it (Womack & Jones, 2003: 83). Production of item or goods without immediate demand leads to unnecessary spending to store those items or goods pending when orders will be placed on them (Womack & Jones, 2003: 83). Therefore, the 'applying pull' principle can be applied during the design process by the designers to ensure that the whole design schedule process are executed as programmed without the need for any unnecessary stocks or inventory of information (Marzouk *et al.*, 2011: 52; Velarde *et al.*, 2009: 77).

- **Achieve Perfection**

According to Womack and Jones (2003: 84), achieving perfection in a system requires an organization to accurately specify value, identify the entire value stream, make the value flow continuously, and let customers and clients pull the exact value they need only when they need it. This means that the four initial principles (specifying value, identifying value stream, achieving flow, and applying pull) interact with each other continuously in a cycle so as to enable value to flow faster always by revealing hidden waste in the value stream (Womack & Jones, 2003: 84). This means that to attain perfection in a system, i.e. reduce efforts, time, space, cost, mistakes and all sources of waste in a system so as to give the client the best value for money, is an endless or continuous process or exercise (Marzouk *et al.*, 2011: 53).

Based on the above literature, it can be concluded that to make a design process lean is not a change that can be implemented and expected perfection to be attained immediately. It is rather continuous efforts on the process that will exclude waste of any form completely (Marzouk *et al.*, 2011: 53). Similarly, Womack and Jones (2003: 89) argue that the most important drive to perfection is transparency. That is, if lean principles are to be effectively adopted in a design firm, the design process or every activity in the firm should be clear to everyone. Womack and Jones (2003: 89) are of the view that this will make it easy to discover better ways to create values. This implies that the fifth lean principle in the design process can be attained by continuously applying and reapplying the first four lean principles, while keeping an open eye for new opportunities that can help to take further steps towards becoming lean for continuous improvement (Velarde *et al.*, 2009: 79; Marzouk *et al.*, 2011: 52).

3.2.4 Improving the design phase of projects: The conceptual perspective

In order to have clear knowledge of how lean production theory can be adopted for improvement in the design phase of projects, it is essential to first understand how the philosophy is being used for performance improvements in the manufacturing industry. A typical example of this is the Toyota's Production System (TPS) or the Toyota's Way (TW) (Forbes & Ahmed, 2014: 45). The TPS represents an important foundation of lean construction and has emerged since 1960s (Forbes & Ahmed, 2014: 50). The TPS uses four elements specifically the just-in-time (JIT) and the creative thinking to provide outstanding levels of production, high quality, and low costs (Forbes & Ahmed, 2014: 50). Table 3.1 provides the summary of the four basic aspects of TPS and how lean thinking is being applicable to each aspect.

Table 3.1: A representation of lean thinking in Toyota Way

Toyota Foundations	**Principles**
Problem solving (continuous improvement and learning)	Continual organizational learning; View the situation first hand to thoroughly understand it; Make decisions slowly by consensus (consider all options and Implement rapidly)
People and partners (respect, challenge, and grow them)	Grow leaders who live the philosophy respect, develop, and challenge people and teams; Respect, challenge and help suppliers
Process (eliminate waste)	Create process 'flow' to reveal problems; Use pull system to avoid overproduction; Level out workload; Stop when there is a quality problem; Standardize tasks for continuous improvement; Use visual control (transparency); Use only reliable and tested technology
Philosophy (long-term thinking)	Base management decisions on a long-term philosophy, even at the expense of short-term financial goals

(Forbes & Ahmed, 2014: 50)

In the four basic aspects of TPS concise in Table 3.1, the process (waste elimination) is the most applicable to the construction design process (CDP) (Forbes & Ahmed, 2014: 50). The various process waste that are being eliminated in TW which are also applicable to the CDP are defects or corrections, overproduction, over-processing, transportation, inventory, motion, and waiting time (delay) (these waste and their causes have been elucidated in Chapter 2, section 2.5 of this report). Researchers worldwide have investigated how the above-stated waste can be eliminated in the CDP through the application of different lean tools such as A3 problem-solving report, VSM, 5 Whys, Kamban, and Kaizen (Huovila *et al.*, 1997: 143; Nave, 2002: 73; Schlueter & Thesseling, 2008: 153; Sacks & Barak, 2008: 439; Osmani, 2011: 207; Marzouk *et al*., 2011: 43; Forbes & Ahmed, 2011: 203; Ko & Chung, 2014: 463). However, the findings in the reviewed literature indicate that attention is focused mainly on the CP of projects. The design phase has not been broadly covered. This denotes that as at the time this research was conducted, none of the above-listed tools has been adequately adopted for waste identification and reduction in the structural design phase of projects.

Nave (2002: 73) observes that researchers often find it difficult to decide on the tool to adopt for waste reduction in the CDP. To overcome this dilemma, Nave (2002: 73) points that researchers need to compare the strengths and weaknesses of the various tools. Nave (2002: 73) is of the view that the tool with the less weakness and of more benefits in terms of waste identification and reduction over others should be considered (2002: 73). The strengths and the weaknesses of the common lean tools highlighted above are briefly explained as follows:

- **Kanban**

Kanban is one of the lean tools that is mainly designed to reduce idle time in a production process (Ohno, 1988: 29). It was originally invented as a part of the famous TPS (Ohno, 1988: 29). The main idea behind Kanban in the production system is to deliver what the process needs at exactly when it is needed through the concept of JIT (Shingo, 1989: 30; Drickhamer, 2005: 24). In a study conducted by Chuck (2013: 1), it was discovered that Kanban also means to visualize the workflow in a process. In another words, Kanban means to split activities into pieces, write each item on a card and placed the card on the wall, and use named columns to illustrate where each item is in the workflow (Ohno, 1988: 29; Shingo, 1989: 30; Vernyi & Vinas, 2005: 1; Drickhamer, 2005: 25).

One main benefit of Kanban is to establish an upper limit to the work in process, which consequently avoid the overloading of the manufacturing system (Ohno, 1988: 29; Chuck, 2013: 1). Therefore, processes are streamlined and problems resolved quickly (Ohno, 1988: 29; Shingo, 1989: 30). Another benefit of Kanban in the product design is that all production personnel can see exactly how many customer orders have been placed, and when all orders have been filled (Krafcik, 1988: 41; Drickhamer, 2005: 25; Holweg, 2007: 420). Consequently, materials are always available to meet facilities production demands (Krafcik, 1988: 41; Drickhamer, 2005: 25; Holweg, 2007: 420).

One of the limitations (weaknesses) of Kanban in the manufacturing process is that it can cause a potential loss of sale where the supply response is not quick enough to meet the actual demand fluctuations (Chuck, 2013: 1). Also, for Kanban to be effective, the applied system has to be strictly monitored otherwise, the aim in which it is designed will not be achieved (Ohno 1988: 30). In addition, Kanban is designed to only see the activities that are in the workflow (Ohno 1988: 30). Therefore, it may be difficult for an observer to realize the root cause of problem in a process in which Kanban is applied (Ohno 1988: 30; Drickhamer, 2005: 25; Chuck, 2013: 1).

- **The A3 problem solving-report**

The A3 problem-solving report is a tool that Toyota Motor Corporation uses to propose solutions to problems, give status reports on ongoing projects, and report results of information gathering activity (Sobek & Smalley, 2008: 2; Shook, 2009: 30; Anderson *et al.*, 2011: 275). According to Spear and Bowen (1999: 97), the TPS uses A3 problem-solving report to systematically guide problem-solvers through a rigorous process, document the key outcomes of that process, and propose for improvements. The overall phases in A3 problem-solving report can be summarized as the proposal stage, the problem solving phase, the status reporting and the competitive analysis processes (Spear & Bowen, 1999: 97; Jimmerson *et al.*, 2005: 249; Liker & Morgan, 2006: 27; Ghosh & Sobek, 2006: 1; Sobek & Smalley, 2008: 3; Shook, 2009: 30; Kimsey, 2010: 53).

One of the benefits of A3 problem-solving report is that it fosters deep learning, engaging collaboration, and thoroughness (Sobek & Smalley, 2008: 1). The A3 problem-solving report also has a good visualization method (Lindlof *et al.,* 2012: 1). This implies that the tool enables a process to be transparent and comprehensible in a manner that creates adequate thinking and learning (Jimmerson *et al.*, 2005: 251; Ghosh & Sobek, 2006: 3; Sobek & Smalley, 2008: 3; Shook, 2009: 30). In addition, A3 problem-solving report does not require long hours of specialized training (Hoppmann, 2009: 3; Liker & Morgan, 2006: 7; Sobek & Smalley, 2008: 3).

One of the limitations or weaknesses of A3 problem-solving report is that any form of interruptions in the process will result into a long turn-around time (Hoppmann, 2009: 3). Consequently, rather than to save time in a process, the tool may end up creating unnecessary delay (Jimmerson *et al.*, 2005: 255; Ghosh & Sobek, 2006: 1; Sobek & Smalley, 2008: 3; Shook, 2009: 30; Hoppmann, 2009: 3). Further, the Lean literature shows that A3 problem-solving efforts fail in implementation due to the fact that users of the tool often find it difficult to sufficiently understand the current condition of the process, and the root cause of problems in a system in which it is applied (Jimmerson *et al.*, 2005: 257; Liker & Morgan, 2006: 19). Therefore, for the device to be effective, other tool such as 5 Whys has to be incorporated into the system (Jimmerson *et al.*, 2005: 255; Liker & Morgan, 2006: 20; Sobek & Smalley, 2008: 3).

- **The five Whys**

The 5 Whys is a lean tool that is used to identify the root cause of a problem by asking “why” five times (Sproull, 2001: 1). It is a method of root cause analysis which requires investigators to question how the sequential causes of a failure event arose and identify the cause-effect failure path (Murugaiah *et al.*, 2009: 527). Fantoni *et al.* (2006: 26) emphasize that 5 Whys is commonly used at the first stage in the design process for design requirements and customer value identifications.

One main benefit of 5 Whys is that it can be adopted easily by the investigators (Sproull, 2001: 1; Fantoni *et al.*, 2006: 28). This implies that the apparent simplicity of the 5-Whys makes people to frequently use it (Sproull, 2001: 1; Fantoni *et al.*, 2006: 28). However, its simplicity hides the intricacy in the methodology and people can unwittingly apply it wrongly (Sproull, 2001: 1; Fantoni *et al.*, 2006: 28). Another limitation or weakness of 5 Whys is that it is easy to ignorantly arrive at the wrong conclusion (Sproull, 2001: 2; Fantoni *et al.*, 2006: 29). For instance, a Why question can be answered with multiple answers, and unless there is evidence that indicates the answer is right, an investigator may likely have the wrong failure path in it use (Sproull, 2001: 2; Fantoni *et al.*, 2006: 29).

- **Kaizen**

Kaizen is a Japanese business philosophy that is focused on making constant improvements in manufacturing process (Farris *et al.*, 2009: 91; Ikuma *et al.*, 2011: 551; Nahmens *et al.*, 2012: 91). It is based on the fact that there will always be rooms for improvement in a process (Farris *et al.*, 2009: 91; Ikuma *et al.*, 2011: 551; Nahmens *et al.*, 2012: 91). To be precise, Kaizen aims to improve all activities and processes, and eliminate waste and excess (Nahmens *et al.*, 2012: 91; Ikuma *et al.*, 2011: 551; Farris *et al.*, 2009: 91).

One of the benefits of Kaizen is that it can be implemented in many ways, either as an individual, or with a small-team approach, in a boardroom, almost anywhere at any time (Cheser, 1994: 23; Cane, 1996: 1; Yamada, 2000; 6). In addition, any manufacturing operation can benefit from Kaizen as long as there is a commitment from management toward total involvement in basic Kaizen tenets (Cheser, 1994: 23; Cane, 1996: 1; Yamada, 2000; 6). Also, Kaizen is largely self-motivated as it is driven by individual input and execution. However, this benefit of Kaizen may be of disadvantage to certain extent as it can make a company results or outcomes to vary (Cheser, 1994: 23; Cane, 1996: 1; Yamada, 2000; 6).

Another weakness of Kaizen is that improvements can only be made when people are willing and ready to make suggestions otherwise, the aim of Kaizen in a process will be completely defeated (Cheser, 1994: 24; Yamada, 2000; 6; Farris *et al.,* 2009: 91). In addition, Kaizen is not a "one time" event, but one that must be maintained and encouraged for years before improvements can be achieved (a long time process) (Cheser, 1994: 25; Barnes, 1996: 1). This indicates that true transformation can only occur in Kaizen with steady or continuous maintenance (Cheser, 1994: 25; Barnes, 1996: 1). Therefore, it takes dedication, commitment, and an underlying understanding to implement Kaizen properly in any organization (Cheser, 1994: 25; Barnes, 1996: 1).

- **Value stream mapping**

VSM is a commonly used tool in lean applications. It is a simple process of directly observing the flow of information, material and visually summarizing them as they occur (Mossman, 2009: 13; Rother & Shook, 1998: 4; Nielsen, 2008: 1). Rother and Shook (1998: 4), Mossman (2009: 13), and Nielsen (2008: 1) opine that VSM is a paper-and-pen tool that enables diagrams of a complete process to be drawn with a set of standardized icons. According to these authors, it is easier to analyse and identify any weakness or waste and its source(s) in a system with this map. This means that VSM could be applied to the DP of a project so as to enable a designer or engineer to clearly see any hidden waste and the sources of the waste (Mossman, 2009: 13; Rother & Shook, 1998: 4; Nielsen, 2008: 1). Once these are identified, changes can be proposed, implemented and evaluated for continuous improvements (Mossman, 2009: 13; Rother & Shook, 1998: 4; Nielsen, 2008: 1).

VSM can be used to provide visibility in a system so that companies can choose improvement activities to achieve the maximum benefit (Rich & Hines, 1997: 210). It is a special type of flow chart that uses symbols known as 'language of Lean' to depict and improve the flow of inventory and information (Rother & Shook, 2009: 9). Rother & Shook (2009: 9) further emphasize that VSM is much more useful as a tool, and layout diagrams that produces a tally of non-values adding steps, lead time, distance travelled, and the amount of inventory in a process. This denotes that VSM describes in details how organization activities and facilities should flow or operate so as to create opportunities or space for future improvements (Tapping & Shuker, 2003: 1; Rother & Shook, 2009: 11).

VSM is the only lean tool that shows the linkage between information flow and material flow in organizations process or activities (Rother & Shook, 1998: 4). VSM is used to identify overproduction, waiting, transportation, inappropriate processing, unnecessary inventory, unnecessary movement, and defects in a process (Rother & Shook, 1998: 4; Nielsen, 2008: 1; Belova, 2008: 29; Mossman, 2009: 13). Rother & Shook (1998: 4), Nielsen (2008: 1), and Mossman (2009: 13) add that VSM can also be used to identify the root causes of the above-listed wastes in a process by setting the scope of the process; identify the current state of the chosen process; draw a future, and the desired state, and finally make a work plan to ensure implementation of the identified improvement areas. This implies that VSM can be adopted to identify and reduce the seven forms of waste and their causes in the SDP.

According to Rother and Shook (1999: 11), one main problem of VSM is the inability of an investigator to adequately understand how it future state should appear when applied to a process. This makes perfection in VSM system to be solely depends on the skill of the user. Based on this dilemma, Rother and Shook (1999: 11) suggest that a VSM team should be led by someone that can see across the boundaries over which a product's value stream flows and make change happen in the boundaries. To be precise, Table 3.2 provides the summary of the benefits and the limitations or weaknesses of the five lean tools discussed above.

Table 3.2: Benefits and limitations of some of the applicable lean tools in product design

Lean tools	Benefits	Limitations/weaknesses
Kanban	Kanban enables a process to be streamlined which enables a problem in the system to be resolved quickly. It also allows materials to always be available to meet production demands	On several occasions, Kanban can cause a potential loss of sale. Also, Kanban can only be effective if it is adequately monitored in a system, and may be difficult for an observer to realize the root cause of a problem in a process where it is applied.
The A3 problem-solving report	A3 problem-solving report enables a process to be transparent and comprehensible in a manner that creates adequate thinking and learning. Also, the tool does not require long hours of specialized training	Any form of interruptions in A3 process can create unnecessary delay in a system. Also, A3 problem-solving efforts often fail in implementation in a process.

The 5 Whys	It is simple to use and can be adopted easily by the investigators without the need for any form of training	It simplicity can make investigators to wrongly apply it in a system, and ignorantly arrive at the wrong conclusion in the system.
Kaizen	Kaizen is a lean tool that can be implemented in many ways. It is largely self-motivated as it is driven by individual input and execution	One main weakness of Kaizen is that it can only bring improvement in a system when people are willing and ready to make suggestions.
VSM	VSM is the only lean tool that can be used to identify overproduction, waiting, transportation, inappropriate processing, unnecessary inventory, unnecessary movement, and defects in a process. Therefore, it is the only lean tool that can be used to identify the root causes of the seven forms of waste in a process/product design	VSM cannot be used to adequately understand how the future state of a process in which it is applied should look like. Hence, perfection in adoption of VSM in a system solely depends on the skill of the user.

(Ohno, 1988: 29; Krafcik, 1988: 41; Shingo, 1989: 30; Cheser, 1994: 23; Cane, 1996: 1; Barnes, 1996: 1; Rother & Shook, 1998: 4; 1999: 11; Yamada, 2000; 6; Sproull, 2001: 1; Drickhamer, 2005: 25; Jimmerson *et al.*, 2005: 255; Liker & Morgan, 2006: 19; Fantoni *et al.*, 2006: 28; Ghosh & Sobek, 2006: 1; Holweg, 2007: 420; Sobek & Smalley, 2008: 3; Nielsen, 2008: 1; Belova, 2008: 29; Shook, 2009: 30; Hoppmann, 2009: 3; Mossman, 2009: 13; Chuck, 2013: 1)

3.2.5 Justification for the adoption of value stream mapping tool in this study

The reviewed literature indicates that VSM has greater benefits over many other lean tools as it can be used to analyse virtually all the seven forms of waste in a process (Rother & Shook, 1998: 4; Nielsen, 2008: 1; Belova, 2008: 29; Mossman, 2009: 13). VSM also enables an investigator to clearly see any hidden problem and the sources of the problem in a system (Mossman, 2009: 13; Rother & Shook, 1998: 4; Nielsen, 2008: 1). Based on these benefits of VSM over other lean tools considered in this study, the researcher viewed that the tool might be suitable or less challenging for waste identification and reduction in the SDP.

Further, Rother and Shook (2009: 18) observes that VSM can be adopted by researchers to clearly understand the current flow of work in an organization, map out areas that require improvements, and plans on how the areas can be improved (2009: 18). Based on the observations of Rother and Shook (2009: 11) on VSM, attempts have not been made by researchers to investigate how the tool can be adopted for waste reduction in the field of the structural design practice. Ko and Chung (2014: 472) have adopted the device to investigate how a framework can be developed for waste identification and reduction in the CDP specifically; the AP. Ko and Chung (2014: 472) conclude that VSM is a suitable tool for waste identification and reduction in the CDP. Premised on all these explanation, a lean tool known as VSM is adopted in this study.

3.3 The Conceptual Framework

A conceptual framework is the current version of the researcher's map of the phenomenon under investigation (Milles & Huberman, 1984: 33). It provides a theoretical overview of a researcher proposed study and order within the research process (Weaver-Hart, 1988). Jabareen (2008: 197) contends that the main functions or objectives of a conceptual framework is to help a researcher refine the research goals, develop a realistic or relevant research problem and questions, select appropriate methods, and identify the prospective validity threats that may come up in the conclusion section of the research. Robson (2011: 86) adds that a good research conceptual framework is expected to be constructed, and not found.

Based on the opinions of the above-mentioned researchers on conceptual framework, Melton (2005: 667) developed a lean framework for waste identification and reduction in projects (Figure 3.1).

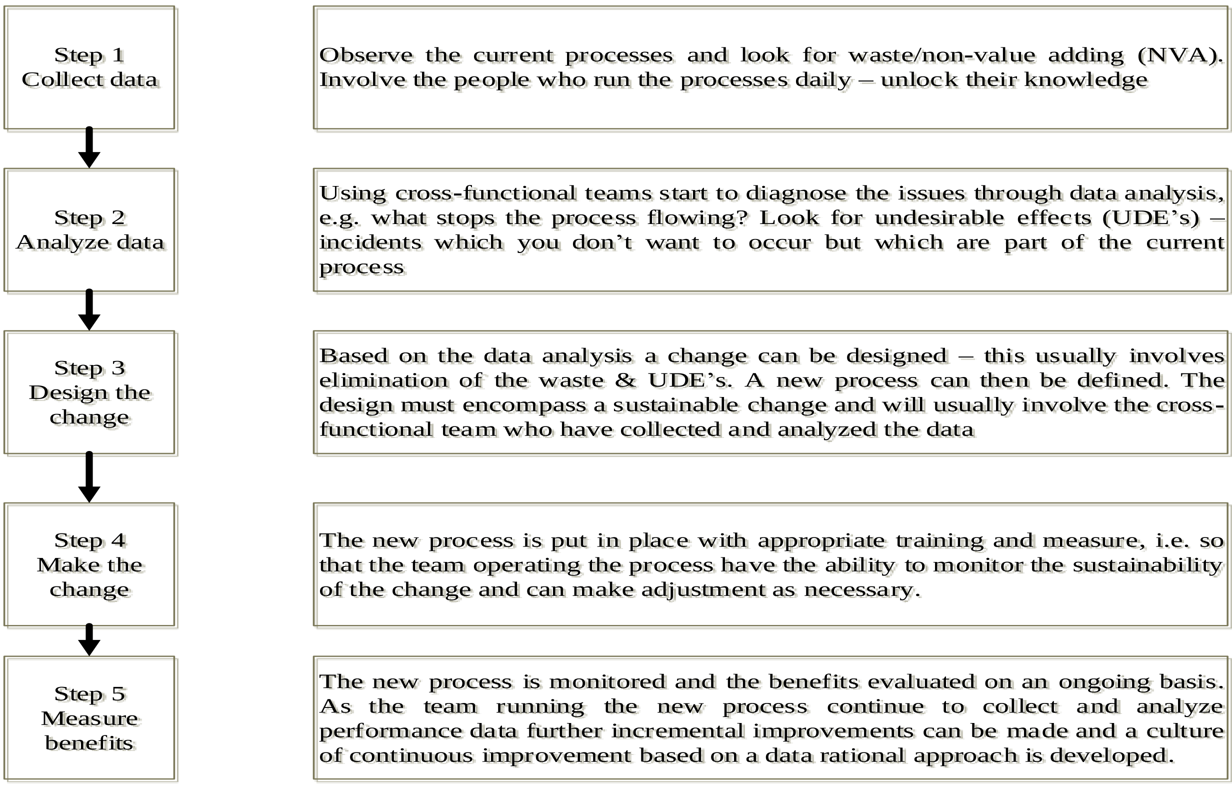

Figure 3.2: A Lean concept for waste identification and reduction in projects (Source: Melton, 2005: 667)

According to Melton (2005: 667), the procedures for waste identification and reduction in the conceptual framework can be summarized as:

- Document the current process performance;
- Define value and then eliminate waste;
- Identify undesirable effects and determine their root cause in order to find the real problem;
- Solve the problem and re-design the process, and
- Test and demonstrate that value is now flowing to the customer of that process.

In a similar study by Rother and Shook (2009: 18), a framework for waste identification and reduction in a process was developed. Rother and Shook (2009: 18) developed the framework through the application of a VSM tool (Figure 3.2).

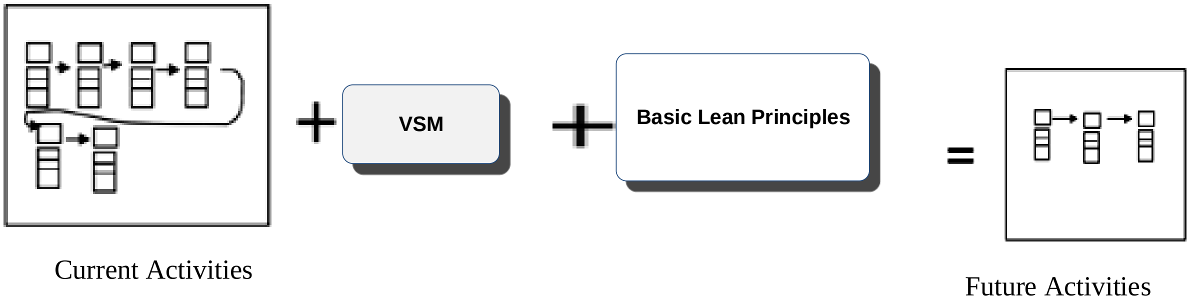

Figure 3.3: A value stream mapping framework for waste identification in an organization process (Adapted from Rother & Shook, 2009: 18)

In the conceptual framework, Rother & Shook (2009: 18) content that VSM can be adopted by an organization manager to clearly understand the current flow of activities, and map out areas that require improvements. Thereafter, plan on how some of the basic lean principles can be used to reduce the NVA activities in the system. Based on the opinions of Rother and Shook (2009: 18), attempts have not been made by researchers to investigate how VSM tool can be adopted for waste identification and reduction in the field of structural design practice. Nevertheless, Ko and Chung (2014: 472) have adopted the concept to investigate how a framework can be developed for waste identification and reduction in the AP. Based on the opinions of Melton (2005: 667), Rother and Shook (2009: 18) on frameworks for waste reduction in projects, a conceptual framework for proper SDP in this study is hereby present in Figure 3.3.

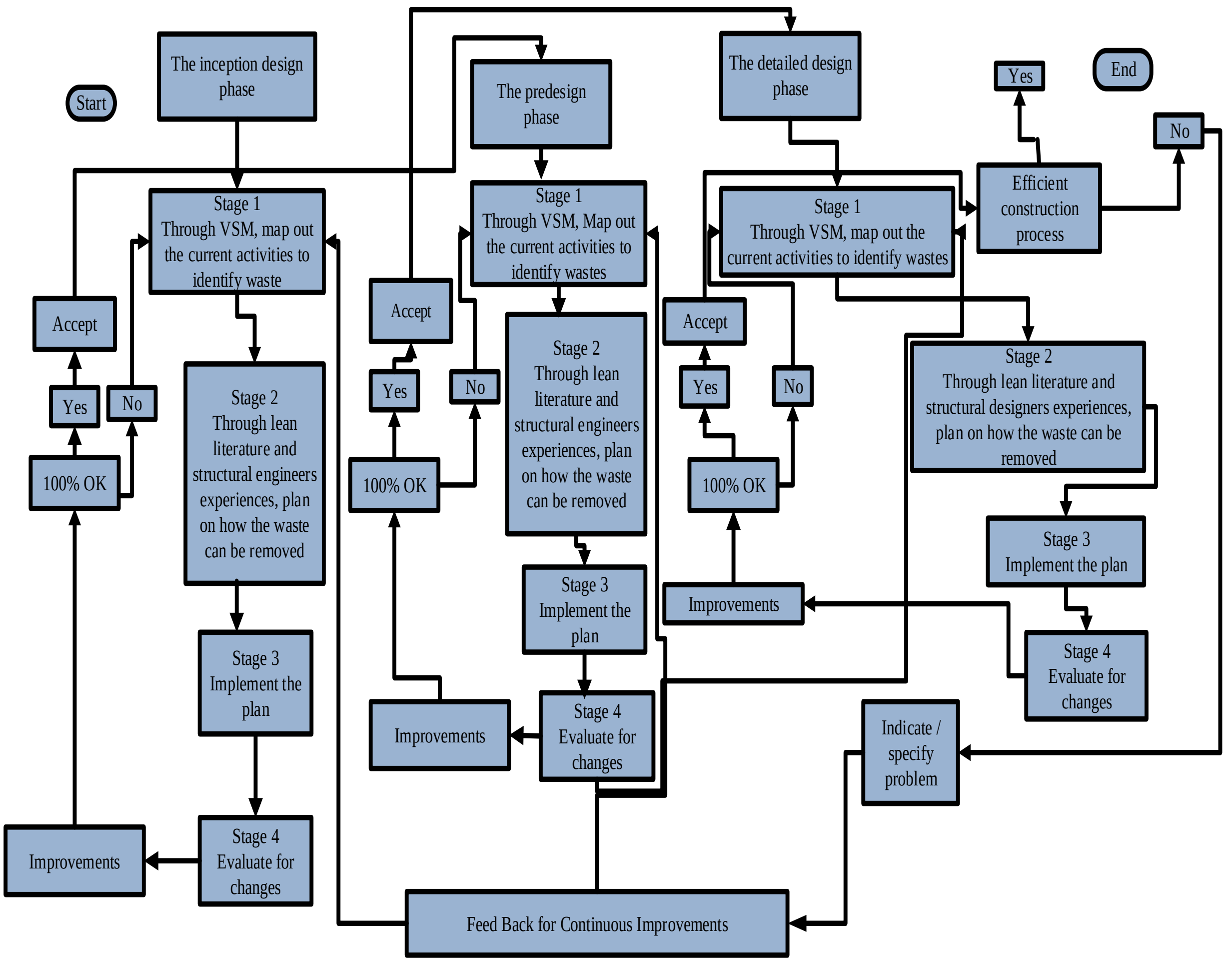

Figure 3.4: A conceptual framework for proper structural design process in this study (Author, 2016)

3.3.1 Operational perspective of the study conceptual framework

The first stage in the conceptual framework present in Figure 3.3 in this study is to establish the various waste and their causes in each phase of the SDP. This can be achieved through collaborative efforts of a group of structural engineers, and application of VSM tool (mapping). The second stage is to come up with the basic lean principles and certain strategies that can be adopted to reduce or eliminate the identified waste in the practice (planning). The third stage is to effect the strategies and the basic lean principles in the system by the researcher and the structural engineers (implementation). After the implementation exercise, the next stage is to evaluate the process so as to observe if the new plans adopted have brought any substantial improvement in each phase of the SDP (evaluation). This implies that with notable improvements in the first phase of the SDP (IDP) after the adoption of the new strategies and some lean principles, the engineers are to move to the next phase (PDP) and repeat the exercise (mapping, planning, implementation and evaluation (MPIE)), and subsequently, to the last phase (DDP).

However, if the outcome in the IDP is not satisfactory after the evaluation process, the overall procedures (MPIE) will be repeated by the engineers until adequate improvements have been achieved. Based on these improvements, the engineers can then, proceed to the next phase, and afterward, to the last phase.

3.4 Summary

In all the four production theories reviewed in this study (CT, BPR and LPP), this chapter concludes that lean concept is most suitable for waste identification and reduction in the CDP. This denotes that this study is anchored on a lean concept. In another words, the chapter suggests that the discovered waste in the CDP can be reduced through the application of lean philosophy. From the lean concept, VSM is a waste identification and elimination tool that has been advocated. This is due to some of it benefits over other lean tools reviewed in this study. Based on this conclusion, this study shall proceed to Chapter 4 so as to understand the philosophy that underpins the study and to investigate how data can be collected in the study context through the experiences of groups of structural engineers and the VSM tool.

4.0 RESEARCH METHODOLOGY

4.1 Introduction

The aim of this research has been stated in Chapter 1 of this thesis. To achieve this aim, a research problem was developed, and questions and objectives were framed. To address the study problem through the set questions and objectives, the research needed to be located within an appropriate philosophical stance (Gill & Johnson, 2002: 1; Gray, 2014: 5). Therefore, the purpose of this chapter is to provide justifications for the philosophy that underpins this study. The chapter also aims to provide insights on the instruments, as well as the procedures that were adopted by the researcher to obtain the necessary data in the course of the study. To be precise, the chapter provides justification for the methodological components of this study. Different researchers have adopted different taxonomies to define and present the various components in a research methodology (refer to Saunder *et al.*, 2009; Blaikie, 2010; Gray, 2014). To maintain consistency in the course of this study, this research adopts the taxonomy, as well as the onion layers model utilized by Saunders *et al.* (2009: 106).

Saunders *et al.* (2009: 106) in their study express that there are important layers of the onion that need to be peeled away. The first two of the onion's layers are the research philosophy and approach. The third, fourth and the fifth layers are the research strategy, choices or methods and the time horizons. While the sixth and the seventh layers of the onion are the procedures for data collection (techniques), as well as the analysis processes. With the exception of the time horizon that was briefly discussed due to the research questions of this study, other layers that form the methodological chapter of this report are extensively elucidated in the following headings.

4.2 Research Philosophy

A research philosophy is a belief or conviction on how data on a particular phenomenon is gathered, analysed and used (Denzin & Lincoln, 2011: 12). It entails the procedures and certain assumptions made by a researcher in the course of a study to arrive at conclusive findings (Collins, 2010: 36). To select an appropriate philosophy for any research, a researcher needs to take into consideration the issues relating to ontology and epistemology (Saunders *et al.,* 2009: 109). However, Pathirage *et al.* (2008: 5) contend that there is need to also put into consideration the issue relating to axiology. Ontology is the starting point of all research, and can be defined as the image of social reality upon which theories are based (Grix, 2002: 177). It is the nature of a reality that raises assumptions on the operation of the world, as well as on how a researcher perceives the world (Blaikie; 2000: 8; Collins, 2010: 37). In a study conducted by Bryman (2001: 16), Saunders *et al.* (2009: 110), it was further discovered that typical examples of ontological positions are those within the perceptions of objectivism, and subjectivism.

Saunders *et al.* (2009: 109) emphasize that argument often comes up in terms of a choice among the various research philosophies specifically between the positivist and the interpretivist. Saunders *et al.* (2009: 109) are of the view that the appropriate philosophy to be adopted in such a situation is pragmatist. Pragmatism argues that the most important determinant of the epistemology, ontology and axiology you adopt is the research question (Saunders *et al.*, 2009: 109). In a related study by Collis and Hussey (2003: 48), Mertens (2007: 215) and Collins (2010: 37), it was realized that axiological assumption is primarily concerned with values that include aesthetics, and ethics. That is, it addresses the issues of ethical dilemma that may arise in an inquiry (Niglas *et al.*, 2008: 176; Saunders *et al.*, 2009: 116). Dainty (2008: 3), Knight and Turnbull (2008: 65), contend that epistemology predominantly concerned with the theories of knowledge, as well as on the conceptions of reality.

> "*It is about how we come to know what we know" (Blaikie, 2000: 8).*

That is, it comprises all the processes through which a researcher acquired knowledge about reality (Gray, 2014: 19). According to Knight and Turnbull (2008: 65), Dainty (2008: 4), Creswell (2009: 6), Collins (2010: 38), epistemology can be viewed under three perspectives namely: the positivism, the interpretivism, and the realism.

Dainty (2008: 10), Knight & Turnbull (2008: 65), Gray (2014: 20) opine that a positivist makes use of the existing theory to develop certain hypotheses, and affirms himself with the data collection process so as to be able to achieve a naturalistic information. According to Crotty (1998:

67), Bryman (2001: 12) and Gray (2004: 20), interpretivists originates from phenomenology, and it has to do with the study of how human beings make senses of the world around them, as well as their symbolic interactionism. That is, the interpretivists' belief that knowledge is socially constructed, subjective, and influenced by culture, and social interactions (Bryman, 2004: 16). While realism primarily deals with the idea that there exists a reality which is quite independent of the human mind (Gray, 2014: 25; Saunders *et al.*, 2009: 114). It is close to positivism as it assumes a scientific approach to the development of knowledge (Saunders *et al.*, 2009: 114). It should be noted that Burrell and Morgan (1982) summarise and clarifying the above explained philosophies (epistemologies and ontologies) into four paradigms namely: functionalist; interpretive; radical humanist; and radical structuralist.

4.2.1 The philosophical position of this study

Considering all the philosophies identified in the literature during this study specifically the positivism, realism, interpretivism, and pragmatism espoused by Saunders *et al.* (2009: 108) in the onion model, interpretivism is adopted for this study. This is due to the aim of this study (stated in Chapter 1, section 1.3 of this report) that required the researcher to conduct the research among a group of structural engineers, rather than objects (Saunders *et al.*, 2009: 116). Therefore, the researcher perceived that as a social actor in this study, there would be need for social interaction among the studied groups for data acquisition (Saunders *et al.*, 2009: 116). In addition, the researcher believed that being an actor (interpretivist) in this study, would enable him to continuously interpret the activities and actions of a group of structural engineers in a particular way based on his or the structural engineers opinions (Saunders *et al.*, 2009: 116). Further, Bryman (2004: 16), Creswell (2009: 6), Saunders *et al.* (2009: 108), and Collins (2010: 36) argue that the choice of a researcher's philosophical assumption depends to a greater extent on what the researcher intends to achieve based on the set research questions and objectives. With the need for partnership, and extensive social interaction and collaboration with groups of structural engineers for realization, and acquisition of knowledge to the research questions highlighted in Chapter 1, it can be debated that the research is interpretivism.

However, it should be noted that interpretivists can be further classified into five groups, among these are the symbolic interactionism; the phenomenology; the hermeneutics; and the naturalistic inquiry (Gray, 2014: 23). In symbolic interactionism, meaning arises from the process of social interaction (Gray, 2014: 24). Gray (2014: 24) is of the perspective that symbolic interactionism permits a researcher and the investigator or observer to interpret the meaning of objects, and actions in the world, and then act upon those interpretations. Gray (2014: 24) also adds that the symbolic interactionism allows meanings or a phenomena understudy to be handled in, and then, built on through an interactive process by groups of researchers and investigators or observers.

Premised on the above factors of symbolic interactionism, one of the methods that is often associated with it or adopted for data collection by this class of the philosophers is participative observation (Gray, 2014: 24). The phenomenologists argue that attempts by a researcher to understand the social reality of a group of people, the researcher has to be grounded in the experiences, and the social reality of the people (Gray, 2014: 24). In phenomenology, values are described not only in the language or understanding of the researcher, but also in the interpretations of the study participants (Gray, 2014: 24). The Hermeneutics is an old theoretical perspective (the nineteenth-century German philosophy), but is related to phenomenology (Gray, 2014: 26), whereas a naturalistic inquiry believes that multiple constructed realities can only be studied and understood holistically (Lincoln & Guba, 1994 cited by Gray, 2014: 26).

Based on all these explanations, it is debatable that the researcher is in the classes of the above-mentioned interpretivists. That is, in the groups of symbolic interactionism which enabled the researcher to focus on the structural designers' ways of interpreting acts or activities through social interaction; the phenomenological study that allowed the researcher to ponder on the structural designers actual lived experience or reality, and the hermeneutics that permitted the researcher to concentrate on how the structural designers make meaning of events in their lives (Stringer, 2014: 37). Grix (2002: 178) points that the assumptions that underpin researches are both ontological and epistemological. Therefore, relating ontological consideration with the epistemological assumption for a research philosophical position, it is arguable in this study that the researcher is in the stance of interpretivist (symbolic interactionism, phenomenology, and hermeneutics) and subjectivism.

4.3 Research Approach

Research approach as earlier stated in section 4.1 of this report is the second layer in Saunders *et al.* (2009: 108) onion model and can be ascribed as the intention to either adopt the deductive or the inductive approach for data collection in a study (Saunders *et al.*, 2009: 124; Gray, 2014: 16). Insofar as it is useful to attach these research approaches to the different research philosophies, deduction is better adopted to positivism and induction to interpretivism (Saunders *et al.*, 2009: 124). Although, Saunders *et al.* (2009: 124) further contend that such postulation is potentially misleading, and may be of no real practical value. It is essential to know that a research may be required to be conducted with one or combination of the two sources (Yin, 2009: 52; Saunders *et al.*, 2009: 127).

Saunders *et al.* (2009: 124) and Gray (2014: 16) assert that the deductive approach enables the use of a theory to develop a preposition, and then design a research framework that will be used to test the proposition. This means that the researcher intends to measure data through quantitative procedures, and generalize to a larger population (Saunders *et al.*, 2009: 124; Gray, 2014: 16). In the inductive approach, plans are made by the researcher for data collection through a set of research questions, after which the data generated will be analysed so as to observe if the patterns that emerge may suggest relationships between the variables (Saunders *et al.*, 2009: 125; Gray, 2014: 17). This indicates that in the inductive approach, the researcher probably wants to get the details of the phenomenon understudy, through the collection of qualitative data (Saunders *et al.*, 2009: 125; Gray, 2014: 17). Succinctly put, Table 4.1 provides the summary of some of the features of the inductive, and the deductive approaches of data collection.

Table 4. 1: Nature of deductive and inductive data

Inductive	**Deductive**
Data generalization is less significant	It main aim is to establish data that is universally generalized through a set of principles that are being tested through empirical observations or experimentation
Gives an understanding of the meanings people attach to various contexts	More scientific principles
Plan are made for data collection by the researcher, after which the data generated are analysed to observe if any pattern that may suggest relationships between the variables that emerge	It moves toward hypothesis testing, after which the principle is established, and reformed
From the observations, it may be possible for the researcher to construct generalization, relationships, and even theories	It focuses attentions on how theories can be tested so as to be able to eliminate wrong information to corroborate the surviving theories
Does not set out to corroborate or falsify a theory, but through the data generated, it attempts to establish facts, consistencies, and meanings	Specifies what the researcher must do so as to measure a concept
The researcher moves to discover a binding principle, taking every measure so as not to dangle into any hasty conclusion base on the data generated	Compare observation data with the theory, and if correlated, the theory will be assumed by the researcher to have been established

(Saunders *et al.*, 2009: 124-125; Gray, 2014: 16-18)

Based on the philosophy that underpins this study, the aim as well as the features of the inductive approach abridged in Table 4.1, the researcher viewed that the inductive approach is suitable for this study. Therefore, the inductive approach that permitted the researcher to develop research questions for 'building theory' which is the premise of the inductive approach was adopted in this study (Saunders *et al.*, 2009: 124).

4.3.1 The primary data

The primary data for this study were obtained from the members of Consulting Engineers South Africa (CESA) that are based in Bloemfontein. Specifically, data were obtained from five different firms in Bloemfontein in 2015-2016. The strategy used to obtain and analyse the data are explained in section 4.4.

4.3.2 The secondary data

The secondary data are the factors, parameters, and statements pertinent to this study. They were obtained from books, articles, and electronically retrieved information that are associated with waste and its elimination techniques in the construction design process (CDP). At the start of the data collection in the cases selected, comparisons were made by the researcher with the information derived from the literature, and the practices in the SDP. There are well experienced structural engineers in different consulting engineering firms in Bloemfontein. The practices of the consulting engineers were investigated and compared with the information obtained in the existing literature. The secondary data enabled the researcher to have the insight of the probable non-value adding activities in the current practices of the SDP in Bloemfontein consulting engineering firms.

4.4 Research Strategy

Saunders *et al.* (2009: 136) refer research strategy as the strategy which the researcher intends to apply in providing answers to the research questions. It typically describes the purpose of the study; the research questions to be addressed; the strategy, the methods and the instruments that the researcher intends to adopt for data collection; the approach that will be adopted for selecting samples, the strategies that will be used to analyze the data generated, and the research ethical issues and consideration (Saunders *et al.*, 2009: 136; Gray, 2014: 128).

Different strategies have been extensively used by many researchers to conduct researches. Among these are experiment, survey, case studies, ethnography, mixed methods, and action research (AR)

(Chein *et al.,* 1948: 33; Buchy & Ahmed, 2007: 358; Morgan, 2007: 48; Hughes, 2008: 1; Yin, 2009; 54; Saunders *et al.,* 2009: 136; Coghlan & Brannick, 2010: 5; Gray, 2014: 128). The findings in the above-stated literature indicate that the choice of a design for a particular research does not only depend on the research questions to be addressed, but also hinge on the philosophical stance of the research (Chein *et al.,* 1948: 33; Yin 2009: 54; Saunders *et al.,* 2009: 136; Gray, 2014: 128; Ivankova, 2015: 37). The nature and the requirements, and the philosophical position of this study have been established in sections 4.2. The requirements and the philosophical stance appear to be similar with some of the characteristics of AR (Lewin, 1948: 217; Elliott, 1994: 133; Gray, 2004: 26; 31; Saunders *et al.,* 2009: 136; Stringer, 2014: 37). AR is any practical research undertaken by those involved in the practice area (The Open University (TOU), 2005: 4; Buchy & Ahmed, 2007: 358; Hughes, 2008: 1). It is a process of enquiry by a researcher into the effectiveness of a particular organization (Buchy & Ahmed, 2007: 358; Hughes, 2008: 1).

Further, research by Lewin (1948: 217), Elliott (1994: 133), (Gray, 2004: 31), Buchy and Ahmed (2007: 358), McNiff and Whitehead (2011: 49), and Ivankova (2015: 37) reveal that studies that are of similar nature or requirements, and of philosophical perspectives to this research have the same approach or strategy for data collection. That is, they have series of cyclical steps known as AR that can be followed by the practitioners to identify the necessary actions that will generate the desire changes in a situation (Lewin, 1948: 217; Elliott, 1994: 133; Gray, 2004: 31; Buchy & Ahmed, 2007: 358; McNiff & Whitehead, 2011: 49; Ivankova, 2015: 37). Ivankova (2015: 38) adds that a research practitioner that intends to improve on the existing practice of an organization must follow the aforementioned steps with limited variation. Based on all these explanations, AR is adopted as the strategy for data collection in this study.

In brief, the qualitative method was adopted for data collection in this study due to the research philosophical position, and the type of the research questions to be addressed.

4.5 Research Choice

Saunders *et al.* (2009: 151) ascribe the process in which a researcher chooses to combine quantitative and qualitative techniques and procedures as a ‘research choice’. Therefore, in choosing a research method, a researcher may either adopt a single data collection method and corresponding analysis procedures (mono method) or use more than one data collection methods and analysis procedures to answer the research questions (multiple methods) (Saunders *et al.*, 2009: 151). Saunders *et al.* (2009: 152) further express that a researcher can adopt mixed method in which both quantitative and qualitative data collection methods and analysis procedures are used in a research design.

Green and Thorogood (2004: 22) opine that the interpretivists normally adopt the qualitative method in the course of their inquiries. Therefore, the qualitative method is associated with the inductive-subjectivism-contextual domain (Morgan, 2007: 48). The qualitative method also allows for the adoption of certain techniques such as individual or focus interviews, physical observation, and documentary evidence for data collection (Gray, 2014: 161). Based on these explanations, the mono method (qualitative) was adopted for this study.

4.5.1 The need to adopt qualitative method in action research

AR originates from Lewin in 1948 and it purpose or intention is to learn through actions that can lead to personal or professional development (Elliott, 1994: 133). Lewin (1948: 217) proposes the first AR methodological steps and explains AR as a cyclical process of four iterative stages of reflecting, planning, acting, and observing as shown in Figure 4.1.

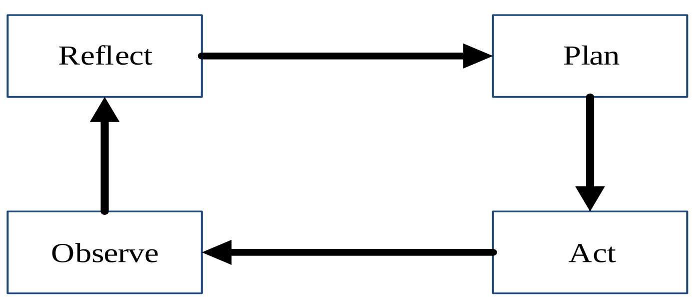

Figure 4. 1: Action research methodological steps (Lewin, 1948: 217)

According to Lewin (1948: 217), the idea of AR as a research approach started when practitioner researchers came across problems that needed immediate attention in their work. Lewin (1948:

217) emphasizes that the practitioners reflected as many times as possible on the problems so as to be able to understand the factors that necessitated it. Lewin (1948: 217) affirms that the practitioners thereafter, developed plans on how to overcome the problem; implemented the plans, and observed the outcomes that the plans brought. Lewin (1948: 217) asserts that the practitioners further reflected on the outcomes several times so as to know where there could be improvement. According to Lewin (1948: 217), the practitioners proceeded to repeat the procedures several times until the problems were solved.

In a similar study by McNiff and Whitehead (2011: 49), it was observed that the cyclical process proposes by Lewin (1948: 217) in AR is a bit complex for data collection. To overcome this difficulty, Stringer (2004: 69), Mill (2011: 19), McNiff and Whitehead (2011: 49) introduce both qualitative and quantitative methods of data collection into AR. Stringer (2004: 69) and Mill (2011: 20) further point that a researcher can make use of qualitative or quantitative or combination of both methods in some or all the cycles involved in AR. However, Mill (2011: 19) argues that the qualitative method seems to fit AR efforts more appropriately than the quantitative due to the fact that the qualitative method:

- Provide understanding and description of people's personal experiences of phenomena;
- Allow accuracy in operationalizing and measurement of specific construct;
- Is useful for studying a limited number of cases in depth;
- Can be adopted to describe complex phenomena;
- Provide individual case information;
- Give room for group comparison;
- Enable model specification and testing in research;
- Allow a researcher to conduct cross-case comparisons and analysis;
- Describe in detail the phenomena under investigation as they are situated and embedded in local contexts;
- Enable data to be collected in naturalistic settings, and
- Allow participants to explore on how and why phenomena under study occur.

In the later study conducted by Stringer (2014: 104), it was further discovered that the primary source of data collection in AR is interviews with some key stakeholders. Stringer (2014: 104) emphasizes that interviews constitutes the most important research strategy for AR due to the fact that the interview:

- Provides opportunities for participants to describe the situation in their own terms;
- Is a reflective process that enables the interviewee to explore his/her experience in details, reveal the features of that experience on the issues under investigation, and
- Is a process that does not only provide a record of participants' views/perspectives but also symbolically recognizes the legitimacy of their experience.

Corroborating with the argument advocate by Mill (2011: 19) and Stringer (2014: 104) on AR, Gray (2014: 340) opines that it is unwise for researchers to adopt questionnaires for data collection in AR. Gray (2014: 340) is of the opinion that questionnaires do not normally help researchers to generate the collaborating approach to problem-solving which AR requires. Consequently, Gray (2014: 340) stresses that a researcher can only make use of questionnaires on the basis or condition that other methods such as interviews and physical observation are only difficult to be adopted. Stringer (2014: 104) adds that as the focus of issues under investigation become clearer through interviews, other sources of data collection such as documents or records and physical observation may also become relevant.

