REDUCING MATERIAL WASTE WITH THE APPLICATION OF BUILDING INFORMATION MODELLING (BIM)

AYESHA MALL

SUBMITTED IN FULFILLMENT FOR THE REQUIREMENTS OF THE DEGREE OF MASTER OF BUILT ENVIRONMENT IN THE DEPARTMENT OF CONSTRUCTION MANAGEMENT & QUANTITY SURVEYING, FACULTY OF ENGINEERING AND THE BUILT ENVIRONMENT AT THE DURBAN UNIVERSITY OF TECHNOLOGY

SUPERVISOR DR A.O. AIYETAN

MARCH 2019

Abstract

Every year approximately 13 million tonnes of unused materials go to waste from construction sites. Construction professionals should strive to reduce wastage through the principle of right-first-time. Material waste directly affects the profitability of the contractor and it is a measure of competency and competitive advantage. The construction has a great influence on several industries by procuring products, as well as by providing products to other industries, therefore, by reducing waste there could be great cost savings to the construction industry. The Building Information Modelling (BIM) tool can be used in a construction of a project to motivate the design, construction, and operation of a project from start to finish. Therefore, the 3D BIM model can assist the construction industry in reducing material waste.

The aim of this study is to identify the main causes of waste in the South African construction industry and develop a flow chart through the application of BIM to reduce waste. The objectives of the study include the identification of causes and sources of material waste on construction and the use of BIM to aid in waste minimisation.

The tools used for data collection included questionnaires and site observations. The sample population for data collection included architects, project managers, quantity surveyors, and engineers. A programme called Statistical package for social scientists (SPSS) was employed to analyse the data. Mean score rankings, factor analysis, and Cronbach alpha test were adopted for data analysis. The structured questionnaire indicated whether construction professionals in South Africa have sufficient knowledge of BIM.

Key research findings indicate that BIM has the ability to assist in reducing material waste. BIM enhances practices such as collaboration, detailing, visualisation and simulation, clash detection and improved communication. BIM has a strong influence on the reduction of waste material. BIM has the potential to address the causes of waste, relative to design changes, ineffective coordination and communication, and improvements towards waste minimisation through the construction stage of a project. The results from the data analysis, revealed that the most common contribution to waste on a construction site included material handling and storage factors, design and documentation factors, procurement factors, site management and practice factors and operation factors.

The use of the developed flow chart on the application of BIM in the delivery of a project will minimize material waste. The model developed is recommended to be adopted for use in the South African construction industry for the delivery of projects with minimal wastage costs.

KEYWORDS: Building Information Modelling, Construction industry, Elimination, Material waste, Prevention.

DECLARATION

This dissertation, except where indicated in the text, is the candidate's own work and has not been submitted in part, or in whole, at any other University or University of Technology.

This research was conducted at the Durban University of Technology under the supervision of Dr A.O.Aiyetan.

SUBMITTED BY:

…………………………………..……

Ms A. Mall

APPROVED FOR FINAL SUBMISSION

……………………………….….….……

Dr A. O. AIYETAN: Supervisor

PhD: Construction Management

………………………………………………

F. C. FESTER: Head of Department

Construction Management and Quantity Surveying

Dedication

This thesis is dedicated to my family: my parents and my brother for their encouragement and motivation.

Acknowledgements

This has been an extremely wonderful yet challenging year. Several acknowledgements goes out to;

- All praise be to the Almighty, for providing to me the strength and perseverance throughout my study.
- Dr Ayodeji Aiyetan of DUT for his supervision.
- Razia Mall and Yunus Mall, my parents for their endless support.
- Muhammed Mall, My brother, for his encouragement, motivation, love and constant support throughout my study.
- Ferdinand Cedric Fester, Elke Helen Hefer and Anisha Pirthiraj from DUT for their advice, motivation and encouragement.
- My appreciation goes out to Deepak Singh from DUT and Sury Bisetty for assisting me at a very late stage in my research with an exceptional turnaround time.
- A special thanks to Avenal Jane Finlayson from the Alan Pittendrigh Library (Steve Biko Campus) at DUT for the helpful tips and research support.
- I would like to thank those who participated in the data gathering process of this study, in the form of completing the questionnaires.
- I would like to extend my gratitude to my friends and colleagues for their patience, confidence and moral support.

TABLE OF CONTENTS

ABSTRACT……………………………..……………………………………………….. II

DECLARATION…………………………..…………………….………..…………...IV

DEDICATION……………………………………..………………….……………….V

ACKNOWLEDGEMENTS…………………………..…………………….………… VI

TABLE OF CONTENTS……………………………..…………….………………..VII

LIST OF ACRONYMS…………..…………………..……………….…………..…….XII

LIST OF FIGURES……………………………..…………………..………………..XIII

LIST OF TABLES…………………………………..……………………..……………XIV

CHAPTER 1…………………..……………………..…………………..………………..1

INTRODUCTION………………………………..………………………………..…………..1

1.1. BACKGROUND………………………………………………………………………………………………1

1.2. PROBLEM STATEMENT……………………………………………………………………………………… 2

1.3. RESEARCH QUESTIONS……………………………………………………………………………………...3

1.4. AIM OF THE STUDY……………………………………………………………………………………….. 3

1.5. OBJECTIVES OF THE STUDY………………………………………………………………………………… 3

1.6. THEORETICAL FRAMEWORK……………………………………………………………………………… 4

1.8. CONCEPTUAL FRAMEWORK…………………………………………………………………………………5

1.9. METHODOLOGY……………………………………………………………………………………………6

1.10. LIMITATIONS……………………………………………………………………………………………… 6

1.11. ASSUMPTIONS……………………………………………………………………………………………… 7

1.12. SIGNIFICANCE OF STUDY……………………………………………………………………………… 7

1.11. STRUCTURE OF THE STUDY........ 8

CHAPTER 2........10

LITERATURE REVIEW........10

2.1. INTRODUCTION........ 10
2.2. BACKGROUND TO THE SOUTH AFRICAN CONSTRUCTION INDUSTRY........ 10
2.3. WASTE........ 11
2.3.1. WHAT IS WASTE........ 11
2.3.2. TYPES OF WASTE........ 12
2.3.3. MATERIAL WASTE........ 13
2.3.4. SOURCES OF MATERIAL WASTE........ 14
2.4. MOST COMMON WASTAGE OF MATERIALS........ 16
2.5. WHAT ARE THE CAUSES OF WASTE........ 18
2.6. ACTIONS FOR WASTE CONTROL RECOMMENDED IN PREVIOUS STUDIES........ 21
2.7. BENEFITS OF REDUCING MATERIAL WASTE........ 22
2.7.1. FINANCIAL BENEFITS........ 22
2.7.2. ENVIRONMENTAL BENEFITS........ 23
2.7.3. OTHER BENEFITS INCLUDE........ 23
2.8. BUILDING INFORMATION MODELLING (BIM)........ 24
2.8.1. WHAT IS BIM........ 24
2.8.2. DEFINITION OF BIM........ 24
2.8.3. THE AWARENESS LEVEL OF BIM........ 25
2.8.4. THE BUILDING INFORMATION MODEL........ 26
2.8.5. PRINCIPLES OF BIM........ 26
2.9. BIM ACROSS PROJECT LIFECYCLE STAGES........ 30
2.9.1. DESIGN........ 30
2.9.2. SUSTAINABLE DESIGN........ 30
2.10. BENEFITS OF BIM RELATED TO THE DESIGN PHASE OF A PROJECT........ 31
2.10.1. PROCUREMENT STAGE........ 32
2.10.2. CONSTRUCTION STAGE........ 32
2.11. BENEFITS OF BIM DURING THE CONSTRUCTION PHASE........ 32
2.12. BARRIERS TO THE IMPLEMENTATION OF BIM........ 33
2.13. APPLICATION OF BIM........ 36

2.14. The Influence of BIM on the South African Construction Industry..43
2.14.1. South Africa's BIM adoption..43
2.14.2. Advantages to the implementation of BIM in the South African construction industry............ 45
2.15. BIM and the Quantity Surveying Practice...45
2.15.1. The Role of a Quantity Surveyor...45
2.15.2. What does BIM mean for the Quantity Surveyor Profession..47
2.16. The use of BIM to aid in waste reduction... 47
2.16.1. BIM enhanced design waste minimisation...47
2.16.2. BIM improved demolition waste management.. 48
2.16.3. BIM improved coordination to reduce construction waste... 48
2.16.4. BIM improvement on site waste management.. 48
2.17. Potential to minimise waste using BIM.. 49
2.18. Conclusion...49

CHAPTER 3.. 50

RESEARCH METHODOLOGY...50

3.1. Introduction.. 50
3.2. Definition of Research...50
3.3. Types of research.. 50
3.4. Research esign..51
3.5. Research Paradigms.. 53
3.6. Research method...53
3.7. Primary and Secondary Sources of data..55
3.8. Population..55
3.9. Sampling.. 56
3.10. Sampling techniques..57
3.11. Sample selection...58
3.12. Research Instrument...59
3.13. Questionnaire design...59
3.14. Methods of data Analysis..60
3.15. Method of Administration of research instrument...60
3.16. Ethical issues.. 60
3.17. Limitations of the study...61

3.18. Validity and reliability........61
3.19. Summary........62

CHAPTER 4........63

DATA PRESENTATION AND DISCUSSION........63

4.1. Response to questionnaires........63
4.1.1. Response to phase one questionnaire........63
4.2. Demographic data of respondents to phase 1 questionnaire........64
4.3. Analysis of main question in phase 1 questionnaire........68
4.3.1. Reliability tests........69
4.4. Main questionnaire analysis........74
4.5. Testing of hypothese........93

CHAPTER 5........93

DEVELOPMENT OF A FLOWCHART........93

5.1. Introduction........93
5.2. application of BIM relative to material waste reduction........93
5.2.1. The BIM Process........93
5.3. The model flowchart........94
5.4. BIM flowchart Validation........97
5.5. BIM flowchart validation results........97

CHAPTER 6........104

CONCLUSIONS AND RECOMMENDATIONS........104

6.1. Introduction........104
6.1.1. Discussion on results of main study........104
6.1.2. Conclusions relative to findings........105
6.1.3. Conclusions relative to the main questionnaire........106
6.1.4. Conclusions relative to the hypotheses........108

6.2. CONCLUSIONS BASED ON VALIDATION QUESTIONNAIRE 107
6.3. RECOMMENDATIONS 108

REFERENCES 110

APPENDIX 1 : QUESTIONNAIRE ONE 125

APPENDIX 2 : QUESTIONNAIRE TWO 134

LIST OF ACRONYMS

2D – Two Dimensional: Visual representation of height and width

3D – Three Dimensional: image that has an appearance of depth and field

4D – Four Dimensional: 3D and time sequencing

5D – Five Dimensional: 4D and cost

AEC – Architectural, Engineering and Construction

ASAQS – Association of South African Quantity Surveyors

API - application programming interface

BIM – Building Information Modelling

BOQ’s – Bill of Quantities

CESSM - Collaborative Evaluation of Semantic Similarity Measures

CESA - Consulting Engineers South Africa

EPD - The Environmental Protection Department

GCA - green construction assessment

GPS - Global Positioning System

HVAC - heating, ventilation and air conditioning

IAI - International Alliance for Interoperability

IFC - Industry Foundation Classes

RFID - Radio-frequency identification

RICS - Royal Institution of Chartered Surveyors

SMM – Standard Method of Measurement

SACPCMP - South African Council for Project and Construction Management Professions

WRAP -Waste Resources Action Programme

LIST OF FIGURES

Figure 1.1 Research Methodology……………………………………………………………6
Figure 2.1 Applications of BIM 37
Figure 3.1 Research paradigm.. 51
Figure 4.1 Province of Origin.. 65
Figure 4.2 Gender distribution of respondents 65
Figure 4.3 Distribution of respondents' age 66
Figure 4.4: Category of respondents' qualification... 67
Figure 4.5 Respondents' status in their organisations 67
Figure 4.6 Number of respondents' years of experience 68
Figure: 5.1 Model for BIM waste reduction... 95
Figure 5.2 Gender distribution of respondents 98
Figure 5.3 Age of respondents' 99
Figure 5.4 Respondents' qualification 100

LIST OF TABLES

Table 4. 1 Response rate 63
Table 4. 2 Sector distribution of respondents 64
Table 4. 3 Cronbach's coefficient α value for all factor categories 69
Table 4. 4 Summary of factor analysis conducted for item analysis 70
Table 4. 5 Causes of Material Waste: Procurement factors 74
Table 4. 6 Causes of material waste: Operational factors 75
Table 4. 7 Causes of material waste: material storage and handling 76
Table 4. 8 Causes of material waste: Design and documentation 77
Table 4. 9 Material most prone to waste during construction 78
Table 4. 10 Factors as they contribute to material waste: Tile 79
Table 4. 11 Factors as they contribute to material waste: concrete 80
Table 4. 12 Factors as they contribute to material waste: reinforcement 81
Table 4. 13 Factors as they contribute to material waste: masonry 82
Table 4. 14 Factors as they contribute to material waste: timber 83
Table 4. 15 Factors as they contribute to material waste: pipes 84
Table 4. 16 Preventative measures of material waste 85
Table 4. 17 Benefits of BIM in the delivery of a project 86
Table 4. 18 Challenges of BIM relative to delivery of a project 88
Table 4. 19 Ranking of Factors' according to their MSs 90
Table 4. 20: Summary of p-value tests conducted on the hypotheses........ 93
Table 5. 1 Cronbach's coefficient α value for validation data 100
Table 5. 2 Summary of factor analysis conducted for item analysis 101
Table 5. 3 Respondents perspective on BIM stages 101

CHAPTER 1

INTRODUCTION

1.1. BACKGROUND

The largest portion of global pollution and waste generation stems from the construction industry (Ibrahim *et al.* 2010). According to Begum *et al*. (2009) and Ajayi (2016), the industry generates up to 30% of total material waste during construction.
Waste has been identified to be problematic in the construction industry. The waste generated during a construction project has an impact not only on the efficiency of the construction industry but also on the overall state of the economy of the country (Polat and Ballard, 2004). Designers usually argue that the generation of waste occurs on site during construction activities (Osmani *et al*. 2008 and Nagapan *et al*. 2012), although design flaws, complexities, and procurement contribute to waste generation (Osmani, 2012 and Kareem and Pandey 2013).
The UK Green Building Council (2013) states that 120 million tons of waste are generated by the UK construction industry. It has further been revealed by the Environment Agency (2003) and cited in Ajayi (2016) that 13 million tons of the materials delivered to sites have never been used. In addition, ineffective planning and control of materials on sites could lead to poor performance and undesirable project outcomes (Jayamathan and Rameezdeen, 2014).
Construction material is a great contribution to the cost of a construction project, therefore, material wastage has an adverse impact on construction cost, contractor's profit margin, construction duration, and can be a possible source of dispute among parties involved in the project (Enshassi *et al*. 2009 and Jayamathan and Rameezdeen, 2014). In order to lower the impact on the environment and on the opportunities of material waste by future generations, a change is required (CBS, PBL, Wageningen UR, 2012a)
Building Information Modelling (BIM) is an emerging new tool that is recently being implemented by the Architectural, Engineering, and Construction (AEC) industry (Succar, 2009). The BIM tool has been developed to assist the design, operation, and construction of a project by using computer-generated BIM tools (Azhar *et al.* 2008). Further, this aids architects, contractors, and engineers to have a visual image of what

is being built in a digital environment, permitting them to detect possible difficulties at any stage in the project life cycle.

Eastman (2008) cited in Agyekum (2012) states that wastage generated in a construction project can range up to 20% of the total material purchased for a project. Further, wastage affects the overall cost of the project that in turn decreases overall profit margins. Waste generation can be used as a measure of the level of competence of the contractor. Okorafor (2014) states that the performance of the South African construction industry with regard to quality, cost and project parameters of time is of a very low standard. The poor performance obstructs the delivery of infrastructure projects in South Africa and is generally caused by waste during the construction life cycle (Han *et al*. 2007). The primary concern is whether the professional team on construction sites in South Africa are acquainted with the amount of material wastage and the steps required remedying the solution. Okorafor (2014) argues that poor supervision of construction materials in the industry adversely affects the completion of construction projects that are unsatisfactory to the client due to late delivery, high cost, non-conforming work, and low profitability for those within the frequent construction supply chain.

1.2. PROBLEM STATEMENT

Paine and Dhir (2010) state that the construction industry generates the largest portion of waste and consumes over 50% of mineral resources. According to Defra (2013), the UK construction sites generate up to 44% of waste. Across the globe, it has been identified that approximately 35% of waste is generated from construction sites (Solís-Guzmán *et al*. 2009). The sustainability of an industry is dependent on how well it is able to manage waste generation during a project (Udawatta *et al*. 2015). The delivery of construction projects in South Africa is progressively becoming complex in terms of its design and construction technologies. Resources need to be managed efficiently so that construction projects can be delivered within the programme time and budget. The adoption of the same in South Africa is limited. There is a need for understanding the industry’s readiness for BIM adoption along with the possible process for BIM to aid in waste reduction during the construction stage of a project.