A typical example of a situation where the qualitative method in action research (QMAR) is applicable according to Marshall *et al.* (2006 cited by Koshy *et al.*, 2010: 16) is when a research intends to be conducted in a health care centre where information will be required from both the health workers and patients. Marshall *et al.* (2006) suggest that such research may be to improve the levels of patients' satisfaction through staff services. In such a scenario, the data required for the research can be gathered through formal or informal interviews, focus groups, physical observation, and a review of documents (Marshall *et al.*, 2006). Stringer (2014: 104) and Mill (2011: 19) position on QMAR is supported by Ivankova (2015: 50) in his recent study on AR. Ivankova (2015: 50) recommends the use of either qualitative, quantitative or combination of the two approaches for data collection in some of the cycles involved in the AR.

Based on these discussions, the QMAR recommends by Stringer (2014: 104) was adopted for this study. The QMAR study was conducted in five selected consulting engineering firms located in

Bloemfontein, and the techniques adopted by the researcher for acquisition of data in all the cases selected are: focus interviews, documents or records of the previous executed projects by the various case study firms, and the researcher's observation (Stringer, 2014: 104).

4.5.2 Justification for the adoption of multiple cases in this study

AR is participatory in nature (Lewin, 1948: 217; Gillis & Jackson, 2002: 264). That is, it involves multiple stakeholders to generate knowledge, and adopts series of cases to interfere with a number of groups, using some of the cases as controls (Gray, 2004: 31; Kemmis & McTaggart, 2007: 596; Hinchy, 2008 cited by Ivankova, 2015: 33). Further, Gray (2014: 162) observes that an enquiring research design such as case study, AR or phenomenological study is feasible and legitimate, and can be combined with other research designs in a single study. This means that an AR design may require the adoption of several cases for data collection in a single investigation due to certain reasons to include data generalization (Gray, 2014: 162). In this study, the rationale for using multiple cases in the AR conducted was mainly on the necessity to establish whether the findings of the first case occur in other cases and, consequently, can be generalized to other contexts (Saunders *et al.*, 2009: 146).

In other words, multiple cases were adopted in the QMAR conducted in this study so as to overcome the critic by other researchers such as the positivists on the extent of the validity of the data generated by the qualitative studies (Saunders *et al.*, 2009: 146). To support this view, Yin (2014: 57) contends that multiple case studies may be preferable to a single case study due to several of its advantages over the single case study. Therefore, for the robustness of the findings of the QMAR conducted in this study, multiple cases (evidence) were adopted by the researcher (Yin, 2014: 47).

4.5.3 Focus group interviews as a technique for data collection in this study

A focus group can be defined as an organized discussion among selected groups of people, and its aim is mainly to elicit on specific information about the groups' perspective on a phenomenal (Kitzinger, 1995: 299). The purpose of a focus group may also be to gain a range of opinions about subjects and situations (Gray, 2014: 468). That is, to generate interaction and discussions within a group. The idea of focus groups study started by Merton in 1940, and the first example of focus groups research was on market investigation in 1941 under the supervision of Lazarsfeld, and Merton at Columbia University (Bloor *et. al.,* 2001: 1; Puchta & Potter, 2004: 4). The applied social research was the vehicle that spread focus groups beyond the world of product marketing (Morgan, 1998: 40). Since then focus groups have become increasingly popular as a tool of enquiries in other field such as government, non-profit making, non-governmental organizations, and academics (Krueger and Casey, 2001; 4; Puchta & Potter, 2004: 5). Table 4.2 provides the summary of the various roles that must be adherence to while conducting focus groups, while Table 4.3 indicates the basic requirements (a step-by-step guide) that a researcher needs to understand before, and while conducting the study. These requirements were adopted by the researcher for the success of this study. The details of the procedures that were followed by the researcher while conducting the study are explained in the procedures for data collection section of this study (section 4.4.6).

Table 4. 2: The basic roles in conducting focus groups

Roles	Descriptions
The organizer	In this study, the researcher represented the organizer of the focus groups study. That is, the researcher led the planning of the study, and developed the focus interviews questions
The recruiter	The senior/chief engineer in each case study firm was the recruiter as he invited the participants (other designers)
The moderator	The chief/senior engineer also represented the moderator as he motivated, directed and coordinated the group members in each firm throughout the exercise
The assistant moderator	The researcher occupied this office as he set, and asked the focus interviews questions, and also captured the data (recording of the discussions)
The note takers	The notes were taken by the researcher, and one of the junior engineers that served as the assistance secretary throughout the exercise. The researcher and the assistance secretary took notes of the focus interview discussions individually, and later compared the outcomes for consistency
The transcribers	The researcher and the assistance secretary (the above mentioned junior engineer in each firm) transcribed the recording individually, and later compared the results with each other for consistency.
An analyst/reporter	The researcher represented the analyst as he summarized the data obtained in every phase of the focus interview, and prepared the findings of the exercise

(Adapted from Krueger & Casey, 2001: 5)

Krueger and Casey (2001: 5) contend that a researcher or a participant among the groups can perform or handle all the roles. However, Krueger and Casey (2001: 5) further stress that it is better if the various roles can be conducted within a team of four or five people.

Table 4. 3: The basic requirements of focus groups study and unit of data analysis of the study

Requirements and Characteristics	**Descriptions**
Carefully recruit the participants	In this study, the chief engineer invited individuals (structural designers) in each studied firm that has the characteristics, experience, or knowledge required to provide in-depth information on the topic The chief engineer in each firm limited the size of those invited to form a group of five participants The participants in the five groups form the unit of analysis of the data obtained in this study. That is, the units of analysis of the data obtained in this study were based on the experiences and views of the participants in all the five groups (Gray, 2014: 24) (the units of analysis of the data obtained is further explained in section 4.4.7 of this study). In each firm, the chief engineer avoided power differentials among the participants. Hence, the participants in each group felt comfortable to talk with one another throughout the study
Create a comfortable environment	The researcher held the focus groups exercise in a familiar or neutral setting. That is, in an office building (the chief engineer office) The researcher/the chief engineer ensured that all the participants in each firm contentedly sat throughout the exercise. This was done so that the participants of the study could easily see one another, and conduct the interview in their language. The researcher did not use an interpreter in all the groups. It should be noted that using an interpreter stilts the discussion and turns the process into serial interviews rather than a lively discussion among the participants

	The researcher recorded all the discussions in each phase of the study for immediate analysis.
Use a skilful moderator	The researcher solicited the service of the chief engineer (a moderator) that ensured that the participants in each group felt comfortable to concentrate throughout the focus interview exercise
	The researcher prepared, and asked a set of questions that were designed to get the information needed by the participants
	The researcher also solicited for the assistance of the chief engineer in each firm to create a conducive atmosphere that enabled the participants to have the feeling that the atmosphere was completely safe to talk freely
	The chief engineer also assured the participants the opportunity to express themselves freely throughout the study
	The chief engineer also oriented the participants to be respectful, and non-judgmental of each other throughout the study
Record, transcript and logically analyse the data obtained	The researcher analysed the data obtained systematically in such a way that the process of the analysis could easily be described
	The researcher supported the findings of the analysis with evidences (literature) mainly for validation purpose
	It is anticipated that if a reviewer reviews all the data provided in this study, the reviewer will understand how the analyst of this study arrived at the findings and conclusions based on those data

(Adapted from Krueger & Casey, 2001: 4; Stringer, 2014: 111)

The literature shows that AR is better conducted through focus interviews if the aim of the investigation is to improve on the existing practice of an organization (Stringer, 2014: 111). Therefore, the fundamental reasons for adopting focus interviews as a technique for data collection in this study is due to the method adopted for data collection (QMAR), as well as the philosophy that underpins the study. The focus groups adopted allowed the researcher to focus on the targeted groups of people in the study location (experienced structural designers). It also enabled the researcher to answer the 'what' (narrative content), and 'how' (narrative procedures) questions in the set research questions (Kitzinger, 1995: 299; Holstein & Gubrium, 2004 cited by Jordan *et al.*, 2007: 5).

4.5.4 The criterial adopted for the selection of the case study firms

Table 4.4: The demographic information of the various firms for this study

Firms	**Location**	**Experience (Years)**	**Participants**	**Coded names**
A	President Reitz Avenue, Westdene	> 15	5	Senior engineer (A_1 / A_2), Junior engineers (A_3 / A_4), Technologist (A_5)
B	2nd Ave & Kellner Street, Westdene	> 15	5	Senior engineer (B_1 / B_2), Junior engineers (B_3 / B_4), Technologist (B_5)
C	President Steyn Ave. Westdene	> 10	5	Senior engineer (C_1 / C_2), Junior engineers (C_3 / C_4), Technologist (C_5)
D	President Reitz Avenue, Westdene	> 15	5	Senior engineer (D_1 / D_2), Junior engineers (D_3 / D_4), Technologist (D_5)
E	2nd Avenue, Westdene	> 15	5	Senior engineer (E_1 / E_2), Junior engineers (E_3 / E_4), Technologist (E_5)

(Author, 2016)

Table 4.4 shows the demographic information of the selected cases in this study. Due to ethical considerations, the names of the case firms are referred to by letters of the alphabet, as shown in the table. The entire duration of the study was approximately 18 months (section 4.4.9). In this study, the criteria adopted by the researcher for the selection of the case study firms for the focus groups study was based on purposive sampling techniques (Ritchie & Lewis, 2003: 77; Teddlie & Yu, 2007: 77). That is, it was predominantly on the firms that have engineers with extensive work experience in the SDP. The engineers have to be affiliated with Consulting Engineers South Africa (CESA), and were willing to provide the researcher the required or useful information for the study.

4.5.5 The sampling of the focus group participants

'Sampling frame' is the operational definition of the population (Gray, 2014: 472). It is highly important in survey research, but less significant in a focus group study due to the fact that researchers can easily generalize the information obtained through focus groups beyond the population used (Strickland, 1999: 190; Gray, 2014: 472; Stewart *et al.*, 2007: 42). Stringer (2014: 111) states that most importantly on the participants' sizes, the number should be in a range that each member should have the opportunity to accentuate their views based on the experience they have on the issues under discussion. Supporting the views espouse by Merton *et al.* (1990: 137) and Stringer (2014: 111) on focus groups sizes, Strickland (1999: 190), Gray (2014: 472), and Stewart *et al.* (2007: 42) argue that in a focus group study, a researcher is expected to determine the required number of the participants to be recruited, and the criteria govern the recruitment exercise solemnly depends on the opinions of the researcher.

Based on the literature, it can be concluded that participants' size is irrelevant in a focus group study. Most importantly is the information obtained among a group of expert, and like-minded, or characters that are free to interact, and express their opinions based on their experiences in the study context. A group of two or three people in a study can be justified as a focus group. Based on these explanations, in this study, the researcher recruited five designers (a combination of both senior and junior engineers and a technologist that were available as at the time of this study) that have been working together as a team for not less than five years across the various design projects (residential, commercial and industrial) for data collection.

4.5.6 The rationale for documentary evidence and non-participatory observation

Stringer (2014: 115) and Gray (2014: 502) perceive that documentary evidence is important in the data collection process as it enables the researcher to:

- Gain an insight into the historical evolution of the phenomena being studied;
- Provide information that serves as interview guide which consequently enables the researcher to make some time savings, and
- Establish basis for any bias that may come up during the interviews session.

Physical observation especially in AR studies enables a researcher to build a picture of the lifeworld of those being studied, and to gain insights on how the people perform their everyday activities (Stringer, 2014: 113). The documentary evidence observed in this study includes a 'request for information' form, and the architectural and the structural drawings of the previous work executed by the consulting engineers.

4.6 Time Horizon

Saunders *et al.* (2009: 155) espouse two time horizons in a research namely: the cross-sectional ('snapshot') and the longitudinal (diary) horizons. It is essential to know that these time horizons are independent of the research strategy as well as the choice of method (Saunders *et al.*, 2009: 155). Therefore, this study is situated in a cross-sectional horizon. This is due to the fact that it is an academic study which has to be completed within a time frame (Saunders *et al.*, 2009: 155).

4.7 Procedures for Data Collection in this Study

In this study, the data collection exercise started in the first week of April 2015 and ended in the third week of November 2016. It has been explicated in section 4.4.1 of this study that the tactic used by the researcher for data collection in the five case study firms was QMAR. Visitations to the firms by the researcher were done simultaneously based on when the need arises, as well as when the participants of the study groups were available. Figure 4.2 provides the summary of the overall procedures (QMAR methodological framework) adopted for data collection in this study.

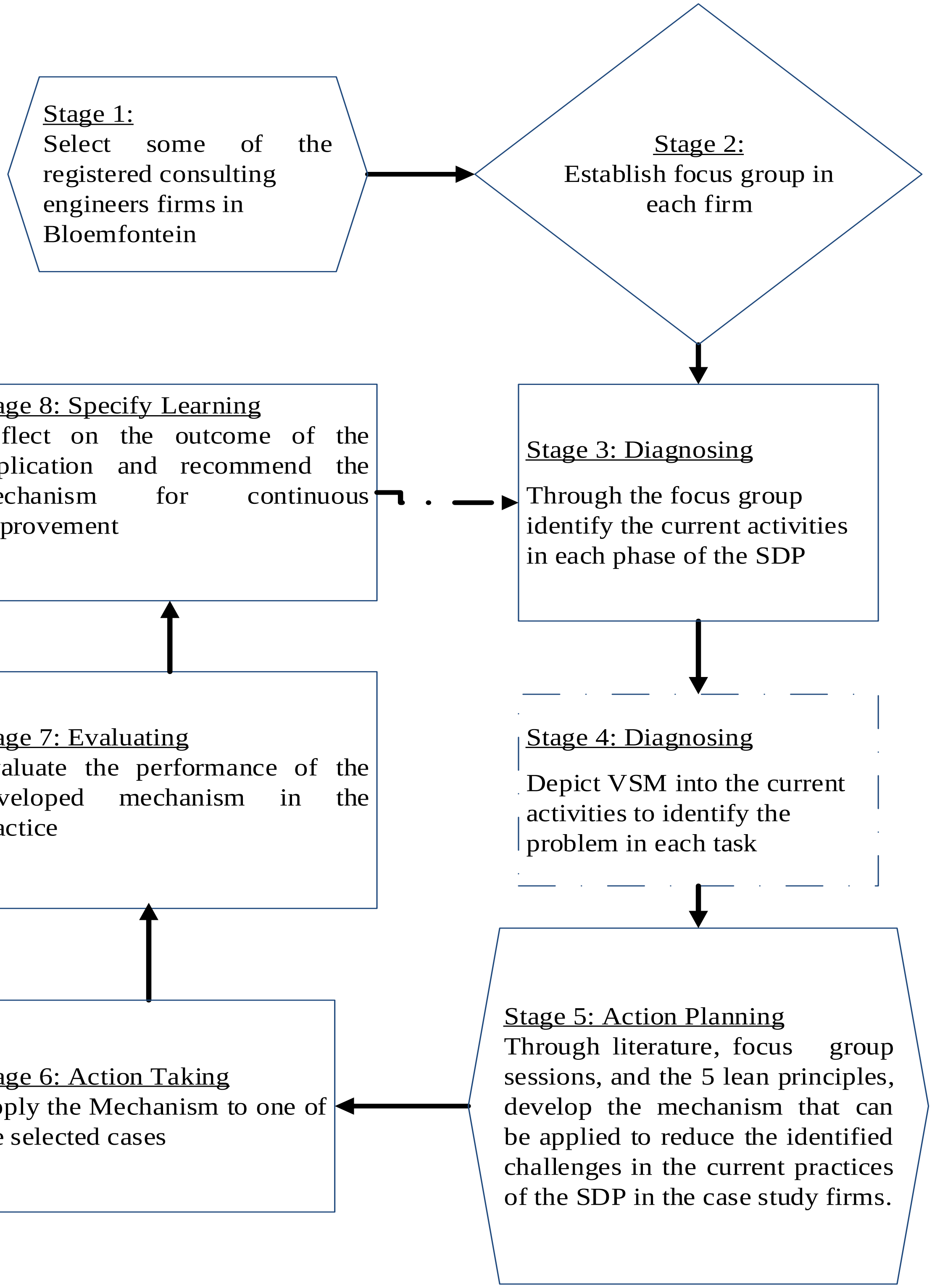

Figure 4. 2: A methodological framework for conducting action research in Bloemfontein based consulting engineering firms (Adapted from Stringer, 2004: 69; Creswell & Tashakkori, 2007: 306; Mill, 2011: 19; McNiff & Whitehead, 2011: 49; Bryman *et al.*, 2008: 261)

As shown in Figure 4.2, the first stage of QMAR in this study was the selection of some consulting engineers firms in Bloemfontein. It has been stated in section 4.4.4 of this study that purposive sampling technique was adopted for the selection of the firms, and the researcher focused attention mainly on the firms with professionals that have more than ten years' experience in the structural design practice. This was achieved through the Bloemfontein Consulting Engineering website as well as a list that contains the necessary information about all the consulting engineers in the Free State (Appendix 2). The list was provided to the researcher in one of the case study firms. Based on this list, not less than eight consulting engineers in Bloemfontein were initially selected by the researcher for this study. Invitations for QMAR study were sent to these eight firms. The invitations were sent through letters, email and phone calls. This exercise commenced on 2 April 2015 and ended on 11 May 2015.

The second stage of this study was the establishment of the focus groups; here the researcher identified the firms (among the eight in which invitations were sent to) in which some of their designers were ready, and willing to be actively involved in the study. Six firms were initially selected at the start of this study. In the six cases selected, four structural engineers, and a technologists represented the focus groups. It is needful to know that to establish focus groups in this study after the identification of the study locations took approximately four days (12 to 15 May 2015).

After the establishment of the study locations and the focus groups, the researcher called the group members together for a brief meeting in each firm. This meeting was held on 18, 19 and 20 May 2015 in the offices of the head of each focus group. In the meetings, the researcher clearly explained to each group what the study entailed to include it purpose, aim, objectives, the problem, the research questions, and the expected data. Thereafter, the researcher and the group members in each firm agreed on the commencement date of the study (focus interviews). Details of the roles of each member as well as the basic requirements adopted for the success of the exercise have been expounded in Tables 4.2 and 4.3 of this study. It is necessary to know that before the actual date of the focus interviews, the researcher briefly conducted a pilot study in all the firms. The essence of the pilot study was to ascertain if the research with the set questions could be conducted in the study context. Hence, the success of the pilot study enabled the researcher to reaffirm the realism of the research, and to proceed for the study as planned. The outcome of the pilot study conducted was used to prepare an article titled: *Types of waste and their causes in the structural design process: The case of South African construction projects* (Appendix 10). After the pilot study that was conducted in all the firms, the researcher could only gain access into only five out of the six case study firms that were initially designated for this study. Therefore, the remaining five cases in which the researcher had access into were used for this study. The pilot study exercise started on 25 May 2015 and ended on the 29th of the same month (approximately one week).

The third stage of the study (the diagnosing process) started in the first week of June 2015 and ended in the last week of February 2016. As part of the QMAR study, two weeks to the start of the focus interviews that was conducted in the diagnosing phase, documents of work executed by the various firms in the past three years were reviewed by the researcher. This was done so as to enable the researcher to have information on the probable activities, and problems in the current practices of the various firms. It also enabled the researcher to be sure, and confident of the information provided by the study participants during the focus interviews (Stringer 2014: 113). Hence, with the assistance of the group leaders in each firm, documents such as architectural and structural drawings (Appendix 1), and request for information forms (RFIs) of the previous projects were obtained and reviewed.

Further, during the focus interviews exercise, the researcher was privileged to conduct a non-participatory observation (NPO) in all the firms (Stringer, 2014: 113) This was viable as often, the researcher in the offices of the team leaders would be on sit for not less than fifteen minutes to anticipate the arrival of the study participants. The outcomes of this exercise are fully discussed in Chapter 5 of this study. The focus interviews exercise in this stage of the study were conducted on three different occasions in each firm. In the first focus interview exercise, the researcher was able to understand the current flow of activities in the SDP (mainly the inception, the predesign, and the detailed design phases), the probable non-value-adding activities in each phase, the factors that necessitated the activities, and the impacts of the activities on the projects. It is essential to know that in the first focus interview conducted in all the firms, some of the designers disagreed on some activities as non-value adding (NVA). The designers contended that those activities are norm in the structural design practices.

Therefore, the information obtained by the researcher in the first focus interview exercise in each firm was adopted to understand the flow of the current activities in each phase of the SDP. Thereafter, the researcher depicted a value stream mapping (VSM) tool into the flow of the activities (Chapter 6, Figures 6.3, 6.4, 6.7, 6.8, 6.11, and 6.12). The essence of this was to clearly bring out the activities in each phase of the SDP, which enabled the researcher to clarify to the structural engineers some of the events that are actually NVA in all the phases. The VSM also enabled the researcher and the engineers to further discover more waste in the system.

This implies that the second focus interview conducted in all the firms, enabled the researcher to clarify on the activities that brought disagreement among the engineers in the first focus interview, and further unravelled more NVA in the SDP. The focus interview exercise was repeated the third term, and the researcher realized consistency in the outcomes. That is, the results obtained in the third focus interview were similar to the outcomes of the second exercise in all the firms. This assured the researcher the exact time to stop the exercise in the diagnosing phase of the study (Stringer, 2014: 113). This indicates that the third focus interviews conducted in all the case study firms enabled the researcher to understand the data saturation stage (Gray, 2014: 389). To be concise, the first, second and third focus interviews exercise, and the VSM tool that was adopted in the study enabled the researcher, and the design team in each firm to fully identify the current activities in each phase of the SDP; the problems encounter in each phase; the origin, and the causes of the problems, and the effects of the identified problems on the firms' performance, and projects.

Generally, each focus interview exercise in each firm was between 60 to 80 minutes in duration, with the exception of the first exercise that ranges between 95 to 110 minutes (approximately two hours) due to the series of disagreements among the structural engineers. The focus interviews exercise was conducted in the offices of the group leaders (the chief engineer). At the commencement of each focus interview, group members were reminded of the research problem as well as the aim, and objectives of the study. Thereafter, members were, reminded of their various responsibilities (Table 4.2). This process was then followed by the interview exercise during which the focus interview protocol was utilized as a guide (Stringer, 2014: 111). Further, in all the focus interviews conducted in all the firms, the researcher ensured that each group member responded properly to each question asked before moving to the next one. Each focus interview discussions in each firm were fully recorded and transcribed accordingly by the researcher, and the firm secretary individually. The results obtained in each firm were compared with each other for consistency before they were analysed accordingly.

It should be noted that the transcript does not reflect the entire character of the discussions as certain information such as nonverbal communication, gestures, and behavioural responses were not being captured during the recordings (Krueger 1994 cited by Krueger & Casey, 2001: 13). In addition, Krueger (1994) contends that the way members of each group use words and the tone with which words were used are important sources of information that can radically alter the interpretation of a statement. In this study, the identified shortcomings of the recording system discovered in the literature were addressed through the notes that were taken by the researcher and the assistance secretary throughout the focus interviews exercise. Before the fourth stage of the study, the analysed data in the third stage were validated accordingly. The validation was achieved by compiling the findings obtained together on a list, and later administered it to the head of each group for their consents.

In the fourth stage of the study (action planning), the researcher and the members of the focus groups in each firm proposed for different strategies that could be used to eliminate the identified waste (the NVA activities), so as to enhance the values in the firms' practices. This was achieved through another focus interviews exercise that were conducted in each firm. The focus interviews exercise in this stage of the study, were also conducted three times by the researcher in each firm. In the first focus interviews in the action planning phase, there were several disagreements among the group members; and at certain points, between the researcher and members of the focus groups in all the firms. However, in the second phase of the exercise, the researcher and the group members in each firm finally came into consensus on the different principles, ideas, techniques, strategies, and systems that can be adopted to eliminate the identified waste in the SDP. The exercise was repeated the third time for consistency, and the results obtained compared favourably with the second exercise. The action planning stage of this study started in the first week of April 2016 and ended in the last week of May 2016.

The fifth stage of the study is the action taking; where the researcher, and the focus groups created a change in the activities of the firms by implementing the suggested principles, ideas, techniques, strategies and systems to the organization practices. This was achieved by selecting one of the case study firms that had an ongoing structural project at hand as at the time of this study. Reason and Bradbury (2001) cited by Azhar *et al.* (2010: 91) affirm that if the same problem or situation is present in a number of organizations of similar nature, then in the action taking stage (the implementation stage), one of the organizations may be chosen as a collaborator for intervention, i.e. for data testing (evaluation). As at the time of this study, group A had a new project (a multi-storey building) at hand. The project is located in the region of Johannesburg, South Africa. Hence, the newly developed mechanisms by the researcher, and the focus groups were implemented in the project right from the IDP to the structural aspect of the CP. As a collaborative effort, designers in other groups were also involved in the activities specifically in the design stage.

In the sixth stage of the study, the researcher and the group members in group A, evaluated the changes that were created on the performance of the firm based on the executed project (further evaluation process). Here the researcher and the members in group A determined whether the theoretical effects of the action taken (the developed mechanism) were realized or not, and whether these effects reduced or completely eliminated the NVA activities, and problems in the SDP. These were achieved by summoning the group members together at the end of the main activities (the structural design activities) in the executed project, and find out from the group if the quality of the structural activities in the design and the construction phases in the newly executed project have been substantially improved through minimal mistakes or errors. The researcher also found out from the group members if the lead time (LT) formerly experienced during the SDP by the team has been significantly reduced, and if the RFIs from the contracting party was also reduced during the structural related activities in the construction phase of the new project.

The researcher ensured that the above highlighted statements were justified by the members of the firm (group A), and the principles, ideas, techniques, strategies and systems adopted for the project were concluded as the sole cause of the success (Gray, 2014: 342). These are further explained in Chapter 6 of this report.

In the last stage of the study, learning was specified by the researcher; that is, the researcher reflected on the overall processes, and outcomes; proposed for new knowledge, and recommends the new knowledge for continuous improvement. This is fully discussed in Chapter 7 of this thesis (the conclusions and recommendations sections).

4.8 Approach Adopted for Data Analysis in this Study

Qualitative data collection techniques and methods generate large amounts of data that tend to overwhelm novice as well as experienced researchers due to few or scarcity of formula for data analysis (Yin, 2014: 133). Premised to this fact, Krueger (1994), Seal *et al.* (1998: 253), Seggern and Young (2003: 272), Gray (2014: 468), and Yin (2014: 133) emphasize that a simple descriptive narrative is often appropriate or adequate for analysis of the data. That is, an analytic technique that involves a transcript of discussions, and a summary of the findings.

Similarly, Robson (1990: 261) and Gray (2014: 601) stress that focus interviews are varieties of qualitative research that have less consensus on how to analyse and interpret the data generated. This means that in qualitative studies such as focus interviews, there is no universal approach to data analysis (Krueger & Casey, 2001: 15; Yin, 2011: 177). Therefore, Gray (2014: 601) point that:

- The main aim of data analysis in focus interview is to reduce the data or information obtained, and
- The method of analysis usually depends on the nature of the research question/the purpose for which the data are to be collected.

Green and Thorogood (2004: 176) add that whichever the approach a researcher intends to adopt, what matter most is to ensure the realization of the study aim. To achieve this end, Yin (2014: 135) points that there are procedures that a researcher needs to follow in qualitative studies. These procedures include examining, categorizing, and tabulating the evidence. Yin (2014: 138) refers these procedures in qualitative data analysis as inductive strategy.

This indicates that before the content of a focus group can be analysed, it must be converted into specific units of information (unit of analysis) that can be competently interpreted by the researcher

(Krueger, 1994; Krueger & Casey, 2001: 15; Krippendorf, 2004: 30; Fade, 2004: 647). Krueger (1994) is of the view that a unit of analysis to be adopted by a researcher depends mainly on the purpose of the research. However, Krippendorf (2004: 97), Krueger and Casey (2001: 15), Fade (2004: 647) simply state that in content analysis, a researcher's unit of analysis may be a sampling or frequency with which a single idea, statement or word appears. This tends to be interpreted as a measure of importance, attention, or emphasis (Krippendorf, 2012: 59). Several researchers to include Krueger and Casey (2001: 17) opine that sampling unit becomes perplexed when only few group of participants answer a particular question or when the same person made the same, or similar, comments several times within the course of a single discussion. In order to overcome this crunch, Krueger and Casey (2001: 15) provide five established criteria that suggest or serve as a framework for interpreting coded data. These criteria include: frequency (sampling); specificity; emotions; extensiveness, and big picture.

It is essential to know that frequency is related to how often a comment or view is made by participants during discussions. Extensiveness refers to the number of participants that express understanding on a particular view (Krueger & Casey, 2001: 17). Dissimilar to frequency, extensiveness gives the analyst a sense of the degree of agreement on a topic (Krueger & Casey, 2001: 17). In focus groups, extensiveness is of a more useful tool than frequency (Krueger & Casey, 2001: 17). Specificity of responses refer to a respondent personal experience as opposed to hypothetical situations (Krueger & Casey, 2001: 17). Krueger and Casey (2001: 17) are of the opinion that responses that are specific and based on participants' experiences should be given more weight than responses that are vague and impersonal. This is synonymous with the view of Murphy *et al.* (2010: 1) on focus groups units of analysis.

Murphy *et al.* (2010: 1) reveal that the units of analysis of focus group interviews should not be limited only to information that researchers view as important due to the response rates of the participants (anticipated themes), but should also cover issues that a participant clearly raises, states or illustrates from his/her personal experience (emergent themes). Atkinson (1983, cited by Bryman & Burgess, 2002: 6) recommends that such inconsistencies but sensitive information or issue (divergent views offer by different groups of individuals) may sometimes enable a researcher to end up generating new concepts. Atkinson (1983) adds that in such a situation, the researcher may occasionally have to relate his or her observations or findings to pre-existing notions or theories. Similar to this, Biggerstaff (2012: 197) argues that in qualitative data analysis, a researcher needs to put into consideration the results/information that are relevant to the existing literature in the study area. This view is supported by the opinion advocates by Yin (2014: 143) on pattern matching in qualitative analysis.

Yin (2014: 143) contends that in qualitative data analysis (case study), an analyst needs to relate the findings of the study with empirical or established facts (findings from related literature). Yin (2014: 142) is of the view that the pattern matching is essential as it has been observed that if adopted during qualitative analysis, the critics of internal and external validities observes in some strategies of qualitative data analysis such as the inductive approach will be overcome.

Based on these explanations, the content analysis proposed by the aforementioned researchers is adopted in this study, and the units of analysis consist of the frequency, extensiveness and specificity of comments or information from a group of designers that have been working together as a team for not less than five years across the various design projects. The units of analysis also consist of the relevance of the structural engineers' arguments, comments, information or opinions to the existing literature in the study area. Consequently, the summary of findings presents in section 5.4 and 5.6 (Chapter 5) of this study are based on the aforementioned units of analysis.

4.9 The Credibility of Research Findings

Saunders *et al.* (2009: 156) suggest two plausible ways that a researcher can adopt to determine the credibility of data namely: reliability and validity of the research strategy. Data is said be reliable if the findings and conclusions drawn from a study by a researcher can be replicated by another researcher that is doing the same research (Gray, 2014: 281). Yin (2014: 48) supports this view and contends that the main objective of data reliability is to be sure that if another researcher investigates the same study over again, the new researcher will be able to arrive at the findings and the conclusions drawn at by the former researcher. Yin (2014: 49) is of the opinion that one effective means of achieving reliability of data collected in a qualitative study is to document the procedures followed by the researcher in obtaining the data (the protocol).

In this study, the AR step-by-step procedures shown in Figure 4.2 of this report, as well as the focus interviews requirements or protocols proposed by Krueger and Casey (2001: 4), Stringer (2014: 111) (refer to Table 4.3 of this report), were duly observed by the researcher to ensure the reliability of the data generated in the course of this study.

Validity is the degree to which the research findings and conclusions conform to what the researcher actually set out to achieve (Saunders *et al.*, 2009: 157). Validity also indicates the extent to which the data collection techniques and the research design answer the research questions (Fellows & Liu, 2003: 157). It can also be said that validity indicates whether the instrument measures what it claims to measure (Fellows & Liu, 2003: 157). In a study conducted by Herr and Anderson (2005: 226), Tomal (2010: 204), Stringer and Genat (2004, cited by Ivankova, 2015: 260), it was observed that AR involves a researcher's personal observation, and analysis through the adoption of small samples or individual case studies. Therefore, the issue of validation is less important while compared to other research conducted with other methodologies (Herr & Anderson, 2005: 226; Tomal, 2010: 204). Similarly, McNiff *et al.* (1996 cited by Gray, 2014: 342) and Waterman (1998: 101) argue that the validation process in AR is strengthen by the 'to-ing' and 'fro-ing' processes in the AR spiral or cycles (plan, act/implement, observe, and reflect). This indicates that with several AR spiral for refinement of ideas and practices, action researchers may not require further data validity procedures (Gray, 2014: 342). Therefore, the validity of data obtained in the course of this study was strengthen by the focus interviews that were conducted three times in action planning and action taking phases of the QMAR conducted.

Further, literature shows that qualitative researchers have been criticized severally by other researchers such as the positivists on the extent of validity of the data generated, due to the few sample of the cases and the participants that are normally adopted or covered during the study. Premised on this criticism, Ivankova (2015: 260) points that on the basis of validity, findings from AR study may be compared with the results from other setting, which can be achieved by conducting further study through other research approaches such as attitudinal surveys or observation checklists on the data generated. The attitudinal surveys propose by Ivankova (2015: 260) was also adopted in this study to further enhance the validity of the data generated.

4.10 The Ethics of Action Research Study

Badger (2000: 201) states that qualitative studies such as AR is posed with few ethical dilemmas as it is based on a philosophy of collaboration for the mutual benefit of the researcher, and the participants. However, it is needful to know that AR is deeply embedded in an existing social organization, and failure to respect the general procedures of the organization may jeopardize the process of it improvement in a study (Gray, 2014: 342). Therefore, to avoid every form of jeopardy during this study, the researcher followed the usual array of requirements for negotiated access and confidentiality (Gray, 2014: 342). That is, before the commencement of this study, the consents and agreements of every group member in all the case study firms were obtained by the researcher in accordance to the ethical procedures governing research and publishing (Yin, 2009: 54; Saunders *et al.,* 2003, cited by Sutrisna, 2009: 56).

The permissions were first sought from the head of the human resources unit in each case study firm, thereafter, from the head of each group in the selected firms, and lastly from the individuals. The researcher also assured the group members in each firm the right to be anonymous throughout the study or even withdraw at any time due to any reason (Gray, 2014: 342).

4.11 Summary

This chapter has stressed on the philosophy that underpins this study as well as on the approach that was adopted to arrive at the methodological frame work. Also, the chapter has explicated extensively on the various steps that were adopted by the researcher for the collection of data so as to have a clear and unbiased analysis. In other words, the chapter provides a platform for the next stage of this study, which are data presentation, interpretations and discussion.

5.0 DATA INTERPRETATIONS AND DISCUSSION

5.1 Introduction

It has been explained in Chapter 4 of this thesis that the action research conducted is in different stages (Figure 4.1). This chapter therefore reports on the information obtained in the third and the fourth phases of the study. The chapter reports on the focus interviews and the chapter presents the data obtained through the qualitative method in action research (QMAR) conducted in the various case firms. The information obtained in the third phase of the study (problems identification) was analysed before that of the fourth phase (problems rectification or action planning). The strategies proposed by the participants in all the firms at the fourth phase of the study are based on the outcome of the information obtained in the third phase.

5.2 The Case Study Firms

It has been stated in Chapter 4 of this report that at the start of the QMAR, invitations were initially sent to eight consulting engineering firms in Bloemfontein. Six responses were obtained from the total of the eight firms in which invitations were initially sent to before the start of the study. This implies that two out of the eight proposed firms declined to participate in the study. The reason behind this as at the time of this study is that the personnel managers of the two firms that declined to participate in the study emphasized that the engineers that were supposed to attend to the researcher were not on ground. This was due to the fact that the jobs that were available in the firms were basically on hydro (water) projects. The personnel managers of the firms affirmed that the available staff might not be competent to provide the researcher the necessary information for the study.

It has been explained in Chapter 4 (section 4.4.7 of this study) that after the pilot study that was conducted in all the firms, the researcher could only gain access into only five out of the six case firms. This was due to the unexpected abdication of the team leader (chief engineer) of the sixth firm. As the group leader resigned his appointment with the firm, the response rates of the remaining members became poor. The researcher has no option than to remove the firm from the list of the cases. This left the researcher with the list of five firms out of the total eight in which invitations were initially sent. Krueger (1994, cited by Masadeh, 2012: 65) argues that there is no appropriate or specific number of focus groups for scientific research and that a researcher may continue running the study from one focus group to another until a clear pattern emerges or when subsequent groups produce theoretical saturation.

However, several authors, such as Krueger (1994), Burrows and Kendall (1997: 244), Evmorfopoulou (2007: 1), suggest that for clear and understandable research questions that yield similar opinions from different groups, the number of groups may be limited to only three or four. Based on the views of Krueger (1994), Burrows and Kendall (1997: 244), Evmorfopoulou (2007: 1), it can be said that the number of cases established for this study was quite adequate (see the demographic information of the selected cases in Table 4.4, Chapter 4 of this report).

5.3 Data Analysis

It has been stated in Chapter 4 of this report that the main instrument for data collection in the QMAR conducted is focus interviews. The reasons for the choice of the instrument have likewise been explained in the same chapter. However, before the analysis of the data obtained through the first phase of the focus interviews conducted, it is essential to briefly discuss on the information obtained by the researcher through a non-participatory observation (NPO) and documents of the previous executed projects in the firms. As emphasized in Chapter 4, two weeks to the commencement of the focus interviews exercise, documents of works executed by the firms in the past three years were reviewed. The problems in the construction phase of projects were noted by the researcher through the documents.

In the NPO session, the researcher observed the junior engineers and technologists leaving their respective offices to that of the senior engineers. They do this in order to submit paperwork to the senior designers for corrections and contributions. The researcher realized that the senior engineers pointed at one mistakes or the other on the paperwork for supplementary improvements. The outcomes of the reviewed documents, and the NPO enabled the researcher to build a picture of the anticipated data in the focus interviews exercise. This assisted the researcher to gain a clearer understanding of the study content for unbiased analysis (Stringer, 2014: 113).

5.3.1 Analysis of the first phase of the focus interviews data

This is the first phase of the focus interviews conducted in this study and it main objectives were to find out the various waste in the SDP; the causes of the waste, and the impacts of the waste on the design, and the construction phases of projects (Appendix 4).

(1) The phases in the structural design process

Participants in all the groups agreed that the SDP is made up of five distinct phases namely, the inception design phase (IDP), the predesign design phase (PDP), the detailed design phase (DDP), the construction phase (CP) and the close-out phase (COP). The highlighted phases in the SDP align to the five main phases of the construction design process (CDP) (Minnaar & Reinecke, 1993: 2; Melhado & Agopyan, 1996: 1; Dupagene, 1991: 24; Soto, 2007: 19; Al-Aomar, 2012: 109; Ko & Chung, 2014: 468). In all the groups, participants emphasized that these phases in the SDP are dependent on one another. This implies that error and mistake experienced in any one of the phases can lead to fault in a subsequent phase. This correspond with the view espouse by Ko and Chung (2014: 463) regarding the impact of design errors on the construction phase of a project.

(2) Value and non-value adding activities in each phase of the structural design process

Participants in the five groups agreed that several problems exist in each phase of the SDP. These problems are discussed as follows:

(a) Problems in the inception design phase of the structural design process

In groups A, B and C, participants stressed that it is in the IDP that the SDT reviews the architectural drawings, defines the scope of the work required, set up the necessary agreements and signs contract agreements between the client, the architect and the SDT. The opinions put forward by the participants in groups A, B and C concur to that of the participants in groups D and E. D_1 stated that …

"It is in the IDP that the design teams assess the architectural drawings."

To support D_1 statement, D_2 asserted that…

"The assessment is usually carried out so as to be able to establish the required project agreements among the various parties."

D_3 added that…

"…the agreements are established after series of meetings among the various actors…"

Premised on D_1, D_2 and D_3 opinions, participants in the group agreed that the agreements between the SDT, the architect and the client may include the scope, appearance of work, the necessary professional fees, method and time of payment. Similarly, in group E, E_1 declared that …

"*... the inception phase is the concept viability where basically the clients will inform the designers what he is planning to do, and where he is planning to do it. ..."*

E_3 stressed that …

"... it is in the inception phase that the architect and structural designers visit the site so as to understand the condition of the site ..."

E_4 opined that …

"... visitation to the site in the inception phase is necessary as it will enable the team to have premonition of the kind of problems such as civil or structural that may likely comes up in the construction phase ..."

E_2 added that …

"... the inception phase enables the designers to prepare a bill of quantity which enables the clients to have a brilliant estimate of the project and to know if he has a budget for the proposed project ..."

E_5 concluded that…

> *"The clients must agree with the estimated budget in the inception phase before the design team can continue with the design."*

Based on the opinions of the participants in all the groups, it can be said that the IDP of the SDP is important, as it is a phase where the SDT identifies the proposed site. It is a phase where issues related to imprecision, requirements, and needs are addressed by the SDT before the start of a new project. This implies that it is in this phase that the necessary agreements between the architect and the client and the SDT are established before the commencement of a new work. This is similar with what has been observed in the literature concerning some of the activities in the inception phase of the CDP (Jensen & Tonies 1979: 22; Melhado & Agopyan 1996: 502; Dupagene, 1991: 24; Soto, 2007: 19; Anderson *et al.*, 2006: 5).

The participants in all the groups emphasized that in the IDP of the SDP, the SDT occasionally advises the clients on the specific areas of work that can influence the project life cycle cost significantly, and provides the necessary information within the agreed scope of work to other consultant engineers that may be involved in a project. The participants discussed that the moment the necessary agreements have been established, SDT usually conducts the topographical survey of the proposed site by using the services of a professional land surveyor. The participants were of the opinions that the topographical survey of the proposed site enables the design teams to acquire a hands-on understanding of the conditions of the site, to determine its nature/size, and to obtain the necessary information on its terrain. In groups A, B and D, participants further declared that in the IDP, the SDT often reviews other existing structures/projects in the vicinity of the proposed site.

This declaration was notable among the participants in group C and E. In group C, C_2 stated that …

> *"... we do conduct site topographical survey and review the existing structures as well as access roads in the surrounding of the proposed site ..."*

C_4 supported C_2 and proclaimed that …

"...we do these activities in the inception phase of work through the service of Land Surveyors..."

C_3 added that …

"*... it is the responsibility of the Land Surveyors to conduct site topographical survey and other relevant activities during the site visits ..."*

E_1 accentuated that …

"*... before we can start any design and even before the architect can start his design, we must appoint Land Surveyor to carry out the topographical survey of the terrain ..."*

E_4 pointed that …

"*... we do appoint Land Surveyor for that and the information obtained is being provided to the architect and the structural design team electronically..."*

Based on the opinion of E_4, E_2 argued that …

"... there are times that the Surveyor can be appointed by the clients or through the architect ..."

Based on the opinions of the participants in all the groups, it can be concluded that in the IDP of the SDP, the SDT may also be obligated to oversee the processes of topographical survey of the proposed sites. It can also be concluded that the review of the existing structures in the vicinity of a proposed site in the IDP of the SDP enables the SDT to analyse the impacts of the existing structures on the anticipated project. This is consistent with the views express by Kent (2005: 3) and Anderson *et al.* (2006: 5) regarding the impacts of the existing structures on a proposed site.

Participants in all the groups also emphasized that in the IDP of the SDP, the SDT often conducts the geotechnical investigation of the proposed site. Notable among the groups' participants, A_1 emphasized that …

"...we often carry out the geotechnical analysis of the proposed site in the IDP, but it is the responsibility of the Geotechnical engineers..."

B_3 declared that …

> *"… the Geotechnical engineers may be employed by the SDT or the architect. At times, he may even be employed by the clients …"*

Remarkable in group C, participants stated at once that …

> "… *after site topographical survey, the SDT often conducts site soil test through the service of geotechnical engineers ..."*

The viewpoint of the participants in groups D and E is not dissimilar to the opinions of other groups. The participants in the two groups also agreed that in the IDP of the SDP, SDT also engages the services of a geotechnical engineer to assist in the establishment of the characteristics of the soil in the proposed site. The participants in groups D and E pointed that the quality/characteristics of soil in a proposed site plays a key role in projects. The participants were of the views that the characteristics of the soil in a proposed site enable the SDT to determine the soil capability to support the anticipated structure. This is synonymous to the emphasis of the participants in groups A, B and C that soil characteristics in a proposed site enable the designers to locate areas where obstacles such as foundation problem may likely occur or come up during construction. In all the groups, participants' indicated that after site investigations, the geotechnical engineers are expected to prepare a site report which will be handed over to the SDT for the necessary structural computations.

This implies that in the IDP of the SDP, the SDT also oversees the compilation process of a site report. The opinions of the participants in all the groups are in agreement with the findings of Aladejana *et al.* (2015: 3) and Department of Public Works and Services Government of the Northwest Territories (DPWSGNT), (2010: 3) concerning some of the benefits of geotechnical investigations of a proposed site.

When asked of the probable problems/challenges experienced in the IDP of the SDP, participants in group B highlighted that there are times that the SDT may have to wait for fund release from the client before the start of the structural work. Participants in groups A, C, D and E disagreed to this statement. A_1 pointed that…

"... I know is very possible for a client not to be financially buoyant before coming to the designers, but we have never experienced it in our firm ..."

C_3 stressed that…

"... for more than 10 years now that we have been in the system, our clients always come to us when they know they are financially buoyant ...."

D_5 maintained that…

"... I do not expect a client to come to the design team knowing fully that he is financially handicapped ..."

E_1 affirmed that …

"...for over 10 years that this firm has been established, our clients usually come to us only when they are set for business ..."

Participants in groups A, C, D and E are of the opinions that the clients are expected to be financially buoyant before coming to the design teams. Based on the opinions of the participants in all the groups, it can be concluded that lateness in the start of activities due to fund challenge is one of the seldom problems experienced by the SDT in the inception phase of the SDP.

Participants in groups B, C and D also emphasized on the issue of the excessive lead time (LT) during geotechnical investigations. The participants stressed that geotechnical investigations take approximately two months in most projects due to site location and the need for several soil tests. Participants in groups A and E did not agree that excessive soil tests, and it consequent LT in the IDP of the SDP is one of the design problems that needs to be addressed, or that requires action by the management. The participants argued that it is mandatory for designers to know the exact bearing capacity of soil in the proposed site, and, as such, they asserted that the professional tasked with this responsibility is obligated to take as many samples as possible during site visits, so as to arrive at a standard or acceptable result that is not compromised. Based on the views of the participants in all the groups, it can be concluded that excessive LT during geotechnical investigation is one of the probable problems experienced by the SDT in the inception phase of the SDP.

In groups A and B, participants' dialog on the problem of ineffective site workflow due to gaps in the topographical survey of the proposed site. However, participants in the groups argued that its tendency during the site topographical activities is very slim. Participants in groups C, D and E disagreed with this problem. The participants argued that such problem has never been experienced since they have been into practice within and out of the South African context. This means that ineffective site workflow is one of the least expected problems in the inception phase of the SDP.

Other activities that were initially disagreed or not perceived as waste in the IDP of the SDP, but were later confirmed, and agreed as problems or NVA by the participants in all the groups after the depiction of the value stream mapping (VSM) into the flow of activities in this phase (Figures 6.2 and 6.3 Chapter 6 of this study) are: delay to establish the scope of the work; excessive meetings especially in the project initiation phase; delay to analyse the project life cycle cost, delays to implement the contract agreement between the clients, and the designers; changes on the architectural drawings, excessive inspections or LT during the geotechnical investigation, poor site report; waiting for the site reports, and delays to establish the inception design documents.

(b) Problems in the predesign phase of structural design process

The PDP is the second stage of the SDP and its main objective according to the participants in groups B, C and E is to further review the architectural drawings for details understanding, finalize the project concept, establish structural predesign criteria, prepare the preliminary process designs/related documents suitable for costing, and clearly layout the procedures needed by the designers to complete the next phase of work (details design). This agreed to the opinions espoused by the participants in groups A and D.

A_4 stressed that…

> *"… we have to thoroughly study the architectural drawings so as to identify the various elements that we need …"*

A_3 proclaimed that…

"... we study the plan and sections to see where there is need for beams and columns ..."

A_5 added that …

"... we also study the architectural drawings so as to understand where there may be need for big windows and doors ..."

A_2 stated that …

"*... in the predesign phase of the SDP, the SDT thoroughly studies the architectural plan, brings out the general layout, the preliminary sizes, and the stability of the proposed structural elements ...*"

Based on A_2 expressions, A_1 said that …

"*... the preliminary sizes and the stability of structural elements such as columns, column footings, foundation, slabs, beams and roof that are suitable for costing by quantity surveyor (Q/S) are computed in predesign phase ...*"

In group D, participants opined that in the PDP of the SDP, SDT assesses the predesign criteria of the architectural drawings, establishes the necessary regulatory requirements/necessary building codes and incorporates them into the drawings. The views of the participants in all the groups can be compared with the expression of Minnaar and Reinecke (1993: 2), Anderson *et al.* (2006: 5), Soto (2007: 19), Ko and Chung (2014: 468) regarding some of the essential activities in the PDP of the architectural process.

Participants in groups A, D and E further discussed that the required structural computations in the predesign phase of the SDP are executed by the SDT in accordance to the requirements of the applicable building codes, as well as the outcome of the site soil tests. This means that the predesign computations cannot commence by the SDT without seen the results of the geotechnical investigation conducted in the inception phase of the SDP. This is correspondent with the views espoused by the participants in groups B and C. The participants in these two groups declared that without the geotechnical investigation results, the SDT will not be able to start the predesign computations. During this discussion, C_3 asserted that …

> *"...you cannot determine the preliminary sizing of your structural elements without first have your soil tests results..."*

while B_4 maintained that…

> *"... the design of every structure starts from the foundation to the roof level. You must wait for the outcome of your soil tests before starting your design ..."*

Hence, participants in all the groups are of the view that geotechnical report enables the structural designers to decide on the foundation type for a particular project, and to identify some of the unforeseen foundation problems that may likely come up during the site activities. This is assent with the findings of (DPWSGNT, 2010: 4) and Aladejana *et al.* (2015: 3) concerning some of the benefits of geotechnical investigations of a proposed site.

Also, in groups A, D and E, participants expressed dissatisfaction that architectural drawings are always incomplete especially in the areas of specifications for the column sizes, the footings and the slab thickness. To overcome this dissatisfaction, participants emphasized that the SDT often interact with the architect in the PDP so as to deliberate on the necessary modifications on the architectural drawings. This means that adjustment of the architectural drawings is another probable problem experienced by the SDT during SDP. Similarly, in groups B and C, the participants acclaimed that there are times that the architect and the SDT may have to attend design and consultant meetings so as to:

- Advise the architect on the necessary design/project modifications, and
- Advise the client on further survey, analyses, soil tests and site investigation that may still be required due to certain reasons such as changes in the architectural drawings.

Based on the opinions of the participants in all the groups, it can be concluded that mistakes or errors that are not discovered during the AP are often corrected in the PDP of the SDP. This is juxtaposed with what has been observation in the literature concerning problems that are not discovered in the design phase of a project as the main causes of rework and delay in the construction phase (Oyedele & Tham, 2007: 2090; Li *et al.*, 2008: 915; Osmani, 2008: 1147; Koskela *et al.*, 2013: 3; Ko & Chung, 2014: 463). Participants in all the groups declared that once the clients, and the architect are satisfied with the predesign computations of the project, the computations will be passed across to the chief engineer of the consulting firms for final review, after which the predesign documents will be prepared and established by the three parties. In all the groups, participants coincided that preliminary design documents, are the documents that are mutually approved and stamped by the clients, the architect and the SDT before structural designers can proceed to the DDP. This means that the predesign documents are the information or work assent by the client, the architect and the SDT to be appropriate for the next phase of the SDP.

In terms of the problems experienced by the team in the PDP of the SDP, participants in all the groups typically stressed on the ambiguities in the architectural drawings as the main challenges at this level of the work. In group C, participants emphasized mostly on the specification for large floor size. In the discussion, C_1 pointed out that …

> "*… large floor size can lead to long beam specification with consequent increase in project cost...*"

Based on $C_{1's}$ point of view, C_5 added that …

> "*...when the architect unknowingly specifies for large floor size in a project, it is the responsibility of the SDT to instruct or advise the architect to rework on the architectural drawings...*"

$C_3/_4$ stated at once:

> *"… we refer to it as design modification …"*

Participants in groups A and E emphasized mainly the columns. The participants declared that there are times that the architect may specify for less than the required number and sizes of the columns in a project. While in groups B and D, the participants explicitly stressed the specification for wrong slab thickness. Participants in groups C and D also debated that the problem of ambiguities in architectural drawings will remain in the system as long as communication gaps continue to exist between the SDT and the architect.

Further, participants in groups A, D and E accentuated on wrong structural computations or computation errors. The participants termed the highlighted problems as some of the problems in the SDP that required management immediate attention (firm management). Contrary to groups A, D and E observations, participants in groups B and C contended that wrong structural computations or computation errors in the PDP of the SDP are the norm, and that such errors should not be categorized as one of the design problems, due to the 'quality assurance' that will have been made by the management of the firm to attend to this menace in the subsequent phases. Premised on the responses of the participants in all the groups, computation errors or wrong structural computation can be established as one of the probable problems experienced in the PDP of the SDP.

Other activities that were later reaffirmed, and established as NVA or problems by the participants in all the groups after the depiction of the VSM into the current flow of the activities in this phase of the SDP (Figures 6.6 and 6.7 in Chapter 6 of this study) are: several meetings and disagreements between the architect and the SDT on the architectural drawings, modifications of the architectural drawings, delays to incorporate the necessary building regulatory and requirements into the project, several repeated structural computations; several printings of the paperwork; excessive supervisions and review of work by the chief or senior engineer, and delay to establish the preliminary design documents.

(c) Problems in the detailed design phase of the structural design process

Participants in all the groups emphasized that the main activities of the SDT in term of this phase is to determine and select the most suitable alternative solutions of the proportions, dimensions and connections of structural elements defined in the predesign phase so as to bring out the complete, perfect and final structural drawings and specifications for the proposed project. In groups A, D and E, participants added that the comments and observations that were made by the chief engineer in the predesign phase of the SDP are expected to be incorporated into the work in this phase before the SDT brings out the final structural drawings. This is similar to the views that was further espoused by the participants in groups B and C. The participants in groups B and C opined that in the DDP of the SDP, the SDT usually incorporates the necessary corrections, adjustment or observations into the work before bringing out the final drawings with the use of the auto card software. The participants affirmed that the corrections and adjustments may either come from the senior designer of the firm, the clients, and the architect or from other consulting firms that may be involved in the project. This means that design correction often take place before the final structural drawings in the DDP of the SDP.

In all the groups, participants declared that once the final drawings are achieved, the designer (junior structural engineer) is responsible to pass the drawings across to the senior/chief engineer of the firm for approval and thereafter, to the project director. This declaration was earlier observed by the researcher during the NPO exercise that was conducted in all the firms. Further, participants in all the groups pointed that in a small consulting engineer firm, a senior or chief engineer also does the work of a project director. Whereas in a large organization, the services of a senior or chief engineer is dissimilar to that of a project director. That is, in a small firm, final approval of the structural drawings is being achieved through the services of a senior or chief engineer only, while in a large firm, the approval is done through the services of a senior or chief engineer, and thereafter, a firm project director.

In groups B, C and E, participants proclaimed that approval of structural drawings by the senior engineer and the project director may take approximately two weeks for minor projects and four to five weeks for the major ones. While in groups A and D participants declared that in ideal situation, approval of final structural drawings may take just a week for minor projects, and approximately a month for the major ones. This means that final approval of structural drawings is not always guarantee or given immediately due to some further corrections/alterations in this level. In all the groups, participants asserted that after the approval of the final drawings, the SDT subsequently establishes the detailed design documents and thereafter, prepare the construction drawings that will be handed over to the contractors.

Participants in groups D and E elaborated that the construction drawings are more detailed in dimensions while compared to the detailed drawings. D_2 highlighted that …

"*...in every project, apart from the detailed drawings, there is need for construction drawings for clarity of information during construction activities ...*"

Premised on D_2's opinion, other participants in the group declared at once that …

"*… the essence of the construction drawings is to make site activities clearer to the contractors ...*"

E_1 stated that…

"... contractors may find it difficult to interpret the structural drawings correctly on the site that is why we still have to produce the construction drawings that is more detailed in dimensions ..."

E_3 supported E_1 and pointed out that …

"*... the structural drawing is too complex to interpret by the contractors on the site ...*"

Based on E_1 and E_3's opinions, participants in the group accorded that the purpose of the construction drawings is to make the site activities clearer to the contractors. There is no doubt about this statement as it has already been observed by the researcher during the review of the record of the previous work executed by the various firms. The researcher observed a clearer difference in term of dimensions in the detailed (final) design and the construction drawings in all the case study firms.

When asked on the various problems experienced in this phase, participants in all the groups avowed that design corrections, excessive printings of draft/paperwork, inability to complete tasks as earlier scheduled, and waiting for the approval of final drawings are the key problems in the DDP of the SDP. These are similar with the findings of Simms (2007: 2), Song *et al.* (2008: 12), Hwang (2009: 187), AbdelSalam *et al.* (2010: 749) and Gatlin (2013: 1) concerning some of the NVA activities in product/engineering design. In groups A and D, the participants argued that the highlighted problems will persist in the system for as long as work hierarchy remains a priority for the firm. That is, where the less experienced junior designers are expected to carry out the main tasks (design computations), while the experienced senior/chief engineer assumes responsibility for supervisions only. Also, participants in groups A and C discussed on the problem of redesign.

However, participants in group A further declared that the problem is not common in practice due to the quality assurance that is made available in the system. During this discussion, A_1 stated that …

> "… *redesign seldom occurs in practice …"*

A_5 restated that …

> *"… yes, redesign in detailed design phase is not applicable to every project …"*

A_2 continued with the discussion and elaborated that…

> *"…it may only occur when the nature of the building changes due to changes in the clients requirements …"*

In order to buttress A_2 opinion, A_3 illustrated that …

> *"… if the clients initially request for a 4-stoery building and suddenly changes his mind that he wants additional floor on top while the design teams have almost completed their work …"*

A_4 concluded the discussion and stressed that …

> *"… in that case, the designers may have no option than to redesign the project completely …"*

In groups B, D and E, participants opined that redesign is the least expected problem in the DDP due to the experienced designers and quality assurance procedures in the firms.

Based on the arguments of the participants in all the groups, it can be concluded that redesign is one of the least expected problems in the DDP of SDP. That is, the probability of occurrence of redesign in the detailed phase of the SDP is very slim. When VSM that was depicted on the activities in this phase of the SDP (Figures 6.9 and 6.10 Chapter 6 of this study), the participants in all the groups realized that the problems or NVA activities in the DDP of SDP are more than their perceptions. The NVA activities or problems that were further cleared to the participants through the adoption of this tool in this phase includes delay in selection of the suitable structural elements computed in the PDP, time wasted to incorporate PDP comments into the structural design, several review of final drawing by the senior designers, delay in the production of the construction drawings, delay to establish the detailed design documents, and time and paper wasted in the production of the draft and the final drawings.

(d) Problems in the construction phase of projects

Literature shows that contractors are predominantly responsible for the CP of every project (Alarcon & Mardones, 1992: 2; Murdoch & Hughes, 2007: 1). Therefore, it is anticipated that in an ideal situation, the construction contractors should be able to effectively handle the execution of projects without the presence or a representative of the SDT. However, from the study conducted, participants in all the groups affirmed that a member of the SDT of the consulting firm is at one time or another, needed on the site especially at the start of every new task. According to the participants, the need for the presence of the designer is to provide final certifications, answer questions, provide interpretation of areas that are not clear to the contractors, prepare the schedules of predicted structural cash flow, inspect the works and issue practical completion and defects lists.

Due to these essential requirements of the SDT on construction sites, participants in groups A and B emphasized that in every project especially the large ones, designers have already made it obligatory to visit their sites at least two times in a month so as to attend to the highlighted problems in the construction phase of projects, and also attend regular site, technical and progress meetings; advise the contractors on the agreed quality assurance plan on works related to the SDP; control the measurement and quality of work; clarify details and descriptions during construction as required; arrange for the delivery of all test certificates and statutory (regulatory) and other approvals as the built drawings and operation manuals.

Likewise, in groups C, D and E, participants stressed that the design team are habitually compelled by the management of the firms to visit their respective sites at least two to three times in a month so as to control or reduce the excessive RFIs from the contracting party, and to inspect the site works for conformity to the contract documentations. Participants in groups D and E added that due to so many construction issues in the past especially in large and highly challenging projects, the management of the firm has already made it mandatory for the SDT to visit the site frequently. That is, as many time as needed. This means that in a large project, the design teams are obligated to visit their respective site on a daily basis. That is, from the start to the completion of the site activities. Also, participants in all the groups affirmed that in a large project, the state or the local statutory authority often requests for the presence of a structural engineer on the site from the start to completion of work so as to oversee every aspect of structural related work, and issue structural engineering construction documents to include reinforcing bending schedules, detailing, specifications of structural steel sections and connections.

The participants also agreed that in a small project, it is the clients that normally request the service of a structural engineer so as to provide certification for every new task; approve every form of claim order; requisition; change order and rework. The opinions of the participants in all the groups are in agreement with the findings in the literature on the need for supervisions in every phase of new task during site activities (Sunjka & Jacob, 2013: 646; Dvya & Ramya, 2015: 47).

On the aspect of the probable problems experienced in this phase, participants in all the groups opined that variations or change orders, ineffective communication flow between the SDT and the construction contractor, excessive RFIs, excessive writing of site instructions, and excessive waiting times during structural reinforcement constitute the main problems in this phase. The participants declared that excessive RFIs and writing of site instructions can occur several times especially in a large project such as commercial or non-residential (multi-storey) and industrial buildings.

Participants in groups B, D and E pointed on rework as another habitual problem in the CP. The participants accentuated that rework may occur several times in a large and highly challenging project such as multi storey buildings. This is parallel to the opinions of the participants in groups A and C. The participants in groups A and C viewed that rework occurs frequently especially in high rise buildings. Participants in all the groups declared that redesign during construction activities is another plausible problem. However, the participants asserted that with the exception of redesign due to changes in the client requirements, the tendency of other forms of redesign during site activities is very slim. The participants in group B argued that several supervisions on the site waste time. The participants deliberated mostly on the aspect of formworks and rebar cage that need to be examined by the engineer at the start and completion before the commencement of concrete work. This is not amazing as studies by Sunjka and Jacob (2013: 644), Dvya and Ramya (2015: 47) reveal that interruption due to supervisions is one of the causes of delay in construction projects.

However, participants in groups C and D did not perceive site supervisions as being excessive. The participants are of the opinions that it is essential for structural engineers to carry out all forms of supervisions on site so as to prevent on-site mistakes. Such on-site mistakes that are related to structural design according to the participants in group C are wrong fabrication of formwork, rebar cage and reinforcing steel. Participants in group D specifically stressed on inadequate spacing of structural reinforcing materials as such on-site mistakes that can lead to reworks and its consequents. Such consequents, according to the participants, include materials wastage, poor quality of construction and increase in the estimated cost of a project. These also correspond to the findings of Mastenbroek (2010: 22) regarding the impact of rework on construction projects.

The insights of the participants in groups C and D corresponded with the perceptions of the participants in groups A and E. In groups A and E, the participants declared that it is mandatory for the design team to investigate most of the on-site activities so as to prevent the problem of excessive cutting and fabrication of structural reinforcing material that are prevalent in every construction site.

(e) Problems in the close-out phase of projects

Participants in all the groups agreed that the close-out phase (COP) in every project is the handing-over stage where final measurement, documentations and drawings (built drawings) are handed over to the clients and the various construction stakeholders for their records. Some of the activities of the SDT in this phase as put forward by the participants in all the groups are to:

- Inspect and verify the rectification of defects;
- Receive, comment and approve relevant payment valuations and completion certificates, and
- Prepare built drawings and documentations.

The above-stated activities in the COP correspond to the findings in the literature regarding the various activities in the COP of the CDP (Jensen & Tonies 1979: 22; Dupagene, 1991: 24; Melhado & Agopyan 1996: 502). This study found that the COP experiences limited problems. Consequently, the researchers shall not discuss this aspect any further.

(3) The factors that necessitate waste in the structural design process

(a) The inception design phase

While trying to address this question during the interview session, B_3 discussed that…

> "… at times, *the design teams may have to wait for fund release from the clients before the start of the structural activities …"*

To support the view of B_3, B_5 stressed that …

> *"… this sometimes takes time as the clients occasionally hesitate whether to proceed with the project after seeing the estimated cost of the project prepared by the Quantity Surveyor …"*

Based on these emphases, the participants in group B agreed that lateness in the release of fund by the clients is the key factor responsible for delay in the start of the structural activities. This is similar with the findings of Aibinu (2006: 132), Assaf (2006: 349), Divya and Ramya (2015: 49), Sunjka and Jacob (2013: 644) concerning the delay constitute by clients in the release of fund during the construction activities.

In group D, D_4 emphasized that …

> "*… there are times that we may agree or plan to start work by January and by February we may still not be able to start the work …"*

D_1 agreed with the discussion and asserted that …

> *"… this occasionally happens when the clients refused to communicate the design teams after awarding the contract …"*

Centred on these views, the participants in group D concurred that indecision or slow decision making by the clients is the main factor responsible for delay in the start of structural activities. This opinion also assents with the views espouse by Chan and Kumaraswamy (1997: 55), Faridi and El-Sayegh (2006: 1167) regarding the delay constitute by clients in the design phase of projects. In group A and E, the participants also attributed the problem of lateness in the start of the structural activities on the clients. The participants pointed that there are times that structural activities may not start as programmed due to sudden changes in the clients' requirements on the proposed project. This is tantamount with the opinions of Koushki *et al.* (2005: 1) and Sweis, *et al.* (2008: 668) concerning the delay constitutes by the client in the construction phase of projects.

In group C, the participants argued that delay in the start of structural activities is due to some design changes necessitate by the architect (design modification). This is in line with the viewpoint of Al-Kharashi and Skitmore (2009: 3), Alsendi (2005: 22) on the delay constitute by the architects in the design phase of projects.

Further, participants in groups A and B acknowledged that ineffective site workflow or difficulties in accessing the site freely by the various construction actors during the site topographical survey is mainly due to sloppy, rocky, valley or high hills surfaces in a proposed site. With respect to this problem, participants in groups C, D and E maintained that that they have never experienced it since they have been in the system. On the aspect of several soil tests, participants in groups B, C and D asserted that the problem occurs when the soil in the proposed site is of a different nature. That is, when the proposed site has unstable soil. Participants in groups C and D added that the problem of several soil tests also occurs when the proposed site is situated in an environment where there are no existing structures similar to the proposed one. The participants proclaimed that in such a situation, the geotechnical engineers in charge of the soil test may find it difficult to make certain assumption that could reduce the number of the trial pits required. This means that the engineers will have no option than to conduct the tests as recommended in the various geotechnical investigation guides. This is corresponding with the findings of Aladejana *et al.* (2015: 3) concerning the procedures for conducting the geotechnical investigation of a proposed site.

In group A and E, the participants maintained that several soil tests is not a problem that should warrant discussions among the various project actors as it is mandated for designers to conduct the necessary soil tests before structural computations can commence. Participants in all the groups opined that delays to establish the scope of the work, implement the contract agreement between the client, and the designers, delay in analysing the project life cycle cost and to establish the inception design documents are mainly due to lateness in the completion of inception design activities as a result of several challenges experienced by the structural designers in the phase. Other factors that may be responsible for unnecessary delays in this phase as emphasized by the participants in groups B, C and E are poor architectural briefing and several changes in the architectural drawings, and delay to understand the scope of the work.

On the aspect of poor site report, participants in groups C, D and E attributed the problem to several vague assumptions made by the geotechnical engineers during site investigations. This is accords with the information raised by the participants in groups A and B. The participants in groups A and B stated that poor site report occurs in the IDP of the SDP when the data provided by the Geotechnical engineers is contrary to the existing knowledge or expectation of the SDT. Participants in all the groups proclaimed that SDT occasionally waits for site report if the report prepared by the geotechnical engineer needs to be corrected due to certain mistakes. Participants also declared that the design team may have to wait for site report if the proposed site is located in a remote environment where the necessary facilities for the site soil tests cannot be easily assessed. Table 5.1 provides the summary of the opinions of the participants on waste and its causes in the IDP of the SDP.

Table 5. 1: Waste in the inception design phase of the structural design process

Waste	Causes	Source (s)
Lateness in the start of the activities in the SDP, and several meetings especially in the initiation phase of a project	Waiting for fund release from the clients	Group B
	Indecision or slow decision making by the clients	Group D
	Changes in the client requirements	Groups A and E
	Changes necessitate by the architect	Group C
Ineffective site workflow during the topographical investigations of the proposed site	Ineffective site workflow or difficulties in accessing the site freely by the various construction actors during site topographical survey is due to gaps in topographical survey. Such gaps includes sloppy, rocky, valley or high hills surfaces	Groups A and B
Several soil tests and several inspections (excessive LT) during the geotechnical investigation of the proposed site	Soil tests may have to be repeated two or three times before satisfactory result is obtained, especially when the proposed site has unstable soil.	Groups B, C and D
	Several soil tests may also occur if there are no existing structures similar to the proposed one in the proposed site	Groups C and D
Delay to establish the scope of the work, implement the contract agreement between the client and the engineers, analyse the project life cycle cost, and to	Lateness in the completion of inception design work as a result of several challenges experienced in the phase	All the groups
	Poor architectural briefing, several changes in the architectural drawings and delay to understand the scope of the work	Groups B, C and E

establish the inception design documents		
Poor site report	This occurs due to several vague assumptions made by the geotechnical engineers during geotechnical investigations	Groups C, D and E
	It may also occur when the information provided by the engineer is contrary to the opinion of the SDT	Groups A and B
Waiting for the site report	It may occur when the proposed site is located in a remote environment	All the groups
	It may also occur if the report prepares by a geotechnical engineer needs to be corrected due to certain mistakes	All the groups

(Author, 2016)

(b) The predesign phase

Participants in all the groups pointed out that ambiguities in architectural design such as wrong specifications of materials, slab thickness and sizes and column sizes are mainly due to poor or inadequate communications between the architect and the SDT during the AP. This is corresponded with the findings of Mohammad (2012: 22), Nagapan *et al.* (2012: 22), Al-Hajj and Hamani (2011: 221) relating to the causes of defects in construction projects. Also, participants in all the groups acknowledged that ambiguities in the architectural drawings are responsible for problems such as disagreements between the architect and the SDT, incessant meetings among the various parties, architectural design modifications and unnecessary waiting times during the modifications exercise.

Based on the opinions of the participants in all the groups, it can be concluded that errors/mistakes that are not detected in the architectural phase are the main causes of design modifications (architectural) in the PDP of the SDP. Participants in groups A and D accepted that computations errors/wrong computations occur in the PDP of the SDP mainly due to human error (mistake). During this phase of the interviews, D_2 observed that …

> *"… mistakes can happen at any time. We are all human and that is why we double check every aspect of the structural calculation …"*

A_2 emphasized that …

> *"… no designer is 100% perfect. Mistake can occur at any time during structural calculations due to human nature, but am very sure before the work goes to site one of the designers will detect the mistake …"*

The impressions of the participants in groups B, C and E are similar to those of A and D. The participants in groups B, C and E are of the opinion that the aforementioned problems may occur in the PDP of the SDP if the SDT misinterprets or not strictly adheres to the required building codes.

In all the groups, participants contended that excessive meetings and disagreements occur between the architect and the SDT when the two parties attempt to clarify every unclear piece of information on the architectural drawings. The participants in groups A, C and E declared that the disagreements can also occur when the architect perceives that the opinion put forward by the SDT may likely affect the aesthetic aspect of the proposed building. C_3 stated that …

> *"… disagreement is actually the beauty of the job as the architect may initially not want to agree with the engineer opinion due to certain reasons most especially on the aesthetic aspect of the building …"*

C_1 added that …

> *"… it is actually a team work and most at times, we do not normally see it as disagreement but as discussions…"*

Participants in all the groups attributed the problem of design modifications to incomplete information/specifications on the architectural drawings. This agrees with the findings of Aibinu *et al.* (2006: 667), Ismail *et al.* (2012: 4969), Halwatura and Ranasinghe (2013: 1) concerning the main causes of modifications on the architectural drawings.

Further, during the interviews, A_3 opined that …

> "*… you cannot do anything when the architect is trying to carry out some changes on the architectural drawings due to the comments made by the SD T…"*

B_2 emphasized that …

> *"… if you continue with some aspect of work while the architectural work is under modifications just because you want to gain time, you may end up spending more time …"*

C_1 stated that …

> *"… when you try to gain time and continue with some aspect of the structural works while the architectural work has not been finalized by the design teams and the clients, you may end up redoing some work …"*

D_1 stated that …

> *"… I think is better to wait for finalization of architectural work among the parties involve before the proportioning of member sizes in PDP…"*

E_4 pointed out that…

> *"… when the architect is trying to rectify the drawing, you have to wait for him. You can only proceed with the structural work after the architect finishes his rectifications …"*

The participants in all the groups accorded that unnecessary waiting time arises in the PDP of the SDP during the modifications of the architectural drawings. This is in agreement with the opinions of Nagapan *et al.* (2012: 23) regarding design modifications (architectural) as the main causes of delays/unnecessary waiting time in projects. Participants in groups A and C emphasized that the problems of several, lengthy and repeated structural computations are due to lack of the suitability of the existing technology. That is, every structural work is unique in nature and must be conducted afresh. This corresponds with the views of the participants in groups B, D and E. The participants in groups B, D and E argued that computations of structural elements on previous projects cannot be used for a new one. This means that in every structural project, designers are required to perform the necessary computations as recommended in the various design guides. The opinions of the participants in all the groups are synonymous with the view espouse by Ren *et al.* (2008: 752) regarding some of the root causes of delay in engineering projects.

In groups A, B and E, the participants termed the problem of several printings of paperwork during structural process mainly on human errors/mistakes, whereas in groups C and D, the participants aligned the problem to the complexity of the architectural drawings. The participants argued that several mistakes are bound to occur during structural computations when the architectural drawing is too complex to be interpreted by the SDT. This means that complexity in the architectural drawings is the main causes of several printing of paperwork during SDP. Participants in all the groups also stressed that excessive supervisions in the PDP occur due to the lay down principles in the consulting firms. That is, the senior engineer needs to cross check every segment of the activities carried out by the junior designer before moving to the succeeding phase.

In all the groups, the problem of delay to establish the preliminary design documents is attributed to the delay experienced by the team in completion of predesign activities. The participants declared that the SDT often find it difficult to complete work as scheduled in this phase due to the probable problems experienced by the team during the various activities. Table 5.2 provides the summary of the opinions of the participants on waste and its causes in the PDP of the SDP.

Table 5. 2: Waste in the predesign phase of the structural design process

Waste	**Causes**	**Source (s)**
Ambiguities in the architectural drawings	Lack of communications between the architect and the SDT during the architectural process	All the groups

Several meetings and disagreements between the architect and the SDT	Disagreement and several meetings comes up between the SDT and the architect in attempts to clarify information on areas such as number and sizes of columns required for the proposed structure	All the groups
	Disagreement also occurs when the opinions of SDT may likely affect the aesthetic aspect of the proposed structure	Groups A, C and E
Modifications of the architectural drawings	Incomplete information and specifications on the architectural drawings	All the groups
Excessive waiting time during structural design activities	Excessive waiting time occurs during structural design activities due to the modifications of the architectural drawings	All the groups
Several repeated structural computations	This is due to lack of suitability of the existing technology; every structural work is unique in nature. That is, computations of structural elements on previous projects cannot be used for a new one	All the groups
Incorrect information or wrong structural computations	These occur due to errors and mistakes (human error) made by the SDT during the computations of the structural elements.	Groups A and D
	Misinterpretation and not strictly adhere to the required building codes	Groups B, C and E
Several printings of paperwork	Mistakes (human error) by the SDT during structural design.	Groups A, B and E
	Complexity in the architectural drawings	Groups C and D
Excessive supervisions of work by the chief engineer	This is due to the lay down principles in the consulting firms; the senior engineer needs to cross check every segment of work carried out by the junior engineer before moving to the next phase of work	All the groups
Delay to incorporate the necessary building regulatory and requirements into the project and establish the preliminary design documents by the project actors	This occurs mainly due to lateness in completion of predesign activities as a result of the problems experience in the process by SDT	All the groups

(Author, 2016)

(c) The detailed design phase

Participants in all the groups concurred that errors/mistakes by the SDT specifically on critical areas at the processing of the structural drawings are the main factors responsible for design corrections, excessive printing of draft/paperwork and lateness in the completion of tasks as scheduled or programmed in the DDP of the SDP. This means that errors or mistakes during the SDP constitute corrections, which consequently lead to several printings of paperwork. These are synonymous with the opinions of Ohno (1988: 45), Simms (2007: 3), ZES (2010: 4), Gatlin (2013: 1), Ko and Chung (2014: 463) regarding errors, omissions or mistakes as the main causes of corrections in engineering design.

Participants in groups B and E stated that the problem of waiting for approval of final structural drawings may be due to the laxity of the senior/chief engineer of the firm. B_3 proclaimed that…

> *"… the junior engineers/technologist are responsible for the execution of the primary aspects of work while the senior designers are responsibility for supervisions only …"*

To buttress the opinion of B_3 during the discussions, B_4 stressed that …

> *"… due to this reason, some senior designers usually get occupy with several activities and may find it difficult to be familiarized with the design right from onset …"*

Premised on B_3 and B_4's opinions, participants in group B emphasized that the senior designers tend to be fully familiar with the project only when the final drawings get to their desk for approval and of such, seldom leads to approval delay. Equally in group E, the participants declared that the approval of the final structural drawings seldom takes time if the senior designer is not fully familiar with the projects and tries to do so when the work finally get to his desk for approval. This means that poor interaction between the chief/senior engineer and junior engineer/technologist is the main causes of delay in the approval of final structural drawings. This coincides to the speculations of the participants in groups A, C and D. Participants in these three groups affirmed that inadequate or poor communication between the senior and the junior engineers or the technologists is the main factor that is responsible for delay in the approval of final structural drawings. The assumptions advocated by the participants in all the groups are corresponded with the findings of Ren *et al.* (2008: 751), Nazech *et al* (2008: 19), Al-Hajj and Hamani (2011: 221), and Hashemi *et al.* (2014: 2212) relating to poor or inadequate communication as the main factor that is responsible for unnecessary delay in the design phase of projects.

The participants in groups B and D highlighted that redesign in the DDP of the SDP may only occur when a structural element that is wrongly computed in the PDP is perceived in the DDP. The participants emphasized that the wrong computations may be due to mistakes, errors or certain vague assumptions made by the designers in the PDP of SDP. The participants stressed that when this happened, the designers may have no preference than to cross check the necessary computations in the PDP and thereafter, recomputed the work. This means that errors or mistakes that are not spotted by the designers in the PDP are the main causes of redesign in the DDP. This is synonymous to the views espouse by AbdelSalam *et al.* (2010: 749) regarding the problems that are not detected in the design phase of a project as the main causes of waste in the construction phase. In groups A, C and E, the participants maintained that redesign may only occur in the DDP of the SDP if there are changes in the clients' requirements.

Participants in all the groups agreed that delay establishing detailed design documents in the DDP of the SDP is due to the problems experienced by the SDT in the phase, while the problem of several copies of the final drawings is ascribed by the participants to one of the existing principles of the respective firms. That is, it is the laid-down principle of the firms that all the project actors should be provided with the copies of the final drawings for documentation purpose. Table 5.3 indicates the summary of the opinions of the participants on waste and its causes in the DDP of the SDP:

Table 5.3: Waste in the detailed design phase of the structural design process

Waste	**Causes**	**Sources**
Design corrections, several review of the design by the senior designers, excessive printings of the draft and paperwork and lateness in the completion of tasks as scheduled	Errors/mistakes by the SDT in critical aspects while structural drawing is in progress	All the groups

Redesign	Redesign occurs when a structural element that is wrongly computed in the predesign phase is noted in the detailed phase of work.	Groups B and D
	It can also occur when certain vague assumptions made by designers in the PDP is detected in the DDP	Groups B and D
	It can occur due to changes in the clients requirements	Groups A, C and E
Waiting for the approval of final drawings from the senior/the chief engineer of the firm	This may be due to the laxity of the senior or chief engineer	Groups B and E
	Poor interaction between the chief or senior engineer and junior engineers or technologists	Groups B and E
	Inadequate or poor communication between the senior and junior engineers and technologists	Groups A, C and D
Delay in selecting the suitable structural elements computed in the PDP, incorporate other consulting requirements into the project, prepare the design development drawings and specifications, produce the construction drawings, and to establish the detailed design documents	These are due to all the current problems experienced by the SDT in this phase of the SDP	All the groups
Several copies of the final drawings	This is due to some of the existing principles of the consulting engineering firms in the study context.	All the groups

(Author, 2016)

(d) The construction phase

Participants in all the groups acceded that lack of or inadequate involvement of construction contractors and client in the design stage of the structural activities is the main causes of variations or change orders, ineffective communication flow between the SDT and the construction contractor, excessive RFIs, and excessive writing of site instructions in the CP of a project. Participants in all the groups also attributed the problem of excessive waiting times specifically during structural reinforcement to complexity in some technical aspect of the structural drawings. The participants argued that construction contractors often find it difficult on the sites to interpret certain aspects of the drawings such as top reinforcement during the construction of foundation and stairs, and of such, lead to unnecessary waiting during these activities.

Participants in groups B and D acknowledged that reworks usually take place during site activities when the contractors miss interpreted the structural drawings. According to the participants, such miss interpretations includes wrong fabrication of the formwork, rebar cage and reinforcing steel, inadequate spacing of structural reinforcing materials and excessive cutting and fabrication of structural reinforcing materials. This is consistent to the views of the participants in groups A, C and E. The participants in these three groups emphasized that reworks occur during site activities due to lateness in identification of the design errors. That is, most contractors identify errors or mistakes in the design after tasks have been executed or completed and are such, constitute reworks during site activities. This is similar with the observations of Zhang (2009: 8), Hwang *et al.* (2009: 187) and McDonald (2013: 1) concerning the causes of rework in construction projects.

Participants in groups A and E also accentuated that reworks during site activities may occur due to improper or inadequate supervision of work by the contractors. The participants argued that there is occasion that vital aspects of work may be subcontracted to nominated specialized subcontractors, and once these subcontractors are not properly coordinated or guided by the principal contractor, reworks are liable to occur in projects. This is coexisted with the findings of Faridi and El-Sayegh (2006: 1167) relating to the significant factors that are responsible for reworks in construction projects.

On the aspect of redesign during site activities, participants in all the groups declared that it might only occur when there are some changes in the clients' requirements in the CP. Participants in group C added that it may as well occur when there are unexpected foundation problems. The opinion of the participants in group C is consistent with the view espouses by Lo *et al.* (2006: 636) regarding unforeseen site problems as the main causes of delay in civil engineering projects. In groups D and E, participants also perceived that lack of or unavailability of the materials initially specified by the designers as the main cause of redesign in the CP of projects.

In all the groups, participants agreed that excessive supervisions occur during site activities due to the need for the industry to comply with the necessary regulatory authorities i.e., there must be supervision in every phase of new task. This implies that for effective construction there must be continuous supervisions by the structural engineers of the consulting firms especially in the start and completion of every new task. This is accorded with the findings of Sunjka and Jacob (2013: 646) regarding over-inspection (excessive vigilant) during construction activities. Table 5.4 gives the summary of the opinions of the participants on waste and its causes in the CP of projects.

Table 5.4: Waste in the construction phase of projects

Waste	**Causes**	**Source (s)**
Variation or change order, excessive RFIs, ineffective communication flow between the SDT and the contractors and excessive writing of site instruction	Lack of involvement of construction contractor and clients in the design stage of the structural activities	All the groups
Construction reworks	Wrong interpretation of the structural drawings by the contractors	Groups B and D
	Lateness in identification of design errors or omission on construction site	Groups A, C and E
	Improper or inadequate supervisions of work by the contractors	Groups A and E
Excessive waiting time during structural reinforcement	Complexity in structural drawings.	All the groups
Redesign	Changes in the clients' requirements in the CP of projects	All the groups
	Unexpected and unforeseen foundation problems	Group C

	Unavailability of the materials initially specified by the designers	Groups D and E
Excessive supervision of work	This is due to the need for the contractors to comply with the necessary regulatory authorities i.e., there must be supervision in every phase of new task	All the groups

(Author, 2016)

(4) Occurrence of waste in structural design process

When asked about the frequency of occurrence of the identified waste in projects, participants in all the groups emphasized that ambiguities in architectural drawings, disagreement between the SDT and the architect, design modifications and unnecessary waiting time due to design modifications may ensue two to four times in simple residential buildings such as two or three bedroom duplex; five to eight times in commercial multi-storey buildings such as shopping mall and four to six times in industrial or factory buildings. In terms of wrong computation or computation errors and ambiguities in structural, the participants stressed that such problems may occur one or two times in simple residential projects; four to five times in commercial multi-storey buildings and two to three times in industrial buildings. Participants in all the groups argued that several printings of paperwork may occur as many times as possible but on an average of three to four times in simple residential buildings; seven to nine times in commercial buildings and five to six times in industrial projects.

The participants in groups A and B alleged that excessive RFIs may range from 17 to 20 times in a month specifically in large and highly challenging commercial projects such as high rise buildings; six to eight times in simple residential projects and 11 to 13 times in industrial buildings. These are consistent to the contentions of the participants in groups C, D and E. The participants in these groups proclaimed that excessive RFIs may occur right from the start to the completion of work, especially in multi-storey buildings; five to seven times in simple residential buildings and 10 to 12 times in industrial projects. Participants in all the groups are of the opinions that on-site rework is liable to occur several times due to inadequate supervisions. However, if the supervisions rate is fair, participants debated that the chances of it occurrence may be slightly. Based on the knowledge of the previous work that have been executed, the participants in all the groups speculated that on-site rework may range from one to two times in simple residential buildings; three to five times in commercial projects and two to three times in industrial buildings.

On the aspect of several on-site supervisions, participants declared that it is on an average of eight to nine times in simple residential building; 20 to 22 times in commercial or high rise buildings and 14 to 16 times in industrial buildings. Based on the information obtained from the participants in all the groups during the focus interview exercise, Figure 5.1 presents the average frequency of waste in different projects. In the figure, Project 1 represents construction of a simple residential building, while Projects 2 and 3 represent construction of non-residential (commercial) and industrial buildings:

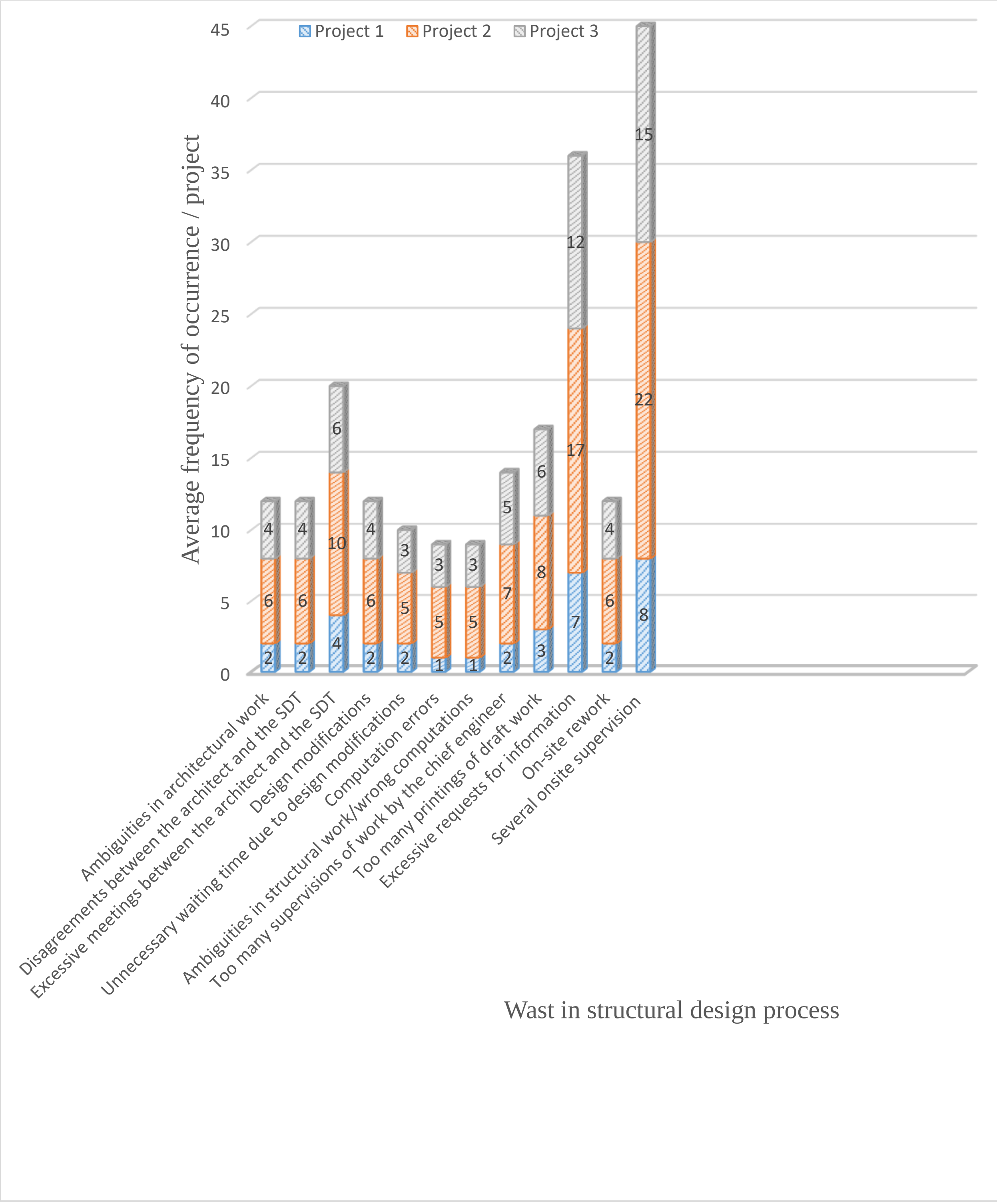

Figure 5.1: Frequency of occurrence of waste in three different construction projects (Author, 2016)

As can be observed in the figure, the probability of occurrence of waste in two and three-bedroom duplex is negligible but high in non-residential and industrial buildings. This means that waste occurs in every form of project but however, differs in magnitude.

(5) Impacts of waste in structural design process

Before the presentation, interpretation and discussion of data obtained on the impacts of the SDP waste on projects, it is pertinent to first classify the waste into different categories. This is necessary as construction management literature shows that waste in projects are often divided into seven categories namely: defects (corrections), over production, over processing, waiting (delay), inventory, motion and transportation. The seven categories can easily be identified in the manufacturing production process (Simms, 2007: 1).

Alarcon (1997: 365) and Koskela (1992: 65) emphasize that waste in the production environment can be grouped into two categories which are waste in the manufacturing and waste in the construction. Typical examples of waste in the manufacturing environment are waste due to defective products, wait periods, overproduction, over-processing and motion. While some of the examples of waste in the construction are rework, error, clarification, excessive vigilance, and work not done. In this study it was discovered that the identified types of waste in the SDP can be grouped into nine categories, namely waiting time, over-processing, motion, excessive vigilance, overproduction, rework, clarification, error and work interruption as shown in Tables 5.6, 5.7, 5.8 and 5.9. The impacts of these categories of waste on the design and the construction phases of projects are fully discussed in the following headings:

(a) The inception design phase

In Table 5.5, the three categories of waste that are associated with the IDP of the SDP are:

- **Waiting time:** Ohno (1988: 45), Womack and Jones (2003: 83), Simms (2007: 3) classify all forms of delay in processing every unit of engineering work as waiting time. Participants in groups A and C were of the opinion that excessive waiting time experienced in the IDP of the SDP consistently leads to delay in the start of site activities. Further, the participants consented that the interruption or setback in the start of the site activities consequently lead to escalation in the overall cost of projects due to fluctuation in the price of construction materials. This is consistent with the observations of Sunjka and Jacob (2013: 644) regarding the impact of delays in the design phase of projects on the construction costs.

The opinions of the participants in groups B, D and E were not contrary to that of A and C. In groups B, D and E the participants accentuated that projects activities are interrelated, combined or interdependent and of such, any delay experienced in the design phase will consequently affect the starting and completion time of the site activities.

- **Over-processing:** Nazech *et al.* (2008: 19) emphasize that over-processing occurs in a project when resources are being used or applied more than needed or required. Simms (2007: 4) defines over-processing as every form of monetary waste in engineering work. The two forms of waste that can be identified as over-processing in the IDP of the SDP are several soil tests and site visits. Participants in all the groups asserted that several soil tests and site visits in order to ascertain the exact bearing capacity of the soil in a proposed site takes time, resources and money. The participants perceived that the aforementioned activities in the IDP also lead to delay in the commencement of the site activities due to excessive LT the activities create in the phase, as well as in the subsequent phases of the SDP.
- **Motion:** According to Womack and Jones (2003: 83), motion includes any unnecessary physical movement or walking by workers which diverts them from actual processing work. It may include difficult physical movements due to poorly designed ergonomics, which slow down the workers. A good example of motion in the IDP of the SDP is ineffective site workflow. Participants in groups A and B declared that ineffective site workflow can lead to delay in the completion of site topographical survey. The participants in group A and B further emphasized that gaps such as high hill, valley or rocky surfaces in a proposed site can make the engineers responsible for the topographical survey to request for additional charges/fees. This means that ineffective site workflow due to gaps in the topographical survey can upsurge the overall cost of a project. Participants in groups C, D and E find it difficult to identify the impact of this problem on projects. The participants maintained that such a problem has never been experienced considering the time they have been in the practice.

- **Rework:** Hwang (2009: 187) and Song *et al.* (2009: 12) contend that correction/rework implies repeating a process or step several times. In all the groups, the participants declared that changes on the architectural drawings in the initiation phase of projects are the main factors responsible for delays in the completion of the structural drawings, and in the start of construction activities.

Table 5. 5: The categories of waste in the inception design phase of the structural design process

The categories of waste	Waste type
Waiting time	Waiting for the start of structural activities; waiting to analyze the project life cycle cost; waiting for the site report; waiting to establish the scope of the work; waiting to establish contract agreement between the clients and the designers, and waiting to establish the inception design documents
Over-processing	Excessive meetings especially in the project initiation phase, and several soil tests, LT and site visits (inspections) during geotechnical investigations
Motion	Ineffective site workflow
Rework	Changes on the architectural drawings

(Author, 2016)

(b) The predesign phase

Table 5.6 shows the seven categories of waste in the PDP of the SDP in this study. These categories include the following:

- **Error:** Participants in all the groups discussed that ambiguities in the architectural drawings and wrong computations are errors or mistakes that are responsible for rework in the PDP of projects. The participants stressed that it is important for the architect and the SDT to detect any form of mistake in the predesign phase of the SDP, in order to make any necessary amendments, so as to reduce the number of RFIs in the CP of a project. This means that mistakes that are not detected in the design phase are the main cause of excessive RFIs in the construction phase. This is consistent with the findings of Ko and Chung (2014: 468) and AbdelSalam *et al.* (2010: 749), Mryyian and Tzortzopoulos (2013: 450), Zoya-Kpamma and Adjei-kumi (2011: 102), and Sommerville (2007: 391) regarding the impact of design error on construction projects.

- **Overproduction:** In engineering design, processing an order before it is needed, or any processing that is done on a routine basis regardless of the current demand, is known as overproduction (Ohno, 1988: 48). In this study, the participants in all the groups agreed that excessive printing of work in the PDP of the SDP leads to wastage of materials (paper and ink). This is similar with the finding of Ohno (1988: 48) regarding some of the impacts of overproduction waste in product design.
- **Over-processing:** Participants in all the groups emphasized that over-processing in form of excessive meetings between the client and the design actors in the PDP often lead to delays in the start of the construction activities.
- **Motion:** Simms (2007: 4) establishes motion in engineering work as all forms of waste that can be likened to using inefficient software. In this study, the only waste identified as motion in PDP of the SDP was several computations of the structural elements. In all the groups, the participants asserted that computation of elements such as slabs and beams requires extensive time, and that the procedures used in performing the computations are slow and boring. In groups B and D, the participants concluded that design computations occasionally lead to human errors, which could lead to corrections, rework, late completion of work, and poor design quality.
- **Excessive vigilance and waiting time:** Participants in all the groups specifically groups C, D and E argued that several supervisions of work by the chief engineer, and unnecessary waiting time due to delays to establish the preliminary design documents in this phase disrupt the schedule of work, and consequently lead to delays in the start of work in the subsequent phases.
- **Clarification:** Participants in all the groups stressed that disagreements between the architect and the SDT due to clarification of information in the architectural drawings often lead to slow speed of structural activities, which consequently lead to delay in the start of the construction phase.

Table 5. 6: The categories of waste in the predesign phase of the structural design process

The categories of waste	Waste type
Error	Ambiguities in the architectural drawings, and incorrect information/wrong structural computations
Rework	Modifications of the architectural drawings
Overproduction	Several review and printings of paperwork
Over-processing	Several meetings between the client, the architect and the SDT
Motion	Several repeated structural computations
Excessive vigilance	Several supervision of structural activities by the chief engineer
Waiting time	Unnecessary waiting time due to design modifications; waiting to establish the preliminary design documents, and waiting to incorporate the necessary building regulatory and requirements into the project
Clarification	Disagreements between the architect and the SDT

(Author, 2016)

(c) The detailed design phase

The four categories of waste in the DDP of the SDP in this study include the following (see Table 5.7):

- **Overproduction:** Participants in all the groups declared that three copies of final drawings are handed over to the contractors, two copies to the architect, and a copy to the quantity surveyor and the client. This means that overproduction due to excessive paperwork leads to material wastage in the DDP of the SDP.
- **Rework:** In all the groups, the participants maintained that mistakes are the main cause of redesign/design correction, which is responsible for delays in the completion of the structural drawings, as they reduce the pace of the work. Apart from delays, participants in group B asserted that redesign due to variation and changed orders could lead to disagreements between the SDT and the architect or the client, which sometimes lead to changes in the agreed-upon contractor's fee, particularly when the redesign problems arise from the client.

- **Waiting time:** This study reveals that the two forms of waste associated with waiting time in the DDP are approval of final work by the chief engineer/project director, and delays in establishing the detailed design documents. In all the groups, participants stressed that waiting for the approval of final drawings, and establishment of detailed design documents require time. The participants argued that these activities in the DDP of the SDP waste much time, and are the main factors responsible for lateness in the start of activities in the CP of a project.
- **Work interruption:** In this study, the researcher observed that inability to complete work as programmed by the SDT due to several interruptions in the DDP is another causes of delay in the start of the CP.