1.2.1. THE SUB PROBLEMS

- Construction professionals have limited knowledge of the types and causes of material wastes in construction as identified in the survey.
- BIM is relatively new in South Africa, therefore, there is a lack of awareness pertaining to the barriers associated with the implementation of BIM.
- Inadequate design in the form of, inter alia, incomplete and late information results in waste.

1.3. RESEARCH QUESTIONS

The following are the research questions:

1.5.1 What are the types and causes of material waste on construction sites?
1.5.2 How will BIM aid in waste minimisation?
1.5.3 What are the benefits of BIM in the delivery of a construction project?
1.5.4 What systems can be put in place to reduce material wastage?

1.4. AIM OF THE STUDY

The research aims to identify the causes of waste in the South African construction industry with the view to develop a Building Information Model (BIM) to reduce waste.

1.5. OBJECTIVES OF THE STUDY

The objectives of this study are to:

1.5.1 Identify and assess the types and causes of material waste on construction sites.
1.5.2. Identify and assess barriers to the successful application of BIM; to aid in waste minimisation in the South African construction industry.
1.5.3 Identify and assess the benefits of BIM relative to the delivery of a construction project.
1.5.4 Develop a flowchart based on BIM application for the minimisation of waste in the South African construction industry.

1.6. HYPOTHESES

The hypotheses to be tested are stated below:

Hypotheses one:

The null hypothesis states that:

Ho = There are significant causes of waste in construction.

The alternative hypothesis states that:

H1 = There are no significant causes of waste during construction processes on construction sites.

Hypotheses two:

The null hypothesis states that:

Ho = There are significant sources that contribute to waste in construction.

The alternative hypothesis states that:

H1 = There are no significant sources that contribute to waste during the construction of a project.

1.7. THEORETICAL FRAMEWORK

The adoption of a new technology requires new business processes and amended contractual relations. It is a complex phenomenon, and notably poorly researched in the construction industry (Huovinen, 2010). The literature reviewed in the following sections has the potential to provide a framework for this research. Within this section, the appropriateness of BIM theories is discussed.

1.7.1 BUILDING INFORMATION MODELLING (BIM) GOALS

BIM's goal is to obtain on time project delivery, with a decrease of rework during design and improved value from the consultants due to lesser faults and shorter lead times (Huovinen, 2010 and Zhang and Li, 2010).

1.7.2 BIM PLANNING

Ease of replications during construction, which therefore, enables better construction preparation and cash flow analysis (Porwal and Hewage, 2012).

1.7.3 DECISION MAKING

A better decision basis with trustable calculations and improved understanding between designers and end users (Porwal and Hewage, 2012).

1.7.4 CLASH DETECTION

Enable coordination, collaboration, and clash detection, between fragments of the design and construction process, through enhanced communication due to the shared model. This allows for the minimisation of mistakes and increases the quality of the design. It also lessens collisions and variations during the construction phase. (Ahankoob *et al.* 2012 and Volk *et al.* 2014).

1.8. CONCEPTUAL FRAMEWORK

It is of great importance for the professional team to identify how BIM can benefit them, as well as the organisation. This is relative to BIM goals which are project performance and can comprise items such as increasing quality, reducing the cost of changed orders, and reducing the schedule duration (Huovinen, 2010; Zhang and Li, 2010). Change tends to occur very slowly or not at all and obstacles seem impossible when business owners are unable to connect business BIM implementation to clear business goals (Olatunji and Sher, 2009). With correct implementation, BIM can provide many benefits to a project. BIM's value has been illustrated through well-planned projects that provide improved fabrication of projects due to predictable conditions, increased quality through effective analysis cycles, and improved efficiency by visualizing the planned construction schedule (Kovacic *et al.* 2013). There have also been a few examples where the project teams did not effectively plan the implementation of BIM and therefore, incurred delays due to missing information, increased costs, and little or no value (Porwal and Hewage, 2012). Therefore, the implementation of BIM requires extensive planning and necessary process modification by the project members in order to achieve the value from the available model information.

1.9. METHODOLOGY

In an attempt to achieve the objectives of the study, a quantitative approach will be adopted which will include a questionnaire survey.
The research methodology will involve the following, namely:

- Extensive literature review;
- Data collection by means of questionnaires;
- Analysis of the data collected;
- Validation of the findings from the analysed data to the literature; and
- Formulation of a flowchart;
- Formulation of effective recommendations

To achieve the objectives of the study, the research methodological approach as depicted in Figure 1.1 will be followed.

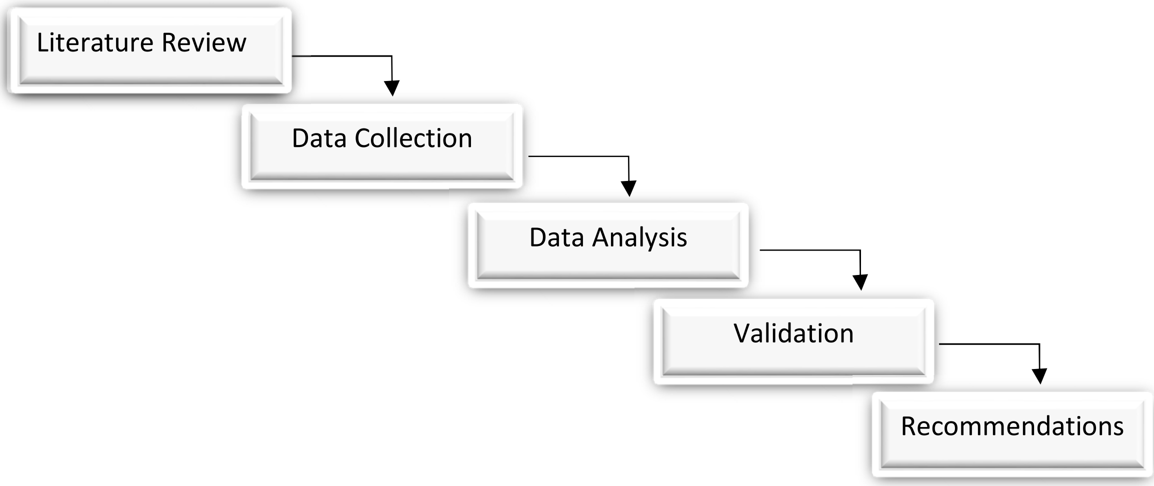


Figure 1.1 Research Methodology

1.10. LIMITATIONS

The study is subject to the following limitations:

- The study was conducted over a period of eight months;
- The sample is limited to contractors and subcontractors operating in South Africa;
- The study focuses on the impact of waste in the construction industry;

- The study focuses on the development of a Building Information Model (BIM) to assist a contractor during the construction stage of a project.

1.11. ASSUMPTIONS

It is assumed that the people/organisations to be approached to participate in the questionnaire and focus groups have sufficient knowledge and appropriate experience to provide quality data/responses required.
It is further assumed that the responses from the participants are honest and can be considered as accurate and reliable information.

1.12. SIGNIFICANCE OF STUDY

The significance of this study is to assist those involved in the construction industry in South Africa to minimise the wastage that is currently being generated by production, handling, transportation, and storage. This reduction will primarily be achieved through the implementation of BIM.
With regard to controlling waste, Tam *et al*. (2007) revealed there is a level of acceptability that can be reduced through an upgrade in the production system. Waste can be categorised into preventable waste where the cost of material waste is much higher than the actual cost to avoid waste, and non-preventative waste is where the initial amount required to reduce material wastage is higher than the economy produced.
According to Gaviln and Bernold (2011), wastage in the construction industry is a major source of all waste. Each year many tons of waste are generated due to demolition and construction activities (design and specifications). This increasing rate of waste has a great impact on the environment (carbon dioxide emissions), therefore, waste in the construction industry is a major concern. It has been found that different building materials can be applied to different construction project types, and the application of different building materials to the various projects can have an effect on the amount of waste generated. With correct construction methods and management tools, wastage can be reduced.
According to Lu and Yuan (2011), material wastage creates great concern for the environment and increases costs. Scherer and Schapke (2011) and Hjesleth (2010)

state that currently BIM is implemented throughout all stages in a project to achieve various performance targets. Many research studies investigating the use of BIM to reduce waste, such as waste minimisation through informed design decision making (O'Reilly, 2012), waste related resource efficiency (WRAP, 2013a), demolition waste management (Cheng and Ma, 2013), structural reinforcement of reinforcement reduction (Porwal and Hewage, 2012), waste reduction by improved coordination (Ahankoob et al. 2012) and on site waste management (Porwal and Hewage, 2012) have been carried out.

In addition, Hamil (2011) believes BIM has the potential to reduce construction waste during design and construction through the building design and construction industry. Moreover, the Waste Resources Action Programme (WRAP, 2013a) developed guidelines in achieving resource minimisation through the implementation of BIM, in an attempt to align it with lifecycle stages of building projects, from concept to handover. Although these guidelines focused on carbon reduction and energy efficiency, with little consideration to the context of reducing construction waste.