Table 5. 7: The categories of waste in the detailed design phase of the structural design process

Categories of waste	Waste type
Overproduction	Unnecessary or excessive printing of draft work and several review of structural drawings by the senior engineers, and several copies of final drawings
Rework	Design corrections and redesign
Waiting time	Delay in the selection of the suitable structural elements computed in the PDP; delay to incorporate the comments made in the PDP into the project; delay to incorporate other consultants' designs and requirements into the project; delay in the preparation of the design development drawings and specifications; waiting for the approval of the final drawings; delay in the production of the construction drawings, and Waiting to establish the detailed design documents
Work interruption	Inability to complete structural activities as earlier scheduled

(Author, 2016)

(d) The construction design phase

The four categories of waste in the CP of the SDP in this study include the following (see Table 5.8):

- **Rework:** Participants in groups A, D and E felt that correction due to variation/change order, redesign, and inadequate spacing of structural reinforcing materials in the CP of projects are the main factors responsible for on-site disputes. The participants argued that disputes arise when none of the actors is prepared to accept responsibility for damages that have accrued through corrections. This is similar with the findings of Emuze (2011: 205), Taher and Pandey (2013: 460) regarding design corrections as the main causes of dispute in projects. In groups B and C, the participants speculated that corrections in the CP can lead to increase in the estimated cost of a project. Participants in group C also stressed that corrections in the form of rework could reduce the overall performance and efficiency of the work, and could cause the project director to procure additional construction materials, with a consequent increase in the overall cost of a project. This corresponds with the findings of Mastenbroek (2010: 27) and Al-Aomar (2012: 111) regarding as the main cause of material wastage in construction projects.

- **Over-processing:** In groups A and C, participants emphasized that over-processing such as inadequate spacing and excessive cutting and fabrication of structural reinforcing materials are the main factors responsible for materials wastage on the construction site. This is in agreement with the opinions of Womack and Jones (2003: 82), Kourd (2009: 28) relating over-processing as one of the causes of materials wastage during site activities. In groups B, D and E, the participants asserted that the highlighted waste diminish the overall performance/efficiency of site activities, which consequently leads to poor quality of work.
- **Waiting time:** Participants in all the groups observed that excessive waiting time due to clarification of information during structural reinforcement, and ineffective communication flow between the SDT and the construction contractor are the main factors responsible for lateness in the completion of work in the CP of a project.
- **Excessive vigilance:** Excessive vigilance occurs in the CP of a project due to the quality assurance requirements. That is, it is expected that there be supervision at every phase of a new task on site, as stipulated by the appropriate authority. Participants in all the groups agreed that several supervision of work in the CP of a project is the main factor responsible for delays in the completion of work.

Table 5. 8: The categories of waste in the construction phase of projects

Categories of waste	Waste type
Rework	Variation/changed orders, wrong fabrication of formwork; rebar cages and reinforcing steel, redesign, and inadequate spacing of structural reinforcing materials
Over-processing	Excessive requests for information, and excessive cutting and fabrication of structural reinforcing materials
Waiting time	Excessive waiting time during structural reinforcement, and ineffective communication flow between the SDT and the construction contractor
Excessive vigilance	Several on-site supervision

(Author, 2016)

5.3.2 Summary of findings from the first phase of the focus interviews and its relationships to the study research questions

What type of waste is synonymous with the structural design process?

At the end of the first phase of the focus interviews conducted, this study discovers that the SDP are in five main phases. The identified phases align to the five main phases of the CDP in the literature. These phases are dependent on one another. This implies that defects experienced in any one of the phases can lead to defects in a subsequent phase. However, the study also discovers that various activities exist in each phase. Some of these activities are essential to construction projects (they are-value adding) while some of them are not (non-value adding). In addition, the study also observes that certain incidences are problematic and constitute waste in each phase.

This study also shows that the IDP of the SDP is important, as issues related to imprecision, requirements, and needs are addressed in this phase by the SDT before the start of a new project. From the structural engineering perspective, the important activities of the SDT in this phase are to:

- Attend project initiation meetings so as to implement the contract agreement (IDP-1);
- Review the architectural drawings of the project at hand (IDP-2);
- Define the services and scope of the works required (IDP-3);
- Advise on the specific areas of activities that can influence the project life cycle cost significantly (IDP-4);

- Provide necessary information within the agreed scope of work to other consultant engineers involved (IDP-5);
- Schedule and inspect on the required site topographical surveys, analyses, and other necessary site investigations (IDP-6);
- Schedule and inspect on the necessary soil tests (IDP-7);
- Oversee the compilation process of site report (IDP-8), and
- Sign the necessary inception design documents (IDP-9).

The PDP is the second stage of the SDP and its main objective from the study conducted is to finalize the project concept and clearly layout the procedures needed by the designers to complete the next phase of work (detailed design). From structural engineering point of view, the essential activities of SDT in this phase are to:

- Attend the design and the consultant meetings (PDP-1);
- Review the architectural drawings in details (PDP-2);
- Modification of the architectural drawings, and advise the client on further survey, analyses, soil tests and site investigation that may still be required or needed (PDP-3);
- Establish regulatory authorities' building codes and incorporate them into the drawings (PDP-4);
- Establish structural predesign criteria (PDP-5);
- Refine and assess the predesign criteria to ensure conformance with all regulatory requirements, and building codes and consents (PDP-6);
- Compute the general layout, preliminary sizing and stability of the proposed structural elements of the project (PDP-7);
- Prepare the preliminary process designs and related documents suitable for costing (PDP-8);
- Review the overall work for approval to the next phase (PDP-9). This is explicitly the responsibility of the chief engineer of the firm, and
- Establish preliminary design documents (PDP-10).

The DDP is the third phase of the SDP and it main activities involves detail consideration, determination and selection of the most suitable alternative solutions of proportions, dimensions and connections of structural elements defined in the predesign phase to bring out the complete, perfect and final structural drawings and specifications for the proposed project. The significant activities of the SDT in this phase are to:

- Attend design and consultants' meetings (DDP-1);
- Review the predesign documentation plans with other consultants that may be involved (DDP-2);
- Select the most suitable proportions (sizes), dimensions and connections of structural elements computed in the predesign phase (DDP-3);
- Incorporate of the necessary corrections, comments and observations in the predesign phase into the work (DDP-4);
- Incorporate other consultants' designs and requirements into the work (if any) (DDP-5);
- Prepare the design development drawings including draft technical details/specifications (DDP-6);
- Review of the developed final drawings (DDP-7). The review is done by the senior engineer of the firm;
- Approve the final drawings (DDP-8). The approval is done by the firm project director or chief engineer;
- Produce the construction drawings (DDP-9), and
- Establish the detailed design documents (DDP-10).

The CDP is the fourth phase of the SDP and the main activities of the SDT in the stage are to:

- Attend site handover;
- Issue structural engineering construction documents to include reinforcing bending schedules, detailing and specifications of structural steel sections and connections;
- Prepare the schedules of predicted structural cash flow;
- Attend regular site, technical and progress meetings;
- Advise the contractors on the agreed quality assurance plan on works related to SDP;
- Inspect the works for quality and conformity to contract documentation on an average of every two weeks during the course of works;
- Clarify details and descriptions during construction as required;

- Inspect the works and issue practical completion and defects lists, and
- Arrange for the delivery of all test certificates, statutory (regulatory) and other approvals as built drawings and operation manuals.

The COP is the fifth phase of the SDP. This study reveals that it is the handing-over phase where final measurement, documentations and drawings (as-built drawings) are handed over to the client and the various construction stakeholders for their records. Some of the activities of the SDT in this phase are to:

- Inspect and verify the rectification of defects;
- Receive, comment and approve relevant payment valuations and completion certificates, and
- Prepare built drawings and documentations.

This study also shows that waste exists in the current practices of the SDP, although the magnitude or frequency of occurrence of the waste may differ from one project to another. This means that waste in construction also emerges from the structural design practices. With the exception of COP, the identified wastes are applicable to all the phases of the structural design i.e., the inception, the predesign, the detailed design and the construction phase. Hence, ***typical examples of waste that are synonymous with the SDP are shown in Figure 2:***

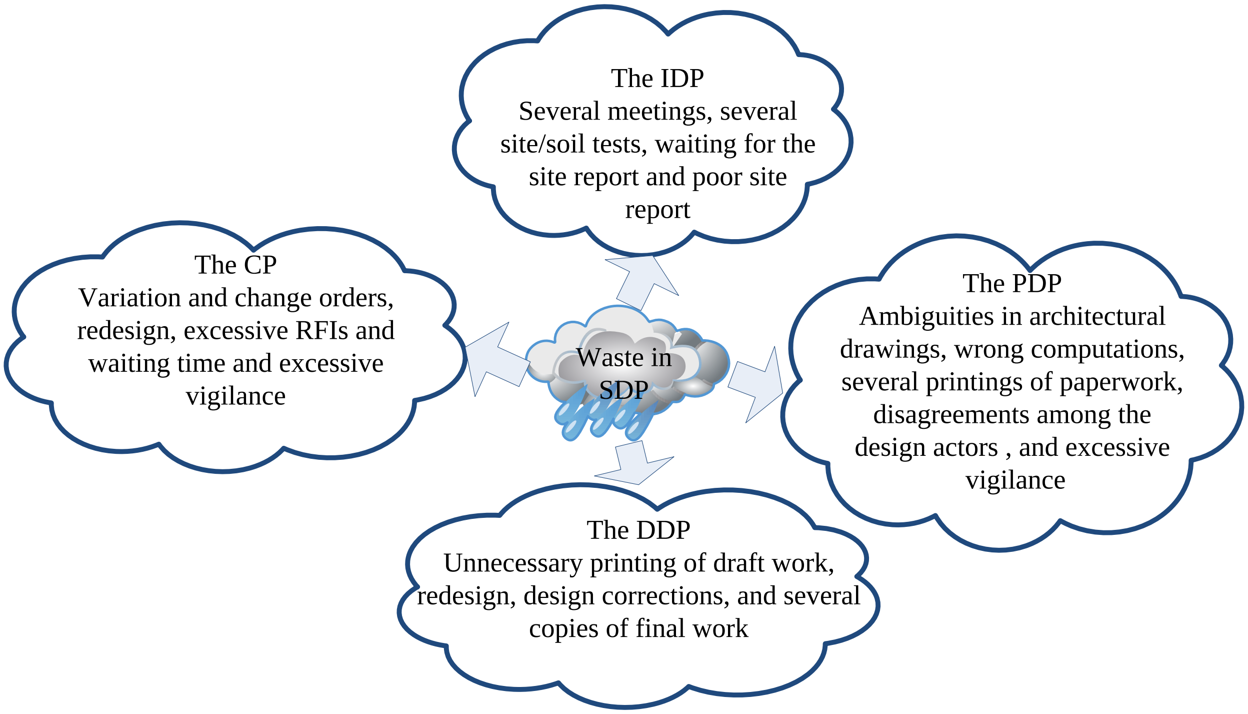

Figure 5.2: Examples of waste in the structural design process (Author, 2016)

What are the remote and immediate origins of the discovered wastes in the SDP?

This study also shows that ***the remote and immediate origins of waste in the SDP are shown in Figure 3:***

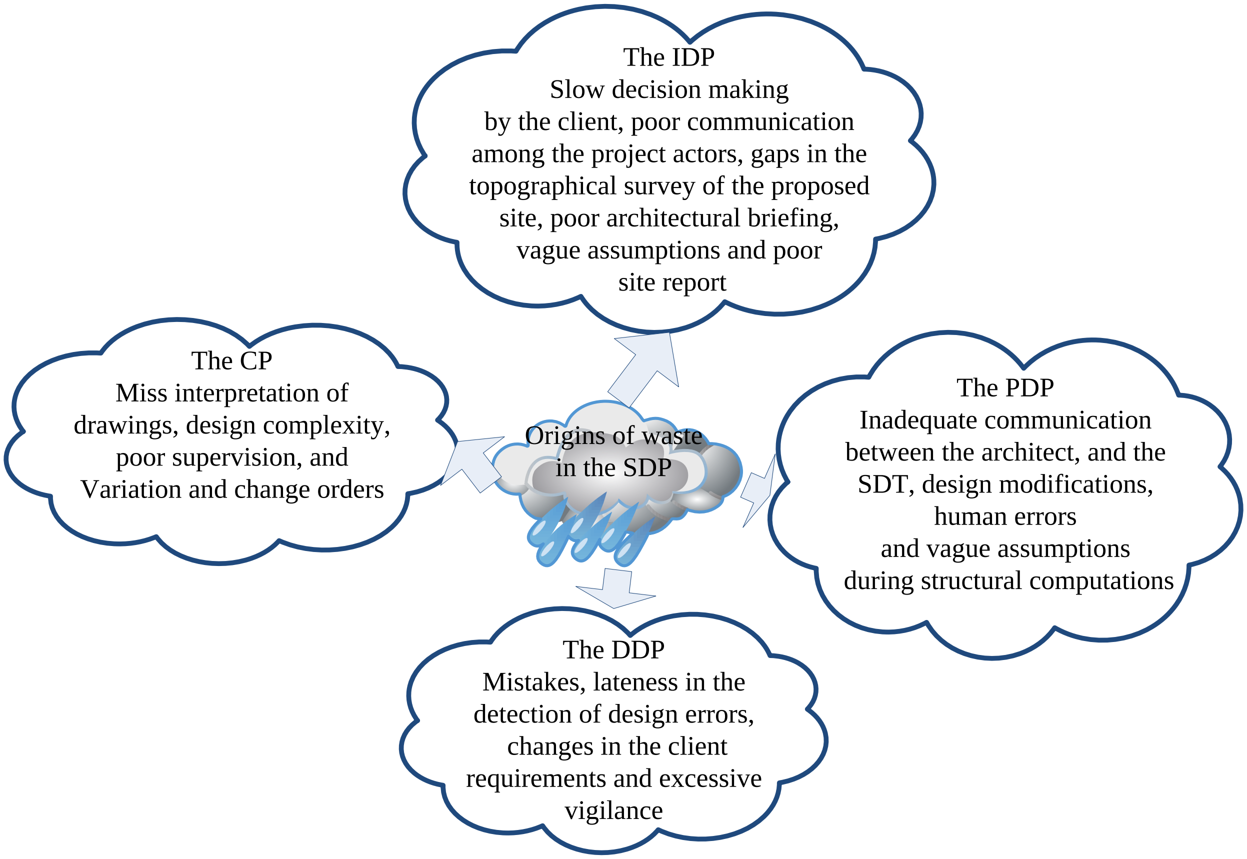

Figure 5. 3: Examples of the origins of waste in the structural design process (Author, 2016)

What are the impacts of such waste on the construction projects?

The overall waste in the SDP can be grouped into error, waiting time, over-processing, motion, excessive vigilance, overproduction, rework/correction, clarification, and work interruption. The 9 categories have significant impacts on the design and the construction phases of projects. ***These impacts are shown in Figure 4 below:***

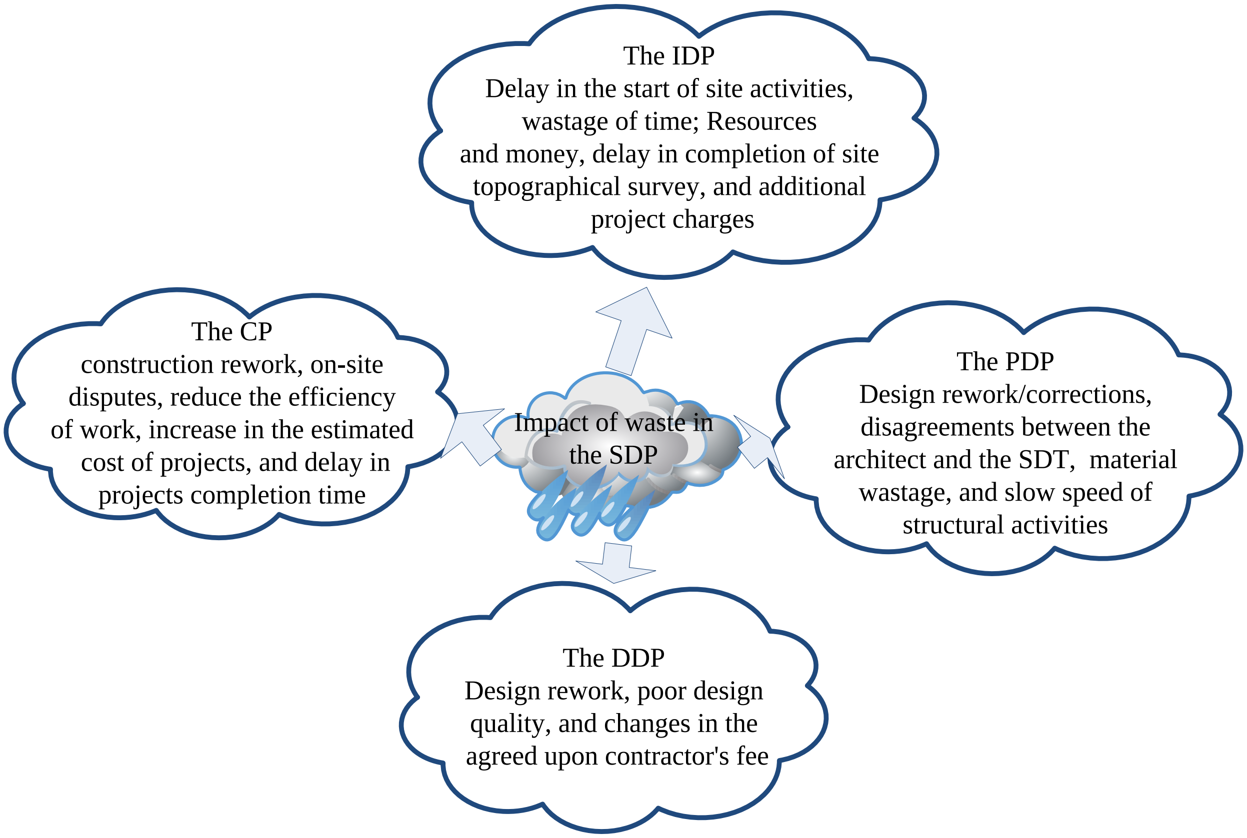

Figure 5. 4: The impacts of waste in the structural design process on projects (Author, 2016)

5.3.3 Analysis of the second phase of the focus interviews data

This is the second phase of the focus interviews conducted in this study and its main objectives is to determine the various strategies that can be adopted to reduce and eliminate the identified waste in the SDP (see Appendix 6).

(1) Level of awareness of the identified problems in the SDP by the management of the case study firms

In all the groups, participants declared that the design teams as well as the firm's management are aware of some of the problems experienced during the SDP especially the LT in the inception phase.

(2) Measures that have been put in place by the management of the case study firms to overcome the identified problems in the SDP

In all the groups, participants emphasized that there is no practical measure that have been or intends to be put in place by the firms' management to overcome the identified problems in the SDP. The participants argued that virtually all the problems experienced in the SDP are inevitable and may not necessary require any form of improvement. However, in groups A and B, the participants further discussed on design optimization techniques (DOT) that is applicable to large projects. In these two groups, A_1 opined that.

> *"DOT can be adopted in the predesign phase for computation of structural elements so as to reduce the number of columns."*

A_3 said that …

> *"… in a large project such as high rise or multi-storey building, assuming the architect specifies 500 columns in the drawings, design optimization techniques can be applied by the structural engineers or designers to reduce the number of the columns specified by the architect to around 450 or 460 …"*

A_5 asserted that…

> *"… However, in a small project, the reduction may not be significant even if design optimization techniques is applied …"*

The participants in group A were of the agreement that DOT can be adopted to reduce the number of columns in a large project. This means that DOT is being adopted during the SDP so as to ensure that projects are cost effective during construction. This is not surprising as studies by Ilozor (2008:

40) and Young *et al.* (2010: 244) indicate that design optimization innovation can be adopted by the designers to reduce the overall materials that will be required in a project.

In group B, B_4 also pointed out that …

> *"… apart from column design, DOT is also applicable to beam design ..."*

However, other participants in the group declared that its application in large or small projects unlike column has no substantial difference while compared to the normal method of design. This means that DOT has no significant difference from the normal method in terms of beam design. Further, participants in groups A and B declared that DOT is not applicable to foundation design. The participants opined that any attempt by the designers to reduce the project cost in foundation design may jeopardize the primary aim of structural design (safety and functionality).

When asked of the brain behind DOT, participants in groups A and B accentuated that the knowledge of DOT was developed through long term experience, staff and workshop trainings, and regular participation in annual general meetings organized by the Institute of Civil Engineering locally and internationally.

In groups C, D and E, it was discovered that structural designers failed to adopt any specific strategy during the SDP. The participants in these groups maintained that the SDT only adhered strictly to the various building codes/regulations. That is, the design team tries to give the best to the client by ensuring that the design is cost effective. For instance, C_1 said that …

> *"…for over 15 years now that we have been in the system, we do our very best to satisfy our clients and none of our clients has ever complained of the service we rendered …"*

This is similar to the opinion of D_1 that …

> *"… for more than ten years now, apart from the norm projects issues, we never have any problem with our client s…"*

This also concurs with the view put forward by E_2 that …

> "… since we have been practicing, *our clients always appreciate the service we render within and out of* Bloemfontein …"

When asked their opinions on lean design, none of the participants in all the groups was able to make any contribution on this question. This means that as at the time this focus interviews was conducted; lean design was not being practiced in Bloemfontein consulting engineering firms.

(3) Measures that can be adopted by the SDT to overcome the identified problems in the SDP

In all the groups, the participants advocated that to start the reduction or elimination of most problems experienced during the SDP, the SDT needs to be adequately involved in the architectural process (AP). The participants were of the opinion that involvement of the SDT in the AP would enable the design actors (the architect/the SDT) to detect and rectify most of the problems encountered in the SDP, and subsequently come up with an appropriate architectural drawing (AAD). This is in agreement with the opinions of Yassine and Braha (2003: 165), Azhar, and Sketo (2008: 1), Forbes and Ahmed (2011: 216), Eastman *et al.* (2011: 21) regarding the application of information and communication technology platforms for waste identification and reduction in the design and the construction phases of projects. It should be noted that in this study, an architectural drawing that is free of modification during the SDP is termed as AAD.

Also, participants in all the groups suggested that at the commencement of the AAD, the necessary site topographical survey and the soil tests should start as early as possible so as to be able to overcome the problem of waiting for site report during the SDP. This means that the SDT can as well start some of/all the activities in the IDP during the AP. Other alternatives strategies that can be adopted to further reduce or eliminate waste in the SDP are explained under the following headings:

(a) The inception design phase

- *Several meetings especially at the project initiation phase*

In groups, A, C, D and E the participants suggested that phone calls and internet-enabled communication (IC) such as Email, Facebook and 'Whatsapp' can be adopted. Participants were of the perceptions that phone calls and IC can be used to reduce the excessive or incessant meetings that always occur between the client, the architect and the SDT especially in the initiation phase of a project. Participants in group B disagreed to these suggestions. B_5 argued that…

"… phone calls and IC cannot be as effective as face-to-face discussion s…"

B_3 continued with the arguments and stressed that …

"… face-to-face discussion enables every actor to properly express his/her feeling in every phase of a project …"

To buttress B_5 and B_3 arguments, B_2 in the group added that …

"… the design process is complex and encompasses so many issues that may require face-to-face discussions by the parties involve …"

This is consistent with what has been observed in the literature (Marzouk *et al.*, 2011: 44). Marzouk *et al.* (2011: 44) describes the design phase of every project as a complicated process that requires many interdependent complex procedures. Based on the opinion of B_2, B_1 argued that …

"…phone calls and IC can be adopted to issues or matters that may not necessary require face-to-face arguments …"

That is, a less complex situation or issue. Premised to B_1 opinion, the participants in group B agreed that phone calls and IC can only be used to reduce persistent meetings among the various actors in a project. However, the participants' stressed that critical issues that cannot be resolved through these facilities will still have to require face-to-face discussion in every phase of a project.

- *Waiting for fund release from the client/lateness in the start of the structural activities*

In group A, A_1 stated that …

"There was a time a client wanted a specific type of building. Based on that, we got the scope of the work from the client. Later on, the architect did the design, later on the Structural/Civil engineers did their works. After the Quantity surveyor (Q/S) brought up the price for the particular design. Later, we discovered that the client has no sufficient fund for the project. We then agreed on cost engineering process which means

we must redesign for all the disciplines involved. So the architect came out with a new layout which deviated from the original or initial scope of the work that the client gave us".

Corroborating the views espoused by A_1 in the group, A_2 declared that …

"I think a client has to be realistic right from the beginning even before coming to the designers."

Suffice to these arguments, there was a consensus among the group participants on the need for prospective clients to be realistic about their budget right from the onset.

Comparable to what the participants in group A concluded at, in group B, B_3 affirmed that…

"… *in every project, to overcome unnecessary delay due to lateness in fund release by the client, the client must start from high level discussion ..."*

Supporting the opinions of B_3, all the participants in group B agreed that in every project, the client should start the necessary discussions from the architect and the Q/S before the involvement of structural designers. In groups C and E, the participants' opinions juxtaposed to the views expressed by the participants in groups A and B. The participants in these two groups clarified that in government projects, there is implementation or study phase where the SDT puts construction, operation and maintenance costs of a project into consideration. C_5 alleged that…

"... in the implementation study, the SDT seriously looks at the capacity of the clients and advises the clients on the type of project to go for based on his/her capacity ..."

E_3 declared that …

"... it is in the study phase that the design teams put so many factors into consideration, and even decides whether to advise the client to continue with the particular project or go for an alternative one ..."

The opinion of the participants in group D is a bit different to that of other groups. The participants in the group highlighted that to overcome the problem of waiting for fund release from the client, appropriate communication and regular meetings with the client can be adopted by the management of a firm (MOF). The participants argued that it is in such meetings/communication that the MOF will be able to observe if the client is financially capable to start the project. The participants in group D asserted that if a client is constrained to start a project due to funding issues, the MOF usually advises on a long-term loan from the various available funding agencies such as the department of trade and industry (DTI), the national empowerment fund (NEF), the industrial development corporation (IDC) and government loan.

- *Gaps in the topographical survey of the site*

Participants in all the groups declared that ineffective site workflow due to gaps in the topographical survey is not common in practice. However, participants in groups A and B postulated that to overcome such menace/challenge during the SDP, site topographical survey should be promptly conducted through the service of an experienced land surveyor. The participants opined that timely comportment of the activity may avail the professionals in charge the adequate time to carry out the necessary work on the proposed site. In groups C, D and E, the participants maintained that such a problem had never been experienced and were unable to propose any reasonable measure that can be adopted to overcome the problem in the future projects.

- *Several soil tests*

Participants in all the groups unanimously highlighted the essential nature of soil tests in every project. The participants stressed that it is essential to adequately conduct the required soil tests in every structural project and the necessity is not expected to be compromised for any reason. Hence, participants in groups A and E were reluctant to posit any reasonable measure that can be adopted to reduce the number of soil samples to be collected for geotechnical investigations. However, in group C, C_3 and $_5$ declared that in both public and private projects, it is possible for the SDT to start work as soon as the contract is awarded by assuming certain design variables premised on the geotechnical information of the existing buildings on the proposed site. Nevertheless, C_1 in the group maintained that…

> *"… too many assumptions in structural design work is risky and may even make a client to spend more …"*

C_2 supported C_1 opinion and added that…

> *"... historical information of the existing building in a proposed site can be helpful at time, but there is no how you can get the whole of the information that can make you to completely forgo the geotechnical tests ..."*

Whereas C_4 in the group was of the view that …

> *"... historical information is only reliable when the soil condition is fairly uniform ..."*

Based on these positions, all the participants in the group agreed that for safety and functionality motives, assumptions should be limited and the basic geotechnical requirements of every proposed site should be conducted.

Correlating with group C perception, in group D, D_1 accentuated that …

> *"... the number of soil tests may reduce if it is possible for the SDT to obtain the records of information on the geotechnical characteristics of the existing buildings on the proposed site ..."*

The speculation of D_1 agrees with what has been reviewed in the literature (DPWSGN, 2010: 3). To buttress the argument of D_1, D_2 added that …

> *"... in such case, few soil samples of six to eight trial pits will be collected and the results obtained will be compared to the existing information ..."*

Subject to D_1 and D_2's declarations, participants in the group harmoniously agreed that soil tests should be minimal if the results obtained from the few test agreed with that of the existing buildings. Otherwise, the appropriate procedures or channel for geotechnical information has to be followed by the engineers. This is also synonymous with the findings of Aladejana *et al.* (2015: 1) and American Society for Testing Materials (ASTM) (D6913-04), (2009: 1) on the techniques for geophysical/geotechnical investigation of a proposed site.

In group B, participants maintained that there is a guideline for the required number of trial pits or samples to be conducted on a proposed site and the number depends on the size of the site. B_3 in the group said that …

> *"... although we do experience it that the client will want the design to start immediately the contract is awarded so as to start the site activities in a good time …"*

B_4 continued with the discussion and stressed that …

> *"…the client is not always happy with the lead time as it takes close to two months in most projects but I do not think is a good idea to reduce the specific number of trial pit tests or completely side step geotechnical investigation of a proposed site …"*

Premised on B_3 and B_4's assertions, all the participants in the group concurred that in every project, soil tests should be conducted as stipulated in the guideline so as not to situate or position the proposed structure at future risk.

- *Waiting for/poor site reports*

Participants in groups D and E emphasized that several processes are involved during soil tests in the laboratory. The participants are of the consensus that the soil samples have to be soaked in water for certain time, allowed to saturate over a period of time, washed and oven-dried before any test can be conducted on it. Participants in the groups further debated that the timeliness of site report also depends on the location of the site. The participants asserted that if the proposed site is located in a secluded environment where the necessary facilities to perform the tests are not easily accessible or within the reach, the geotechnical engineer will be confronted with the need to take the samples of the soil collected to a municipal or metropolitan Centre where the necessary tests can be performed.

Based on these assertions, the participants in groups D and E speculated that the promptness of the site report depends to a large extent on the availability of the geotechnical results. This means that to overcome the problem of waiting for the site report, the various soil tests and land topographical survey need to be conducted as early as possible by the various professionals. This is in line with the earlier stated view in this study that to overcome some of the problems experienced in the SDP, most structural activities need to start during the AP.

The participants in group B assented that several tentative assumptions during site topographical survey and soil tests can lead to poor site report which may later result to unnecessary delay (waiting for the site report). B_5 opined that …

> *"…at time you may think that the proposed site is uniform and make certain assumptions and at long run, you will be disappointed that the site is not uniform …"*

To support B_5 opinion, B_3 and B_4 declared at once that …

> *"You cannot make some assumptions based on what you see."*

Premised to these arguments, participants in group B concluded that to overcome the problem of waiting for the site report during the SDP, the SDT needs to limit assumption and properly carry out the required geotechnical investigation exercise.

Simultaneous to these propositions, in groups A and C, participants proclaimed that in every project, the geotechnical engineers' work in accordance to the required tests and specifications prescribed or recommended by the SDT. Therefore, to overcome the problem of waiting for/poor site report, the participants in the two groups stressed that the SDT has to be realistic and be sure of the prescriptions or specifications that will be tendered to the geotechnical engineers. This means that designers are expected to be experienced so as to understand the exact and the necessary information required by the geotechnical engineer. Table 5.9 provides the summary of the participants' opinions on the strategies that can be adopted by the SDT to overcome the identified waste (NVA activities or problems) in the IDP of the SDP.

Table 5. 9: Strategies for waste reduction in the inception design phase of the structural design process

Waste	Strategies	Source (s)
Several meetings especially in the project initiation phase	Adoption of phone calls and internet enabled communication (IC) during the SDP	All the groups
Lateness in the start of the structural design activities due to delay in the release of project fund from the client	Appropriate communication and regular meetings with the client	Group D
	Long-time loan from the various available funding agencies	Group D
	Commencement of every structural project from high level discussion before the involvement of the SDT	Groups A, B, C and E
	All clients need to be realistic wright from on-set	Group A
Gaps in the topographical survey of the proposed site	Timely conduction of the site topographical survey through the service of experienced land surveyors	Groups A and B
Several soil tests	Assumptions of certain design variables based on the geotechnical information of the existing buildings in the proposed site	Groups D and C
Waiting for/poor site reports	Early investigation of the various soil tests and land topographical survey by the various professionals	Groups D and E
	Minimize assumptions during the geotechnical investigation of the proposed site	Group B
	The use of an experienced designer that understand the information required by the geotechnical engineers for the necessary soil tests	Groups A and C

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(b) The predesign phase

- *Ambiguities in the architectural drawings*

Participants in groups C and E proposed that ambiguities such as error and unclear information in the architectural drawings can be overcome by adopting quality assurance (QA) strategy in every architectural firm. This is similar to the view espouse by Gatlin's (2013: 6) regarding defects minimization technique in the design phase of building projects. The opinion is also juxtaposed to the perception put forward by the participants in group D. D_3 stated that …

> *"… quality assurance during the architectural process will go a long way as two heads are better than one …"*

Again, D_3'spoint of view is in line with the findings in the literature. Literature shows that most of the hidden defects in the design phase of projects are the main causes of waste during site activities (Abdelsalam *et al.*, 2010: 749; Ko & Chung, 2014: 463). Based on D_3 statement, participants in group D recommended that for effective QA, two designers should be adopted in every architectural firm namely: a senior architect and a structural engineer. The participants emphasized that the architect will be responsible to oversee all forms of architectural problems while the engineer will be assigned to take care of every aspects of activity that may be related to structural design. This means that with the adoption of the proposed QA procedures in the AP, most of the hidden problems in the process will be discovered and rectified before the SDP.

Participants in groups A and B highlighted that ambiguities in architectural work is inevitable but can be kept to a minimum. In order to reduce its occurrence in every project, B_2 declared that …

> *"Architect needs to produce a sketch layout plan first and meet with the client."*

B_3 continued with B_2 proposition and asserted that …

> *"… if the client is satisfied with the sketch, the architect should then notify the SDT to carry out work on the preliminary structural elements that will be required …"*

B_1 joined the discussion and opined that …

> *"… if the SDT does not perceive or foresee any structural problem at this level, the sketch work should then be approved by the three parties …"*

Based on B_1, B_2 and B_3, perceptions, the participants in group B stressed that the agreed work (sketched) should not be altered by any of the parties throughout the progress of work. B_5 in the group added that …

> *"… if there is need to make any alteration on the agreed work, the factor that necessitates the adjustment must be justified by the three parties before taking any action ..."*

To support the view expressed by B_5, all the participants in the group speculated that such modification should be minimal enough to be tolerated by the preliminary sketched of plan that has already been appropriated by the architect and the SDT. That is, if there is need to make any change on the approved work, the alteration must be negligible not to create any unnecessary delay during the progress of the project.

The opinion of the participants in group A is synonymous with the expression advocated by the participants in group B. However, A_1 in the group contended that …

> *"… occasionally, the SDT may not be opportune to know the architect ..."*

While A_5 maintained that …

> *"… at time, the architectural drawings might have been completed before the involvement of the structural designers …"*

A_3 affirmed that …

> *"… the architect and the structural engineer may not be privileged to be in the same environment …"*

Based on the opinions of A_1, A_5 and A_3, participants in group A argued that in individual or private projects, it may be difficult for the SDT and the architect to work hand in hand. Premised to this argument, the participants suggested that the various building regulatory need to be reviewed by the appropriate body. The participants argued that such reviews should include a clause or statement that …

"For every structural design project, the architect and the structural engineer must have a means of interactions or communication throughout the architectural process".

This means that to overcome the problem of ambiguities in architectural drawings, there is need for continuous interaction between the architect and the SDT throughout the AP. The participants in group A further suggested that if there is constraint between the architect and the structural engineer in terms of face-to-face interactions, phone calls and IC communication can be adopted, and the adoption between the two parties must be from time to time or as the work progresses. Arising from the arguments/opinions of the participants in all the groups, it can be concluded that to reduce or eliminate ambiguities during the SDP, the architect(s) and the SDT need to work together throughout the AP. That is, in every project, there must be continuous interactions between the architect and the clients and the SDT. This is corresponded with the views espouse by Yassine and Braha (2003: 165), Eastman *et al.* (2008), Sacks and Barak (2008: 439), and Sacks *et al.* (2009: 18) regarding the application of information and communication technology platforms for waste identification and reduction in the design and the construction phases of projects.

- *Excessive meetings and disagreements between the architect and the SDT*

Participants in all the groups agreed that architectural drawings are expected to be free of error or mistakes if a member of the SDT is fully engaged in the AP. Consequent to this assumption, the participants' stressed that limited and tolerable argument will emanate during the SDP, and the number of meetings before consensus by the actors may be negligible. This means that if ambiguities in the architectural drawings are overcome before the start of the structural design; few disagreements will ensue during the SDP, and the need for clarification of information by the architect during the SDP may not necessarily arise. To further overcome the problem of unnecessary or unplanned meeting in the PDP, participants in groups C and D added that in every project, a meeting agenda as well as a schedule of activities should be prepared. The participants stipulated that the agenda should be strictly adhered to by all the project actors right from the inception to the completion stage of a project.

- *Modifications of the architectural drawings and unnecessary waiting time due to the design modifications*

In terms of this problem, participants in all the groups maintained that once ambiguities in the architectural drawings have been addressed before the start of the structural design, there will be no need for the modification of architectural drawings, and consequently, all forms of delay constituted by the modifications exercise may not occur.

- *Several repeated structural computations*

Apart from the PROKON that was discovered by the researcher in all the firms as the general software for fast structural design calculations/computations, participants in all the groups were of the opinions that with certain mathematical formulae, excel spread sheet can be programmed and used for most of the repeated computations. This implies that the adoption of a programmable spreadsheet can lead to a reduction in the incidence of repeated computations. At this session of the focus interviews, A_1 emphasized that …

> *"… from experience, you can develop some generic assumptions or a design software such as REVIT structure (an AutoCAD programme) to reduce the lead time created by several repeated structural calculations …"*

However, other participants in the group sounded a note of warned that if a designer used any of the aforementioned computation strategies, the designer must cross check or review the calculations thoroughly so as to be sure that the proportioned structural elements are devoid of mistakes/errors that can lead to redesign in the subsequent phases. This implies that designers need to be extremely careful in certain assumptions during structural computations so as to avoid error or mistakes in the process.

- *Computations errors/ambiguities in the structural drawings*

Participants in all the groups opined that mistakes in structural design are unavoidable. In group D for instance, D_4 declared that …

"...we are all human; mistake is inevitable during the SDP. Even the best engineer in the world with many years of structural experience can still make mistakes..."

To support D_4 declaration, D_2 emphasized that …

"... even if you make use of different design software for most of your calculations, there can still be mistakes as we are all human ..."

Based on D_4 and D_2's points of view, the participants in group D concluded that to overcome the menace of computation errors/ambiguities in the structural design, there is need for consistent quality assurance procedures in every phase of the SDP.

Correlating with the opinion pointed by the participants in group D, in groups A, B and E, participants suggested that to curb most of the design errors or mistakes in the SDP, complete involvement of a long term and experienced designer such as the chief/senior engineer in the necessary design computations may be of great impact. The participants in group C consented to the view advocated by the participants in groups A, B and E but argued that the idea may not be totally accepted or entertained in the industry as there is need for continuity. That is, the senior engineers have to continue to train the junior ones for the lingering of the industry. In addition, C_4 debated that …

"... the senior engineers are always engaged in several activities to include management protocols or decisions and may find it difficult to be fully involved in the calculation aspect of the structural design especially when the firm has several projects to execute at a time ..."

While corroborating the position of C_4, C_1 in the group emphasized that …

"... it is actually the private consulting set up to take the responsibility of supervision only as we are always involved in a lot of crash crunchy works ..."

C_2 continued with the conversation and deliberated that …

"... with a lot of crash crunchy works, the organization realized that we need couples of junior designers under us to take care of some aspects of the works ..."

Based on C_4, C_1 and C_2's arguments, the participants in group C concluded that if a senior designer is completely engaged with the calculation/computation aspect of structural activities, the output may be much better. However, the participants further stressed that the management of the firm must be ready to highly compensate the senior designer for fully involved in the calculation aspect. Subject to the opinions of the participants in all the groups, it can be concluded that to reduce computation errors/ambiguities in the structural design, senior designers need to be more engaged in the computation aspect of the SDP.

- *Several printings of paperwork*

Participants across the groups suggested that excessive paperwork can be avoided through the adoption of electronic communication (EC). That is, design computations and drawings should be passed across from one office to another or from one designer to another for corrections and contributions electronically. In group B, for instance, B_3 stated that …

> *"… at the completion of work, working or construction drawing can be signed electronically by the designers and mailed to the contractor and other project actors …"*

To buttress B_3's opinion, participants in the group advocated that adopting EC for passing across of information during the SDP will not only reduce paperwork in the organization, but will as well guarantee appropriate or adequate record keeping. This means that drawings and other design documents that may be transferred electronically from one party to another will be appropriately documented.

Although in group A, A_1 declared that …

> *"… I am a bit old in age and review works electronically may not be easy …"*

Nonetheless, all the participants in the group agreed that electronic review would reduce paperwork to a great extent if it can be generally adopted by all the project actors. Participants in groups A, C and E further recommended that during the AP, the architects should ensure that every design information is clearly spelt out for flawless interpretation by the structural designers. This implies that complexity in the architectural drawings needs to be avoided. The participants in the groups solicited that the idea will prevent several unnecessary mistakes that can lead to several printing of paperwork in the SDP.

- *Excessive supervisions of works by the chief engineer*

Participants in all the groups agreed that supervisions may not be necessary if an experienced designer such as the chief/senior engineer is completely engaged in the necessary design computations. Although, in group D, D_5 argued that…

> *"… structural design cannot be completely free of error, omission or mistake …"*

However, other members of the group agreed that the engagement of a senior designer in the computations aspect of the structural design will drastically reduce the number of supervisory sessions in every project.

- *Delay to incorporate the necessary regulatory requirements/building codes into the project and to establish the preliminary design documents*

Participants across the groups also emphasized that design documents in the PDP of the SDP will be available as scheduled or programmed if the SDT is able to overcome all the highlighted problems experienced during the SDP. Participants argued that it is such problems that normally central to delay to incorporate the necessary regulatory requirements and building codes in to the project, and consequently lead to delay in the preparation of preliminary design documents. This means that if the various problems in the PDP of the SDP are addressed, activities will be conducted as programmed or scheduled and every necessary document will be completed as stipulated or planned by the SDT. Table 5.10 indicates the summary of the participants' opinions on the various strategies that can be adopted by the SDT to reduce or overcome waste in the PDP of the SDP.

Table 5. 10: Strategies for waste reduction in the predesign phase of the structural design process

Waste	Strategies	Sources
Ambiguities in the architectural designs	Adoption of quality assurance (QA) strategy in every architectural design firm	Groups C, D and E
	Involvement of the structural designers in architectural process	All the groups
	Adequate and continuous communication between the SDT and the architects during the architectural process	Groups A and B
Excessive meetings and disagreements between the architect and the SDT	Involvement of the SDT in the architectural process	All the groups
	Adoption of meeting agenda and schedule of work or roster in every project	Groups C and D
Modifications of architectural drawings and unnecessary waiting time due to the design modifications	Involvement of the SDT in the architectural process	All the groups
Several repeated structural computations	The use of programmed excel spread sheet, adoption of some developed generic assumptions or a design software such as REVIT structure for structural computation	All the groups
Computations errors/wrong computations	Carefulness in the adoption of certain design assumptions and some structural software	Group A
	Proper adoption of QA procedures	Group D
	Complete engagement of a long time and experienced senior engineer in the necessary structural computations	Groups A, B, C and E

Several printings of paperwork	Adoption of EC by the various project actors	All the groups
	Avoidance of all form of complexities in the architectural and the structural drawings	Groups A, C and E
Excessive supervisions of work by the chief engineer	More engagement of a senior designer in the calculation aspect of the structural work	All the groups

(Author, 2016)

(c) The detailed design phase

- *Design corrections*

Participants in all the groups affirmed that design corrections occur due to errors/mistakes by the SDT on certain areas during the structural design/drawings. The participants argued that it may be difficult for the structural designers to completely overcome the problem of design corrections in the SDP. The participants contended that mistakes/errors in the structural process are unavoidable. D_3 declared that …

> *"…we are all human, mistake is inevitable during the SDP, and as long as designers make mistakes or errors during the progress of work, corrections will continue to exist…"*

Similar to the case of computation errors/wrong computations, participants in all the groups concluded that to overcome the problem of design correction, complete involvement of a long term and experienced designer such as the chief/senior engineer in every aspect of structural design is essential, as this may reduce most of the design errors or mistakes that normally lead to correction in the DDP of the SDP.

- *Redesign*

Participants in all the groups emphasized that incessant or unnecessary changes in the architectural drawings/projects during the SDP necessitate most of the redesign activities in the DDP. To overcome this problem, the participants suggested that all form of variabilities should be evaded in the DDP. That is, design variation/change orders should be completely avoided by the various parties once structural activities get to the DDP. In order to effectively establish this strategy, participants in groups A, C and E advocated that a *'design variability space policy (DVSP) or a grace period (GP)'* should be implemented in the SDP. That is, a time frame that all the design actors and the client will be able to implement changes in the design process. This implies that once DVSP or GP has elapsed, subsequent variability will not be tolerated.

The participants in groups B and D supported this proposition and further added that if it is mandatory to make any change on the project while DVSP or GP has already been elapsed, then the defaulter (s) should be extremely penalized. That is, the defaulter should be fined. The participants were of the opinion that penalizing the defaulter will curb unnecessary design changes in project specifically in the DDP. Further, in groups A, C and E participants stressed that poor or inadequate involvement of the clients in the structural process is another factor that may be responsible for most of the variation or change order that consequently lead to redesign in the DDP. To effectively reduce this problem, the participants speculated that in every project, clients should be adequately involved in every stage of the SDP. This opinion is similar with what has been observed in the literature concerning consistent interaction between the client and the architect during the AP (Gatlin, 2013: 6)

Also, participants in groups B and D, proclaimed that wrong computations or computation errors due to several tentative assumptions in the proportioning of the structural elements is another cause of redesign in the DDP. To overcome this problem, the participants opined that designers should avoid vague assumptions in the PDP of the SDP. Similar with this view, in groups A, C and E, participants' declared that errors or mistakes that are not detected in the PDP are the main causes of redesign in the DDP. For instance, C_1 stated that …

> *"… if something goes wrong in the detail phase of design process, it means that the previous phases were not properly done. If there are no problems in the previous phases, it reduces chances of problems in the detailed phase …"*

Hence, the participants in all the groups submit that to effectively reduce the chances of occurrence of redesign in the DDP, structural designers should ensure that predesign activities are properly conducted.

Participants in groups B, C and E added that adequate involvement of an experienced designer such as chief engineer or senior engineer in the necessary design computations in the PDP will also reduce the chances of occurrence of redesign in the DDP. This means that if experienced designers are fully involved in the proportioning of the structural elements in the PDP, errors/mistakes and vague assumptions that can lead to redesign in the DDP will be expressively reduced.

- *Delay in the selection of suitable structural elements computed in the PDP, incorporation of comments made in the PDP into the design and inability to complete work as earlier scheduled*

In term of these problems, D_2 declared that …

> *"If everything works or goes as expected in the various phases of the structural design, the structural designers will be able to deliver as programmed or planned."*

Based on D_2's declaration, participants in the group agreed that the highlighted problems in the SDP would be overcome if every activity in the design process goes as planned. That is, if all the problems in the current practices of the SDP are addressed, the designers will be able to promptly select suitable structural elements computed in the PDP, and complete the detailed drawings as programmed. The opinion expounded by the participants in group D is tantamount to that of the participants in group D. During the discussion, A_3 pointed out that …

> *"... if you have all the information available at hand and you can still not meet up with the design deadline, that means your performance as a designer is poor ..."*

The participants in groups B and E were also of the same side to the assertion put forward by the participants in groups A and D. However, the participants added that the moment a designer envisages that the project at hand is going to be completed behind scheduled, the designer should immediately communicate with the chief engineer of the firm for additional hands. In groups C, the perception of the participants was not contrary to that of the other groups. However, participants in this group further discussed that to effectively overcome the highlighted challenges during structural activities, the client and the designers need to be committed financially and in the discharge of duties. Based on the discussions and suggestions in all the groups, it can be concluded that to timely and effectively complete work as scheduled in the SDP, adequate planning among the designers, appropriate communication between the junior, the senior engineers and the clients and total commitments among the various parties are some of the essential tools.

- *Waiting for the approval of the final drawings*

To overcome this problem, C_1 posited that …

> *"… the junior designers should try as much as possible to work ahead of time so as to be able to complete every necessary work before the time frame …"*

To support the emphasis of C_1 during this conversation, participants in the group affirmed that working ahead of time will enable the junior designer to conferral all completed works to the chief/senior engineer earlier than expected, which will consequently avail the chief engineer with the opportunity of adequate time for reviewer and approval. Expressing similar views with those espoused by the participants in group C, B_4 proclaimed that …

> *"… the moment a junior designer is able to complete work; the designer should communicate the chief engineer in a good time …"*

B_5 concurred with the discussion and stressed that …

> *"… the junior designer also needs to keep on pressurizing or reminding the senior designer from time to time the urgent need of his approval on the submitted works …"*

Hence, participants in group B agreed that proper planning as well as adequate flow of communication among the various actors should be adopted.

Compared with this suggestion, in groups A and E participants proposed that a register or time record book that would indicate the time the work was submitted and when it was approved, could be adopted as well. The participants were of the opinion that the adoption of register at the approval phase of work may facilitate the two parties (the senior and the junior engineers) to be more committed to their works. The response of the participants in group D concurred to that of other groups but advised that the junior designers should not be left with the primary aspect of the work. D_4 pointed out that …

"... I mean the senior designer needs to be fully involved in the work and absolutely familiarized with the drawings and specifications before the work get to his table ..."

Participants in the group argued that approval of final drawings may not take time if the senior engineer is already used to the whole design and specifications before it gets to his table. This means that approval of final structural drawings takes time when the senior engineer intends to understand the detailed of the drawings at the late hour. Table 5.11 gives the summary of the opinions of the participants on the strategies that can be adopted by the SDT to reduce waste in the DDP of the SDP.

Table 5.11: Strategies for waste reduction in the detailed design phase of the structural design process

Waste	**Strategies**	**Sources**
Design corrections	Adequate involvement of experienced designers such as senior engineers in every aspect of the SDP	All the groups
Redesign	Implementation of DVSP or GP in the SDP	All the groups
	Penalizing DVSP defaulters	Groups B and D
	Avoidance of vague assumptions and design variations in the SDP	Groups B and D
	Adequate involvement of the client in every phase of the SDP or proper communication between the client and the SDT in every phase of the SDP	Groups A, C and E
	Adequate engagement of an experienced designer such as senior engineer in the computation aspect of the structural design	Groups B, C and E
Delay in selection of the suitable structural elements computed in PDP, delay to incorporate the comments made in the	Proper planning and communication between the senior and the junior engineers and the client	All the groups
	Total commitment among the various design actors and the client	Group C

PDP into work and inability to complete work as earlier scheduled	Appropriate communication for additional resources such as man powers when the need arises	Groups B and E
Waiting for approval of the final drawings	Proper planning as well as adequate flow of communication among the various actors	All the groups
	Adoption of a register or time record book among the designers for proper commitment to work	Groups A and E
	The junior designers should not be left with the primary aspects of the design.	Group D

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(4) The construction phase

- *Excessive RFIs, Construction reworks excessive writing of site instructions and excessive waiting time during structural reinforcement*

Participants in all the groups speculated that to reduce or overcome problems such as excessive RFIs and writing of site instruction, rework and some other structural design related waste during construction activities, construction drawings and specifications should be free of mistakes/errors. In addition to this, participants advocated that both the architectural and structural drawings should be comprehensible, coherent and lucid to the contractor and subcontractor. This means that complexity in construction drawings are to be completely avoided by the design teams. Based on the participants' opinions, it can be debated that limited problems will exist in the CP of projects if perfection is attained or achieved in the design phase.

In groups C and E, participants further contemplated that construction contractors may as well be partially be involved in some aspects of the structural design so as to be acquainted with the structural drawing before site activities commenced, and to be able to advise the SDT on the aspects of work that may likely bring problem in the CP. However, contrary to the speculations of the participants in groups C and E, in groups A, B and D, participants recommended that a structural engineer should rather be engaged during the site activities right from the inception to the completion stage. The participants were of the view that the part time appointment that is currently in vogue in the study context is not sufficient for efficient construction. During this discussion, A_3 stressed that …

> *"… if the client cannot afford to fully engage the engineer due to financial constraint, then the engineer should be engrossed for reasonable hours so as to clearly explain some of the complicated or technical information on the drawings to the contractor before the start of the site activities…"*

Based on A_3 opinion, the participants in the group postulated that the explanations between the engineer and the contractor should not be less than three hours, and should be tape recorded for efficient utilization. Similarly, participants in groups B, C, D and E agreed to the suggestion espoused by the participants in group A, and added that after the necessary clarifications by the designers, the contractor should spend a day or two to study the drawings and specification properly and ensures that all the information on it are clearly understood prior to the commencement of the site activities. For proper design interpretation, participants in groups A, B and D advised that the structural designer that provided the necessary information in the AP is in better position to be engaged for clarification of the necessary information in the CP.

- *Variations/change orders and redesign*

To overcome these problems, participants in all the groups expressed that all form of variabilities during site activities should be avoided by every project actor. To actualize this in practice, the participants in groups A, B and C suggested that the technical aspects of work that may be liable to changes during site activities should be deferred until final decision has been taken by all the project stakeholders. This means that such aspects of work will not be executed until all project actors have agreed or concluded at a final option, idea or decision.

- *Wrong fabrication of formwork, rebar cage, reinforcing steel and excessive cutting or fabrication of structural reinforcing materials.*

Participants in all the groups argued that if a contractor/subcontractor understand the construction drawings accurately, mistakes or errors during site activities will be very minimal. The participants' stressed that mistakes or errors are bound to occur when a contractor and subcontractor has inadequate knowledge of the construction drawings. They asserted that the services of experienced contractors and subcontractors should be engaged in every project. Participants in groups A, B and D further maintained that in large projects, a structural engineer should be engaged on a full time basis so as to be able to clarify every ambiguous information in the working drawings. Although, the participants argued that the full time engagement has more financial commitment when compared to the part time. Nonetheless, the participants in the three groups agreed that the advantages of full time in term of waste elimination/reduction outweigh that of the part time appointment. Based on these explanations, it can be stressed that the practice of full time appointment of structural engineers during the site activities should be encouraged in South African context.

- *Ineffective communication flow between the SDT and the construction contractors*

Apart from the need to evade complexity in design which has earlier been suggested as one of the strategies for overcoming waste during the site activities, participants in groups C, D and E also suggested that it is essential for the SDT to produce more sections or details of the construction drawings. The participants accentuated that more sections or details of some technical aspects of the construction drawings may facilitate the contractors to better understand the design which may consequently lead to proper communication between the two parties. Participants in group A and B maintained that the service of an experienced contractor and subcontractor should be engaged for every aspect of work. This means that with an experienced contractor and subcontractor, the flow of communication among the various actors will become effective or enhanced.

- *Excessive site supervision*

In spite the fact that participants in all the groups argued that several supervisions occur during site activities. The participants cautioned that the supervisions should not be side-step or compromised for any reason. In group B, C, D and E the participants emphasized that the designers as well as the consulting firm are liable for any damage which may accrue on site due to any imperfection or deficiency in the structural drawings. Therefore, the participants declared that it is mandatory for the SDT to carry out adequate or continuous supervision from time to time to prevent all forms of defect during the site activities. Coexisting to this viewpoint, A_4 argued that…

"…the time a designer spend for inspection during steel reinforcing even if it is half a day is preferable because it can save the designer several rework or wasteful expenditures that may later occur if the inspection was not done or properly done…"

A_5 supported A_4 point of view and pointed that…

"…the contractor that may be engaged in the site activities may be skilful enough to carry out work as specifies in the drawings and specifications but the subcontractor may not be lettered enough. This may constitute problem that can lead to problems during site activities."

Based on A_4 and A_5 arguments, A_1 declared that…"

"…so to be at the safer side, I think it is better to carry out supervision of work from time to time..."

Based on the suggestions of the participants in all the groups, it can be said that appropriate supervisions during site activities is one of the tools that can be adopted to reduce waste in construction projects. This means that effective supervisions is one of the waste minimization techniques in the CP of projects. Table 5.12 summarizes the opinions of the participants in all the groups on the strategies that can be adopted to reduce waste in the CP of a project.

Table 5.12: Strategies for waste reduction in the construction phase of projects

Wastes	**Strategies**	**Sources**
Excessive RFIs, Construction reworks, excessive writing of site instructions and excessive waiting time during the structural reinforcement	Production of drawings that is free of mistakes/errors and unambiguous to understand and interpret on the site	All the groups
	Involvement of construction contractors in the design process	Groups C and E
	Full time engagement of a structural engineer at the construction phase of projects	Groups A, B and D
	Engagement of a structural engineer for reasonable hours for clarification of the technical aspect of construction drawings before the start of site activities	All the groups

Variations/change orders and redesign	All forms of project variability are to be avoided during site activities	All the groups
	Project actors are to defer the execution of the technical aspects of work that are liable to changes during construction activities until final decision has been taken by all project actors	Groups A, B and C
Wrong fabrication of formwork, rebar cage and reinforcing steel and excessive cutting or fabrication of structural reinforcing materials.	Engagement of the services of experienced contractors and subcontractors	All the groups
	Full time engagement of a structural engineer at the construction phase of projects	Groups A, B and D
Ineffective communication flow between the SDT and the construction contractor	Production of more sections or details of some technical aspects of construction drawings for simplicity of every design information	Groups C, D and E
	Engagement of the service of an experienced contractor	Groups A and B

(Author, 2016)

5.3.4 Summary of findings from the second phase of the focus interviews and its relationships to the study research questions

How should lean construction remove waste in the structural design process?

At the end of the second phase of the focus interviews conducted, it was discovered that lean concept is not being adopted during the SDP in Bloemfontein consulting engineering firms. What was in vogue to certain degree as at the time of this study in two of the case study firms was design optimization technique (DOT), which is only applicable to large projects in the proportioning of columns. In term of beam designs, it was discovered that DOT has no significant difference from the normal method. Also, DOT was not applicable to foundation design as the study conducted shows that attempts to reduce project cost at foundation design by the SDT may jeopardize the primary aim of the structural design. The study conducted also shows that the brain behind DOS in the two case study firms was through long term experience, staff and workshop trainings and annual general meetings organized by Institute of Civil Engineering locally and internationally.

Despite that the SDT were aware of the various problems in the SDP, this study shows that there was no practical measure that have been or intends to be put in place by the management of the various firms to overcome or reduce the problems experienced in the system. However, literature shows that lean principles/techniques can be applied to projects so as to weed out waste in the process ((Ko & Chung, 2014: 463; Ko & Tsai, 2013: 2409; Ko & Chen, 2012: 101; Hicks, 2007: 233). In the course of this study (mechanism development process), it was discovered that a lean tool known as the VSM, and the five lean principles namely; specify value, identify value stream, let the values flow, immediate pull/push of activities or information, and continuous improvement can be adopted by the structural engineers in every phase of the SDP so as to identify and remove waste in the practice. The procedures to this are fully explained in chapter 6 of this study. Therefore, ***lean concept can be used to remove waste in the structural design process*** through the application of the VSM and the five lean principles.

What mechanism should be used to remove waste in the structural design process?

Apart from the knowledge of the lean thinking that can be adopted by the designers to remove waste in the SDP, this study reveals that ***one main mechanism that can be used to further remove waste in the design process*** is adequate engagement of the SDT in the architectural process (AP). It was discovered in this study that engagement of the SDT in the AP will enable the design actors to detect, and rectify most of the problems encountered in the process, and consequently come up with an appropriate architectural drawing (AAD). This study also shows that engagement of the SDT in the AP will also enable the SDT to start the required site topographical survey and geotechnical investigation at the right and appropriate time, which will avail the team the opportunity to further reduce waste such as waiting for site reports in the process.

5.4 Summary

This chapter has explicated on the overall data obtained in this study. The data were collected through focus interviews which were in two phases. The first phase enabled the researcher to discover the various waste in each phase of the SDP, their origins, and impacts on projects. The second phase availed the researcher the opportunity to ascertain certain strategies that can be adopted by structural engineers to reduce the discovered waste in their practice. This implies that the analysis of the data generated through the QMAR in this study abetted the researcher to arrive at several findings. This chapter aids the researcher to compare these findings to the set research questions for appropriate conclusions. Based on these findings and conclusions, this study shall proceed to Chapter 6 so as to develop and test the proposed waste reduction mechanism in the SDP.

6.0 DISCUSSION OF THE PRIMARY FINDINGS OF THE STUDY

6.1 Introduction

This chapter presents the proposed lean mechanism for waste identification and reduction in the structural design process (SDP) in South African construction, which is basically the aim of this study. The discussed results in Chapter 5 of this report serve as the basis for the development of the mechanism. Also, the chapter discusses how the developed mechanism was evaluated before recommending it as a waste reduction tool in the SDP.

6.2 The Proposed Lean Mechanism for Waste Reduction in SDP

The proposed mechanism was developed from a juxtaposition of different sources, namely: QMAR study, researcher's experiential knowledge pertaining to the subject matter, the review of state-of-the-art lean construction literature on value stream mapping (VSM), and related lean principles. In the mechanism development process, a VSM was adopted to analyse the current flow of activities in each phase of the SDP. The VSM was espoused to:

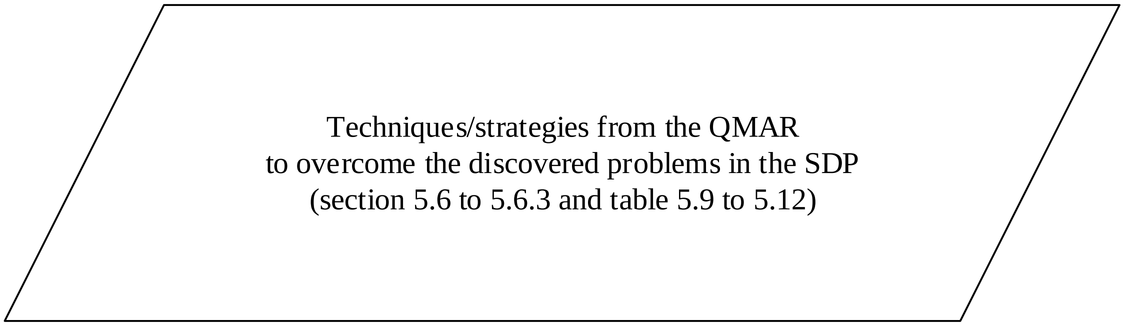
- Observe the flow of the current activities (value and non-value adding (NVA)) as they occur in practice in each phase of the SDP;
- Summarize the activities in order to see the hidden waste such as lead time (LT) as well as their sources, and
- Depict the basic lean principles, experience and knowledge obtained from this study into the system so as to reduce or eliminate the various waste and problems.

The developed mechanism was to be enhanced for accuracy through the adoption of design correctness (DC). This was necessary as literature and the data collected from the study show that problems or NVA discovered in the later phases of design are mainly due to errors/mistakes that are not detected in the earlier stages.

> *"Design correctness can be regarded as a metric to measure the degree to which design meets the needs of the user or application … Accuracy calculations and statistical analysis*

results are represented as the quality of product design, which could be used to provide feedback for design correction and revision (Ko & Chung, 2014: 464)".

Based on the literature, DC can be achieved in a project through the service of an experienced staff member (quality assurance process). This denotes that in every phase of the SDP, a senior designer can be appointed to adequately cross-check every segment of work so as to ensure that 100% accuracy is achieved before moving to the next phase. Hence, before the validation exercise that was later conducted in this study to modify the developed lean mechanism, a senior or chief engineer has been earlier suggested as the DC officer. Precisely, Figure 6.1 shows the analytical diagram of the proposed mechanism for this study, while Table 6.1 shows the various VSM symbols adopted.



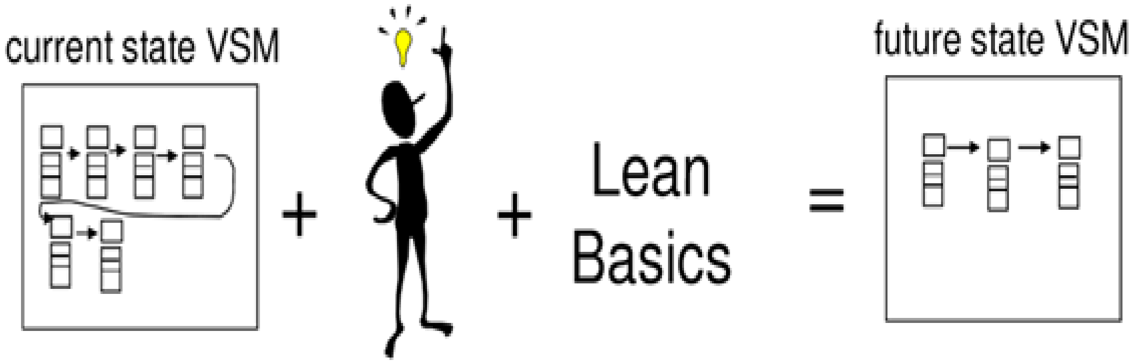
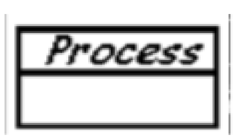
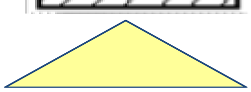
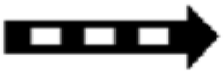


Figure 6. 1: Analytical diagram of the proposed lean mechanism for this study (Adapted from Rother & Shook, 2009: 14).

Table 6.1: Symbols for value stream mapping process

Symbols	Description
	Customer/Supplier Icon (C/SI): represents the Supplier when in the upper left, customer when in the upper right, the usual end point for material
	Dedicated Process Flow Icon (DPFI): a process, operation, machine or department, through which material flows. It represents one department with a continuous, internal fixed flow
	Shared Process Icon (SPI): a process, operation, department or work center that other value stream families share
	Inventory Icons (II): show inventory between two processes

Shipments Icon (SI): represents movement of raw materials from suppliers to the Receiving dock/s of the factory. Or, the movement of finished goods from the Shipping dock/s of the factory to the customers

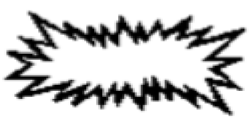


Push Arrow Icon (PAI): represents the ‘pushing' of material from one process to the next process

Production Control Icon (PCI): This box represents a central production scheduling or control department, person or operation

Manual Info Icon (MII): A straight, thin arrow shows general flow of information from memos, reports, or conversation. Frequency and other notes may be relevant

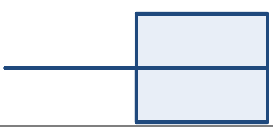
Electronic Info Icon (EII): This wiggle arrow represents electronic flow such as electronic data interchange (EDI), the Internet, Intranets, LANs (local area network), WANs (wide area network). You may indicate the frequency of information/data interchange, the type of media used ex. fax, phone, etc. and the type of data exchanged



Kaizen Burst Icon (KBI): used to highlight improvement needs and plan kaizen workshops at specific processes that are critical to achieving the Future State Map of the value stream

Operator Icon (OI): represents an operator. It shows the number of operators required to process the VSM family at a particular workstation

Time Line Icon (TLI): shows value added times (Cycle Times) and non-value-added (wait) times. Use this to calculate Lead Time and Total Cycle Time



Time Line Total (TLT): gives the summary or total lead time or inventory and processing time in a system

(Adapted from Rother & Shook, 2009: 14)

It has been explained in Chapter 5 of this report that SDP is sited basically in four phases, namely: the inception design phase (IDP), the predesign phase (PDP), the detailed design phase (DDP), and the construction phase (CP). Findings from this study indicate that the moment a contract is awarded; structural activities start immediately after the completion of the architectural drawings. The key or basic activities in the SDP start from the IDP, and end in the CP. It is essential to know that the underpinning theme for the proposed lean mechanism is anchored on the need to build compelling explanations on how the waste in every phase of the current SDP can be identified and reduced so as to enhance values in the practice (future state VSM). Therefore, for easy understanding of the proposed mechanism, the current and future states of the activities in the four main phases of the SDP are emphasized separately in the following sections:

6.2.1 The proposed mechanism for the inception design phase

With the exception of the site topographical survey, and soil tests that are delegated to the professionals, every other activity in the inception phase of the SDP is the responsibility of the structural design team (SDT). To the SDT, the work flow in the IDP of the SDP was perfect and might not need to be ameliorated (Chapter 5, section 5.4). However, after the adoption of the VSM to the flow of the activities, several issues were clearly identified to the teams as problems (Figure 6.2). The teams in each firm realized that most of their weekly and daily activities in the IDP of the SDP consist of wasteful steps or LT (3 weeks, 3 days). This is similar to the observations of Ko and Chung (2014: 467) on the application of VSM on AP. Details of the activities that are presented in Figure 6.2 and the subsequent ones are shown in Appendix 9 of this thesis.

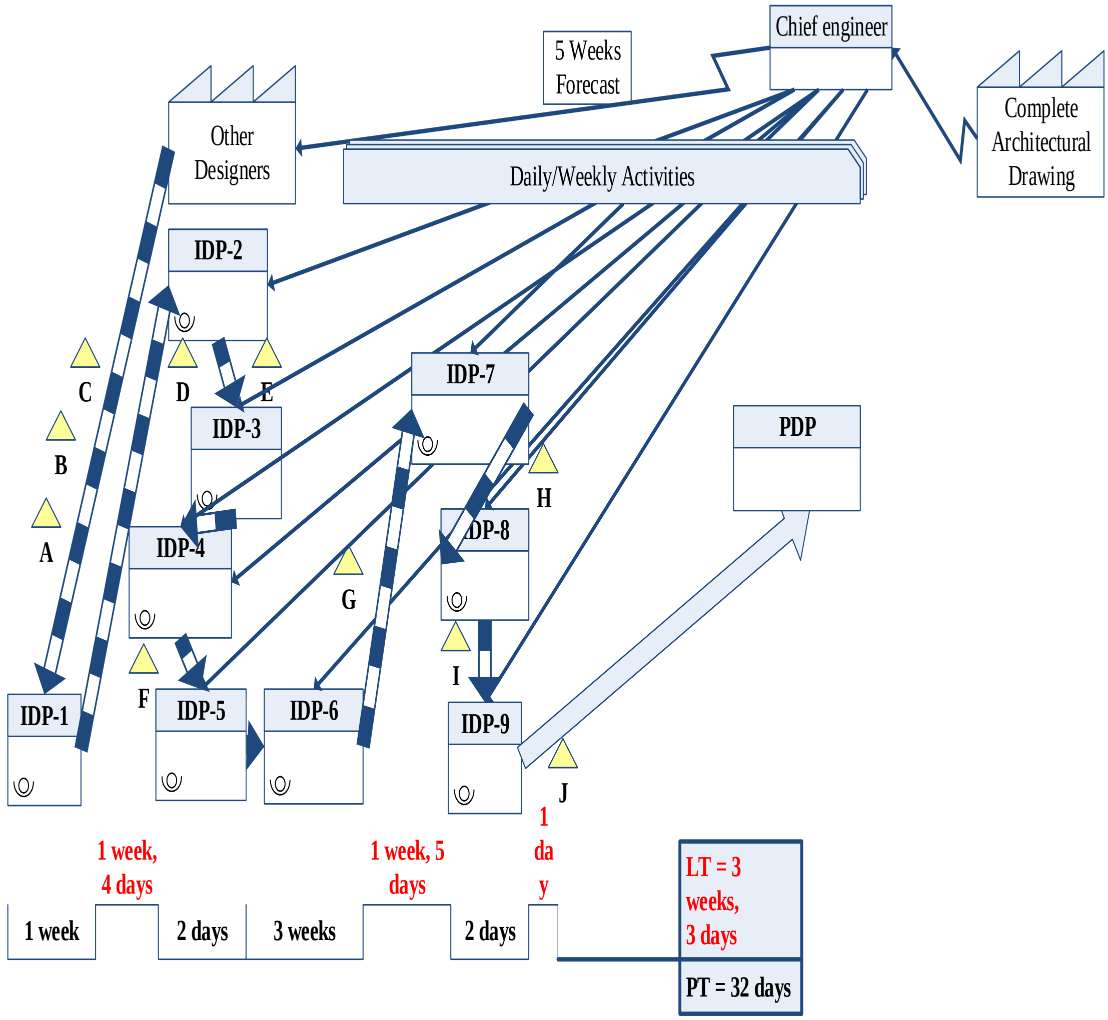


Figure 6. 2: The current state value stream mapping of the inception design phase (Author, 2016)

During this study, the SDT and the researcher reached consensus that the LT due to problems in the system need to be avoided or reduced as they constitute unnecessary delays that prolong or extend the completion or actual processing time (PT) of the value-adding activities (VAA). These problems are clearly marked out with the use of VSM symbol known as the Kaizen burst in Figure 6.3. These discoveries are consistent with the findings of Osmani *et al.* (2008: 1147), Mossman (2009: 24) and Nagapan *et al.* (2012: 22) regarding some of the waste in projects. It is essential to know that all the LT and PT shown in all the figures in this study were obtained from the participants in all the groups based on their experiences in the previous executed projects. Hence, the LT and PT are premised to the design of any highly challenging commercial or industrial buildings such as high rise or multi-storey structures.

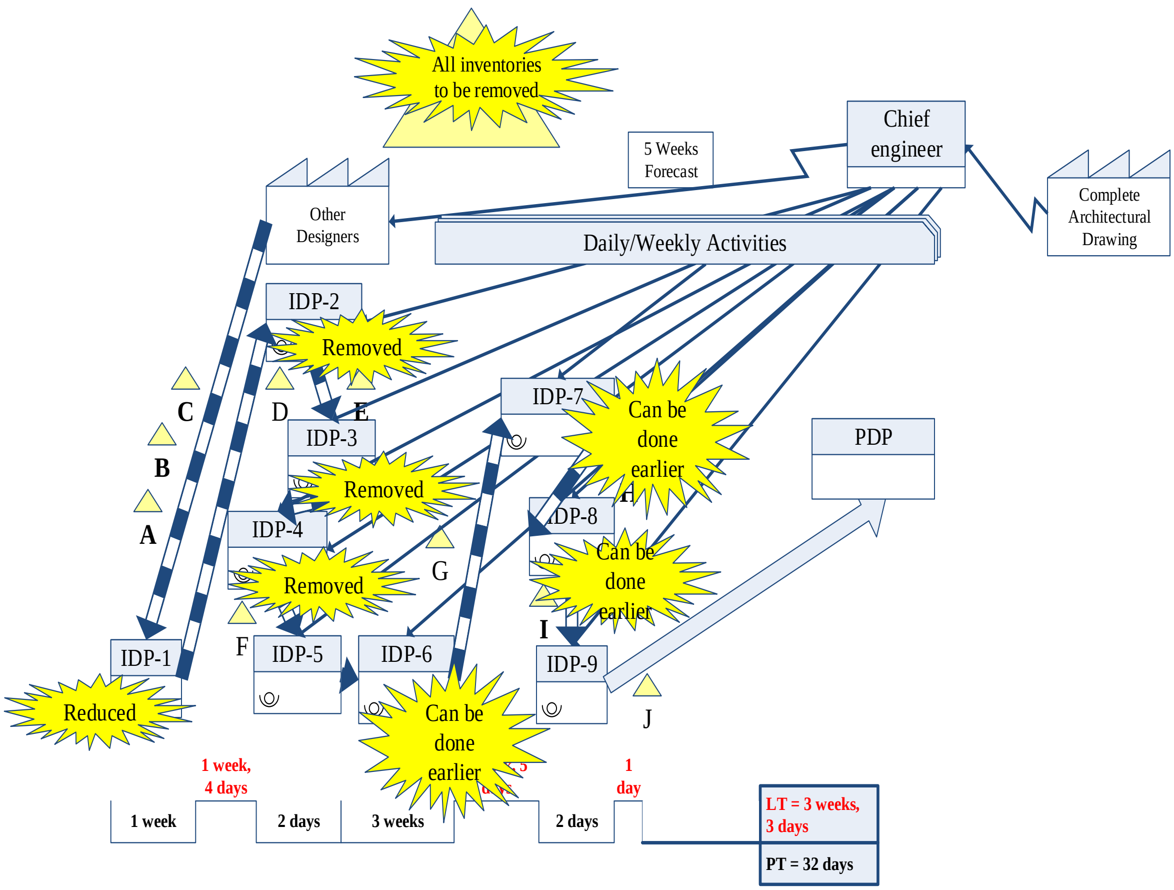


Figure 6. 3: Waste elimination process in the current state value stream mapping of the inception design phase (Author, 2016)

To overcome the analysed issues in the current state VSM of the IDP so as to come up with the future state, the procedures in the analytical diagram in Figure 6.1 was adopted by the researcher and the SDT. This implies that the information in Table 5.9 of this thesis and the basic lean principles such as specify value, identify the value stream, let the values activities flow in time without interruption, immediate pull/push of activities or information, and continuous improvement were adopted. This is in agreement with the opinion of Rother and Shook (2009: 14) on waste elimination strategies in an organization process. It was observed in Chapter 5 of this thesis that the intention to encompass the SDT in the AP is not only to enable the teams to come up with appropriate architectural drawings (AP + SDT = AAD), but to also avail the team the opportunity to conduct some of the activities in the inception phase of the SDP earlier than expected. This indicates that activities such as review of the architectural drawings, defining the services and the scope of the project, give favourable advice in term of the project life cycle costs, attend project initiation meetings so as to implement contract agreement between the client and the designers, schedule and inspect on the necessary land topographical survey and soil tests, and oversee the compilation process of site reports in the current IDP of the SDP can be conducted earlier if the SDT are adequately involved in the AP (Figure 6.4).

Therefore, challenges such as delay in establishing a contract agreement between the client and the SDT, delay to establish the scope of the work, delay in analysing the project life cycle cost, waiting for site report, slow speed of activities during the topographical survey and geotechnical investigations of the proposed site, and delay in establishing the inception design documents can be reduced or overcome in the IDP of the SDP. This is synonymous to the opinions of Forbes and Ahmed (2011: 50), Eastman *et al.* (2011: 152) regarding the application of information and communication technology platforms for waste identification/reduction in the design and the construction phases of projects. It should be remembered that to reduce the unnecessary LT due to several meetings, especially in project initiation phase, phone calls and internet enabled communication (IC) such as e-mail and Facebook can be adopted. This implies that most of the project issues or discussions can be addressed through this facility without the need for the various actors to come together. It is also good to remember that the problem of poor site report can be overcome in the current IDP of the SDP if the SDT avoid or limit most of the vague assumptions during site geotechnical investigations.

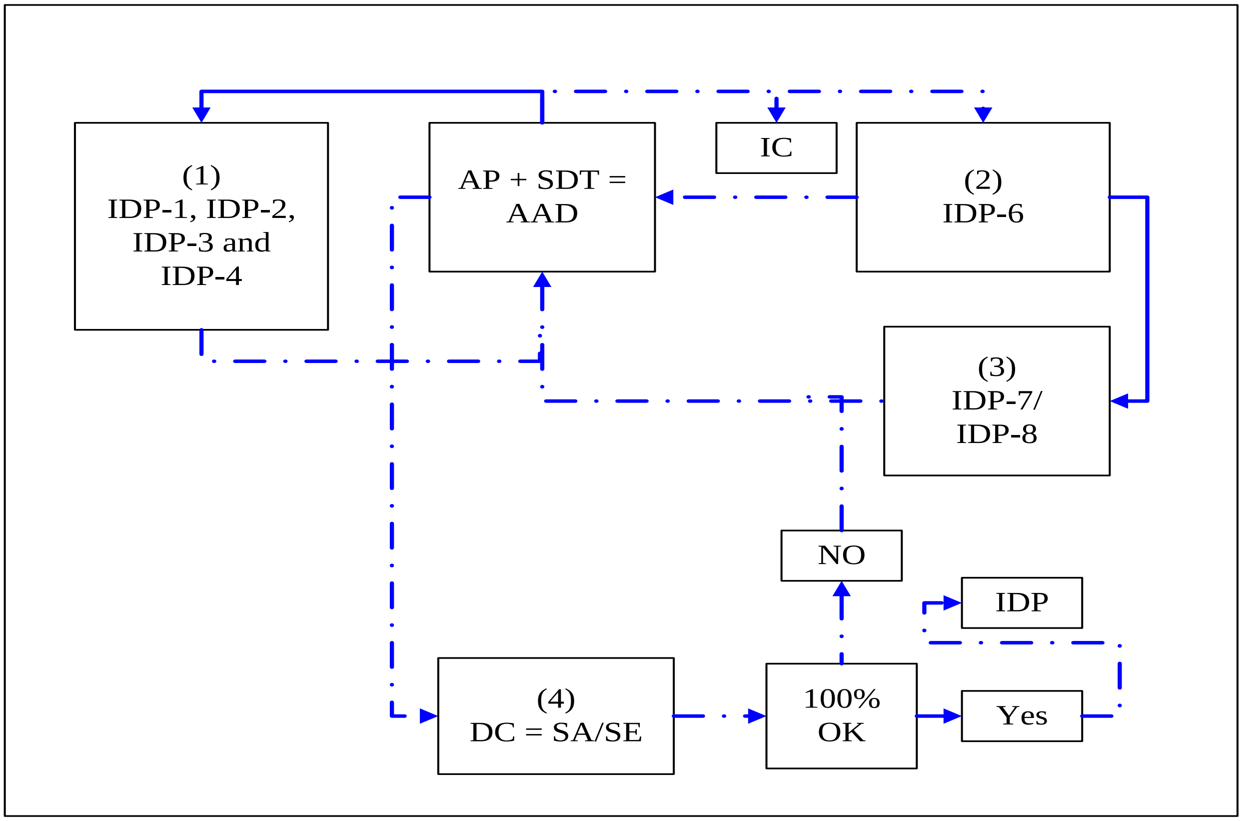


Figure 6.4: Appropriate architectural design process (Author, 2016)

Provided that the SDT is able to conduct most of the activities in the IDP during the AAD process, it becomes apparent for the team to provide the information required by other consultants (if any), and perform some of the PDP activities in the IDP (Figure 5.5). That is, activities such as establishing the necessary regulatory requirements and the building codes, and incorporating them into the project (PDP-4) can be performed in the IDP of the SDP. Once the team is able to successfully achieve these, the next activity is to re-examine all the activities and process through the DC. If 100% accuracy is confirmed in the system, the documents in this phase (IDP) can be signed immediately by the parties involved. Subsequently, the team can proceed to the next phase.

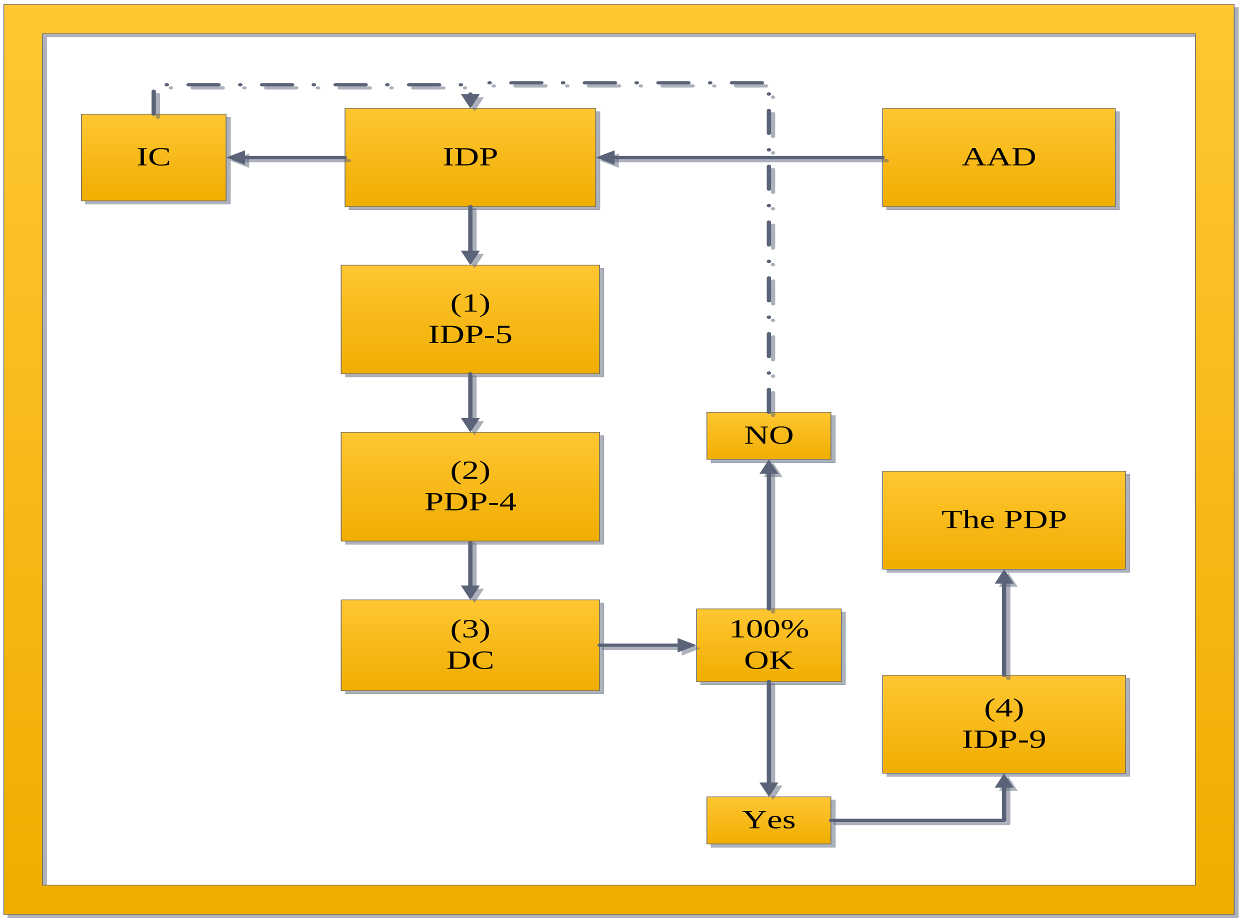


Figure 6.5: The future state value stream mapping of the inception design phase (Author, 2016)

6.2.2 The proposed mechanism for the predesign phase

In terms of this phase, the overall activities are the responsibility of the SDT with the exception of the modifications of the architectural drawings that require the services of the architect. The current flow of activities in the PDP of the SDP also appears impeccable to the SDT (Chapter 5, section 5.4), but after the adoption of the VSM (Figure 6.6), the teams in all the groups realized that several activities in this phase are also problems or LT that need to be avoided or improved for appropriate flow of the VAA.

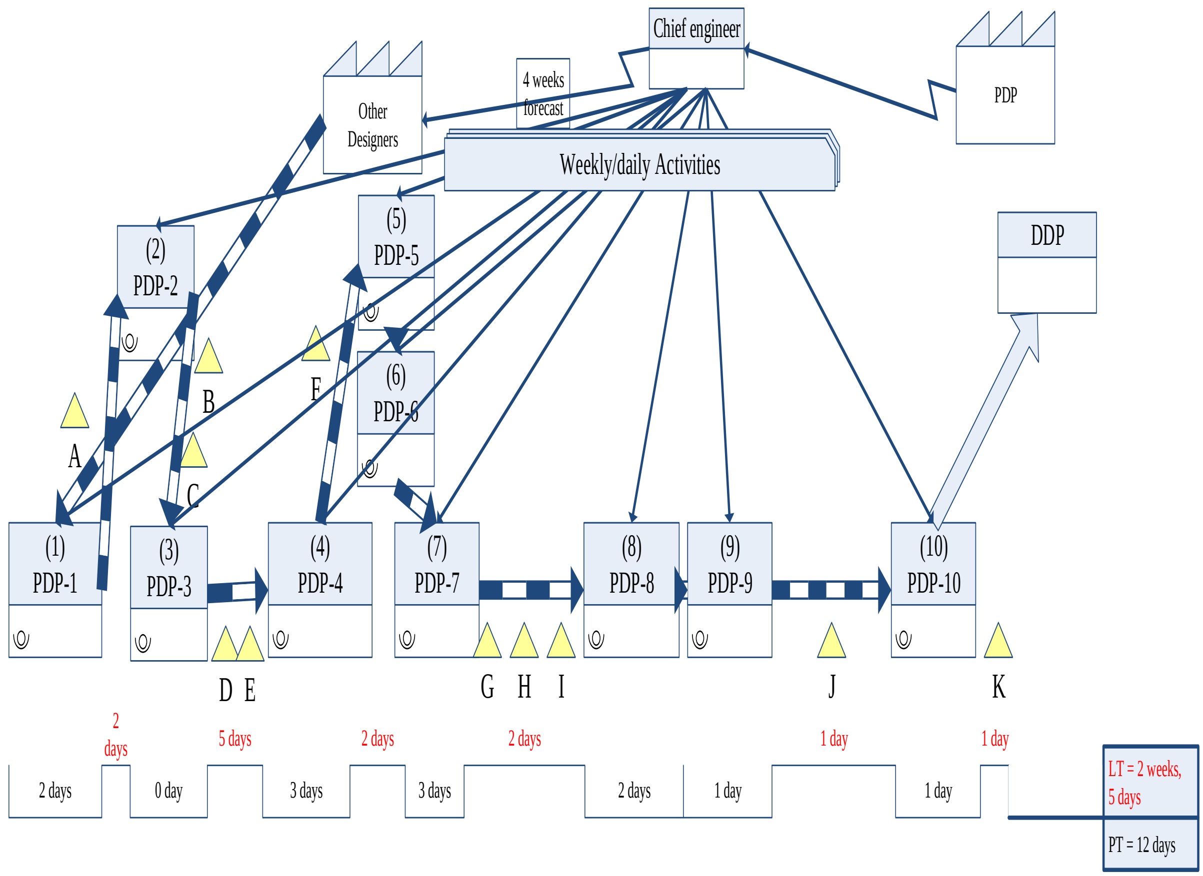


Figure 6.6: The current state value stream mapping of the predesign phase (Author, 2016)

It is essential to know that under ideal conditions, the actual PT for the activities in this phase is not expected to be more than two weeks and three days. However, with the LT of two weeks, the completion time of activities is around four weeks, three days (LT +PT). Therefore, the activities that are needed to be removed in the flow so that the overall work will be able to complete within the planned two weeks and three days are clearly marked out with the use of kaizen burst in Figure 6.7. The results in Figure 6.7 are similar to the findings of Simms (2007: 3) and Gatlin (2013: 1) concerning some of the waste in engineering design.

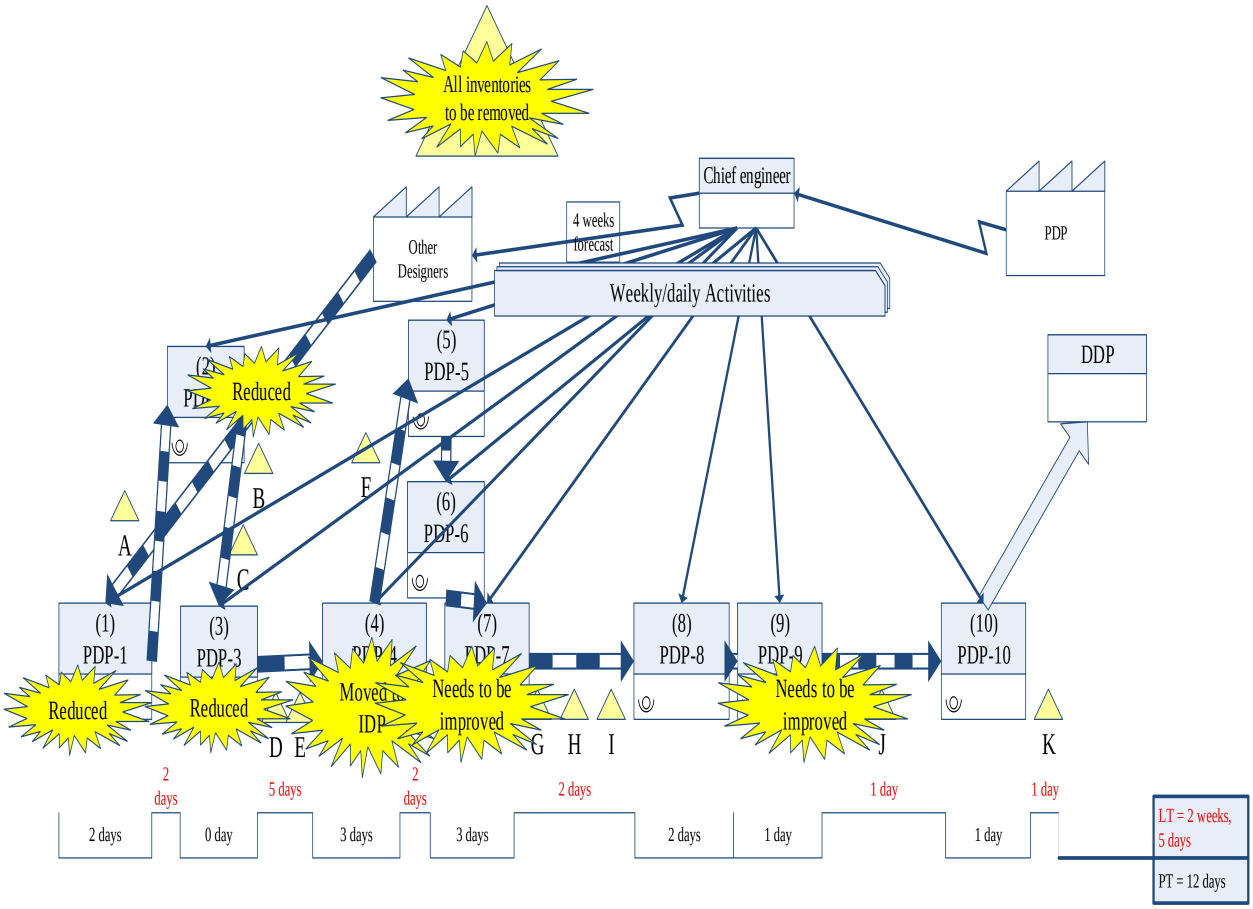


Figure 6.7: Waste elimination process in the current state value stream mapping in the predesign phase (Author, 2016)

To reduce or eliminate the analysed problems in the current state VSM to come up with the future state, the procedures in the analytical diagram in Figure 6.1 was also adopted by the researcher and the SDT. The problems such as ambiguities in the architectural design, several reviews of the architectural drawings, disagreement between the architect and the SDT, design modifications (architectural), and delays in incorporating the necessary regulatory requirements and building codes into the project can be reduced or conducted earlier if the SDT are fully involved in the AP, and the SDT conducts some of the activities in the PDP of the SDP during the AP, as illustrated in

Table 5.10. This is consistent with the opinions of Minnaar and Reinecke (1993: 2), Huovila, *et al*. (1997: 143) concerning concurrent engineering in projects.

It is good to remember that problems such as several repeated structural computations and/or wrong computation, excessive supervision, and several reviews of structural computations by the senior engineers can be reduced through the adoption of certain programmed excel spreadsheets or design software, and proper engagement of a senior designer in the calculation aspect of the predesign activities. Problem such as excessive printing of paperwork can be reduced if errors are minimized during SDP, and if electronic communication (EC) is utilized by every project actor to review and approve design and other related documents, while the problem of several meetings can be reduced through the adoption of internet enabled communication (IC).

Once all the problems in the PDP have been overcome, it becomes easy for the SDT to create the necessary structural predesign criteria, and ensure that the criteria established conform with the require building codes and regulatory requirements without delay, compute the preliminary sizes of the various structural elements with tolerable LT and minimal mistakes, timeously prepare the preliminary process design and related documents suitable for costing, and immediately establish the preliminary design documents once 100% accuracy is achieved in the system (Figure 6.8).

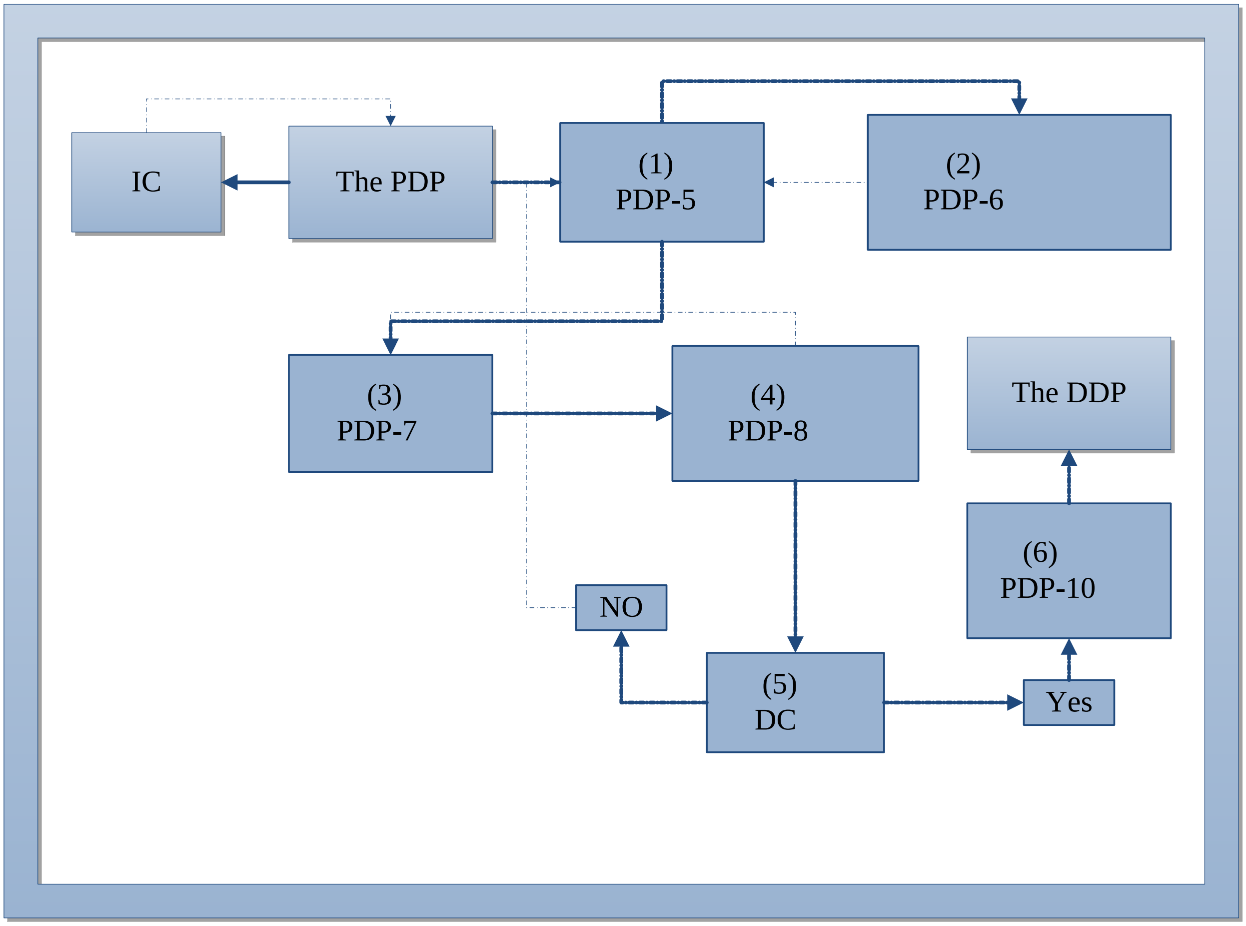


Figure 6.8: The future state value stream mapping of the predesign phase (Author, 2016)

6.2.3 The proposed mechanism for the detailed design phase

In terms of this phase, the overall activities are the responsibility of the SDT. It was also discovered that the work flow in the DDP of the SDP (Chapter 5, section 5.4) appeared perfect to the SDT, but after the adoption of the VSM, several activities were identified and were clear to the teams as wasteful iterations or LT needed to be avoided for an efficient project (Figure 6.9).