Research studies have been undertaken to reduce waste with the use of BIM, a different approach will be analysed to reduce waste during the construction phase of a project aimed at the contractor as waste is generated during the construction stage of a project.

1.11. STRUCTURE OF THE STUDY

Chapter One: Introduction – This chapter presents the background, problem statement, aim, objectives, research questions, theoretical and conceptual framework, limitations, assumptions, and chapter outline.

Chapter Two: Literature Review - This chapter reviews Waste and BIM – The types and causes of waste are explored. It further goes on to explore what is BIM and BIM in the construction industry.

Chapter Three: Research Methodology This chapter starts by defining what research is and the different types of researches that are conducted. It also discusses the research method employed, population and sample size determination, the process and procedures for administering the research instrument, the data collection, and analysis used, as well the justification of the research method used.

Chapter Four: Data analysis and Findings - This chapter discusses the research findings and data analysis of the study. The data obtained from the questionnaire survey is presented and analysed with tables and figures.

Chapter Five: Development of Flowchart – BIM Process, model flowchart, and a validation survey are carried out. This chapter is developed to address the fourth objective by providing a solution to reducing material waste during construction. A flowchart is proposed and a questionnaire is used to validate the flowchart. Results of the validation questionnaire are analysed and discussed.

Chapter Six: Conclusions and recommendations – Conclusions are drawn based upon data analysis, linking them to the problem statement, and objectives of the subject under investigation. Further recommendations for phase one questionnaire; recommendations for validation of the flowchart and recommendation for further studies are addressed.

CHAPTER 2

LITERATURE REVIEW

2.1. INTRODUCTION

The literature reviewed in this chapter investigates the relationship between construction waste and Building Information Modelling (BIM). It reviews the literature and focuses on three areas: waste, BIM and the relationship between waste and BIM. In the first section on waste, definitions and types of waste are defined. In addition, the sources and causes of material waste are identified, as well as an assessment on current waste practices is examined.

2.2. BACKGROUND TO THE SOUTH AFRICAN CONSTRUCTION INDUSTRY

The South African construction industry is underachieving in aspects such as efficiency and quality and requires a radical improvement to deliver its projects (Okorafor, 2012). It was further concluded that the South African construction industry's reputation is much lower in terms of productivity as compared to other sectors of the economy such as manufacturing. According to Booyens *et al.* (2013), research undertaken in the construction industry of South Africa signifies the industry has the ability to deliver complex and innovative projects at times.

Major enhancements to delivery will require experts to put their present practices under review and improvement (Okorafor, 2012). According to Lawal and Wahab (2011), the construction industry is said to be one of the most wasteful sectors. It is estimated that 15% of materials, 40% of energy and 12% to 16% of fresh water purchased by the construction industry ends up as waste. It is essential to improve construction waste management in terms of sustainability and economic quality (Okorafor, 2014). In order to achieve this waste reduction, measures need to be undertaken in all stages of the construction process. A research undertaken by Augustine (2011) identified that for over two decades the South African construction industry has been undergoing a recession. The decline in capital investment and activity in infrastructure delivery in the late 1970s and lack of efficiency in construction processes have all contributed to this.

According to research conducted by Lawal and Wahab (2011) and supported by Okorafor (2012), waste generated in construction is a burden to the client, as waste is unforeseen additional cost. Okorafor (2012) further states that for contractors this may be a problem as it leads to profit loss and in turn contributes to bankruptcy.

Due to inadequate control on site, great quantities of materials are wasted on site. The responsibility of the correct management of waste on a construction project is imperative in terms of sustainability (Okorafor, 2012).

A study conducted by Lawal and Wahab (2011), states that the cost of materials in a construction project is between 55% and 60%. In order to reduce the cost of a construction project, there should be maximum material control on a construction site. According to Poon (2007), the environment and cost implications of construction activities are found to have high energy and resource consumption. Furthermore, it is reported that the construction sector generates unreasonable levels of material waste by figures much larger than what is allowed for in the tender documents.

2.3. WASTE

2.3.1. What is waste?

According to Augustine (2011), the unnecessary depletion of natural resources, environmental damage, and unnecessary costs are known as waste. This can be avoided by improved waste ethics.

The United Nation Organisation (Morrison *et al*. 2004) defines waste as any matter prescribed to be waste under national legislation, any material listed as waste in appropriate schedules and in general, any surplus or reject material that is no longer useful and which is to be disposed of.

Ibn-Homaid (2002) indicates that 50 - 60% of the project cost depends on materials and 80% is controlled by material related activities based on expert estimates and historical data analysis. It is evident from the figures that accomplishing high construction productivity and safety is dependent on the correct management of material and construction waste. Material waste is defined by Mahesh (2011) as the difference between the value of materials delivered and accepted on site and those properly used as specified and accurately measured in the work, after deducting the cost saving of substituted materials transferred elsewhere, in which unnecessary cost and time may be incurred by material wastage.

The Environmental Protection Department (EPD) of Hong Kong (2000) and Joro (2015) defines waste as unwanted materials created during construction activities, including defect structures and materials, extra ordered materials that are now surplus to supplies, and materials that have been used and thrown away.

Kulatunga *et al*. (2006) define construction waste based on other sources. Therefore, they have indicated that: waste is defined as the difference between the purchased materials and those used in a project. According to Hong Kong Polytechnic (1993), construction waste is the by-product generated and removed during construction, renovation and demolition places on construction sites. Further, construction waste has been defined as building and site improvement materials and other solid waste resulting from construction activities, renovation or repair work.

According to Hosseini *et al.* (2012) and Fernández-Solis and Rybkowski, (2015), a broader definition of waste is to include not only material waste, but also waste produced in a construction project such as waiting times, transportation times, and setup time.

2.3.2. Types of waste

According to Okorafor (2014), there are three categories relating to construction waste: labour, machinery and material waste.

Formoso *et al.* (2002) state that waste is an inefficiency in labour, equipment, and capital. Further Al-Moghany (2006); Patel and Vyas (2011) and Nagapan *et al*. (2012) classify waste based on the following categories:

- Overproduction waste: waste that relates to the production of a greater quantity than required. A case of this sort of waste is the overproduction of concrete that cannot be utilized on time
- Transportation waste: relates to the movement of materials on site internally. This type of waste can be caused by excessive handling. It is related to a poor layout and a lack of planning on material flows.
- Substitution waste: Waste is as a result of substituting a material for a more expensive one.

- Waiting time: relates to the time delay caused by the lack of synchronisation and material flows
- Processing waste: Relates to the nature of the processing activities, which can be avoided only by adopting a different construction method.
- Inventories: excessive or unnecessary inventories lead to material waste (losses, vandalism, theft, and deterioration).
- Production of flawed products: this occurs when the final product does not suit the quality specified, therefore, leading to rework.
- Material waste: relates to materials that have been purchased for a specific task are either too much in quantity, of the incorrect specification, placed incorrectly, damaged due to standing time or degraded in storage.
- Others: waste that is different from those previously mentioned, such as theft, inclement weather, damage, and accidents.

2.3.3. Material waste

Yahya and Boussabaine (2006) state that material waste refers to materials from construction sites that cannot be used for its specified purpose and has to be disposed of. Further, Kareem and Pandey (2013) state that Material waste can be defined as any material that does not come from the earth, materials that need to be carted away from the construction site or used other than for its intended purpose due to non-compliance with specifications, damage or excess (Okorafor, 2014).

Agyekum (2012) and Okorafor (2014) define material waste as materials from construction sites that are unsuitable for its specified purpose and has to be discarded for various reasons. Furthermore, Agyekum (2012) states that material waste is any material apart from natural materials, which needs to be transported elsewhere from the construction site or used on the site itself other than for the intended use for the project due to damage, excess, non-use or which cannot be used due to non-compliance with the specifications, or which is a by-product of the construction process.

According to Oyedele *et al.* (2013), material waste refers to materials that are unwanted after the purpose for which it was required is met, therefore, they are meant to be taken off site. This could be various materials bought for a variety of construction activities to those generated on site such as demolished and excavated materials.

2.3.4. Sources of material waste

Construction waste comes from refurbishment, repair work, and construction. Activities that take place during the construction and design process that takes up both effort and time adds to the generation of waste.

2.3.4.1. Natural Waste

There is a certain limit to which material waste can be prevented, further than that, any action that is used to prevent waste will not be feasible because the cost of saving will exceed the value of the materials saved, therefore natural waste is allowed for at the tender stage (Nagapan *et al.* 2012). According to Memon *et al*. (2014), there are two types of waste: direct waste related to the physical waste of materials during construction, in specific, the debris; and indirect waste, related to monetary waste and the use of materials in excess of what is required.

2.3.4.2. Direct waste

Waste that can be prevented and involves the actual loss/removal and replacement of material is known as direct waste (Nagapan *et al*. 2012).

Direct waste does not end up in the cost of material but occurs with the cost of disposing and removing. Therefore, by preventing direct waste, financial benefits can also be obtained. Direct waste can occur at any point in time in the construction process prior to delivery of material and after the use of materials in the project (Nagapan *et al*. 2012). Memon *et al*. (2014) argue that direct waste can be a result of:

I. waste due to overproduction: this is related to the production of a larger quantity than required or much earlier than required. This may cause waste of materials, equipment or time.

II. waste in source and internal transportation: poor storage conditions of materials and the passage and equipment of inadequate internal transportation;

III. waste during the construction phase: materials knocked down or discarded during the application of the material;

IV. waste as a result of replacement: financial waste caused by the replacement of one type of material by another of greater cost, the execution of a task by an over-skilled worker, or the use of very sophisticated equipment where a much simpler one would suffice;

V. waste that spills over onto other teams: due to a lack of efficient relationships in the construction phases, reworking and delays are caused which have an effect on other teams; and

VI. other examples such as theft, vandalism, and accidents are included in waste according to its nature.

2.3.4.3. Indirect waste

According to Nagapan *et al*. (2012), there is indirect waste when materials are not physically lost, therefore, causing only a monetary loss. It is further stated that indirect waste is created by the substitution of materials, caused by over-allocation, where materials are applied in a greater quantity of those indicated or not clearly explained on contract documents, from errors and waste caused by negligence. However, Memon *et al*. (2014) indicated indirect waste is identified by the overuse of materials in construction, for example:

I. over-allocation of materials are applied in greater quantities than indicated or where quantities are not clearly defined in contract documents;

II. materials used in addition to what is required is classified as negligence by the contractor. Direct waste relates to materials damaged during construction or resting period of materials and cannot be reused.

2.4. MOST COMMON WASTAGE OF MATERIALS

According to Al-Moghany (2006); Nagapan *et al*. (2012) and Kareem and Pandey (2013), material waste on sites includes tile, concrete, reinforcement, masonry, timber, pipes.

2.4.1. Tile

A source of waste on tiles is the need to cut on average, 27.4 % of the pieces on walls and 35% of pieces on floors. The main causes of cuts are the in integration between architectural and structural design and modular coordination. In some sites, it has been identified that poor planning in the distribution of materials contributes to waste. In most cases, an entire package of tiles is sent out to installation places, based on demand by work crews. Pieces are cut and left as debris when the work crew moves to the next task (Adewuyi and Otali, 2013).

2.4.2. Concrete

According to Napier (2012), there are two types of mixed concrete, concrete site mix, and concrete ready mix. Concreting is a major building process. Concrete is the most widely used material for superstructure and substructure of buildings (Tam *et al*. 2007). According to Poon (2007), on average, 3-5% of material goes to waste and most of it is due to over ordering, poor quality or broken formwork and rework due to poor concrete placement quality. Shen *et al*. (2003) state that wastage results from the mismatch between the quantity of concrete ordered and that required in the case of ready-mix concrete supply. A contractor may not know the necessary quantity required due to poor planning. This leads to over-ordering and over-filling of the means of transport and formwork. If formwork is overfilled, skimming is necessary, i.e., levelling of the concrete poured into the formwork (Kareem and Pandey, 2013).

2.4.3. Reinforcement

Reinforcement bars are a common material used in buildings (Agyekum, 2012). The control of reinforcement on construction sites is difficult because it is cumbersome to handle due to its shape and weight (Adewuyi and Otali, 2013). The main cause of wastage of reinforcement is as a result of cutting, damages during storage, and rusting. Adewuyi and Otali (2013) further state that the reason for likely waste of reinforcement is damage to mesh and bars, loss in mud, and excess use of tying wire. According to Agyekum (2012), reinforcement waste can be identified by three main reasons:

I. Some bars may be extremely large in diameter due to fabrication problem and trespassing.
II. Structural design that is poor in terms of standardization and detailing, causing waste due to the non-optimised cutting of bars.
III. Short unstable pieces that are produced when bars are cut.

2.4.4. Masonry

Bricks are the most used walling materials. The main cause of brick waste is cutting for various shapes. Unpacked supply may increase wastage of broken bricks because of the fragile nature of materials. Unused bricks left on site may ultimately end up in the trash skip (Agyekum, 2012). According to Al-Moghany (2006), at most poorly performing sites, the combination of material waste causes are related to the delivery of materials, such as the lack of control in the number of bricks actually delivered and the damage of bricks whilst in storage.

2.4.5. Timber (formwork)

Timber is a major contributor to construction waste, accounting for 30% of all waste identified in sites in Hong Kong. Timber possesses several advantages that make it a popular construction material (Agyekum, 2012). It is affordable, light in weight, and has a high load-bearing capacity. It is also pliable and can be readily cut and it can be shaped for producing any distinct forms of concrete elements. Although its low durability and reusability make it a material of high wastage. The main causes of wastage are the natural deterioration resulting from usage and cutting waste. Both are difficult to avoid (Agyekum, 2012). Most of the timber waste is generated from formwork with a smaller quantity resulting from cutting timber for internal finishing and fittings. In the case of formwork, most of the timber materials delivered to the site will eventually be discarded as waste (100 % wastage) after several uses. According to a survey undertaken by Al-Moghany (2006), the results show that contractors would be required to use a new set of timber formwork after every 8-15 floor cycles as dictated by the building design.

2.4.6. Pipes and wires

Keeping a record of electric wires, electric pipes and hydraulic and sewerage pipes that is waste is a complex task (Nagapan *et al*. 2012). In most construction projects, electrical and plumbing services are generally subcontracted, and a specialised subcontractor sometimes provides the materials (Nagapan *et al.* 2012). As this activity tends to be very fragmented on site, such materials are often moved into and out of site. Another difficulty related to the measurement of waste is the fact that both plumbing and electrical service designs are often poorly detailed, and many changes in the routings of pipes are made during the installation (Kareem and Pandey 2013). A major waste contribution for these materials is the short unusable pieces produced when pipes are cut and poor planning in the distribution of materials which does not encourage cutting optimization (Agyekum, 2012).

2.5. WHAT ARE THE CAUSES OF WASTE

A study of attitudes toward the causes of construction waste by contractors and architects indicates that construction waste is related to construction activities such as procurement, material handling, and design and site operation. (Osmani et al. 2006). Previous studies on construction waste (Lu and Yuan, 2011; Tam *et al*. 2007; Urio and Brent, 2006; Osmani et al. 2008 and Azis *et al*. 2012) reveal the causes of construction waste can rise from all phases of the construction lifestyle of which procurement, operational, material handling, design and residual waste are considered to be the major processes.

2.5.1. Procurement Waste

Procurement procedures is essential to deliver a project on time, on budget and to a high quality (CIOB, 2010). During the construction process, many projects face procurement problems (Lu and Yuan, 2011; Tam *et al.* 2007; Gamage *et al*. 2009 and Nagapan *et al*. 2012) these include; packaging materials, ordering errors, use of low quantity materials and incorrect quantity estimation (Gamage *et al*, 2009; Wong *et al*. 2008). According to Osmani, (2013), the three main causes of procurement waste relate to contract and tender arrangements. These include errors such as:

(i) Incomplete tender documents at the commence of construction: Specifications and detailing under development; incomplete information from the design team; not sufficient design and detailed information; disjointed information release schedule

(ii) Limited architect's input: insufficient waste minimisation recommendations in the tender documentation

(iii) Not entrenched in the tender documentation: No implementation and target setting guidance; lack of waste minimisation tender agreements; no financial allocation of waste in the Bill of Quantities (BOQ).

2.5.2. Operational / Construction Waste

Operational waste relates to the activities occurring on site which causes accidents, the use of incorrect materials, poor site management and supervision, errors by tradesmen, poor site conditions, inadequate knowledge and poor workmanship (Nagapan *et al.* (2012); Kofoworola and Gheewala, 2009; Wahab and Lawal, 2011). Waste during construction stage is classified into eight categories. These are material procurement, material storage, design changes and rework, site operation and residual, transit, material handling on site management and planning (Osmani et al. 2008; Osmani, 2013 and Al-Hajj and Hamani, 2011). Although Al-Hajj and Hamani, (2011) state that culturally related issues can also be a source of waste, i.e. lack of waste prevention training, lack of awareness and lack of incentives to reduce waste. Osmani *et al.* (2008) states that human error is the main cause of waste during construction. Labour on site has direct contact with materials being used and wasted, thereby playing a major source in waste generation.