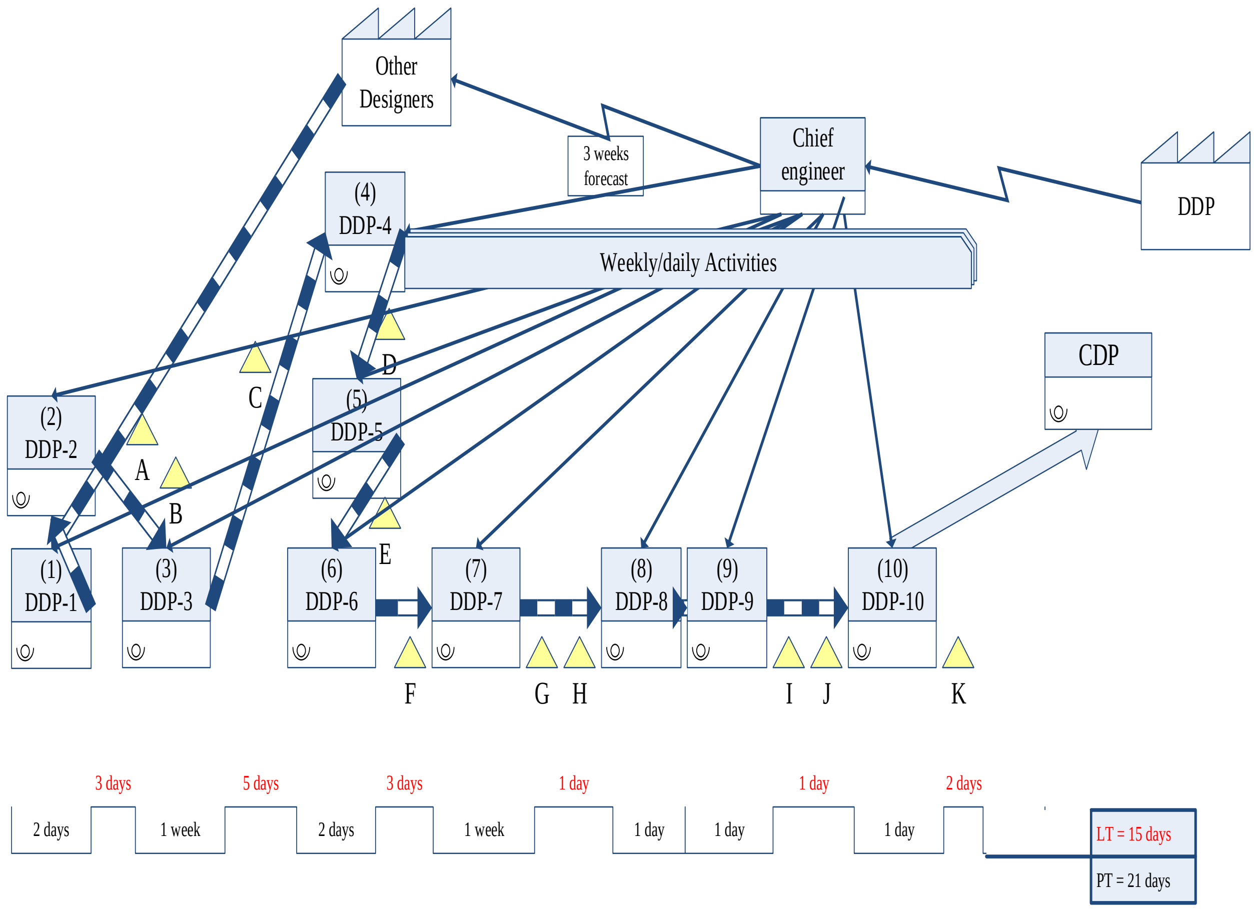


Figure 6. 9: The current state value stream mapping of the detailed design phase (Author, 2016)

Under normal circumstances, the actual PT for the various activities in this phase is expected to be three weeks and some days. However, with the LT of two weeks and a day, the overall completion time of activities is six weeks. Therefore, the activities that are required to be reduced or eliminated in the system so as to complete the work within the expected or required PT are clearly marked out with the use of the kaizen burst in Figure 6.10. These findings in Figure 6.10 are also consistent with the observations of Minnaar and Reinecke (1993: 2), Huovila, *et al*. (1997: 143) regarding waste in projects.

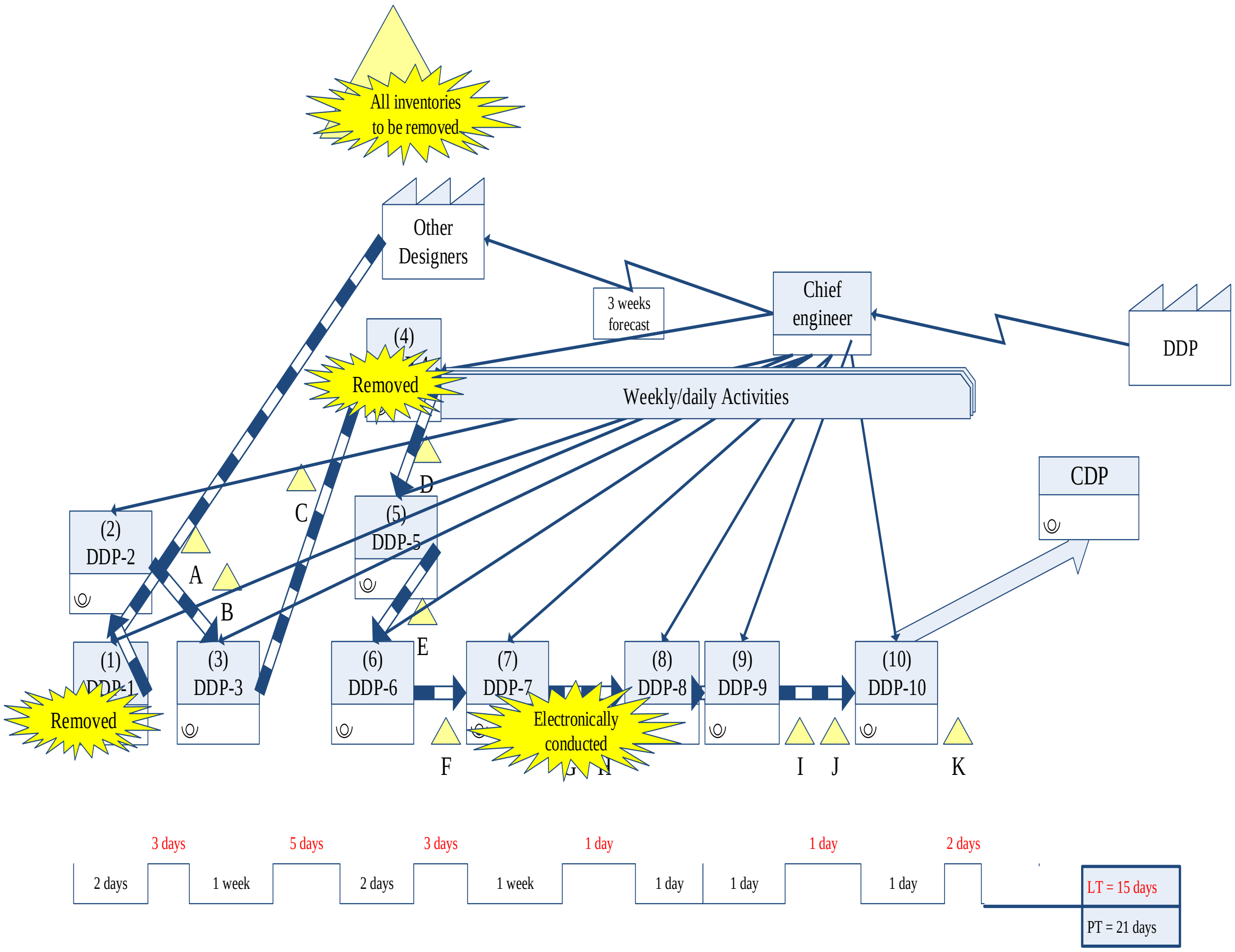


Figure 6.10: Waste elimination process in the current state value stream mapping of the detailed design phase (Author, 2016)

From the study conducted, it was observed that the SDT might experience few or no problems in the DDP of the SDP provided the activities in the IDP and the PDP are properly conducted. If senior engineers are fully involved in the predesign activities, and other proposed waste reduction strategies are adequately utilized in the IDP and the PDP of the SDP (Table 5.9 and 5.10), problems such as corrections, redesign, several printings of paperwork, delay in selecting the suitable elements computed in the PDP, inability to complete work as scheduled or planned, and delay in establishing the detailed design documents experienced in the DDP will be minimal. This is consistent with the opinion of Mryyian and Tzortzopoulos (2013: 449) concerning waste minimization techniques in projects.

To eliminate the few problems or challenges that may remain in the system so as to come up with the future state VSM, the procedures in the analytical diagram in Figure 6.1 were followed. This denotes that to further reduce the possibility of design corrections/redesign in the DDP, vague assumptions and design variations are to be limited or completely avoided in the IDP and the PDP of the SDP (Table 5.11). It should be remembered that the problem of several printings of paperwork can be overcome with the adoption of EC for correction, and approval of structural activities and final drawings.

Once all forms of LT or problems in the system have been eliminated or reduced, it will be less complicated for the SDT to select the suitable structural elements computed in the PDP, incorporate other consultants design requirements into the design, if any, prepare design development drawings, approve the final design without the need for several reviews by the senior designers, timeously produce the construction drawings, and establish the detailed design documents as scheduled (Figure 6.11).

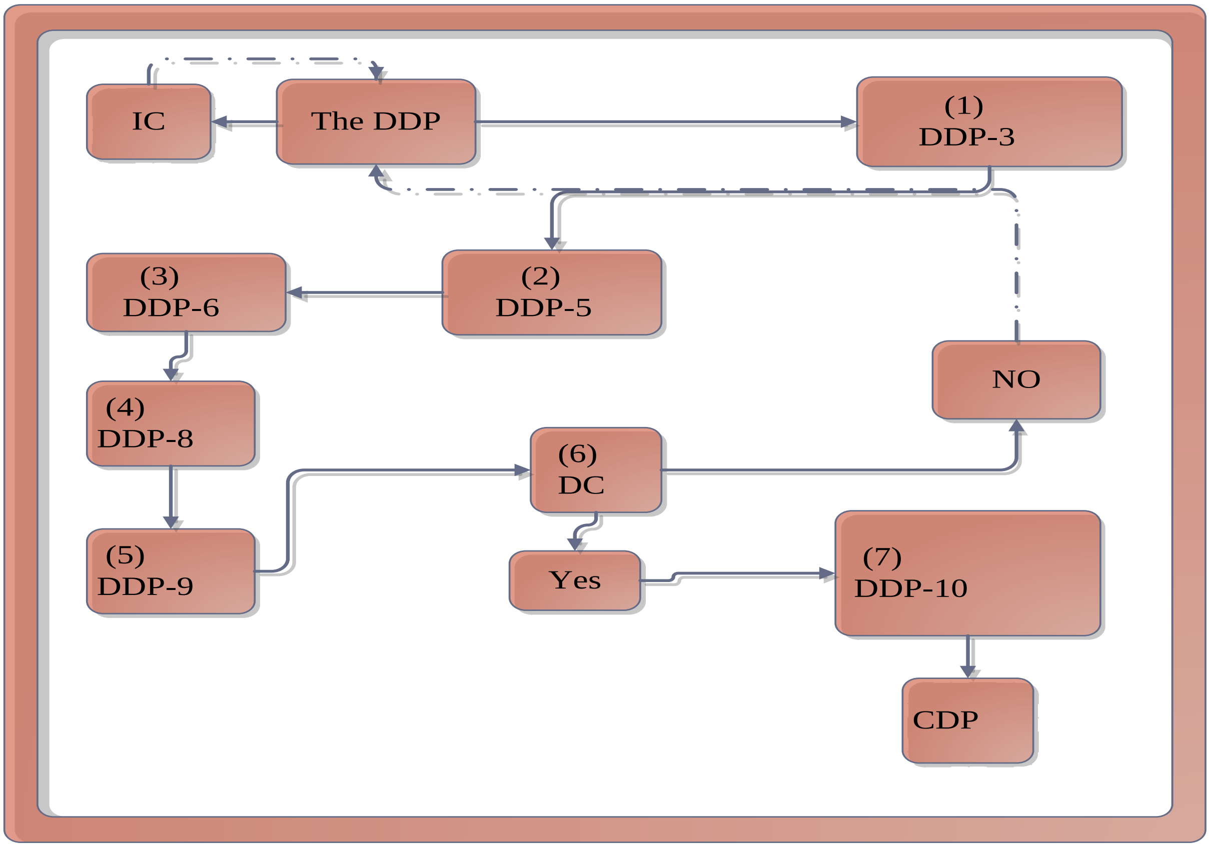


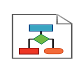
Figure 6.11: The future state value stream mapping of the detailed design phase (Author, 2016)

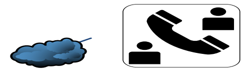
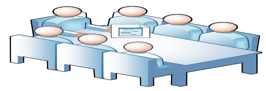
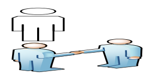
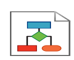
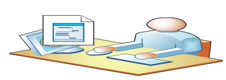
6.2.4 The proposed mechanism for the construction process

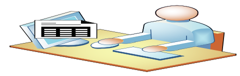
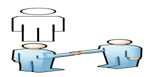
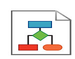
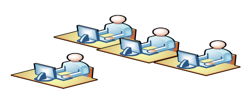
Despite most of the construction activities being the responsibility of the contractors, the study conducted shows that excessive requests for information (RFIs), waiting time during structural reinforcements, construction reworks, variation and change order, redesign, wrong fabrication of formwork; rebar cage and reinforcing steel, excessive writing of site instructions, ineffective communication flow between the SDT and the contractors, inadequate spacing of the structural reinforcing materials, unnecessary supervision, and lateness in resolution of design error/omission necessitate the need for structural engineers always to be on the site from the start to the completion of structurally related activities. It is anticipated that if the proposed mechanism in the IDP, the PDP, and the DDP are correctly adopted by the structural designers, the aforementioned waste will be minimized or completely overcome in the CP. However, certain measures are required to be put in place by the client or the project actors so as not to jeopardize the whole effort in the design phases. These measurements are clearly stated in Table 5.12 of this study. Most important among these is the need to engage the service of a structural engineer for at least three hours for clarification of the necessary design information to the contractor and the subcontractor before the start of the site activities (preconstruction phase).

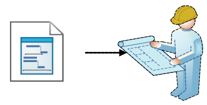
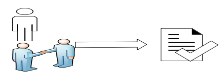
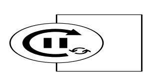
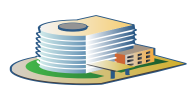
For economic consideration, this strategy was adopted in this study as the other option (full engagement) is expensive. Based on all the explanations so far and the conceptual framework presented in Chapter 3 of this report (Figure 3.3), a lean mechanism for waste reduction in the SDP is hereby present (Figure 6.12). For adequate understanding, Table 6.2 shows the various elements used to represent the various activities and strategies for waste elimination in the SDP in the proposed lean mechanism.

Table 6.2: The various elements used in the proposed lean mechanism

S/No	**Activities**	**Elements**
A	Engage SDT in AP to come up with AAD, and perform some of the IDP activities during the process	AP+SDP= AAD
B	Inception design phase	IDP
1	Bring out all the activities in the IDP through the VSM tool	
2	Reduce/eliminate the NVA activities in the phase through some of the basic lean principles observed in the literature and the various waste reduction strategies in Table 5.9, Chapter 5 of this thesis	

3	Adopt IC as well as meeting agenda to reduce the incessant meetings among the project actors	
4	Provide the Information Required to other Consulting Engineers (PIRFOCE), establish the necessary regulatory requirements and building codes and incorporate them into the project (ENRR/BC)	
5	Design correctness (DC) = A senior engineer	
6	Establish Inception Design Documents (EIDD) (parties involve: the client, the architect, and the SDT)	
C	Predesign phase	PDP
1	Bring out all the activities in the PDP through the VSM tool	
2	Reduce/eliminate the NVA activities in the phase through some of the basic lean principles observed in the literature and the various waste reduction strategies in Table 5.10, Chapter 5 of this thesis	
3	Establish structural predesign criteria (ESPC), and ensure that the criteria establish conform to the required building codes and regulatory authorities (ECECRBCRA)	

4	Perform the necessary computations and preliminary sizing with programmed excel spread sheet through the service of a senior engineer (PNCPS), avoid vague assumptions and prepare the preliminary process designs and related documents suitable for costing (PPPDRDSC)	
5	Design correctness (DC) = A senior engineer	
6	Establish the preliminary design documents (EPDDs) (parties involve: client, architect and SDT)	
D	Detailed design phase	DDP
1	Bring out all the activities in the DDP through the VSM tool	
2	Reduce/eliminate the NVA activities in the phase through some of the basic lean principles observed in the literature and the various waste reduction strategies in Table 5.11, Chapter 5 of this thesis	
3	With the collaborative efforts of junior and senior designers, review detailed design document plans with other consultants electronically (RDDPOC) so as to reduce paper waste and save time, select the suitable structural elements computed in the predesign phase (SSSECPP) and incorporate other	

	consultants' designs and requirements into the work (IOCDRW)	
4	Prepare the design development drawings (draft) and specifications (PDDD/S), and produce the construction drawings (PCDs)	
5	Design correctness (DC): A senior engineer	
6	Establish detailed design documents (EDDDs) and approval of final work by the firm project director/management (AFDFPD) (parties involve: client, architect and SDT)	
E	Preconstruction phase	PCP
1	Engagement of a structural engineer for three hours for clarification of design information to the contractor and the subcontractor before the start of site activities (ESECDIC/SC). Record all the activities between the two parties either by tape or through video coverage	
F	Construction phase:	CP
1	Limit/avoid project variation or change orders (L/APVCO)	
2	Efficient construction	
3	Start and stop	

(Author, 2016)

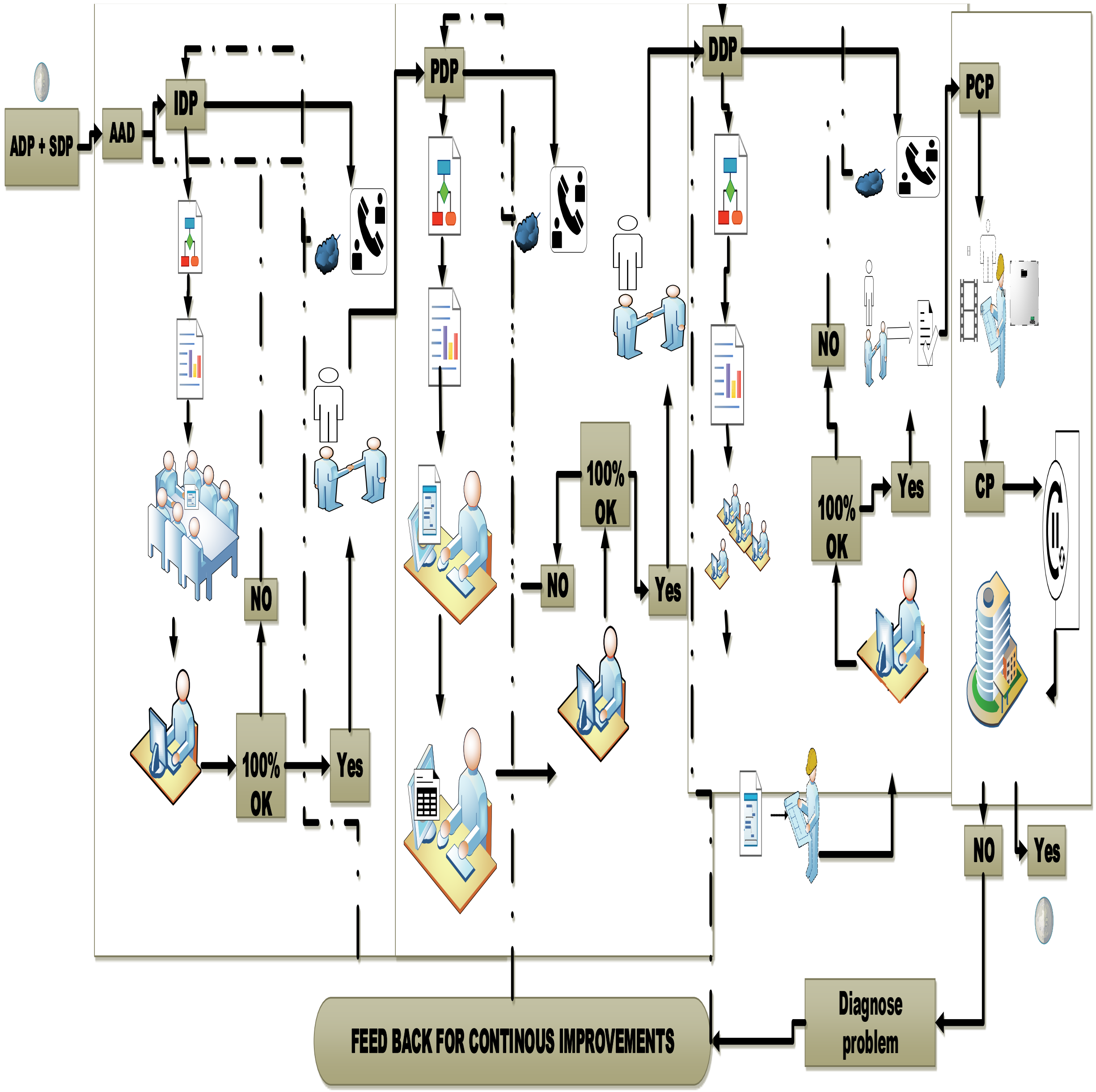


Figure 6.12: A lean mechanism for waste reduction in the structural design process (Author, 2016)

The first stage in the proposed mechanism shown in Figure 6.12 is to bring out the various activities in each phase of the SDP. This will be achieve through the adoption of the VSM tool in each phase. The second stage is to apply the suggested waste reduction strategies (Table 5.9, 5.10 and 5.11) to reduce or eliminate the identified NVA activities in each phase. The third stage is to enable the value adding activities (VAA) in each phase to flow without any interruption through the application of the suggested strategies (Table 5.9, 5.10 and 5.11) and the basic lean principles such as immediate pull/push of activities. Once all the NVA activities have been executed in each phase, a senior structural engineer is expected to evaluate the overall exercise so as to observe if there is any further error in the system (DC), and to also find out if the new plans adopted in the system have brought any substantial improvement. If the evaluation exercise conducted by the senior engineer in the first phase of the SDP is 100% satisfactory, the design team will proceed to the next phase (PDP) and thereafter, to the last phase. However, if the outcome of the exercise in the first phase (IDP) is not satisfactory after the evaluation process (DC), the overall procedures will be repeated by the structural engineers until adequate improvements have been realised in the system. Based on this improvements, the team will then, proceed to the next phase, and afterward, to the last phase.

Further, in the preconstruction phase (PCP) of the proposed mechanism, the client needs to engage the service of a structural engineer for at least three hours for clarification of the necessary design information to the contractor and the subcontractor before the start of the site activities. This exercise will be tape/video recorded and documented as shown in the figure. The documentation is essential as it will serve as backup for the contractors during site activities. This implies that the contractors can always fall back at the recorded information for any clarification in the construction phase of a project. The last stage of the mechanism is the diagnosing process where the contractors intimate the engineers of any form of problem that may be encounter during site activities for continuous improvement. If the above explanations in the proposed mechanism are properly observed by the structural engineers and contractors, and all forms of project variation/change orders are minimized during site activities, without doubt, the mechanism will be effective for waste reduction in the design phase and the CP of every project will be appropriate.

It is essential to know that the proposed mechanism is recommended for the three types of building, namely: the residential, the commercial, and the industrial. During the QMAR study conducted in all the firms, some of the groups' participants emphasized that to completely overcome waste in the SDP may be slightly challenging due to human errors, the nature of the design process itself, i.e. complex process, and the fact that the process is completely different from production. However, when human errors are removed, and the proposed mechanism is adequately emulated by the SDT, and the construction contractors, the exploratory validations exercise that would be conducted should show that the LT or delay, and problems such as design error that constitutes waste in all the phases of projects, have been significantly reduced or completely eliminated in the practice.

6.3 Mechanism Implementation Stage

The implementation phase in the QMAR conducted is a stage where the developed mechanism was adopted in the practice of one of the case study firms (action taking) (Reason & Bradbury, 2001 cited by Azhar *et al.,* 2010: 91). However, before the adoption of the mechanism in the selected case firm, questionnaires were prepared and administered to some consulting engineering firms in South Africa specifically in Johannesburg, Pretoria, Western Cape Province, and Free State (survey). The essence of the survey was to seek for the opinions of the structural engineers who are involved in construction projects across South Africa concerning the viability of the developed mechanism. Details of the survey and action taking exercise are explained in the sub-sections of this thesis:

6.3.1 The viability of the proposed mechanism

It is stated in the above section that to ascertain the feasibility of the proposed mechanism in the study conducted, questionnaires were prepared and administered to some consulting engineering firms in some South Africa regions. Specifically, 192 questionnaires were prepared and sent through electronic e-mails to the respective firms. The e-mail addresses were obtained through the website of the CESA. The selection of the firms was purposive as the e-mail addresses on the website were indicative of those professionals who were practicing consulting structural engineers. Hence, it was predominantly based on the firms that the researcher was able to obtain their valid e-mail addresses, as well as their respective call numbers through the website. Table 6.3 gives the summary of the breakdown of the questionnaires that were sent out, and those that were returned by the respondents.

Table 6.3: Number of questionnaires administered and returned by the respondents

Location of the firms	Questionnaires administered	Questionnaires returned
Johannesburg	44	9
Pretoria	37	7
Western Cape Province	76	15
Free State	35	20
Total	192	51

(Author, 2016)

- **Analysis of the questionnaires that were returned by the respondents**

The various questions asked and the responses from the questionnaires returned are presented as follows (Appendix 7):

Section A

Table 6.4: The various questions, and the number of affirmations (A) and negations (N)

Typical questions asked	A	N
1. Do you agree that the following are the frequent problems (waste) experienced during structural design process?	31	20
2. Do you agree that the identified waste in the Tables above constitute excessive lead time (LT) or delay during structural design process?	51	-
3. Are you aware of any mechanism for overcoming some or all the identified waste?	51	-
4. If yes, how would you assess the performance of such a mechanism?	51	-
5. Do you agree that this mechanism covers the highlighted problems in the SDP?	51	-
6. If No, kindly suggest the strategies that you think can be better adopted to improve on the proposed mechanism	21	30

(Author, 2016)

(1) ***Do you agree that the following are the frequent problems (waste) experienced during structural design process?***

This question was asked in order to find out from the respondents if the identified problems during this study are the common waste in the SDP. Thirty-one of the 51 respondents agreed that the identified waste in the IDP, the PDP, the DDP, and CP are common problems that are often experienced in the design process. The remaining 20 respondents agreed with the identified activities as problems experienced during SDP. However, the 20 respondents disagreed with some other activities such as waiting for site reports, several lengthy and repeated structural computations, excessive soil tests, and design variations as problems in the system. The disagreement also occurred during the focus interviews study in the selected firms. Consensus was only established among the participants in the various firms after a depiction of the VSM on the identified activities.

(2) ***Do you agree that the identified waste in the Tables above constitute excessive lead time (LT) or delay during structural design process? Yes ( ), No ( )***

This question is similar to the first one but the responses were different. That is, all the respondents agreed that the identified activities constitute excessive LT or unnecessary delays in the SDP. It is amazing that the 20 respondents that disagreed with some of the identified activities as waste also agreed that all the activities constitute excessive LT during the SDP. With the responses from the second question, it is clear without doubt that all the discovered NVA activities in every phase of the SDP during this study are probable waste, which need to be eliminated or reduced in the system so as to promote values in the practice.

(3) Are you aware of any mechanism for overcoming some or all the identified waste? Yes ( ), No ( )

This question was asked so as to know if the developed mechanism is a replication of what is already obtainable in the practice or perhaps, to know if a similar device is already in use or in circulation. All the 51 respondents answered No to this question. With the response rates, it may be perceived or claimed that the proposed mechanism is not a duplication of what is already obtainable in the structural design practice, and may find a great application as a waste identification and reduction tool in the system specifically in the study location.

(4) If yes, how would you assess the performance of such a mechanism?

None of the respondents made any suggestion in this question. This is due to the fact that all the respondents have already answered No to the previous question did not answer to this one.

Section B

(5) Do you agree that this mechanism covers the highlighted problems in the SDP?

Yes ( ), No ( )

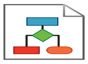
This question was asked so as to know if all the identified waste in the study have been fairly addressed through the proposed lean mechanism or probably, if the mechanism might be required to be improved or modified in certain aspects. All the respondents answered Yes to this question. This means that the proposed lean mechanism for waste identification and reduction in the SDP is justified and can be recommended for practices within the study context.

(6) If No, kindly suggest the strategies that you think can be better adopted to improve on the proposed mechanism.

In spite of all the respondents answering Yes to question number (5) above, it was a surprise that 21 out of the 51 respondents made a comment on this very question. The 21 respondents commented that the DC in the proposed mechanism is not necessary. The respondents stated that the proposed mechanism requires a collaborative teamwork among the structural designers in each phase of the SDP. Therefore, it is expected that the various activities in each phase will be conducted, monitored and controlled for waste elimination collectively by the group. This implies that the DC may not be required in each phase as flawless events are anticipated in the flow of the activities. The respondents pointed out that instead of the DC in the proposed lean mechanism, VSM should be depicted again in each phase after the completion of the activities, and if any NVA activity is further detected, a new strategy should be developed on how the waste can be eliminated. The respondents specified that these procedures should then continue until no further waste is detected in the very phase before the SDT moves to the succeeding phase. These opinions were explained to the participants in the study groups during the brief meeting that was conducted with the groups before the implementation phase of the device (section 6.3.2), and the participants supported the new ideas.

After the adoption of the comments made by the respondents, the proposed lean mechanism is modified as shown in Figure 6.13. Table 6.5 indicates the additional elements that were adopted in the modified version of the device.

Table 6.5: The additional elements used in the proposed lean mechanism (modified version)

Activities	Elements
Repeat VSM process at the end of all activities in each phase of the SDP. If further waste is not detected, accept yes, and go to the next phase. If further waste is detected, accept no, and	
Develop the strategy that can be adopted to eliminate the waste (the five lean principles may be depicted on the activities again), and repeat the whole exercise in the phase several time until further waste is not detected	

(Author, 2016)

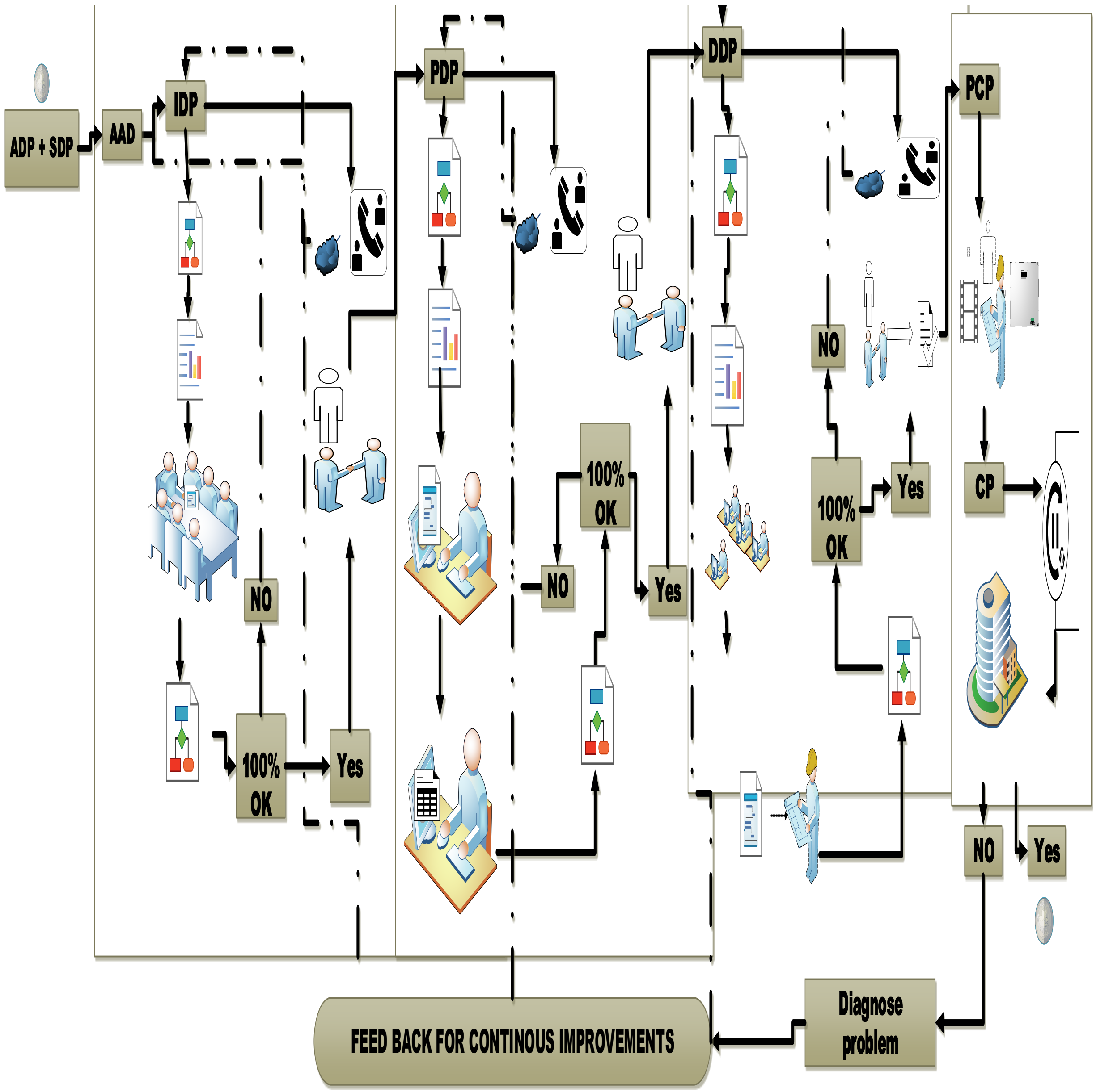


Figure 6. 13: A lean mechanism for waste reduction in the structural design process (modified version) (Author, 2016)

In the modified version of the proposed lean mechanism in Figure 6.13, once all the activities have been completed in each phase of the SDP, the VSM will be adopted to identify further potential areas of redundancies, waste, or NVA in the phase, and the basic lean principles and engineers experiences will be used to eliminate them (Corrective action). This process will continue in the phase until it is completely free of waste. Thereafter, the engineers will move to the next phase of the SDP. It is crucial to know that preventive action is also needed by the SDT to ensure that the problems detected in the SDP in a project do not reoccur in the subsequent projects.

6.3.2 The action taking stage

Findings from this study show that in the traditional project design, the moment a contract is awarded to the architect, specifically by a private body (client), the architect completes the architectural drawings, which may take approximately two months or more depending on the type, the size, and the nature of the project, as well as the time the architect and the client are able to establish the contract agreement. Thereafter, the structural designers selected by the client or the architect commence the structural design aspect of the project. In such a traditional practice, if any improper or unrealistic design is found in the architectural drawings during the SDP, the architectural design has to be returned to the architect for correction. When this process is repeated continuously, it increases change orders, rework, project delay/time, and cost overruns. Therefore, this study section also seeks to build compelling explanations of how the above-explained problems in the tradition practice of project design can be overcome.

It has been elucidated in Chapter 4 (section 4.4.9) of this report that the fifth stage of the QMAR conducted in the five firms is action-taking (the implementation stage), and was achieved by selecting one of the case study firms that had an ongoing structural project in hand at the time of this study (group A). Hence, the implementation of the proposed lean mechanism started with a brief meeting that was held in the office of the chief engineer in group A. The heads of other study groups, as well as the junior designers, were also involved in the meeting as the researcher made them understand that they were also part of the implementation exercise due to the strategy that was adopted in the study. Hence, the researcher emphasized that their support or concerted efforts would be highly appreciated in this phase of the study. It should be noted that the invited structural designers from other study groups also served as other structural consulting engineers in that their services or structural advice/opinions were consistently required in highly challenging projects such as the one in hand. Consequently, their involvement enabled certain activities such as attending consultant meetings and review of the project with other consultant designers in the PDP and the DDP traditional method of design to be observed or conducted during the AAD process.

It is essential to know that the meeting (staff training) in this phase of the study served as an avenue for the researcher to explain in detail what the proposed mechanism entailed, and how it could be properly adopted in a project for effective improvement or change. The meeting also served as an avenue for the researcher to explain to the designers how the five lean principles and lean tools such as the Black Belt team, the Just-In-Time, the daily huddle meetings, and the look-ahead schedule could be appropriately adopted in the design phase of projects. After the necessary explanations in the meeting, the researcher ensured that the participants asked one or two questions for further clarification. Thereafter, with permission from the firm management (head of human resources unit) who was also aware of the on-going QMAR study, all the participants agreed on the date that the new project would commence. Thereafter, the architect that was responsible for the architectural drawings who had been informed earlier of the on-going study, was notified through the head of group A. The head of the group A also solicited his maximum collaboration in the anticipated exercise.

As stated in Chapter 4 of this report, the project is a multi-storey building located in the region of Johannesburg, South Africa. Hence, on the commencement date of the project, all the participants including the architect came together to produce with an appropriate architectural drawings (AAD), and some other structural activities as indicated in Figure 6.4 of this study. This was the first stage of the exercise. Subsequently, the SDT conducted the various activities in each phase of the SDP as outlined in Figures 6.5, 6.8, and 6.11 of this thesis. In short, Table 6.6 shows the various activities as well as the duration in days, of each activity in the newly executed project through the adoption of the proposed lean mechanism.

Table 6.6: The various activities and duration of the activities in the newly executed project

Alphabetically	**Activities**
A =	AAD = (AP) + (IDP-1 + IDP-2 + IDP-3 + IDP-4) + (IDP-6 + IDP-7 + IDP-8) = 83 days approximately
B =	IDP = (IDP-5 = 2 days) + (PDP-4 = 3 days) + (IDP-9 = 2 days) = 7 day
C =	PDP = (PDP-5 = 2 days) + (PDP-6 = 2 days) + (PDP-7 = 4days) + (PDP-8 = 3 days) + (PDP-10 = 1 day) = 12 days
D =	DDP = (DDP-3 = 9 day) + (DDP-5 = 1 day) + (DDP-6 = 2 days) + (DDP-8 = 1 day) + (DDP-9 = 1 day) + (DDP-10 = 1 day) = 15 days
E =	The overall working days or months = 117 working days (approximately four months)

(Author, 2016)

As shown in the table, the AAD commenced on 8 June 2016, and ended on 30 August 2016, approximately three months. The activities in the IDP were not less than seven days in duration, while that of PDP were exactly 12 days. The activities in the last phase of the design process, the DDP, was approximately 15 days. The overall activities from AAD to DDP in the lean design process started and were completed within the space of 117 working days, approximately four months. Hence, the overall design activities ended on 6 October 2016. Comparing these durations to the traditional method of design (Table 6.7), it can be observed that the reduction in the LT is 56 working days, approximately two months. Hence, the reductions in the LT in each phase of the designs process (Figure 6.14) are observed to be -27 days, 47 days, 11 days, and 19 days respectively.

Table 6.7: The various activities and duration of the activities in the traditional structural design process (From Figures 6.3, 6.7, and 6.11)

Alphabetically	**Activities**
A' =	AP' = Traditional architectural process = 56 days approximately
B' =	IDP' = (IDP-1 + IDP-2 + IDP-3 + IDP-4 = 18 days) + IDP-5 (2 days) + (IDP-6 +IDP-7 + IDP-8 = 33 days) + IDP-9 (3 days) = 56 days
C' =	PDP' = (PDP-1 + PDP-2 = 4 days) + PDP-3 (5 days) + (PDP-4 + PDP-5 + PDP-6 = 5 days) + PDP-7 (5 days) + PDP-8 (2 days) + PDP-9 (2 days) + PDP-10 (2 days) = 25 days
D' =	DDP' = (DDP-1 + DDP-2 = 5 days) + (DDP-3 + DDP-4 + DDP-5 = 1 week, 5 days) + (DDP-6 = 5 day) + (DDP-7 = 1 week, 1 day) + (DDP-8 = 1 day) + (DDP-9 = 2 days) + (DDP-10 = 3 days) = 36 day
E' =	The overall working days or months = 173 working days (approximately six months)

(Author, 2016)

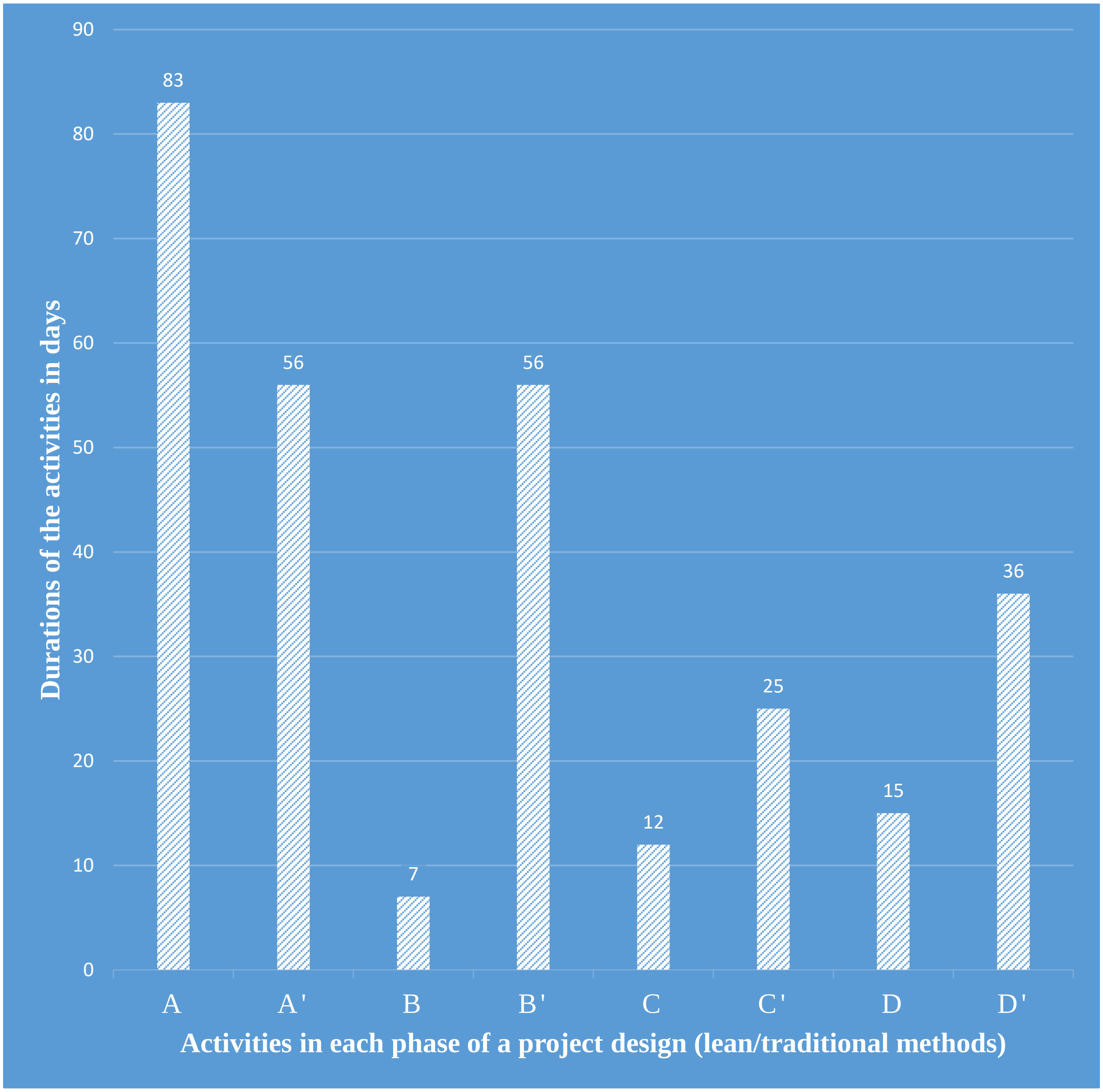


Figure 6.14: Durations of activities in lean and traditional structural design process (Author, 2016)

The next phase of the implementation stage consists of the construction activities, which commenced immediately after the completion of the lean design. To be precise, the construction activities started approximately two weeks after the completion of the structural drawings (18th of October 2016). Before the start of the construction phase, the SDT as well as the architect adequately explained every aspect of the designs to the contractors for not less than three hours as set out in the proposed mechanism. The explanations between the three parties were recorded and documented for unforeseen or unanticipated needs during the site activities. As at the time of the evaluation exercise that was conducted by the researcher after the implementation of the proposed mechanism (21^{st} of November 2016), the project was still under construction. However, the foundation tasks had been successfully completed. Based on the schedule of the construction activities prepared by the contractors before the start of the site activities, it is expected that the CP will be appropriately completed in the second week of March 2017.

6.3.3 The evaluation process

The evaluation phase is the penultimate stage of the QMAR conducted in this study (Chapter 4, Figure 4.2). Its purpose was to assess or appraise whether the lean mechanism adopted on the newly executed project actually brought all the great changes observed specifically in the design phase. To achieve this aim, the participants in group A were summoned together on 21^{st} of November 2016, and the following questions were asked for their responses (Appendix 8):

(1) What was your experience while adopting the lean mechanism in your new project?

This was the first question that was raised during the evaluation exercise. In an attempt to address the question, A_1 stated that…

> *"Although, the architectural phase of the project actually took time, our aim of participating in the process was achieved. This made the inception, predesign, and the detailed phases of the structural process to be appropriately executed, and fast."*

A_3 supported the expression of A_1 and declared that…

> *"... the information in the architectural drawings was clear to us during structural design. There was no need for us to invite the architect for any form of correction in the inception, and the predesign phases of the structural process as we used to experience in the previous projects. Neither was there need for any form of architectural modifications that always lead to delay in the previous projects…*"

A_4 continued with the discussion and pointed out that …

"... there was smooth flow of work throughout the structural activities. Mistakes, correction, redesign, and paperwork were significantly reduced in all the phases ..."

A_1 added that…

"…the contractors were able to start the construction phase as scheduled. Since the start of the construction activities, the contractors have not requested for any information from us..."

A_2 buttressed the additional information afforded by A_1 and affirmed that …

"…our team only visited the site when the contractors wanted to start the project for proper handing over, and approval of the start of site the activities ..."

A_3 added that …

"... as we are talking to you now, the foundation has been completed and two of our team only went for checking and certification of the exercise. All the structural design-related activities in the foundation exercise were satisfactory ..."

A_5 supported A_3 and declared that …

"... the activities were carried out as specified in the construction drawings that were handed over to the contractors ..."

Premised on the declarations of all the participants in the group in the evaluation phase of the study, it can be observed that the participants' experience in adopting the lean mechanism in the new project was positive, in the sense that there was a smooth/proper flow of work in the design and the construction phase of the project due to the lean mechanism that was adopted. Hence, mistakes/errors were greatly reduced in the design phase of the project, which consequently reduced the problems, and LT in the design and construction phases of the project. Hence, an acceptable project delivery is anticipated in March 2017 as scheduled by the contractors.

(2) What are the advantages of the mechanism with respect to the newly executed project, and your organization at large?

Typical examples of the advantages of the lean mechanism with respect to the newly executed project as emphasized by the participants in the group are significant reduction in:

- The mistakes/errors that constitute problems in the design, and the construction phases of a project;
- The excessive requests for information in the design, and the construction phases of a project;
- The LT formerly experienced in the SDP, and
- The disagreements and excessive meetings between the architect, and the SDT.

The participants further claimed that the advantages of the mechanism are not only for the newly executed project but also for the entire organization and the industry at large. Some of the examples of the advantages of the mechanism on the organization and the industry as espoused by the participants in the group are: reduction in the activities' cycle times in the design phase of a project, which consequently reduce projects delay and cost overrun; reduction in the number of steps in the SDP, which consequently leads to design simplification; increased process transparency between the architect and the SDT, which also leads to reduction in the organization staff stress level, and brings outstanding improvement to the SDP.

(3) Will you recommend this mechanism to other consulting engineers firms, irrespective of the size, location, and the types of the project handles by the firm?

When this question was asked, the participants in the group declared that due to the several advantages/benefits of the mechanism in the design and the construction phases of a project, as well as to the organization, they would like to recommend the mechanism in every form of structural project.

(4) What are the shortcomings of the mechanism?

When this question was raised, none of the participants in the group provided any form of weakness or shortcoming in the developed lean mechanism. The participants perceived that the lean mechanism is fairly adequate as far as waste identification and reduction in the SDP is concerned.

(5) How can the shortcomings be overcome?

There was no any additional comment from the participants when this question was raised in the evaluation exercise due to the information the participants have provided in the previous question (question number 4 above).

(6) How can lean thinking as well as the proposed mechanism improve SDP practice in South Africa?

To propagate the need for the adoption of lean principles and tools and the proposed mechanism during the SDP, the participants in the group proposed two significant strategies. The participants asserted that these two strategies can be adopted by the SDT or by the management of a consulting engineers firm. These strategies entail the use of workshop trainings for most structural designers, and also the use of annual conference and seminar on the subject matter. The participants were of the opinion that it is in such meetings or gatherings that the benefits to adapt the concept/lean mechanism by every consulting engineering firm as well as the menace of not adapting it during SDP can be fully discussed and understood.

6.4 Summary

This chapter expressed explanations of how the lean mechanism can be developed and adopted during the SDP. Apart from these, the chapter has also pointed out the benefits of the developed mechanism to the consulting engineers' industry and to the clients. Further, the chapter also enabled the researcher to better understand the findings drawn from the proposed mechanism. Premised on this chapter conclusion, this study proceeds to the last chapter to discuss the overall conclusions, specifically on the QMAR conducted, after which recommendations were proposed based on the conclusions.

7.0 GENERAL SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

This chapter emphasized the general summary observed from this study. Based on this summary, conclusions and recommendations are proposed on how the main research problem that led to the study can be mitigated. It is essential to remember that the main problem identified in this study is the lack of a suitable mechanism for waste identification and reduction in the SDP. Such waste promote task conversion problems during the construction activities.