2.5.3. Material Handling Waste

Material handling occurs mostly once the material is on site, this involves incorrect storage methods and damage during transportation on site (Urio and Brent, 2006; Kofoworola and Gheewala, 2009; Lu *et al.* 2011 and Patel and Vyas, 2011).

2.5.4. Design

Design waste generally occurs before construction. An error in the contract document, poor coordination during the design stage, complexities in design, poor project coordination, design changes, and unclear specification (Gamage *et al*. 2009), therefore, a substantial percentage of waste is caused by errors that occur in the design stages. According to Innes (2004), 33% of waste may be influenced by design concepts. WRAP (2007a) states that there is a bigger opportunity to reduce and avoid waste at the design stage than later stages. This is due to the reason that vital design changes relating to material shape, size and intricate designs are likely to have a greater impact on waste.

Osmani (2013) identifies that incorrect work on standard dimensions and unawareness of the causes of material waste due to design changes are substantial design waste producers. The generation of construction waste during design is a result of inadequate communication and coordination, therefore, resulting in redundant on site off cuts (WRAP, 2007a). According to Babatunde (2012), material waste off cuts are a great source of waste during construction while Al-Hajj and Hamani (2011) argue that material off cuts due to design changes are out of the contractor's control but that of designers. Osmani (2013) states that there is limited understanding by designers on the causes of design waste.

2.5.5. Residual

Residual waste stems from the design and includes waste from uneconomical shapes, off cuts and the incorrect process of application (Patel and Vyas, 2011).

According to Mansi (2012), the following are causes of material waste on a construction site:

I. Lack of awareness in the industry - the greatest barrier in the industry is the limited awareness amongst construction professionals with regard to waste management techniques and approaches. The majority of the waste that is produced during the construction lifecycle is due to poor handling techniques.
II. Lack of proper training and education - lack of professional institutes and training institutes in the country that could significantly raise awareness among the clients and contractors about the economic benefits.

III. Lack of interest from clients - another main reason is the lack of importance given by clients in imposing waste reduction and management practices into the construction projects. Clients do not support those activities, which do not offer tangible benefits to them. Potential of significant cost saving is not yet voluntarily implemented in projects and timing is given major preference.

IV. Lack of skilled labour – the major portion of construction labour in the industry is unskilled. Due to which correct waste handling techniques are not adopted. Therefore, it is very important that contractors develop awareness and skills in the labour force that is mostly illiterate.

V. Lack of market competition - the barriers mentioned fragments the industry as a whole and fails to extract evident aspects. This leads to lack of competition among contractors, for example, if one contractor makes good cost savings from a project and increases their profit margins, this should then eventually incentivise other contractors to get involved with waste minimization and management techniques. However, mostly from a contractor's viewpoint, taking up waste minimization management is more of a forecast where risks are associated with the contractor to bear the cost implications. This will become well known only after taking the project initiative and then benefiting from them.

2.6. ACTIONS FOR WASTE CONTROL RECOMMENDED IN PREVIOUS STUDIES

According to Harris (2001) and Azis *et al*. (2012), construction companies spend a great amount of time controlling plant and labour issues than they do controlling materials. Harris (2001) and Azis *et al.* (2012) suggest that the following systems can be applied in materials control, once a reliable storekeeper, who has adequate clerical experience and is well skilled in stores control has been employed:

- Maintaining a well-continued accounting framework, physically or utilize a PC framework
- Double sign conveyance notes, especially for ready mix concrete.
- Keeping a well laid out site with satisfactory storage room and a space for development.
- Insisting on palletised delivery of brick.

- Checking all deliveries thoroughly against notes as the goods are being unloaded.

Control procedures and principles to be implemented in the pursuit of waste reduction recommended by Haile and Hartono (2017);

- Notification to providers of the development procedure prerequisites;
- Implementation of ordering material just before it will be used and guarantees that the materials will be delivered on site as when they are required, thereby avoiding damage while the materials are stored on site as well as any additional relocation of materials;
- Ensure proper material sizes are purchased to reduce cutting, and appropriate quantities are purchased to avoid having extra left over;
- Scrutinise materials once they enter the site in order to reduce the losses due to poor packaging or damage due to transportation
- Ensure the use of appropriate vehicles or delivery service plants for the removal of the materials from the storage area to the workplace in order to incur the minimum damage;
- Avoid double handling; the area of unloading should also be the final position of stacking; and
- Select easy access areas for cutting and storage so reusable pieces can easily be identified.

2.7. BENEFITS OF REDUCING MATERIAL WASTE

2.7.1. Financial benefits

Agyekum (2012) and Jayamathan and Rameezdeen (2014) state that reducing material waste can have great financial benefits and in some cases can even save cost on time. Financial benefits include:

- Reduced disposal cost of waste materials,
- Decreased transportation cost for wasted materials (Less transport due to less material waste) this includes transportation to and from the site and disposal, and

- Increased returns can be achieved by selling waste materials to be reused and recycled.

2.7.2. Environmental Benefits

According to Agyekum (2012) and Lu and Tam (2013), waste minimisation can provide environmental benefits, which are important due to the alarming situations of material waste on construction sites. These environmental benefits are:

- Efficient use of waste generated,
- Minimise the effects on the environment as a result of disposal, e.g. pollution and noise,
- Reduced quantity of waste generated and
- Reduced transportation of waste to be disposed of (therefore less noise, vehicle pollution and energy used).

2.7.3. Other benefits include (Yunpeng (2011) and Lihua *et al. (*2013)).

- Increased work efficiency,
- Increased image of the company, and
- Increased site safety.

Furthermore, Lihua *et al.* (2013) state benefits could be improved if green buildings and sustainable designs are considered at the same time, these include:

- Indirect benefits (healthier to use, psychological advantage, enhanced company image) and
- Direct benefits (economy on fuel bills, market advantage, lower long-term exposure to environmental or health problems, greater productivity of workplace).

There are significant contributions towards material waste during construction. In this chapter, the focus was on the types of material waste that comprises tile, concrete, reinforcement, masonry, timber, pipes, and wires. Further, the causes of material waste during construction were identified and these included procurement waste, operational waste, material handling waste, design waste and residual waste. Based on this BIM can be used as a tool to mitigate waste.

2.8. BUILDING INFORMATION MODELLING (BIM)

2.8.1. What is BIM?

According to Eastman *et al.* (2011), Building Information Modelling (BIM) is known as a virtual representation of the functional and physical characteristics of a project in the Architectural, Engineering, and Construction (AEC) industry. Further, BIM's primary goal is to improve collaboration and interoperability among the stakeholders of the project during the construction process.

BIM is continuously developing as a concept because the boundaries of its capabilities continue to expand as technological advances are made (Johannides *et al*. 2012).

The basic feature of BIM is the three dimensional (3D) visualisation although, it is more than the elaborated 3D drawings, and it is more than an electronic version of the project document. BIM is about information use, reuse, and exchange (Parvan, 2012).

2.8.2. Definition of BIM

Ahmad *et al*. (2012) and the State of Ohio, (2012) explain that the BIM acronym can refer to:

(i) Product – Building information model, an organised dataset describing a building for simulation, automation, and presentation;

(ii) A building process or activity- Building information modelling, the act of creating, scheduling and organisation; and

(iii) A system – Building information management, the business structure of work and communication that increases quality and efficiency like preservation, querying the model, maintaining, and organisation.

Eastman *et al.* (2011) state and it is agreed by Khosrowshahi and Arayici (2012) and Abbasnejad and Moud (2013) that BIM is defined differently by organisations due to perceptions, background, and experiences.

BIM has been viewed as an integrative process driven by 3D computable, digitized images linked to the internet-based building cost information services according to Smith *et al.* (2004). Although Howard and Bjork (2008) highlight that by saying, BIM has the ability to transfer information digitally throughout the construction process.

Dzambazova *et al*. (2009) define BIM differently as the management of information through the lifecycle of a design process from the design stage through to the construction completion of a project. In the BIM handbook, Eastman *et al*. (2011) state that BIM is more of a human activity, i.e. modelling, instead of seeing it as an object-oriented approach or being a particular programme.

According to BuildingSmart (2012), BIM is defined as a 3D object that can be visualised, has rich data and structured information. Building Information Modelling is a process of representing building and infrastructure over its whole life cycle from planning, design, construction, operations, maintenance, and recycling. BIM provides a framework for collaboration, a multi-disciplinary environment that brings together all the parties that design, construct and operate a facility, suggesting a new model of procurement, Integrated Project Delivery (IPD).

According to Eastman *et al*. (2011), BIM is viewed as a technology that constructs digitally one or more accurate virtual models of a building to support design through its phases for better analysis and control than a manual process.

According to Yan and Damin (2008) and agreed by Azhar (2011), BIM is a new powerful technology which combines all the functions of a 3D computer-aided design (CAD) and constructs an accurate virtual model of the building.

Autodesk (2011) defines Building Information Modelling (BIM) as an intelligent model-based process that provides insight for creating and managing building and infrastructure projects faster, more economically, and with less environmental impact.

2.8.3. The awareness level of BIM

According to many literature related to BIM, it has been found that there is a demand for understanding and improved knowledge of BIM across the industry. According to Mitchell and Lambert (2013), the limited knowledge regarding BIM has led to a slow uptake of this tool and ineffective management of adoption.

It has been concluded that there is a lack of awareness of BIM and its benefits in the construction industry. Furthermore, there is a lack of value of BIM from a financial perspective. Particularly a lack of understanding of BIM and its practical applications throughout the construction project. There also seems to be a lack of technical skills that professionals require to use the software, as well as poor knowledge on the implementation of the BIM software to assist in the construction process (Elmualim and Glider (2013); Arayici *et al.* (2009); Khosrowshahi and Arayici (2012)).

2.8.4. The Building Information Model

Eastman et al. (2008) state that BIM is a collective model, where various models from all disciplines are combined. According to the BIM handbook, the BIM model is characterised by the following;

- Building Components – these are represented with intelligent digital representations (objects) that 'Know" what they are and can be associated with computable graphic data attributes and parametric rules.
- Components that include data that describe how they behave – as needed for analysis and work processes e.g. Specification and take off.
- Consistent and non-redundant data – Such that changes to component data are represented in all views of that component
- Co-Ordinated data – All views of the model is represented in a synchronised way (Eastman *et al.* 2008).

2.8.5. Principles of BIM

According to Keller (2005), since the establishment, in September 1995, The International Alliance for Interoperability (IAI) has published three releases of the Industry Foundation Classes (IFC). This was the start for setting the standards for data modelling. The type of standards that define the interoperability of object-based data modelling for the AEC industry. Each member that is involved in the construction project should be able to access a building model to supply data to the engineers and architects in a 3D space. Interoperability involves the exchange of information among applications and platforms that serve the building community throughout the life cycle of facilities (Lindblad, 2013).

Although there are programmes used across the construction industry, there is now a platform to transfer data to something that could be readily accessible to others in the industry, this platform is known as the 3D model (Wong *et al.* 2012).

BIM is a new design methodology and is defined by Autodesk (2004) as a building design and documentation methodology characterised by the creation and use of co-ordination, internally consistent computable information about a building project during design and construction. BIM integrates the use of 3D visualisation techniques with a data-driven, object-based imaging as a tool by all facets of the industry (Holness, 2006).

The programming technique differs from the current practice of designs being put on paper with engineers by designing the structure and supporting elements of the building (Cheng and ma, 2013). Once the designed documents are completed, a 3D model can be generated, showing walk throughs and provide a 3D rendering of spatial relationships (Ahankoob *et al.* 2012). Further, the tools are useful and can assist those who are unable to visualise 3D space from 2D drawings.

According to Seaman (2006), BIM is used for estimating the cost of materials and the ability to manage the cost of the building. Material suppliers can directly input their data and cost into the BIM programme and with the relevant cost factors and from this, a solid cost estimate can be created. Changes can be easily adjusted to any of the products, by creating new estimates and building costs. Once changes are made, they can be assignable to the architect and engineers. This can determine responsibilities for payment or changed order (Seaman, 2006).

According to Lindblad (2013), Building information modelling has greater benefits over the general 2D technology. By improving the management of information in construction projects, a better work process can be adopted. BIM can also be used to improve productivity on smaller projects.

2.8.5.1. Improving productivity due to easy access to information

According to Barlish *et al*. (2012), BIM software allows ease of access to information for all members of the team, as well as easy linkage and retrieval of information when required. The system is designed to function off a server that can be accessed by the various parties involved in the project. Barlish *et al*. (2012) identified the advantage as each user has access to up to date information, which reduces the risk of design changes being missed by other parties. All parties involved are automatically informed by the system of changes. Lindblad (2013), states an advantage of BIM being available online, is the distance between the team members involved in a project is no longer a problem as it, therefore, allows the design team, employer, and construction site to be situated on different continents.

2.8.5.2. Improved visualisation

Ahankoob *et al*. (2012) states that BIM is a cohesive workflow built on reliable and co-ordinated information about a project from design to construction. BIM allows engineers and architects to use digital design information to analyse, simulate and visualise their projects, cost performance and appearance, therefore, increasing the quality of work (Ahankoob *et al*. 2012).The prediction of the way in which an architectural design influences neighbours, visitors, occupants and how these will interact and react with the building is important to the design.

2.8.5.3. Increased speed of delivery

According to Lindblad (2013), the entire system is linked, the purpose of the software is to function as one single unit and is available to all parties of the project. This includes the speed of documentation available to members involved in the project, to design changes, quantify, and schedule a project.

2.8.5.4. Early Clash detection

The BIM model of various disciplines is brought together and checked for geometrical design irregularities. Areas in which the models of various disciplines overlap each other when combined are detected and can then be rectified. Furthermore, visual errors which can lead to poor esthetical quality can be identified and rectified (Eastman, *et al*. 2008 and Volk *et al*. 2014).

2.8.5.5. Reduced Cost

Giel and Issa, (2013) state that the reduction in cost will be in the form of time spent in coordination and designing of the documentation, reduced standing time, defect waste, over production waste, and material waste to name a few. From the above, it can be seen that BIM offers several benefits and advantages to the users. In the past, several studies found ways to reduce waste with site procedures, but have not looked at reducing waste with the application of BIM.

Eastman *et al.* (2008; 2011) describe BIM as an innovative way to design, preconstruction, construction and post-construction of a building as opposed to the traditional drawing method.

I. Preconstruction benefits to the client (Eastman *et al.* 2011)
   - The concept, design and feasibility benefits
   - Improved building performance and benefits
   - Improved collaboration using integrated project delivery

II. Design benefits (Dowsett and Harty, 2013)
   - Earlier and more precise visualisation of design
   - Automation low level corrections when changes are made to design
   - The earlier collaboration of multiple design disciplines
   - Generation of accurate and consistent 2D drawings at any phase of the design
   - Easy verification of consistency to the design intent
   - Improvement of energy efficiency and sustainability
   - Extraction of cost estimates during the design stage

III. Construction and fabrication benefits (Barlish *et al.* 2011)
   - Fast updates to design changes
   - Better application of lean construction methods
   - Synchronization of procurement with design and construction
   - Detection of design errors and omissions prior to construction
   - Use of design model as a foundation for fabricated components
   - Synchronization of design and construction planning

IV. Post construction benefits (Nguyen, 2016)
- Improved supervision and operation of facilities
- Enhanced commissioning and handover of facility information
- Integration with facility operation and management systems.

2.9. BIM ACROSS PROJECT LIFECYCLE STAGES

BIM is a computer database model containing information regarding building design, procurement, construction and maintenance (Alwisy *et al.* 2012).

2.9.1. Design

Design is responsible for defining the success of a project through its lifecycle. According to Eastman (2009), BIM applications assist in capturing the requirements of the client, such as visual impact, budgets, building functions and other more common factors. BIM's current use includes multi-level cost estimation, early design life cycle analysis, spatial planning, site selection and site planning (Cheung et al. 2008; Isikdag *et al.* 2008; Lee *et al.* 2008).

It has been identified that BIM tools and techniques are currently being used to assist design related activities (Love et al. 2011; Lee et al. 2008; Nassar, 2010; Alwisy *et al.* 2012; Rekola *et al.* 2010):

- Assessment of sustainable issues (e.g. carbon, energy, and material),
- Enable prefabrication of components prior to construction,
- Estimate the cost of assisting the decision making of design usability and constructability, and
- Communicate and coordinate the design of multiple disciplines and identify design conflicts (Clash detection) prior to construction.

2.9.2. Sustainable Design

There is a greater emphasis placed on sustainable design by clients demanding material efficiency, waste reduction, reduced carbon emissions and less water usage (Malkin, 2010). According to Azhar and Brown (2009), these demands can be achieved with BIM.

Wong *et al.* (2012), and Mah *et al.* (2011), state that the BIM technique in construction projects for material, waste, carbon, and water focuses on the construction phase.

Material resource efficiency can be achieved with BIM through accurate material quantities and effective scheduling (Hardin, 2009). According to Razavi and Haas (2010), BIM is equipped with several techniques such as Global Positioning System (GPS) and Radio-frequency identification (RFID), and Enterprise Resource Planning, therefore, lesser materials will be damaged before its use due to fewer materials being stored on site, while ensuring the correct amount of materials are stored on site when needed (Cidik *et al*. 2014).