7.2 General Summary for the Study

Based on the reviewed literature during this study, it was discovered that the lean concept has been extensively used by researchers for waste reduction in the construction design process (CDP), particularly in the architectural process (AP). However, the concept has not been broadly adopted in the SDP. This research therefore investigated how the lean concept can be extended to the SDP so as to further eliminate waste in the design, and the construction phases of a project. To achieve this aim, a problem was formulated through literature and research questions and objectives were set. To explain the research, this thesis was compiled in seven chapters.

Chapter 1 points out the gap in the existing literature that actually led to the formulation of the research problem and questions. Whilst attempting to identify a suitable mechanism that can be adopted to address the identified problem, an extensive literature relevant to the study was reviewed (Chapter 2 and 3). Waste and its causes in the CDP as well as the impact of the identified waste on projects were investigated (Chapter 2). Based on the conclusions drawn on Chapter 2, this report proceeded to Chapter 3 to highlight the key variables in the study. Chapter 3 thus shows that a suitable lean tool can be effectively adopted for waste elimination in the SDP.

Based on the suitable lean tool concluded on in Chapter 3, this report proceeded to Chapter 4 where a philosophical stance (subjectivism and interpretivist (symbolic interactionism, phenomenology and hermeneutics)), a research approach (inductive reasoning), a research strategy (qualitative method in action research), and data collection techniques (focus interviews, non-participatory observation and documents of previous executed projects) were established for effective and unbiased data collection and analysis. It should be remembered that the methodological framework presented in Chapter 4 of this report (Figure 4.2) was adopted by the researcher to obtain the necessary data in the qualitative method in action research conducted. The data obtained during the study were presented in Chapter 5 of this thesis.

Premised on the findings obtained in Chapter 5, a lean mechanism for waste identification and reduction was developed and presented in Chapter 6 of this thesis. The findings drawn in the overall chapters (1 to 6) are presented in this chapter as the general conclusions of the study. These are discussed in the subsequent sections of this report.

7.3 General Conclusion of this Study

Based on the findings of this study, it can be concluded that waste occurs in the current practice of the structural design process (SDP), although the frequency of the waste may differ from one project to another. This denotes that waste in projects also emanate from structural design practices. Such waste is found in every phase of the SDP, namely the inception, the predesign, the detailed design and the construction phases. The waste in each phase of the SDP can be identified through the application of a lean tool known as VSM. The identified waste can be reduced through the application of some basic lean principles such as immediate push/pull of activities. Such waste can also be reduced by adopting certain strategies proposed the structural engineers in the study location.

7.3.1 Conclusion on the research problem

The study justifies the main research problem statement that lack of a mechanism for waste identification and reduction in the SDP promotes task conversion problems during construction activities. The findings from the study support the problem statement that several unnecessary delays or lead time (LT) in the construction phase (CP) are due to the mistakes, errors and complexities in the structural drawings (Chapter 5, Table 5.4). It is essential to know that waste associated with the SDP in a project do not only lead to excessive LT in the CP, but also constitute unnecessary delays in the design phase itself.

7.3.2 Conclusions on the research questions

The research questions set out at the start of this research are also justified through the findings of the study. These are explained in the following headings:

(1) What type of waste is synonymous with the SDP?

Based on the study conducted, it can be concluded that waste that are synonymous to the IDP of the SDP are delay in the start of the structural design activities due to lateness in the release of the project fund; delay to establish contract agreement between the SDT, and the client or the architect; delay to analyse the project life cycle cost; several meetings between the architect or client/the SDT specifically in the project initiation phase; lateness to establish the scope of the work; several site visits and soil tests; ineffective work flow during the topographical survey of the proposed site; poor site report and waiting for the site report, and delay to establish the inception design documents (Table 5.1, Chapter 5 of this report).

The wastes associated with the PDP of the SDP are several disagreements between the architect and the SDT; several unclear information items in the architectural drawings; excessive meetings between the architect and the SDT; design modifications (architectural drawings) during SDP; excessive waiting due to the modification of the architectural drawings; several repeated structural computations; computations errors/wrong computations; several printing of paperwork; excessive supervisions of design activities by the chief engineer, and delay to establish the preliminary design documents by the project actors (Table 5.2, Chapter 5 of this thesis).

Typical examples of wastes that can be identified in the DDP of the SDP in this report are design corrections and redesign; excessive printing of draft/paperwork; lateness in the completion of a task as scheduled; waiting for the approval of final drawings from the senior or the chief engineer of the firm; delay to select the suitable structural elements computed in the PDP; delay to incorporate other consulting engineers requirements into the project; delay in preparing the design development drawings and specifications, delay in producing the construction drawings and establish the detailed design documents, and several copies of the final drawings (Table 5.3, Chapter 5 of this report). In the construction phase, the activities that are related to the SDP and can be classified as waste are: variation or change order; redesign; excessive RFIs; ineffective communication flow between the SDT and the contractors; excessive writing of site instructions; construction reworks; excessive waiting time during structural reinforcement, and excessive supervision of structural design related activities (Table 5.4, Chapter 5 of this report).

When this study was conducted, it can be concluded that the close-out phase (COP) of the SDP was free of waste.

(2) What are the remote and immediate origins of such waste?

Based on the findings of the study, it can be established that the remote and immediate causes of waste in the IDP of the SDP are slow decision-making by the client, poor communication among the project actors, gaps in the topographical survey of the proposed site, poor architectural briefing, vague assumptions during geotechnical investigations, and poor site reports (Table 5.1, Chapter 5 of this report). In the PDP, the probable causes of waste are poor or inadequate communication between the architect and the SDT, design modifications, human errors, and vague assumptions during the structural computations (Table 5.2, Chapter 5 of this thesis). The observable causes of waste in the DDP of the SDP during this study are errors or mistakes that are not detected in the PDP, inadequate interaction among the design actors, and excessive vigilance (Table 5.3, Chapter 5 of this thesis). While in the CP, misinterpretation of drawings, design complexity, poor or inadequate supervision, and variation/change orders are established as the main causes of waste (Table 5.4, Chapter 5 of this report).

(3) What are the impacts of such waste on the construction projects?

In general, waste in the SDP can be grouped into nine categories, namely waiting time, over-processing, motion, excessive vigilance, overproduction, rework, clarification, work interruption and error. The nine categories of waste in the SDP have severe impacts on projects. In this study, it can be deduced that rework has the most significant negative impacts in the design phase of projects as it occurs virtually in every of the phase (refer to Table 5.5 to 5.7 of this thesis). It can also be said that rework has the highest negative impacts in projects as it can lead to inefficiency or poor quality of work in the design and the construction phases, extension in a project completion time, and an increase in the estimated cost or agreed-upon charges for a project.

(4) How should lean concept be used to remove waste in the SDP?

This study also establishes that the lean concept is not being used in the SDP in Bloemfontein consulting engineering firms. What was being practiced to a certain extent when this study was being conducted was the DOT, which is applicable to large projects in the proportioning of columns. Despite lean design is not being practiced by the consulting engineers in Bloemfontein during SDP, this study shows that a lean tool, VSM, and the basic five lean principles, namely: specify value, identify value stream, let the values flow, immediate pull/push of activities or information, and continuous improvement, can be adopted by the engineers in every phase of the SDP so as to identify/remove waste in the practice (Section 3.2.4, Chapter 3 and 6.2 Chapter 6 of this study).

(5) What other mechanism should be used to remove waste in the SDP?

Apart from the lean tool that can be adopted to reduce waste in the SDP, another strategy or mechanism that can be applied by the structural engineers to further eliminate waste in the process is adequate involvement of the SDT in the architectural process (AP). This process will enable the two parties to come up with an appropriate architectural drawing (AAD) and to implement most of the IDP and PDP activities during the architectural process (AP). This strategy avails the SDT the opportunity to reduce waste such as waiting for site report in the process (Table 5.10, Chapter 5 of this report).

(6) How should lean thinking drive practice in the SDP in South Africa?

The two main strategies that can be adopted to proliferate or drive the adoption of the proposed lean mechanism discovered in this study during the SDP in South African consulting engineering firms are: workshop training for most structural engineers, and the use of annual conferences and seminars on the subject matter (see section 6.3, Chapter 6 of this thesis).

7.4 Contributions to Knowledge

The contribution to the body of knowledge in the study conducted can be classified into different aspects. These are explained in the following headings:

7.4.1 South Africa consulting engineers

The developed mechanism is explicit and easy to understand by all levels of structural designers in the study context. It offers guiding information on how lean concept can be adopted to identify and reduce waste in the SDP. The mechanism serves as a platform that allows structural designers to identify gaps in their implementation efforts, focus attention on areas for improvements and assess the benefits of the lean approach in the design and the construction phases of projects. In summary, the possible contributions of the exploratory work to South Africa construction industry include:

- It provides structural designers in South African consulting engineering firms a tool (VSM) that can be used to identify and reduce waste such as overproduction, over-processing, motion, waiting time, excessive vigilance, clarification, correction/rework, error and work interruption during the SDP;
- It provides structural designers in South African consulting engineering firms a tool that can be adopted to reduce design problems such as errors/mistakes and rework, and the consequent projects time and cost overruns, and
- It offers a knowledge base for consulting engineering firms that intend to implement lean in their organization practice.

7.4.2 South Africa construction industry

This study serves as a platform that can be adopted for waste reduction in South Africa construction, which consequently provides motivation for continuous improvement of work process in the organization. The study also enables the construction industry to identify a process through which the two main phases of a project design (AP, and the structural design) can be treated as a single design process, rather than separate phases that can contribute to projects delay. In addition, the study enables structural design problems to be viewed and solved collectively in the industry through lean concept, work experiences and feedbacks as opposed to an isolated treatment resolution of issues.

7.4.3 Methodological contribution

This study provides a methodological framework that will enable prospective researchers to effectively conduct AR in consulting engineering environments.

7.4.4 Theoretical knowledge of the subject matter

This study conducted in Bloemfontein South Africa consulting engineering firms contributes to the existing literature on the waste type in the CDP as it confirms SDP as another source of waste in projects. It also identifies work interruption as the ninth form of waste in projects.

7.5 Recommendations

In general, since the identified waste in the SDP constitutes negative impact on practice, a lean mechanism that will enable the SDT to adopt the five lean principles and a tool such as VSM is recommended for waste identification and reduction in the design phase of a project. The following sub-sections are the essential recommendations in this study:

7.5.1 Recommendations for consulting engineering practice

This study recommends that:

- Internet-enabled communication (IC) and phone calls should be regularly adopted during the SDP to reduce several meetings specifically in the project initiation phase;
- The SDT and the architect should always work together as a team during the AP to come up with an appropriate architectural drawings (AAD);
- A senior structural engineer and a senior architect should be adopted as design correctness officers in the AP, to be able to adequately review the activities that are related to the architectural drawings and those that are associated with the structural design;
- Several activities in the IDP and DDP of the SDP such as topographical survey/geotechnical investigation of the proposed site should be conducted during the AP, so as to eliminate

problems such as waiting for site report, lateness in incorporation of the building regulatory codes and requirements into the project;

- Senior structural designers should be more involved in the computation aspect of the structural design, so as to come up with a design that is fair of error/mistakes;
- Electronic review of structural drawings should be encouraged in every structural design firm;
- The architect and the SDT should ensure that the information in the construction drawings are properly spelt out to the contractors in the preconstruction phase – that is, the two design actors (architect/SDT) should dedicate at least three hours to explain all the information contain in the construction drawings to the contractor before the start of the construction activities;
- The architect and the structural engineer must have a means of interacting or communication throughout the AP, and
- All forms of variability should not be encouraged by the various actors the moment a project get to the DDP and the CP.

7.5.2 Recommendation for future research

- For proficient and well-organized future state VSM, a more compressive VSM software that is independent of the skill or ability of the operators should be investigated or developed by future researchers;
- This study recommends the methodological framework developed in Chapter 4 of this report (Figure 4.2) as a suitable outline for prospective researchers that intend to conduct AR in consulting engineering firms, and
- Further studies should also be conducted by prospective researchers on the applicability of VSM as waste identification and reduction in other aspects of CDP; phases such as electrical and mechanical designs are thus recommended.

7.6 The Limitation of the Study

At the start of this study, the researcher intended to recruit eight participants in each selected case as recommended by some authors of focus groups studies. However, the access difficulty experienced by the researcher in most firms in Bloemfontein at the time of this study, coupled with the low number of engineers that are well experienced in the structural design practices, limited the researcher to recruiting five participants in each study firm. During this study, the researcher discovered that the number of structural engineers in most of the firms ranges from four to six, with the exception of group A that has seven designers. In fact, there was a firm to which the researcher had access, but the structural engineers in the firm numbered only three. This dissuaded the researcher to adopt this firm as one of the selected cases. In addition, the researcher also realized that structural engineers, due to the nature of their work (site activities) are difficult to meet in the office. Based on this difficulty, the researcher had no alternative than to make use of the prevalent number of the engineers in the cases selected. Therefore, the action research conducted in this study was challenging due to the need for groups of structural engineers that struggled to maintain their commitment to the research project over the time.

Despite the above-explained challenge, the five participants used for this study satisfied the conditions for participating in a focus group (Chapter 4, section 4.4.7). The research aim and objectives were realized at the end of the study. Further, literature shows that the cyclical process in AR studies needs to be repeated several time for continuous improvement. This implies that after the developed mechanism, the overall exercise needed to be repeated perhaps three or four times before being drawn to a conclusion. However, it should be noted that construction design process is a project that may take 10 to 14 months in duration (from the inception stage to completion). Also, a doctoral study in Central University of Technology, Free State has to be completed within three years. This made the researcher reach the conclusion of the AR study after the first cycle. With the single cycle conducted, the purpose of this study was observed to be met as the researcher ensured that the action-planning and action-taking phases in the AR plan were repeated until the saturation states were reached (three times). With these saturation states, it can be contended that if the exercise (AR cycle) is repeated the second time, there might be no additional information or new knowledge or findings. Therefore, the purpose of the study was actually achieved by the researcher.

Literature shows that the data obtained in AR study may be difficult to generalize to a population of interest. This is due to the few sample of the cases and the participants that are normally adopted or covered during the study (Chapter 4, section 4.5). Therefore, the findings in this report are limited to the practices of the study context (Bloemfontein consulting engineering firms).

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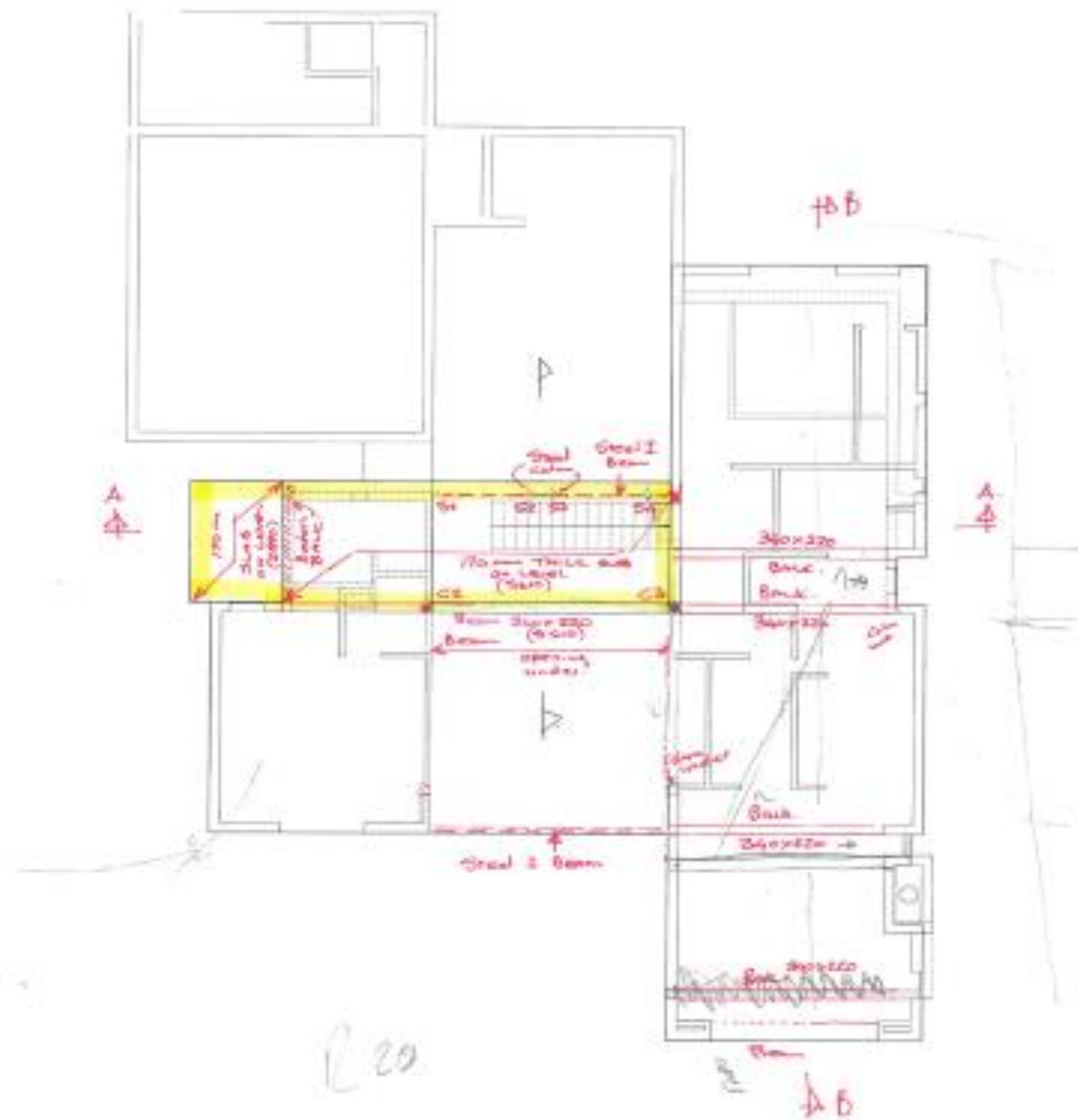
Appendix 1 Architectural / Structural Drawings



Appendix 2 A List of Information of all the Consulting Engineers in Free State, South Africa

ree State

Firm	Acoustics	Agricultural	Building Services	Chemical	Civil	Development	Electrical	Electronic	Environmental	Geotechnical	Industrial	Mechanical	Marine	Mining	Process Engineering	Structural	Transportation	Architecture	Rural Development	Project Management	Quantity Surveying	Town Planning	Dispute Resolution	Expert Witness / Insurance Claim	Information Systems / Technology	Facilities / Maintenance Management	GIS	QMS
:OM (SA))e Koker PR Eng 20060262, PMP1556968 ate Bag X11, Suite 40 Brandhof 9324 'resident Steyn Avenue Westdene +27 051 448 2721/2 : +27 051 447 7579 om.bloemfontein@aecom.com			√		√	√	√	√	√	√	√	√		√	√	√	√		√	√	√	√	√	√	√	√	√	√
RECON SOUTH AFRICA (PTY) LTD 3 Jordaan PrEng 20040096 ate Bag X11 Suite 70 Brandhof 9324 ro Park 135 President Reitz Avenue Westdene +27 51 408 9600/ +27 51 430 3111 : +27 51 447 9751 / +27 51 447 9403 mfontein@aurecongroup.com		√	√		√	√	√	√	√	√	√	√	√	√	√	√	√		√	√	√	√	√	√	√	√	√	√
IECON SOUTH AFRICA (PTY) LTD Pierini Pr Tech Eng 9870054 Box 1779 Sasolburg 1947 emland Street Sasolburg +27 16 970 3480 +27 16 973 1891 lburg@aurecongroup.com		√	√		√	√	√	√	√	√	√	√	√	√	√	√	√		√	√	√	√	√	√	√	√	√	√
EN AFRICA i Kwagile Box 8994 Bloemfontein 9300 floor 86 Kelner Street Westdene +27 051 430 1423 +27 051 447 0352 mfontein@bigenafrica.com Robert Street 2nd Ave cnr Kellner		√	√		√	√	√					√		√	√	√	√			√	√	√			√	√	√	√
/ICON CONSULTING ENGINEERS CC I A Schoeman PrEng 850307, PrCPM D/1044/2006 Box 11010 Universitas 9321 e 28, Meditas Centre Mudd Square Universitas +27 051 522 4314 +27 051 522 4315 ian@bovicon.co.za					√															√								√
CONSULTING ENGINEERS FREE STATE (PTY) LTD MBER: BVI GROUP) I J J Grobler Pr. Eng (900233), PCPM (D/185/2006), SAIEE 0) ius 12441 Brandhof 9324 President Reitz Avenue Westdene +27 051 447 2137 +27 051 447 6056 @bvifs.co.za					√	√	√	√								√				√								√
CONSULTING ENGINEERS FREE STATE (PTY) LTD MBER: BVI GROUP) J van Rooyen Pr. Eng (860082), MSAISI Box 2894 Welkom 9460 ent House - 1st Floor 7 Second Street Voorspoed +27 057 353 2499 +27 057 353 2213					√	√	√	√								√				√								√

Free State

Firm	Acoustics	Agricultural	Building Services	Chemical	Civil	Development	Electrical	Electronic	Environmental	Geotechnical	Industrial	Mechanical	Marine	Mining	Process Engineering	Structural	Transportation	Architecture	Rural Development	Project Management	Quantity Surveying	Town Planning	Dispute Resolution	Expert Witness / Insurance Claim	Information Systems / Technology	Facilities / Maintenance Management	GIS	QMS
CKE ENGINEERS Mr BJ Joubert Pr Eng 20040041 P O Box 28568 Danhof 9310 CKE House 2A Thomson Road Westdene Tel: +27 051 444 4728 Fax: +27 051 444 4729 enquiries@cke.co.za			√				√	√																√				√
CONIC CONSULTING ENGINEERS & PROJECT MANAGERS (PTY) LIMITED Mr H Brisley PR Tech Eng No 201170196 P O Box 39008 Langenhovenpark Bloemfontein 9330 29 Witherson Place Maretha Maartens Street Langenhovenpark Tel: (051) 432 0128 Fax: (051) 447 5538 info@conic.co.za					√											√			√					√				√
DIBETSI CIVIL ENGINEERS & PROJECT MANAGERS Mr M Malahleha PrTechEng 200670098 PO Box 6183 Bloemfontein 9300 76 General Dan Pienaar Drive Dan Pienaar Tel: +27 051 436 1611 Fax: +27 086 660 8999 admin@dibetsi.co.za					√											√	√											√
DIHLASE CONSULTING ENGINEERS (PTY) LTD. (BLOEMFONTEIN) Mr B S Ngamlane 200770041 (29 March 2007) Pr. Tech. Eng Postnet 258, Private Bag X01 Brandhof 9324 Conraad House 143 Zastron Street Westdene Tel: +27 051 447 1636 Fax: +27 051 430 8316 bloemfontein@dihlase.co.za			√			√	√	√			√	√							√	√						√		√
DMV BAELETSI (PTY) LTD. Mr H H Louw PrEng - 790034 - 08/01/1979 P O Box 912 Harrismith Harrismith 9880 Garvock Street 28 Harrismith Tel: +27 058 622 2576 Fax: +27 058 623 0271 ansie@dmvconsultants.co.za			√		√	√				√	√					√	√											√
DOMBO, DU PLESSIS & PARTNERS (AFRICA) (PTY) LTD Mr E P Du Plessis 9570072 PO Box 13141 Noordstad 9302 Oubos Estate 6 Universitas Tel: +27 083 633 5890 Fax: +27 051 433 1041 duplessis.e@ddpcivils.co.za		√			√	√										√	√	√		√								√
EE SERVICES Ms M van Zyl PrTechEng PO Box 42231 Heuwelsig 9332 8 Alphastreet Old East End Tel: +27 051 447 2251 Fax: +27 086 519 0221 Info@eeservices.co.za					√																							√

Free State

Firm	Acoustics	Agricultural	Building Services	Chemical	Civil	Development	Electrical	Electronic	Environmental	Geotechnical	Industrial	Mechanical	Marine	Mining	Process Engineering	Structural	Transportation	Architecture	Rural Development	Project Management	Quantity Surveying	Town Planning	Dispute Resolution	Expert Witness / Insurance Claim	Information Systems / Technology	Facilities / Maintenance Management	GIS	QMS
FLAGG CONSULTING ENGINEERS (PTY) LTD Mr G A L Ambrose PrEng 20030008 PO Box 864 Frankfort 9830 6 Mark Street Frankfort Tel: +27 058 813 2173 Fax: +27 058 813 4254 graeme@flaggconsulting.co.za					√											√												√
FLAGG CONSULTING ENGINEERS (PTY) LTD Mr L Ambrose PrTechEng 201370161 50 Louw Wepener Street Dan Pienaar Bloemfontein 9301 50 Louw Wepener Street Dan Pienaar, Bloemfontein Tel: +27 051 436 0280 Fax: +27 086 664 4859 lloyd@flaggconsulting.co.za					√											√												√
GIBB Mr C F de Wet PrEng - 970415 P O Box 20063 Willows 9320 3 Bermakor Park 52 Reid Street Westdene Tel: +27 051 447 1711 Fax: +27 051 447 1714 info@gibb.co.za		√	√		√	√	√	√	√	√		√			√	√	√		√	√		√			√		√	√
ILIFA AFRICA ENGINEERS Mr J J Olivier Pr. Eng, LSAISI, IODSA P.O. Box 802 Harrismith 9880 Piet Retief Street 35A Harrismith Tel: +27 058 622 1297 Fax: +27 058 623 0827 harrismith@ilifa.biz					√	√			√						√	√	√			√				√				
ILIFA AFRICA ENGINEERS Mr C P Claassens Pr. Eng, LSAISI, IODSA P.O. Box 1184 Sasolburg 1947 Roseberry Street 15 Sasolburg Tel: +27 016 976 0850 Fax: +27 016 976 2547 sasol@ilifa.biz					√	√			√						√	√	√			√				√				
ILISO CONSULTING (PTY) LTD Mr C G Koopman PrEng (760067)PrCPM Suite 127 Private Bag X01 Brandhof 9324 Khoisan Office Park 78 Victoria Street Willows Tel: 086 11 45476 Fax: 051 444 6196 ilisobloem@iliso.com					√				√							√	√			√								√
ISA & PARTNERS (PTY) LTD Mr C N Kimaru PrEng 20010141 Postnet Suite 230, Private Bag X01 Brandhof 9324 Suite 16, Kellner Park 65 Kellner Street Westdene Tel: +27 051 447 9710 Fax: +27 051 447 9398 infobfn@isspartners.co.za					√	√									√	√								√		√		√

Free State

Firm	Acoustics	Agricultural	Building Services	Chemical	Civil	Development	Electrical	Electronic	Environmental	Geotechnical	Industrial	Mechanical	Marine	Mining	Process Engineering	Structural	Transportation	Architecture	Rural Development	Project Management	Quantity Surveying	Town Planning	Dispute Resolution	Expert Witness / Insurance Claim	Information Systems / Technology	Facilities / Maintenance Management	GIS	QMS
ISA & PARTNERS (PTY) LTD Mr J Kihlu Pr. Eng 20130009 Postnet Suite 252, Private Bag X25 Welkom 9460 66 Nyala Street Doorn Tel: +27 057 352 4099 Fax: +27 057 352 6116 infowkm@isapartners.co.za					√	√									√	√								√		√		√
LHL CONSULTING ENGINEERS Mr DuT Human Pr Eng. MSAACE, MSAICE, MWISA, MIMESA PO Box 1164 Bethlehem 9700 40 Lindley Street Bethlehem Tel: +27 058 303 6646 Fax: +27 058 303 4215 info@lhlce.co.za					√															√								√
LIDWALA CONSULTING ENGINEERS (SA) (PTY) LTD Mr AM Raspi PrTechEng P O Box 2930 Nelspruit 1200 20 du Preez street Brandwag Tel: 0861 543 9252 Fax: 086 766 2829 info@lidwala.com			√		√				√	√						√	√			√						√	√	√
LMV RAADGEWENDE INGENIEURS & STADSBEPLANNERS (EDMS) BPK Mr S J Boshoff Pr Eng PO Box 61 Kroonstad 9500 Aris Court Building 74 Hillstraat CBD Tel: +27 056 215 2260 Fax: +27 056 212 3381 lmv@lmv.co.za			√		√	√				√	√					√								√				√
MAKHAOTSE, NARASIMULU & ASSOCIATES (PTY) LTD Mr M Makhaotse PrTechEng 200970214 PO Box 157 Theunissen 9410 Cassy's Cave Building 35 Van Heerden Street Theunissen Tel: +27 057 733 1169 Fax: +27 057 733 2665 mmakhaotse@mna-sa.co.za					√											√	√		√									√
MEKAN ENGINEERING SERVICES Mr M SSS Tabane PrTechniEng PO Box 22696 Extonweg 9313 9 Connor Avenue Westdene Tel: +27 051 448 4864 Fax: +27 051 448 4123							√					√																
MPS CONSULTING ENGINEERS (5) Mnr C H Magson 770101 Dec 1973 Pring, LSAISI Posbus 3367 Bloemfontein 9300 MPS Consulting Engineers President Steynlaan 17 Westdene Tel: +27 051 448 3232/5 Fax: +27 051 430 4658 sonja@mpseng.co.za			√		√	√										√			√			√						√

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MTHOMBENI & ASSOCIATES CC Mr M J Mthombeni PrTechEng P O Box 32590 Fichardt Park 9317 Suite 5, Reitz Park 74 - 78 President Reitz Avenue Westdene Tel: +27 051 448 3826 Fax: +27 051 448 3827 mthombeni@mweb.co.za			√		√						√					√												
MVD XARIEP CONSULTING ENGINEERS CC Mnr J Steyn Pring, LSAISI Posbus 1634 Bethlehem 9700 Murraystraat 36A Bethlehem Tel: +27 058 303 4581 Fax: +27 058 303 7444 mvdbeth@imaginet.co.za			√		√	√				√	√					√				√			√					
PHETHOGO CONSULTING CC Mr T M Phakoe PrTechEng, SAICE PO Box 43284 Heuwelsig 9332 122 Nelson Mandela Drive Westdene Tel: +27 051 448 6006 Fax: +27 051 448 6728 meshack@phethogo.co.za			√		√												√			√		√						
PROPER CONSULTING ENGINEERS CC Mr J M Earle PrTechEng 9770106 PO Box 26415 Langenhovenpark 9330 Plot 35 Frans Kleynhans Road Groenvlei Tel: +27 051 451 1721 Fax: +27 051 451 1857 admin@propercon.co.za					√																							
ROYAL HASKONINGDHV Mr F P J Visser Pr Eng P O Box 12671 Brandhof 9324 Rosestad Building 163 Nelson Mandela Drive Westdene Tel: +27 051 400 7200 Fax: +27 051 430 8220 bloemfontein@rhdhv.com		√	√		√	√	√	√	√		√	√			√	√	√	√	√	√		√		√	√	√	√	√
RPS ENGINEERING CC Mr LJ Sibanda PrEng P O Box 1670 Westville 3630 Unit 3 87 Kellner Street Westdene Tel: +27 031 266 9505 Fax: +27 088 266 9505 info@rpsengineering.co.za			√				√								√													√
S & W CONSULTING (PTY) LTD Mr S Wessels PrTechEng 20061019 PO Box 1682 Harrismith 9880 38 Garvock Street Harrismith Tel: +27 058 622 2263 Fax: +27 086 613 9120 shane@swconsulting.co.za							√	√																				√

Free State

Company	Acoustics	Agricultural	Building Services	Chemical	Civil	Development	Electrical	Electronic	Environmental	Geotechnical	Industrial	Mechanical	Marine	Mining	Process Engineering	Structural	Transportation	Architecture	Rural Development	Project Management	Quantity Surveying	Town Planning	Dispute Resolution	Expert Witness / Insurance Claim	Information Systems / Technology	Facilities / Maintenance Management	GIS	QMS
SMEC SOUTH AFRICA (PTY) LTD Mr G I Jacobs PrEng 8850161 Suite 122 Private Bag X01 Brandhof 9324 23 Second Avenue, cnr 2nd Ave & Kellner St Westdene Tel: +27 051 418 8700 Fax: +27 051 447 6000 bloemfontein@smec.com			√		√	√	√	√		√		√		√		√	√		√	√			√	√	√	√	√	√
SNA CIVIL & STRUCTURAL ENGINEERS (PTY) LTD Mnr JAE Swanepoel 20080015 P O Box 12079 Brandhof 9324 12 Lilyvale Road Rayton Tel: +27 051 436 6727 Fax: +27 051 436 1788 bft@sna.co.za					√	√			√	√			√	√		√	√		√	√			√	√		√		√
THEODOR HOFFMANN AND MOUTON ENGINEERS T/A THM ENGINEERS Mr B J Swart PrEng 800071 1980-01-21 MSAICE PO Box 12464 Brandhof 9324 117 President Reitz Avenue Westdene Tel: +27 051 447 5689 Fax: +27 051 447 9079 office@thm.co.za			√		√											√								√				
THUSABATHO CONSULTING ENGINEERS Mr L R Kruger PrTechEng, MSAICE, MNHBRC P O Box 32289 Fichardpark 9317 57 Melville Street Brandwag Tel: +27 051 444 5616/422 4505 Fax: +27 051 444 5616 wouter@thusabatho.co.za		√	√		√	√				√						√	√		√	√								√
THUSO DEVELOPMENT CONSULTANTS Mr L Pretorius PrTechEng 200270126 PO Box 29312 Danhof 9310 75B Dan Pienaar Drive Dan Pienaar Tel: +27 051 436 0357 Fax: +27 051 4365938 thuso@consulteng.co.za			√		√	√				√						√				√								√
UWP CONSULTING (PTY) LTD Mr S Kou Cand Eng PO Box 33232 Fichardt Park 9317 UWP House, Suite1 58c Kellner Street Westdene Tel: +27 51 447 9670 / 1 Fax: +27 86 560 3648 bloemfontein@uwp.co.za					√	√								√		√	√		√	√				√	√	√	√	√
V & V CONSULTING ENGINEERS Mr C L Bakkes ECSA PO Box 32858 Bloemfontein Bloemfontein 9300 Birmakor Park, Suite 5, Reid Str Westdene Tel: +27 051 4107800 Fax: +27 051 4107810 delarey@vvconsult.co.za					√	√				√							√			√					√		√	√

Free State

Company	Acoustics	Agricultural	Building Services	Chemical	Civil	Development	Electrical	Electronic	Environmental	Geotechnical	Industrial	Mechanical	Marine	Mining	Process Engineering	Structural	Transportation	Architecture	Rural Development	Project Management	Quantity Surveying	Town Planning	Dispute Resolution	Expert Witness / Insurance Claim	Information Systems / Technology	Facilities / Maintenance Management	GIS	QMS
WORLEYPARSONS RSA (PTY) LTD Mr C J Mentz Pr Eng, ECSA 760400 P O Box 38157 Langenhoven Park 9330 Genius Loci Office Park, Bldg No 8 6 C P Hoogenhout Street Langenhoven Park Tel: +27 051 410 8700 Fax: +27 051 446 0540 bloemfontein.office@worleyparsons.com		√	√		√	√	√		√	√	√	√	√	√	√	√	√		√	√							√	√
WORLEYPARSONS RSA (PTY) LTD Lodewyckx Pr Eng ECSA 20100357 25 NJ van der Merwe Crescent Sasolburg 1948 25 NJ van der Merwe Crescent Sasolburg Tel: +27 (0) 16 970 3720 Fax: +27 (0) 00 000 0000 jw.lodewyckx@worleyparsons.com		√	√		√	√	√		√	√	√	√	√	√	√	√	√		√	√							√	√
WSP SA CIVIL AND STRUCTURAL ENGINEERS (PTY) LTD Mr E M Goosen PrTechEng, 970118, TMSAICE, PMISA, IPET P O Box 100872 Brandhof 9324 1st Floor 46 Second Avenue Westdene Tel: +27 051 447 1586 Fax: +27 051 430 4957 eddie.goosen@wspgroup.co.za					√	√										√	√			√				√				√

Appendix 3 Pilot Test Questions

FACULTY OF ENGINEERING AND INFORMATION TECHNOLOGY

The Chief Engineer / Project Director,

Sir / Madam,

Re: A Mechanism for Waste Reduction in Structural Design Process in South African Construction

This pilot test interview is part of a research project aimed at meeting the requirement for a Civil Engineering doctoral qualification at the Central University of Technology, Free State.

The aim of this phase of interview is to find if this research with the set questions can be conducted in the study context.

Please be assured that the confidentiality of your response is guaranteed.

Should you have queries, please do not hesitate to contact the promoter of the study, Prof FA Emuze on +27714509442 or per e-mail: femuze@cut.ac.za.

Many thanks for the anticipated favourable consideration of the request.

……………………………………………….

Aka Adefemi (Doctoral Student)

……………………………………………….

Prof FA EMUZE

Head of Department: Built Environment

Pilot Test Questions

- How long have you been involved in structural design process?
- From experience, what are the stages in structural design process?
- Can you explain the procedures and activities in each stage?
- Which of the activities are (i) highly significant, (ii) less significant (iii) not significant to the structural design process?
- How do the highly significant and less significant activities affect structural design process for efficient project performance?
- What kind of stake holders influences the activities in the structural design process and how?
- What are the factors that necessitate the activities that are less/not significant to the structural design process?
- Do you have an understanding of what lean principles are?
- Have you ever applied any of the principles to the structural design process? If yes,
- How can it be applied to eliminate the non-value adding activities in the practice?
- How can it be used to also reduce the less significant activities in the practice?
- If you have never adopted any of the principles during structural design process, do you believe the principles can help to eliminate the non-value adding activities, and reduce the less significant one during structural design process for effective project performance?
- Based on your experience, do you have any recommendation on how structural design process can be made more efficient or improve? If yes,
- How can your recommendations drive practice in the structural design process in South Africa construction?

Appendix 4 First Focus Interview Questions: Waste in the SDP, the causes of the Waste, and the Impacts of the waste on the Design, and the Construction Phases of Projects

FACULTY OF ENGINEERING AND INFORMATION TECHNOLOGY

The Chief Engineer / Project Director,

Sir / Madam,

Re: A Mechanism for Waste Reduction in Structural Design Process in South African Construction

This interview is part of a research project aimed at meeting the requirement for a Civil Engineering doctoral qualification at the Central University of Technology, Free State.

The aim of this phase of interview is to find out the various non-values adding activities/problems (waste) in each phase of a typical structural design process (SDP). The interview also aims to investigate the causes of the waste, and their impacts projects.

Please be assured that the confidentiality of your response is guaranteed.

Should you have queries, please do not hesitate to contact the promoter of the study, Prof FA Emuze on +27714509442 or per e-mail: femuze@cut.ac.za.

Many thanks for the anticipated favourable consideration of the request.

…………………………………………………

Aka Adefemi (Doctoral Student)

…………………………………………………

Prof FA EMUZE

Head of Department: Built Environment.

Interview Questions

Name of the firm: ……………………………………………………………………………...

Name of the interviewees: ……………………………………………………………………..

Position Held in the firm: ………………………………………………………………………

Years of SDP experience in the firm: ………………………………………………………….

- What are the various phases in the structural design process?
- What are the various values, the non-value-adding activities, and the problems in each phase of the structural design process?
- What are the factors that constitute the non-value-adding activities and problems?
- What is the frequency of occurrence of the non-value adding activities/problems in different projects?
- What are the impacts of the non-value-adding activities/problems on the design and the construction phases of projects?

Appendix 5 Second Focus Interview Questions: Validity of the Non-value Adding Activities in each Phase of Structural Design Process

FACULTY OF ENGINEERING AND INFORMATION TECHNOLOGY

The Chief Engineer / Project Director,

Sir / Madam,

Re: A Mechanism for Waste Reduction in Structural Design Process in South African Construction

This interview is part of a research project aimed at meeting the requirement for a Civil Engineering doctoral qualification at the Central University of Technology, Free State.

The aim of this phase of interview is to ensure the validity of the identified non-values adding activities/wastes at each phase of a typical structural design process (SDP).

Please be assured that the confidentiality of your response is guaranteed.

Should you have queries, please do not hesitate to contact the promoter of the study, Prof FA Emuze on +27714509442 or per e-mail: femuze@cut.ac.za.

Many thanks for the anticipated favourable consideration of the request.

……………………………………………….

Aka Adefemi (Doctoral Student)

……………………………………………….

Prof FA EMUZE

Head of Department: Built Environment.

Interview Questions

Name of the firm: ……………………………………………………………………………...

Name of the interviewees: ………………………………………………………………..

Position Held in the firm: …………………………………………………………………

Years of SDP experience in the firm: …………………………………………………….

- Which of the followings problems occur in the inception phase of the SDP?

a. Waiting for fund release before the start of work?

b. Late commencement of work?

c. Too many soil tests?

d. Ineffective site workflow?

e. Waiting for site report?

f. Delay in contract agreement between the client and designers?

h. Gaps in topographical survey of site?

i. Poor/lateness in site report preparation/writing?

- Which other problems differ from the aforementioned occur in the inception phase of the SDP?
- What are the factors that necessitate the occurrence of the above-mentioned problems in the inception phase of the SDP?
- What are the impacts of the problems in inception phase of the SDP on projects?
- Which of the followings problems occur in the predesign phase of the SDP?

a. Ambiguities in architectural drawings?

b. Disagreement between the SDT and architect?

c. Too many meetings between the architect and SDT?

e. Modifications of architectural drawings?

f. Unnecessary waiting time due to design modifications?

g. Too many structural design computations?

h. Computations errors due to structural design computations?

i. Ambiguities in structural works / wrong computations?

j. Too many printings of paper works?

k. Excessive supervision of work by the chief engineer?

l. Comprehensive study of architectural drawings?

m. Review of the applicable building codes?

n. Review of draft work by the senior engineer for approval to the next phase of work?

- Which other problems differ from the aforementioned occur in the predesign phase of SDP?
- What factors necessitate the occurrence of the problems in the predesign phase of the SDP?
- What are the impacts of the problems in the PDP of SDP on projects?
- Which of the followings problems occur in the detail design phase of the SDP?

a. Design corrections?

b. Redesign?

c. Too many printing of draft works?

d. Inability to complete work as earlier scheduled?

e. Waiting for approval of final work?

f. Too many copies of final work?

g. Selection of the most suitable proportions (sizes) dimensions and connections of structural elements computed at predesign phase?

h. Incorporation of the corrections and observations at the predesign phase into the work?

i. Preparation of final / complete drawings (auto card drawings)?

j. Review and approval of final drawings by senior engineer of the firm?

k. Review and approval of final drawings by the chief engineer?

- Which other problems occur in the detail design phase of the SDP?
- What factors necessitate the occurrence of the problems in detail design phase of the SDP?
- What are the impacts of the problems in the detailed phase of the SDP on projects?
- Which of the following structural design related problems occur in the construction phase of projects?

a. Excessive request for information?

b. Reworks?

c. Excessive waiting time during structural reinforcement?

d. Variation / change orders?

e. Redesign?

f. Wrong fabrication of formwork, rebar cage and reinforcing steel?

g. Ineffective flow of information between SDT and construction contractors?

H. Inadequate spacing of structural reinforcing steel?

I. Excessive supervision of work?

J. Excessive cutting of structural reinforcing steel?

- Which other problems differ from the aforementioned occur in the construction phase of projects?

- What factors necessitate the occurrence of the structural design related problems in the construction phase of projects?
- What are the impacts of such problems on projects?

Appendix 6 Third Focus Interview Questions: The Strategies that can be adopted to Reduce Waste in the Structural Design Process

FACULTY OF ENGINEERING AND INFORMATION TECHNOLOGY

The Chief Engineer / Project Director,

Sir / Madam,

Re: A Mechanism for Waste Reduction in Structural Design Process in South African Construction

This interview is part of a research project aimed at meeting the requirement for a Civil Engineering doctoral qualification at the Central University of Technology, Free State.

The aim of this phase of interview is to develop mechanisms that can be used to reduce or eliminate the identified problems (wastes) in each phase of a typical structural design process (SDP).

Please be assured that the confidentiality of your response is guaranteed.

Should you have queries, please do not hesitate to contact the promoter of the study, Prof FA Emuze on +27714509442 or per e-mail: femuze@cut.ac.za.

Many thanks for the anticipated favourable consideration of the request.

……………………………………………….

Aka Adefemi (Doctoral Student)

……………………………………………….

Prof FA EMUZE

Head of Department: Built Environment

Interview Questions

Section A: The Inception Phase of Structural Design Process

(a) It has been discovered in the previous interviews that the following problems exist in the inception phase of SDP:

- Waiting for fund release before the start of work;
- Lateness in the start of work;
- Too many soil tests;
- Ineffective site workflow;
- Waiting for site report;
- Delay in contract agreement between the client and designers; and
- Poor / lateness in site report preparation / writing.

(b) Is the management of your firm aware of these problems?

- If yes, what measure(s) have been or intend to be put in place by the management to overcome the stated problems?
- What is the drive behind these measure(s)? Order wise, how did your management come about the stated measures?
- In your own opinion(s), what measure(s) do you think can be put in place by the structural design team to overcome the stated problems?

Section B: The Predesign Phase of SDP

(a) It has been discovered in the previous interviews that the followings problems occur in the predesign phase of the SDP:

- Ambiguities in architectural drawings;
- Disagreement between the SDT and architect;
- Too many meetings between the client, architect and SDT;

- Modifications of architectural drawings;
- Unnecessary waiting time due to design modifications;
- Too many structural design computations;
- Structural design computations errors;
- Ambiguities in structural works / wrong computations;
- Too many printings of paper works, and
- Excessive supervision of work by the chief engineer.

(b) Is the management of your firm aware of these problems?

- If yes, what measure(s) have been/intend to be put in place by the management of your firm to overcome the stated problems?
- What is the drive behind these measure(s)?
- In your own opinion (s), what measure do you think can be put in place by structural design team to overcome the stated problems in the predesign phase of SDP?

<u>Section C: The Detailed Design Phase</u>

(a) It has been discovered in the previous interviews that the followings problems occur in the design phase of the SDP:

- Design corrections;
- Redesign;
- Too many printing of draft works;
- Inability to complete work as earlier scheduled;
- Waiting for approval of final work;
- Too many copies of final work;

(b) Is the management of your firm aware of these problems?

- What measure(s) have been/intend to be put in place by the management of your firm to overcome the stated problems?
- What is the drive behind these measure(s)?

- In your own opinion (s), what measure do you think can be put in place by structural design team to overcome the stated problems in detail design phase of SDP?

Section D: The Construction Phase

(a) It has been discovered in the previous interviews that the followings problems associated with SDP occur in the construction phase:

- Excessive request for information;
- Reworks;
- Excessive waiting time during structural reinforcement;
- Variation / change orders;
- Redesign;
- Wrong fabrication of formwork, rebar cage and reinforcing steel;
- Ineffective flow of information between SDT and construction contractors;
- Inadequate spacing of structural reinforcing steel;
- Excessive supervision of work, and
- Excessive cutting of structural reinforcing steel.

(b) Is the management of your firm aware of these problems?

- If yes, what measure(s) have been/intend to be put in place by the management of your firm to overcome the stated problems?
- What is the drive behind these measure(s)?
- In your own opinion (s), what measure do you think can be put in place by structural design team to overcome the problems associated with SDP at the construction phase?

Section E

- Do you adopt lean principles/techniques during the design process in your firm?
- If yes what aspect of lean principles/techniques has your firm adopted and to what aspect of the SDP?
- How effective is the implementation?

- Which of the following lean principles do you think can be applied to the inception, predesign, and the detailed design phases of the SDP so as to overcome the stated problems?

(1) Specifying Value?

(2) Identifying Value Stream?

(3) Achieving Flow?

(4) Applying Pull? And

(5) Achieving Perfection?

- How can the principle (s) be effectively applied?
- Which of the following lean techniques do you think can be applied to the inception, predesign and detailed design phases of the SDP to overcome the stated problems?

(1) Kaizen Events?

(2) Value Stream Mapping (VSM)?

(3) Black Belt Team (BBT)?

(4) Cellular Manufacturing (CM)?

(5) Just-In-Time (JIT)?

(6) Last planner?

(7) Daily huddle meetings (DHMs)? And

(8) The 5S Principles?

- How can the technique (s) be effectively applied?

Appendix 7 Fourth Focus Interview Questions: Validity of the Proposed Mechanism

FACULTY OF ENGINEERING AND INFORMATION TECHNOLOGY

Sir/Madam,

Re: A Mechanism for Waste Reduction in Structural Design Process in South African Construction

This questionnaire is part of a research project aimed at meeting the requirement for a Civil Engineering doctoral qualification at the Central University of Technology, Free State.

The aim of the questionnaire is to validate a mechanism that has been developed for waste reduction in the structural design process. The mechanism was developed through the focus interviews which were recently conducted among consulting engineers in Bloemfontein.

Please be assured that the confidentiality of your response is guaranteed.

Should you have queries, please do not hesitate to contact the promoter of the study, Prof FA Emuze on +27714509442 or per e-mail: femuze@cut.ac.za.

Many thanks for the anticipated favourable consideration of the request.

……………………………………………….

Aka Adefemi (Doctoral Student)

……………………………………………….

Prof FA EMUZE

Head of Department: Built Environment

Kindly indicate with either Yes or No in the following questions

Section A

- Do you agree that the following are the frequent problems (waste) experienced during structural design process?

The Inception Design Phase

Waste	**Yes**	**No**
Several soil tests		
Poor site report		
Waiting for site report		
Several site visits		
Delay in establishing the scope of the work		
Delay in implementing contract agreement		
Delay in establishing inception design documents		

The Predesign Phase

Waste	**Yes**	**No**
Ambiguities in architectural drawings		
Disagreements between the architect and the SDT		
Excessive meetings between the architect and the SDT		
Modifications of architectural drawings		

Excessive waiting time due to the design modifications		
Wrong structural computations		
Several, lengthy and repeated structural computations		
Several printings of paperwork		
Excessive supervisions of work by the chief engineer		
Delay in establishing preliminary design documents		

The Detailed Design Phase

Waste	**Yes**	**No**
Design corrections		
Redesign		
Excessive printings of draft work		
Excessive copies of final works		
Waiting for approval of final drawings		
Delay in establishing detailed design documents		

The Construction Phase

Waste	**Yes**	**No**
Variation or change order		
Excessive requests for information		
Excessive writing of site instructions		
Ineffective communication flow between the SDT and the contractors		
Excessive waiting time during structural reinforcement		
Wrong fabrication of formwork; rebar cages/reinforcing steel		
Inadequate spacing of structural reinforcing materials		
Excessive cutting/fabrication of structural reinforcing materials		
Several on-site supervision		

- Do you agree that the identified waste in the Tables above constitute excessive lead time (LT) or delays during structural design process? Yes ( ), No ( )
- Are you aware of any mechanism for overcoming the identified waste? Yes ( ), No ( )
- If yes, how would you assess the performance of such a mechanism?

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Section B

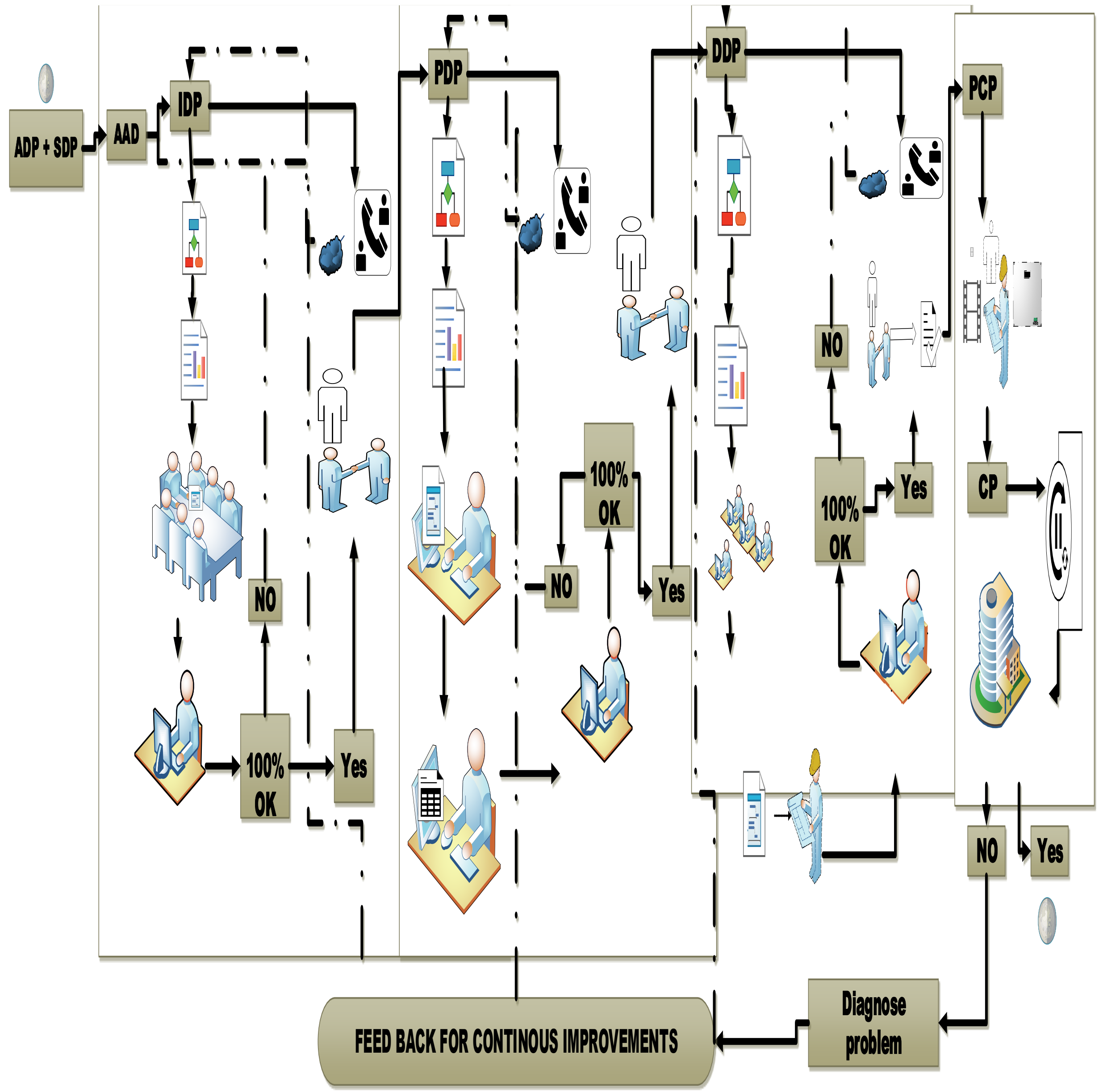

Figure: A lean mechanism for waste reduction in the structural design process

In figure 1, ADP = Architectural design process; SDT= Structural design team; EAD = Efficient architectural drawings; IDP= Inception design process; PDP= Predesign process; DDP = Detailed design phase; PCP= Preconstruction phase, and CP= Construction phase

It is anticipated that the proposed mechanism in figure 1 will enable the adoption of several strategies that can be used to overcome the identified problems in SDP. These strategies are summarized in Table 1 below.

Table 1: The strategies for waste reduction in SDP

Wastes	**Strategies**
Inception Design Process	
Several meetings especially at project initiation phase	Adoption of Phone calls and internet enabled communication (IC) during SDP
Waiting for fund release from the client/Lateness in the start of structural design	Appropriate communication/regular meetings with the client, and commencement of every structural project from high level discussion before the involvement of the SDT
Gaps in topographical survey	Timely conduction of site topographical survey through the service of experienced land surveyors
Several soil tests	Timely conduction of site geotechnical tests, and assumptions of certain design variables based on geotechnical information of the existing buildings in the proposed site,
Waiting for/poor site reports	Early investigation of the various soil tests and land topographical survey by the various professionals, minimize assumptions on geotechnical condition or characteristic of the proposed site and the use of an experienced designer that understand the information required by the geotechnical engineers for the necessary soil tests.
Predesign Process	

Ambiguities in architectural drawings	Adoption of quality assurance (QA) principle in every architectural design firm, involvement of structural designers in some aspects of architectural works (ADP+SDP = EAD), and adequate/continuous communication between the SDT/architect during the architectural drawings
Excessive meetings /disagreements between the architect and the SDT	Involvement of SDT in architectural process, adoption of meeting agenda and schedule of work or roster in every project
Modifications of architectural drawings/unnecessary waiting time due to design modifications	Involvement of SDT in the architectural process
Several repeated structural computations	The use of programmed excel spread sheet, adoption of some developed generic assumptions or a design software such as REVIT structure for structural computation
Wrong structural computations	Carefulness in some design assumptions, proper adoption of QA procedures, and complete engagement of a long time/experienced senior designer in the necessary computations
Several printings of paperwork	Adoption of electronic communication by the various project actors, and avoidance of complexity in structural drawings
Excessive supervisions of work by the chief engineer	More engagement of a senior designer in the calculation aspect of structural work
Detailed Design Process	

Design corrections	Adequate involvement of experienced designers such as senior engineers in every aspect of SDP
Redesign	Implementation of design variation space period in SDP, avoidance of vague assumptions and design variations in SDP, adequate or proper communication between the client/SDT at every phase of SDP, and adequate engagement of an experienced designer such as senior engineer in the computation aspect of structural work
Delay in selection of suitable structural elements computed at PDP, incorporation of comments at PDP into work, and inability to complete work as earlier scheduled	Proper planning/communication and total commitment among the various design actors, as well as additional resources such as man powers
Waiting for approval of final drawings	Proper planning as well as adequate flow of communication among the various actors, and adoption of a register or time record book for proper commitment of the senior/junior designers
Construction Phase	
Excessive RFIs, Construction reworks, excessive writing of site instructions and excessive waiting time during structural reinforcement	Production of drawings that is free of defects and unambiguous to interpret on the site, and engagement of a structural engineer for 3 hours for clarification of design information to the contractor/subcontractor before the start of the site activities.
Variations/change order and redesign	All forms of project variability are to be avoided during site activities, and project actors should defer the execution of

	the technical aspects of work that are liable to changes during construction until final decision has been taken
Wrong fabrication of formwork, rebar cage and reinforcing steel/excessive cutting or fabrication of structural reinforcing materials.	Engagement of the services of experienced contractors/subcontractors, production of drawings that is free of defects and unambiguous to interpret on the site, and engagement of a structural engineer for 3 hours for clarification of design information to the contractor/subcontractor before the start of the site activities.
Ineffective communication flow between SDT and construction contractors	Production of more sections or details of some technical aspects of working drawings for simplicity of every design information

- Do you agree that this mechanism covers the highlighted problems in the SDP?
  Yes ( ), No ( )
- In other worlds, do you think that the proposed mechanism can be used to resolve the identified problems in the SDP? Yes ( ), No ( )
- If No, kindly suggest the strategies that you think can be better adopted to improve on the proposed mechanism.

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Thanks for your anticipated contributions.

Appendix 8 Fifth Focus Interview Questions: The Performance of the Proposed Lean Mechanism

FACULTY OF ENGINEERING AND INFORMATION TECHNOLOGY

Sir/Madam,

Re: A Mechanism for Waste Reduction in Structural Design Process in South African Construction

This focus interview exercise is part of a research project aimed at meeting the requirement for a Civil Engineering doctoral qualification at the Central University of Technology, Free State.

The aim of the focus interview is to evaluate the performance of a lean mechanism that has been adopted in the design and the construction phases of a new project recently handled by your organization. The mechanism was developed through the focus interviews that were conducted with your firm, and 4 others in Bloemfontein recently.

Please be assured that the confidentiality of your response is guaranteed.

Should you have queries, please do not hesitate to contact the promoter of the study, Prof FA Emuze on +27714509442 or per e-mail: femuze@cut.ac.za.

Many thanks for the anticipated favourable consideration of the request.

…………………………………………………

Aka Adefemi (Doctoral Student)

…………………………………………………

Prof FA EMUZE

Head of Department: Built Environment

Questions

- What was your experience while adopting the lean mechanism in your new project?
- What are the advantages of the mechanism with respect to the newly executed project, and your organization at large?
- Will you recommend this mechanism to other consulting engineers firms, irrespective of the size, location, and the types of the project handled by the firm?
- What are the shortcomings of the mechanism?
- How can the shortcomings be overcome?
- How can lean thinking as well as the proposed mechanism improve SDP practice in South Africa?

Many thanks for your contributions

Appendix 9 Details of the Activities in the Structural Design Process

Activities in the Structural Design Process

IDP	PDP	DDP
Main activities: Attend project initiation meetings so as to implement the contract agreement (IDP-1); review the architectural drawings of the project at hand (IDP-2); define the services/scope of the work required (IDP-3); advise on the specific areas of activities that can influence the project life cycle cost (IDP-4); provide necessary information within the agreed scope of work to other consultant engineers involved (IDP-5); schedule/inspect on the required site topographical surveys, analyses, and other necessary site investigations (IDP-6); schedule/inspect on the	Main activities: Attend the design and the consultant meetings (PDP-1); review the architectural drawings in details (PDP-2); modification of the architectural drawings (PDP-3); establish regulatory authorities requirements/necessary building codes and incorporate them into the drawings (PDP-4); establish structural predesign criteria (PDP-5); refine the predesign criteria to ensure conformance with all regulatory requirements/building codes and consents (PDP-6); compute the general layout, preliminary sizing and stability of the proposed structural elements of the project (PDP-7); prepare the preliminary process designs and related documents suitable for costing (PDP-8); review the overall work for approval to the next phase (PDP-9); establish	Main activities: Attend consultants meetings (DDP-1); review the predesign documentation plans with other consultants that may be involved (DDP-2); select the most suitable proportions, dimensions and connections of structural elements computed in the predesign phase (DDP-3); incorporate the necessary corrections, comments and observations in the predesign phase into the work (DDP-4); incorporate other consultants designs and requirements into the work (if any) (DDP-5); prepare the design development drawings including draft technical details/specifications (DDP-6); review of the developed final drawings

necessary soil tests (IDP-7); oversee the compilation process of site report (IDP-8); sign the necessary inception design documents (IDP-9). Waste: Several meetings (A); waiting for fund release before the start of the structural design activities (B); delay in establishing contract agreement between the client/the designers (C); changes on the architectural drawings (D); delay to establish the services/scope of the project (E); delay to analyse the project life cycle cost (F); slow speed of work during geotechnical investigation (G); several soil tests (H); waiting for site report (I), and delay	preliminary design documents (PDP-10). Waste: Excessive meetings among the project actors (A); several changes/corrections on the project (B); clarification of information on the architectural drawings (C); disagreements between the architect/the SDP on the critical aspects of the project (D); waiting for the modified drawings (Architectural drawings) (E); delay to establish/incorporate the necessary building requirements/codes into the project (F); several design computations (G); unnecessary mistakes/errors during the computations (H); several corrections by the senior designers during the computations exercise (I); further clarify areas that are needed to be corrected or improved (paperwork) (J), and Waiting for preliminary design documents (K)	(DDP-7); approve the final drawings (DDP-8); produce the construction drawings (DDP-9), and establish the detailed design documents (DDP-10). Waste: Several consultant meetings (A); design corrections (B); redesign(C); delay in the selection of the suitable structural elements computed in the PDP (D); delay to incorporate the observed comments into the project as earlier scheduled (E); delay to incorporate other consultants requirements into the project as earlier scheduled (F); several printing of the draft drawings (G); waiting for the approval of the final drawings (H); unnecessary copies of the final drawings (I); delay in the production of the construction drawings (J), and delay to

to sign inception design documents (J)	establish detailed design documents (K)

Appendix 10 an Article Titled: Types of Waste and their Causes in the Structural Design Process: The Case of South African Construction Projects

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ABSTRACT

The construction design process consists of five main phases: the inception design phase, the predesign phase, the detailed design phase, the construction phase, and the close-out phase. Each of these phases is fraught with waste, which affects project performance. This research investigates such waste and its causes in the structural design process (SDP), through an analysis of in-depth interviews that were conducted among 25 consulting engineers in Bloemfontein, South Africa, in 2015. The engineers have extensive experience in the SDP, and are affiliated with Consulting Engineers South Africa. Data was collected through face-to-face semi-structured questions, and was then analysed thematically. The findings from the study indicate that waiting time, error, over-processing, excessive vigilance, overproduction, and correction/rework are the main forms of waste in the SDP. Based on these findings, the research concludes that waste occurs in virtually all phases in the current practice of the SDP. The research recommends that further studies, which go beyond merely establishing correlations, and which attempt to evaluate the causal pathways of the dominant waste in the SDP, should be conducted. Further research that explores mechanisms for waste identification and reduction in the SDP is thus recommended.

Keywords: Construction, Design, Engineers, Waste

1.0 INTRODUCTION

The structural design phase of a construction project entails a systematic means of investigating the stability, strength, and rigidity of a structure (Al Nageim *et al* 2010). The main objective of this phase is to produce a structure that is capable of withstanding all imposed load without failure during its intended lifetime (Nelson *et al* 1988). This objective is explicitly carried out by a structural design team (SDT) in the construction design process (CDP) (Nelson *et al* 1988). The

CDP is made up of five distinct phases, namely the inception design phase (IDP), where the design team carries out a project feasibility study, the predesign phase (PDP), where the procedures needed to complete the detailed drawings are clearly laid out, the detailed design phase (DDP), where the complete plans of the project are carried out, the construction phase (CP), where the drawings/specifications are handed over to the construction contractors, and the close-out phase (COP), where final measurements, documentation and drawings (as-built drawings) are prepared and handed over to the clients and other construction stakeholders (Al-Aomar 2012; Melhado & Agopyan 1996).

The literature shows that the abovementioned phases are full of activities and problems that constitute waste in construction (Ko & Chung 2014; Koskela *et al* 2013; Li *et al* 2008). Such activities include errors that require correction, unnecessary movement, and excessive waiting for employees at the site of work (Womack & Jones 2003). According to Koskela (1992), waste is any form of unnecessary work done and material loss that can increase production costs but not add value to the product itself. Such unnecessary work done and material loss includes waiting time, quality costs, lack of safety, rework, unnecessary transportation trips, long distances, improper management procedures, and poor constructability.

Waste in construction has been the subject of several studies worldwide (Koskela *et al* 2013; Nagapan *et al* 2012; Li *et al* 2008). For instance, one study conducted in the UK reveals that poor design management and late approval of decisions by the client are two major sources of waste (El Reifi & Emmitt 2013). Ko and Chung (2014), AbdelSalam *et al* (2010), and Li *et al* (2008) maintain that of all the processes in a project, the design phase is the most critical aspect. This phase is critical, as it is in this phase that values are explored and expressed, and when this phase is well managed, waste and associated problems can be minimised in the construction phase (Li *et al* 2008; Ko & Chung 2014).

Researchers have investigated how construction waste can be reduced or eliminated through the design phase of a project (AbdelSalam *et al* 2010; Ko & Chung 2014). However, the findings in the reviewed literature indicate that attention is focused mainly on architectural process; the aspect of the SDP is still unexplored. Ko and Chung (2014) emphasise that architectural design is by nature a multidisciplinary effort that requires the consideration of many aspects, such as structural composition, water drainage, and many more. Based on this emphasis, it can be assumed that the analytical frameworks devised by previous researchers for waste elimination in the CDP may be generalised to other aspects of project design. However, the desire of the SDT to produce a structure that is capable of resisting all imposed load without failure during its expected lifetime necessitates that structural design be explicitly distinguished from architectural process. Hence, further studies are required to expand on the existing theories and knowledge in other aspects of the CDP such as SDP. Premised on this requirement, an exploratory study was conducted in Bloemfontein, South Africa, to investigate the various types of process waste that originate from the SDP.

2.0 THE REQUIREMENTS OF THE SDT AND THE CLIENT IN BUILDING PROJECTS

Kamara *et al* (2002) emphasise that "a client is considered as a 'body' that incorporates the interests of a buyer of construction services, the prospective users and other group interests". Latham (1994) stresses that client requirements constitute the primary sources of information in the design and construction phases of a project, and are therefore of vital importance to the successful planning and implementation of a project. In a study conducted by Huovila and Seren (1998), it was discovered that the SDT usually consists of a group of engineers that design and oversee the supervision of building projects, so as to ensure that the projects are unyielding or stable when subjected to the intended loads. It can thus be concluded that the main objective or requirement of the SDT in building projects is to identify the needs of the client, and to translate these needs into requirements, so as to be able to effectively manage all form of technicalities in the design and construction phases of a project (Huovila & Seren 1998).

3.0 RESEARCH METHODOLOGY

This research aims to identify the various categories of waste that are significant to the SDP in the South African context. It also investigates the causes of these types of waste, as well as their impact on the design and construction phases of building projects. In order to achieve these aims, in-depth interviews were conducted in 2015 with consulting engineers in five different firms located in Bloemfontein. The selection of the firms was based on purposive sampling techniques (Ritchie & Lewis 2003). That is, firms that have designers with extensive work experience in the SDP, and who are affiliated with Consulting Engineers South Africa (CESA), were chosen. Specifically, five designers (a combination of both senior and junior engineers) and a technologist that have been working together as a team for not less than five years were interviewed through face-to-face semi-structured questions. To facilitate analysis of the anticipated data, the interview questions were focused on three different types of structures, namely residential, commercial and industrial buildings. The questions that were asked during the interviews were intended to produce in-depth understanding in the following specific aspects:

- The various phases in the SDP;
- The various values, non-value-adding activities, and problems at each phase;
- The factors that cause non-value-adding activities or problems, and the frequency of their occurrence in different projects; and
- The impact of non-value-adding activities or problems on the design and construction phases of projects.

At the start of each interview, the respondents were reminded of the research aim and objectives. Each respondent was also asked their experience as far as the SDP is concerned. The respondents were then given a short questionnaire to complete. This process was followed by the actual interview questions, which were guided by a semi-structured protocol (McNamara 2009). The interviews were conducted over a two-month period in 2015, and the duration of each interview session ranged from 45 to 55 minutes. In total, 25 engineers took part in the study, since at each firm, five designers constituted the focus group for the interviews. As recommend by Arksey and Knight (1999), all the interview discussions were tape-recorded and transcribed.

After transcription, the resultant information was analysed using content analysis. This approach was adopted as it enables verbal or behavioural information to be categorised for the purposes of classification, summarisation, and tabulation (Krippendorff 2012). In the analysis section, the verbal information and the behavioural information were categorised into two groups. The first aspect is the important opinions, which are relevant to the research under study, while the second aspect is the non-essential ideas (Bryman 2001). After categorisation, the important information was further summarised into themes. The themes were then validated by means of follow-up interviews, which were conducted by the researchers with the head (the chief engineer) of each group of respondents in the studied firms (McNamara 2009). Table 1 shows the demographic information of the selected firms in this study. Due to ethical considerations, the names of the case firms are referred to by letters of the alphabet, as shown in the table.

(Insert Table 1)

4.0 FINDINGS

4.1.0 Activities and problems in the SDP of construction projects

From the group interviews conducted in this study, it was discovered that the phases in SDP corresponds with the five main phases of the CDP mentioned in the literature. These phases are dependent on one another. This implies that defects experienced in any one of the phases can lead to defects in a subsequent phase. However, it was also discovered that certain activities occur in each phase. Some of these activities are essential to construction projects (they are value-adding), while others are not (they are non-value-adding). In addition, it was discovered that certain occurrences are problematic, and they constitute waste in each phase. These activities and problems are discussed by phase below.

4.1.1 Activities and problems in the inception design phase

From the study, it was discovered that the inception design phase (IDP) of the SDP is important, as issues related to imprecision, requirements, and needs are addressed in this phase by the SDT before the start of a new project. It is at this phase that the necessary agreements between the architect/the client and the SDT are established. Such agreements include the nature (scope/appearance) of the work, the basic professional charges, and the method and time of payment. Once the necessary agreements have been established, the SDT conducts a topographical survey of the proposed site, using the services of a professional land surveyor. This enables the team to acquire a hands-on understanding of the conditions of the site, to determine its nature/size, and to obtain necessary information on its terrain. A review of other existing structures/projects in the vicinity of the site is also conducted by the surveyor during this visit, so as to enable the SDT to analyse their impact on the proposed project. After the site topographical survey, the SDT often executes a site soil test, using the services of a geotechnical engineer, and it oversees the compilation process of the site report.

Table 2 provides a summary of the different types of waste, otherwise known as non-value-adding activities and problems, in the IDP of a project. In the interviews conducted in all the studied firms, all the respondents agreed that the general categories of waste/problems indicated in the table occur in virtually every construction project, with the exception of the waste categories of "ineffective site workflow" and "waiting for the site report", which occur only occasionally. Some of the respondents did not agree that excessive soil tests in the IDP is one of the design problems that needs to be addressed, or that requires action by management. The respondents argued that it is mandatory for designers to know the exact bearing capacity of soil in the proposed site, and, as such, they asserted that the professional tasked with this responsibility is obligated to take as many samples as possible during site visits, so as to arrive at a standard or acceptable result that is not compromised.

(Insert Table 2)

4.1.2 Activities and problems in the predesign phase

The predesign phase (PDP) is the second stage in the SDP, and its main objectives, according to the responses from the focus group interviews that were conducted, are to finalise the project concept, and to clearly lay out the procedures needed by the designers in order to complete the next phase of work. This means that in the PDP, the SDT thoroughly studies the architectural plan and draws attention to the general layout and the preliminary sizing and stability of the proposed structural elements. Hence, the preliminary sizing and stability of structural elements such as columns, column footings, the foundation, slabs, the beams, and the roof are computed in this phase. The computations are performed in accordance with the requirements of the applicable building codes, as well as the outcome of the site soil tests. The study shows that the architectural drawings are always defective, particularly with regard to specifications for column sizes, footings, and slab thickness. The PDP therefore allows room for comments and interactions between the SDT and the architect, for necessary corrections/adjustments to the architectural drawings. Once consensus has been reached between the architect and the SDT, the predesign activities will be finalised and passed on to the chief engineer of the consulting firm, for final assessment. The SDT then compiles the predesign documents and proceeds to the next phase of work.

Table 3 provides a summary of the types of waste and problems in the PDP of a project. It is worth noting that all the respondents agreed that ambiguities in the architectural drawings are the main challenges at this stage of the work, as they are responsible for most of the problems encountered by the SDT. One of these ambiguities is specification for a large floor size. The respondents explained that a large floor size could lead to long beam specification, with a consequent increase in project costs. The respondents argued that when this occurs, it is the responsibility of the SDT to instruct or advise the architect to revise the architectural drawings. Some of the respondents maintained that the problem of ambiguities in the architectural drawings will persist in the system for as long as communication gaps continue to exist between the architect and the SDT. All the respondents contended that computation errors in the PDP are the norm, and that such errors should not be categorised as one of the design problems, due to the 'quality assurance' that will have been made by the management of the firm to attend to this menace in subsequent phases.

(Insert Table 3)

4.1.3 Activities and problems in the detailed design phase

With regard to the detailed design phase (DDP), it was discovered that this phase involves detailed consideration, determination and selection of the most suitable alternative solution in terms of the proportions, dimensions, and connections of structural elements defined in the predesign phase, in order to create the complete, perfect, and final structural drawings/specifications for the proposed project. In addition, comments/observations made by the chief engineer at the predesign phase are incorporated into the work before the final structural drawings are produced. Once the final drawings have been produced, the designer (the junior structural engineer) passes the drawings on to the senior engineer for approval, and then to the project director of the firm. Approval of work by the senior engineer takes approximately two weeks for minor work, and four to five weeks for major work. This means that approval is not always guaranteed or granted immediately by the senior engineer, due to further corrections/alterations that are sometimes made at this stage. After approval, the SDT compiles the detailed design documents. The team then prepares the construction drawings, which will be handed over to the contractors. Compared to the detailed drawings, the construction drawings are more detailed in their dimensions. The purpose of these drawings, according to the respondents, is to make the site activities clearer to the contractors.

Table 4 provides a summary of the different types of waste and problems in the DDP of projects. In the interviews that were conducted, all the respondents asserted that excessive printing of paperwork and inability to complete tasks as earlier scheduled constitute the main problems in this phase of construction work. Some of the respondents argued that these problems will persist in the system for as long as work hierarchy remains a priority for the firm, that is, where the less experienced junior designers are expected to carry out the main work (calculations and designs), while the experienced senior/chief engineer assumes responsibility for supervisions only. Some respondents maintained that redesign is the least expected problem in this phase, due to the quality assurance that is made available in the system.

(Insert Table 4)

4.1.4 Activities and problems in the construction phase

In an ideal situation, it is anticipated that construction contractors should be able to effectively handle the execution of projects without the presence of a representative of the SDT. However, from the study it was discovered that a member of the SDT of the consulting firm is at one time or another needed on site, particularly at the start of every new task. The reason for this is to answer questions and to provide interpretations for aspects that are not clear to the contractors. Consequently, most of the engineers in the studied firms make it obligatory to visit their sites at least twice a month, in order to control the measurement/quality of work, with the idea being that this will keep the number of on-site requests for information (RFIs) to a minimum. However, the interviews reveal that due to the many construction issues, the number of RFIs at the time that this study was conducted was still very high, to the extent that a member of the SDT visits their site several times within one month. From an engineering perspective, the main activities of the SDT in the construction phase of a project are the following:

- Attend to the site handover;
- To issue structural engineering construction documents, so as to reinforce binding schedules and detailing/specifications of structural steel sections and connections;
- To prepare the schedules for the predicted structural work cash flow;
- To attend regular site, technical and progress meetings;
- To advise the contractors on the agreed quality assurance plan for work related to the SDP;
- To inspect the work for quality and conformity to contract documentation, at an average frequency of once every two weeks during the course of the work;
- To clarify details and descriptions during construction, as required;
- To inspect the work and issue practical completion and defects lists; and
- To arrange for the delivery of all test certificates, statutory (regulatory) and other approvals, as-built drawings, and operation manuals.

Table 5 provides a summary of the various types of waste and problems in the construction phase of a project. According to some of the respondents, excessive RFIs constitute the main problem in this phase, and RFIs may occur as many times as possible, particularly in a large project, such as the construction of a commercial or non-residential (multi-storey) building or an industrial building. Some of the respondents asserted that rework is another common problem, and that it occurs several times in a large and highly challenging project, such as construction of a multi-storey building. Some of the respondents also argued that too many supervisions on site waste time. The respondents highlighted the aspects of formwork and rebar cages, which need to be regularly cross-checked by the engineers.

(Insert Table 5)

4.1.5 The close-out phase of the SDP

Based on the responses from the study, the specific activities of the SDT in the close-out phase (COP) of work are the following:

- To inspect and verify the rectification of defects;
- To receive, comment on, and approve relevant payment valuations and completion certificates; and
- To prepare as-built drawings and documentation.

This study found that the COP experiences limited problems. Consequently, the researchers shall not discuss this aspect any further.

4.2 Average frequency of occurrence of SDP waste in projects

In the interviews conducted, most of the respondents agreed that waste occurs in every structural project, but that the frequency of its occurrence differs from one type of building to another. For instance, some of the respondents asserted that ambiguities in architectural work, and disagreements between the SDT and the architect, may occur between two and four times in the construction of a simple residential building, such as a two- or three-bedroom duplex, between five and eight times in the construction of a commercial multi-storey building, such as a shopping mall, and between four and six times in the construction of an industrial or factory building. Figure 1 summarises the occurrence of waste in different projects. In the figure, Project 1 represents construction of a simple residential building, while Projects 2 and 3 represent construction of non-residential (commercial) and industrial buildings. As can be seen from the figure, the frequency of occurrence of waste in two- or three-bedroom duplexes is negligible, but it is high in the construction of non-residential and industrial buildings. It has been stated that excessive RFIs is the main problem in the construction phase of every project, and that RFIs may occur several times. In this regard, some of the respondents asserted that RFIs may occur right from the start of work to the completion, particularly in construction of multi-storey buildings.

(Insert Figure 1)

4.3 The categories of waste in the SDP

Alarcon (1997) and Koskela (1992) emphasize that waste in the production environment can be grouped into two categories which are waste in manufacturing and waste in construction. Typical examples of waste in manufacturing are waste due to defective products, wait periods, overproduction, over-processing and motion. While some of the examples of waste in construction are rework, error, clarification, excessive vigilance, and work not done. In this study it was discovered that the identified types of waste in the SDP can be grouped into nine categories, namely waiting time, over-processing, motion, excessive vigilance, overproduction, rework/correction, clarification, error and work interruption as shown in Tables 6, 7, 8 and 9. These categories of waste are discussed in more detail in section 4.3.1 below.

4.3.1 A discussion of the discovered nine categories of waste in the SDP

In Table 6, the three categories of waste that are associated with the IDP in this study include the following:

- Waiting time: Womack and Jones (2003) and Simms (2007) classify all forms of delay in processing any unit of engineering work as waiting time. In the current study, most of the respondents agreed that unnecessary waiting in the IDP of a project leads to delays in the start of site activities, and it increases the overall costs of a project, due to fluctuations in the cost of construction materials. This is consistent with the findings of Sunjka and Jacob (2013) regarding the impact of delays on construction costs in the design phase of a project.
- Over-processing: Nazech *et al* (2008) explain that over-processing occurs in a project when resources are being used or applied more than is necessary or required. All the respondents asserted that over-processing, in the form of several soil tests/site visits in order to determine the exact bearing capacity of the soil in the proposed site, wastes time, resources, and money. The respondents further maintained that this could lead to delays in the commencement of site activities, due to the delays that this creates in the IDP and in subsequent phases of the SDP.
- Motion: According to Womack and Jones (2003), motion includes any unnecessary physical movement or walking by workers which diverts them from actual processing work. In the interviews conducted, some of the respondents asserted that ineffective site workflow could lead to delays in completion of the site topographical survey. The respondents explained that when this occurs, the engineers responsible for the work make additional charges. This also leads to an increase in the overall cost of a project.

(Insert Table 6)

Table 7 shows the seven categories of waste in the predesign phase of the SDP in this study. These categories include the following:

- Error: In this study, it was discovered that wrong computation and ambiguities in architectural work are errors/mistakes that are responsible for rework/corrections in the PDP of projects. Most of the respondents stressed that it is important for the architect and the SDT to detect any form of mistake in the predesign phase of the work, in order to make any necessary amendments, so as to reduce the number of RFIs in the construction phase of a project. This means that mistakes that are not detected in the design phase are the main cause of excessive RFIs in the construction phase. This is consistent with the findings of Ko and Chung (2014) and AbdelSalam *et al* (2010) regarding the impact of design error on construction projects.
- Overproduction: In engineering design, processing an order before it is needed, or any processing that is done on a routine basis regardless of the current demand, is known as overproduction (Ohno, 1988). In this study, all the respondents agreed that excessive printing of work in the PDP of the SDP leads to wastage of materials (paper and ink).
- Over-processing: Most of the respondents emphasized that over-processing in form of excessive meetings between the client and the design actors in the PDP often lead to delays in the start of the construction activities.
- Motion: Simms (2007) defines motion in engineering work as all forms of waste that can be likened to using inefficient software. In this study, the only waste identified as motion in PSP was several computations of structural elements. All the respondents asserted that computation of elements such as slabs and beams requires extensive time, and that the procedures used in performing the computations are slow and boring. The respondents concluded that design computations occasionally lead to human errors, which could lead to corrections, rework, late completion of work, and poor design quality.

- Excessive vigilance/waiting time: Most of the respondents also argued that several supervisions of work by the chief engineer, and unnecessary waiting time due to delays in establishing preliminary design documents in this phase disrupt the schedule of work, and consequently lead to delays in the start of work in the subsequent phases.
- Clarification: All the respondents stressed that disagreements between the architect and the SDT due to clarification of information often lead to slow speed of structural activities, which consequently lead to delay in the start of construction phase.

(Insert Table 7)

The four categories of waste in the DDP of the SDP in this study include the following (see Table 8):

- Overproduction: In this study, the researchers discovered that several copies of final work are produced in all the studied firms. For instance, three copies of final work are handed over to the contractors, two copies to the architect, and one copy to the quantity surveyor or the client. This means that overproduction due to excessive paperwork leads to material wastage in the DDP of the SDP.
- Correction/rework: Hwang *et al* (2009) contend that correction/rework implies repeating a process or step several times. In this study, the respondents maintained that mistakes are the main cause of redesign/design correction, which is responsible for delays in the completion of the structural drawings, as they reduce the pace of the work. Apart from delays, some of the respondents asserted that redesign due to variation/changed orders could lead to disagreements

between the SDT and the architect or the client, which sometimes lead to changes in the agreed-upon contractor’s fee, particularly when the redesign problems arise from the client.

- Waiting time: This study reveals that the two forms of waste associated with waiting time in the DDP are approval of final work by the chief engineer/project director, and delays in establishing detailed design documents. These waste much time, and are the main factors responsible for lateness in the start of work in the construction phase of a project.
- Work interruption: In this study, the researcher observed that inability to complete work as programmed by SDT due to several interruptions in DDP is another causes of delay in the start of construction phase.

(Insert Table 8)

The four categories of waste in the construction phase of the SDP in this study include the following (see Table 9):

- Corrections/rework: Most of the respondents felt that corrections/rework due to variation/changed orders, redesign, and inadequate spacing of structural reinforcing materials in the construction phase are the main factors responsible for on-site disputes. The respondents argued that disputes arise when none of the actors is prepared to accept responsibility for damages that have accrued through corrections. Some of the respondents also stressed that corrections in the form of rework could reduce the overall performance and efficiency of the work, and could cause the project director to procure additional construction materials, with a consequent increase in the overall cost of a project. This corresponds to the findings of Mastenbroek (2010) regarding the impact of rework on construction projects.

- Over-processing: All the respondents emphasized that over-processing such as excessive cutting/fabrication of structural reinforcing materials are the main factors responsible for material wastage on the construction site. The respondents further asserted that this waste of over-processing reduces the overall performance/efficiency of site activities, which consequently leads to poor quality of work.
- Waiting time: The respondents agreed that excessive waiting time due to clarification of information during structural reinforcement, and ineffective communication flow between the SDT/the construction contractor are the main factor responsible for lateness in completion of work in the construction phase of a project.
- Excessive vigilance: Excessive vigilance occurs in the construction phase of a project due to quality assurance requirements. That is, it is expected that there be supervision at every phase of a new task on site, as stipulated by the appropriate authority. All the respondents agreed that several supervision of work in the construction phase of a project is the main factor responsible for delays in the completion of work.

(Insert Table 9)

5.0 CONCLUSION, AND RECOMMENDATIONS FOR FURTHER RESEARCH

Based on the findings of this study, it can be concluded that waste occurs in the current practice of the structural design process (SDP), although the frequency of waste may differ from one project to another. This means that waste in construction also arises from structural design practices. Such waste is found in every phase of the SDP, namely the inception, the predesign, the detailed design and the construction phases. Typical examples of these types of waste are several site visits, excessive printing of work, design corrections, waiting for approval of structural work, wrong fabrication of formwork, and misinterpretation of the structural drawings by the construction contractor. The main causes of waste in the SDP are ambiguities in the architectural drawings and design changes due to changes in client requirements.

In general, waste in the SDP can be categorised into defects or corrections, overproduction, over-processing, waiting time, and motion. It can also be argued that waste in the SDP could lead to inefficiency or poor quality of work in the design and construction phases, extended project completion time, an increase in the estimated quantity of construction materials, and an increase in the estimated cost or agreed-upon charges for a project.

Based on the above conclusion, further research is needed to find lasting waste-elimination strategies in the SDP. Such research should explore mechanisms for waste identification and reduction in the SDP.

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Table 1: Demographic information of the various firms in this study

Name of the firm	Location	Participants' experience (years)	Number of participants
A	President Reitz Avenue, Westdene, Bloemfontein	> 15	5
B	Victoria Road, Willows, Bloemfontein	> 10	5
C	Cnr of 2nd Avenue and Kellner Street, Westdene, Bloemfontein	> 15	5
D	2nd Avenue, Westdene, Bloemfontein	> 15	5
E	President Reitz Avenue, Westdene, Bloemfontein	> 10	5

Table 2: Waste/problems in the inception design phase of construction projects

Waste/problem	Cause

Waiting for fund release from the clients before the start of work	Waiting for fund release before the start of structural work often results in wasted time in most of the studied firms, due to slow decision-making by the client.
Waiting for the start of structural work	This occurs due to late release of project funds by the client.
Ineffective site workflow	Ineffective site workflow, or difficulties in accessing the site freely by the various construction actors during the site topographical survey, due to gaps in the topographical survey. Difficulties such as sloping, rocky, valley or high-hill surfaces result in ineffective workflow during this activity.
Several soil tests/site visits	The site soil test may have to be repeated two or three times before a satisfactory result is obtained, particularly when the proposed site has unstable soil. In the ideal situation, the soil test is carried out once, in an environment where there are existing structures that are similar to the proposed one.
Waiting to establish the scope of the work	These are caused by poor architectural briefing and too many changes made to the architectural drawings.
Waiting to implement contract agreement between the client and the designers	These occur mainly due to delays in understanding the scope of the work, due to changes made by the client to the architectural drawings.
Poor site report	This occurs when the information supplied by the geotechnical engineer conflicts with the existing knowledge of the SDT.
Waiting for the site report	Site report writing wastes time, as the study shows that to write a good site report after site visitations takes approximately seven to eight weeks in some of the studied firms, due to laxness on the part of the geotechnical engineer (a poor site report). Waiting for the site report also occurs when the proposed site is in a remote location, where the necessary facilities for conducting the soil tests cannot be easily accessed.
Waiting for the compilation of inception design documents	These occur mainly due to lateness in completion of inception work, as a result of problems encountered in the process by the SDT.

Table 3: Waste/problems in the predesign phase of construction projects

Waste/problem	Cause
Ambiguities in the architectural drawings	Ambiguities, such as wrong specifications of materials, slab thicknesses/sizes, and column sizes, due to a lack of communication between the architect and the SDT during the architectural process.
Disagreements between the architect and the SDT	Disagreements arise between the SDT and the architect in attempts to clarify information on aspects such as the number and the size of columns required for the proposed structure. Disagreements occur due to inadequate structural knowledge by the architect.
Excessive meetings between the client, the architect, and the SDT	Excessive meetings occur before the architect and the SDT reach consensus on issues regarding the architectural work.

Unnecessary waiting time due to design modifications	Unnecessary waiting time occurs during structural work, where the architect needs to effect changes to the architectural drawings, due to comments made by the SDT, or changes in client requirements.
Several, lengthy, and repeated structural computations	This is due to lack of suitability of the existing technology; every structural work is unique in nature. Computations used for structural elements on previous projects cannot be used for structural elements on a new project.
Wrong computations	These occur due to errors and mistakes (human error) made by the SDT during the computation of structural elements. A typical example is the computation of sizes and permissible bending moments for each structural element. The procedures involved in performing these computations are routine in nature, and are sometimes boring, and can thus lead to human error, that is, mistakes. Wrong computations may also occur when the SDT misinterprets the building codes, or does not adhere to them strictly
Several printings of paperwork	This occurs due to human errors/mistakes made by the SDT during the structural work. It also occurs due to complexity in the architectural drawings.
Excessive supervision of work by the chief engineer	This is caused by the stipulation of procedures in the consulting firms; the senior engineer is expected to cross-check every aspect of work carried out by the junior engineer/designer before moving on to the next phase of work.
Waiting to establish preliminary design documents	This occurs mainly due to lateness in completion of the predesign work, as a result of problems experienced in the process by the SDT

Table 4: Waste/problems in the detailed design phase of construction projects

Waste/problem	Cause
Design corrections	Design corrections occur due to errors/mistakes made by the SDT in critical areas during production of the structural drawings.
Redesign	Redesign occurs when a structural element that is wrongly computed in the predesign phase is detected in the detailed design phase of the work.
Unnecessary printings of draft work	Draft drawings at every stage of work are submitted to the chief engineer for necessary corrections and contributions before proceeding to the next stage
Inability to complete work as earlier scheduled	This is an inability of the SDT to complete work in accordance with the prepared work programme. The SDT has “no work timetable” due to the many contributions, corrections, and adjustments in the course of the work.
Waiting for the approval of final drawings	Design work is being carried out by the junior engineer in the consulting firm, which will be submitted to the senior engineer, and thereafter to the project director of the firm or the chief engineer for corrections. This wastes time, as the chief engineer/project director has to thoroughly cross-check every section of the work before final approval
Waiting to establish detailed design documents	This is due to all the problems experienced in this phase of the work by the SDT.

Several copies of final work	Several copies of the final work are made, as recommended by the studied firms. All the construction actors must be given copies of the final work for documentation purposes.

Table 5: Waste/problems in the construction phase of construction projects

Waste/problem	Cause
Excessive RFIs	The construction contractors excessively request the presence of a member of the SDT on site for clarifications of information in the design drawings. This is due to lack of involvement by the construction contractor at the design stage of the structural work.
Excessive waiting time during structural reinforcement	Excessive waiting time occurs during structural reinforcement. This is due to the complexity of the structural drawings. The construction contractors find it difficult to interpret some aspects of the structural drawings on site. A typical example is the top reinforcement of the foundation and stairs.
Variation/changed orders	Changes in client requirements and changed orders occur on site due to sudden changes made by the client regarding the proposed structure, or unforeseen problems, such as foundation problems.
Redesign	Redesign becomes necessary on site when the materials specified are not available.
Wrong fabrication of formwork, rebar cages, and reinforcing steel	This is due to improper or inadequate supervision of work by the construction contractors, or misinterpretation of the structural drawings. It may also be due to the complexity of the structural drawings.
Excessive writing of site instructions	This occurs when there are several mistakes on site, particularly with regard to formwork, rebar cages, and reinforcing steel fabrications.
Ineffective communication flow between the SDT and the construction contractor	This is due to lack of involvement of the construction contractor at the design stage of structural work. Human error is also a factor, that is, failure to understand the problem.
Inadequate spacing of structural reinforcing materials	This occurs on site due to poor or inappropriate supervision of work by the construction contractor. It can also occur due to misinterpretation of the structural drawings.
Excessive supervision of work	This is due to the need for the construction contractor to comply with the necessary regulatory authorities, that is, there must be supervision in every phase of a new task.
Excessive cutting/fabrication of structural reinforcing materials	This is due to misinterpretation of the structural drawings by the construction contractor, or poor supervision of work.

Table 6: The categories of waste in the inception design phase

Waiting time	1. Waiting for fund release from the clients; 2. Waiting for the start of structural work; 3. Waiting for the site report; 4. Waiting to establish the scope of the work; 5. Waiting to execute contract agreement between the clients and the designers, and 6. Waiting for the compilation of inception design documents
Over-processing	1. Several soil tests, and 2. Several site visits
Motion	1. Ineffective site workflow

Table 7: The categories of waste in the predesign phase

Error	1. Ambiguities in architectural work, and 2. Wrong computation
Overproduction	1. Several printings of paperwork
Over-processing	1. Excessive meetings between the client, the architect and the SDT
Motion	1. Several, lengthy, and repeated structural computations
Excessive vigilance	1. Several supervision of work by the chief engineer
Waiting time	1. Unnecessary waiting time due to design modifications, and 2. Waiting to establish preliminary design documents
Clarification	1. Disagreements between the architect and the SDT

Table 8: The categories of waste in the detailed design phase

Overproduction	1. Unnecessary printing of draft work, and 2. Several copies of final work

Corrections/rework	1. Design corrections, and 2. Redesign
Waiting time	1. Waiting for the approval of final work, and 2. Waiting to establish detailed design documents
Work interruption	1. Inability to complete work as earlier scheduled

Table 9: The categories of waste in the construction phase

Corrections/rework	1. Variation/changed orders; 2. Wrong fabrication of formwork; rebar cages/reinforcing steel; 3. Redesign, and 4. Inadequate spacing of structural reinforcing materials
Over-processing	1. Excessive requests for information, and 2. Excessive cutting/fabrication of structural reinforcing materials
Waiting time	1. Excessive waiting time during structural reinforcement, and 2. Ineffective communication flow between the SDT/the construction contractor
Excessive vigilance	1. Several on-site supervision

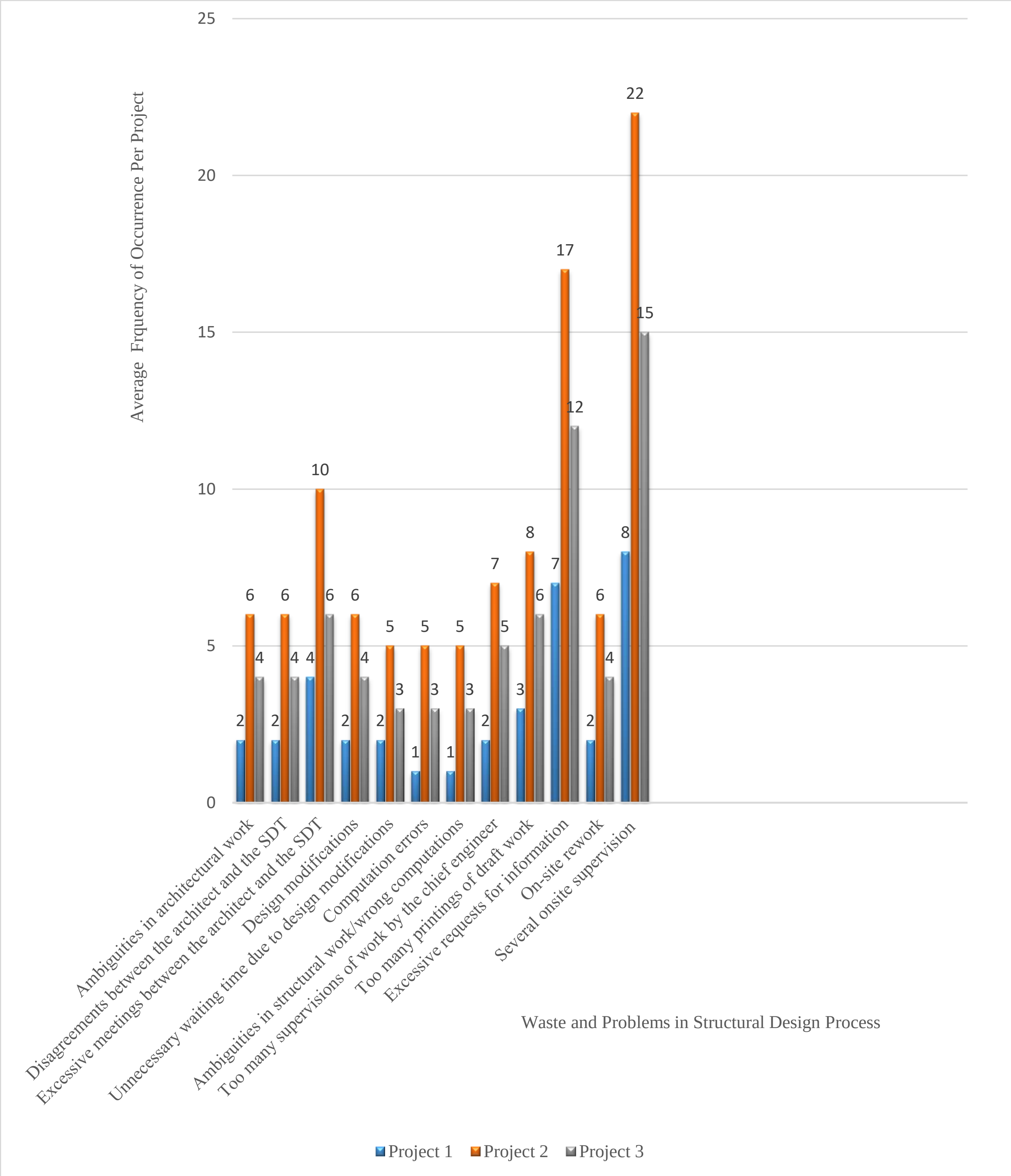

Figure 1: Frequency of occurrence of waste and problems in three different construction projects