2.10. BENEFITS OF BIM RELATED TO THE DESIGN PHASE OF A PROJECT

There is an urgent need for the construction industry to use technology to integrate processes of design and construction. A questionnaire survey was carried out to ascertain the change in the construction industry, concerning innovation design, supervision and the application of BIM (Elmualim and Glider, 2013). The questionnaire response aimed at the United Kingdom (UK) with responses also representing India, Europe, Russia, South Africa, China, United States of America (USA), Australia, United Arab Emirates (UAE) and Malaysia. The responses to the questionnaire were from various sectors across the construction industry such as engineers, designers, managers, architects, and surveyors. A result of this survey indicated a consensus by most respondents that the design team was responsible for design management in an organisation and in a way that BIM technologies provide a new paradigm shift.

Lorîmer, (2011) explained with BIM, efficiencies through the design process are more comprehensible. The single gain would seem to be a simple coordination of components using clash detection software combined with a virtual builder, which means mistakes are identified before construction begins. Ashcraft, (2008) further explained that compared to traditional quantity take-offs, cost estimation occurs late in the design stage, BIM use allows for these estimates to occur much earlier and can be updated as changes are made.

Early decisions in the design process can be significant on the life cycle performance of a building and with the growing environmental concerns and increasing costs of energy, there is a greater demand for sustainable building (Schade *et al*. 2011).

Cheng and Ma, (2013) indicate that there is a global trend towards sustainable design in the construction industry. Kolpakov, (2012) identified that there is a cross over between BIM and sustainability. Both strive to promote lean construction, optimise building performance, and aim to reduce waste (Kolpakov, 2012). In the same context Krygiel *et al*. (2008) explain that BIM could aid in the following areas of sustainable design:

I. Sustainable materials (to reduce material requirements and to recycle materials)

II. Daylighting analysis water harvesting (to reduce water needs in a building)
III. Building massing (analyse building form and optimise the building envelope
IV. Building orientation (Select a building orientation that results in minimum energy costs)
V. Energy Modelling (to reduce energy and analyse renewable energy options such as solar energy).

2.10.1. Procurement Stage

BIM tools during procurement are used for tender and supply chain management (Mahesh, 2011). Furthermore, Ma *et al*. (2013), identified that the tendering documentation can be coordinated without errors.

2.10.2. Construction Stage

Each construction project is unique and complex; there are several difficulties that arise during the design, planning, construction and site management phase (Zhang and Li, 2010). Many vital goals in construction such as change of orders, reduction in a request for information, and more effective construction management can be achieved with the use of BIM. BIM tools are applied to the goals through communication and on site coordination with the implementation of BIM applications (Takim *et al*. 2013).

2.11. BENEFITS OF BIM DURING THE CONSTRUCTION PHASE

BIM is used more during construction as opposed to the design phase; perhaps the reason for this is BIM's ability in achieving efficiency and quality in construction (Ahmad *et al*. 2012). Farnsworth *et al*. (2014) undertook a telephonic survey on the advantages and effects of using BIM in construction. The highest rank of using BIM was as follows: more accurate scheduling and cost estimation, improve communication, coordination, visualisation, clash detection, and more performing quantity take-offs. According to Nepal *et al*. (2012), there is an emphasis on the use of BIM during the design phase, contractors are also using BIM to support various functions.

McGraw-Hill, (2009) identified that 73% of BIM users felt that BIM has had a positive influence on their company's productivity. A company can utilize all of BIMs benefits based on the experience of the user. Eastman *et al*. (2011) agreed that 4D and 5D modelling assists clients and contractors in making decisions by estimation, co-ordination, and scheduling of the construction process.

Eastman *et al*. (2008), explain BIM's clash detection technology helps to resolve conflicts early in the design stage before construction begins. This allows for order changes due to design errors to be avoided. A BIM model is up to date and narrows errors due to miscommunication between architect, engineer, and contractor.

A report conducted by McGraw-Hill (2009), indicates that 80% of contractors in the UK believed that sustainable waste management would become an important practice by 2014. Cheng and Ma (2013), developed a waste estimation system, the system not only serves as a waste estimation tool prior to demolition or renovation but also as a means to calculate waste disposal charging fee according to cart away requirements.

2.12. BARRIERS TO THE IMPLEMENTATION OF BIM

Studies were conducted to identify these barriers to BIM adoption in the construction industry in different countries. The results of some studies will be discussed below;

Results of a questionnaire conducted by Yan and Damian (2008), on the barriers to implementing BIM in the UK and USA are as follows; respondents believe BIM is unsuitable for projects, 20% of respondents from the USA believed that BIM waste's time, as well as human resources and companies, have to allocate a significant amount of time and human resources to the training process, people refuse to learn and think that current design technology is sufficient for them to design a project, the cost of copyright and training (Ghaffarianhoseini *et al*. 2017).

Arayici *et al*. (2009), undertook a survey in the UK on the primary barriers to implementing BIM in construction companies. The barriers are as follows according to their respective ranks from the responses:

- An organisation may not be familiar with BIM use,
- Hesitant to initiate new workflow or train staff,
- Firms do not have sufficient opportunity for BIM implementation,
- Benefits from BIM implementation do not outweigh the cost to implement it,
- Benefits are not tangible enough to warrant its use,

- BIM does not offer enough of a financial gain to warrant its use.

Likewise, Howard and Bjork (2008), in 2006 sent out questions related to BIM through emails to engineers, architects, contractors and I.T specialists in the UK, Sweden, Hong Kong, Denmark, Holland, USA, and Norway. Howard and Bjork, (2008) identified many obstacles from questionnaire responses with the implementation of BIM. The barriers concluded were as follows; the need for sharing information, the need for education, the lack of standards, the absence of legal issues to implement BIM.
Ku and Taiebat, (2011) conducted an online survey with construction companies in the US, questions were asked on the barriers to implementing BIM. The answers were listed as follows:

Sharing BIM with external stakeholders

- The lack of legal and contractual documents
- The difficulty of sharing BIM with external teams or reluctance of others(e.g. Engineers, Quantity Surveyors or Architects)
- Interoperability issues between software programmes.
- Lack of collaborative work process with the external team and modelling standards.

Internal company resource aspects

- The investment cost of BIM in terms of resources and time.
- Lack of skilled personnel and the learning curve of new tools.

Keegan (2010) identified several barriers to the utilization of BIM; lack of knowledge of the software, cost of implementing and updating the system, lack of knowledge about BIM by the owner. Two main challenges to implementing BIM was further discussed by Becerick-Gerber *et al.* (2011), i) Organisational challenges. ii) Technology and process challenges. Becerick-Gerber *et al.* (2011) further explains the detail of each group as follows:

i) Organisational challenges

- Organisation-wide resistance regarding the need for investment in infrastructure.
- Cultural barriers toward implementing new technology.
- The lack of an adequate legal framework for integrating owners view in design and construction.
- Undefined fee structures for additional scope
- The lack of real world cases has been implemented by BIM and proof of positive return on investment.

ii) Technology and process challenges

- The lack of effective collaboration between project stakeholders for modelling and model utilization.
- Unclear roles and responsibility for loading data into the model or databases and maintaining the model.
- Difficulty in software vendors' involvement, including fragmentation among different vendors, competition and lack of mutual interests.

Although BIM has many benefits (Liu 2010), BIMs' adoption in the South African construction industry still faces some challenges such as; the absence of standard documents (Foster, 2008), Inadequate training (Young *et al*. 2008), liability and legal issues related to accountability and taking responsibility for data exchange (Young *et al*. 2008 and Foster, 2008), non-stipulation of precise/standard requirements for ownership of the model (Davidson, 2009), inertia, the time taken for users to become up-to-date with the modalities of the process (Willson, 2010), the overwhelming task of making changes to 'entrenched business cultures' (Davidson, 2009), the growing propagation of non-standardised BIM applications by myriads of software developers (Smith and Tardif, 2009).

Although BIM comes with challenges, proponents of BIM adoption throughout the construction industry maintain that the cost of adopting BIM outweighs the challenges in the sense that BIM adoption will yet ensure savings in 'time, money and effort' (Vogt, 2010). BIM will have great advantages for those companies that will take the steps to implement it (Singh *et al*. 2011). This would vary from a better quality finished product to a decrease in labour and a decrease in wastage. BIM requires a large initial capital outlay that may be a burden to contractors taking the step to implementing it (Takim *et al*. 2013). Furthermore Takim *et al*. 2013 said many professionals will now become obsolete due to technological advantages and in turn, will lead to job losses in the construction industry. Training will become a necessity for all stakeholders in a construction project where BIM is to be implemented.

2.13. APPLICATION OF BIM

According to Kreider and Messner (2013), BIM uses can be classified based on the purpose for implementing BIM throughout the life of a project. Many characteristics can also be defined in addition to the purpose to identify and communicate a BIM use.

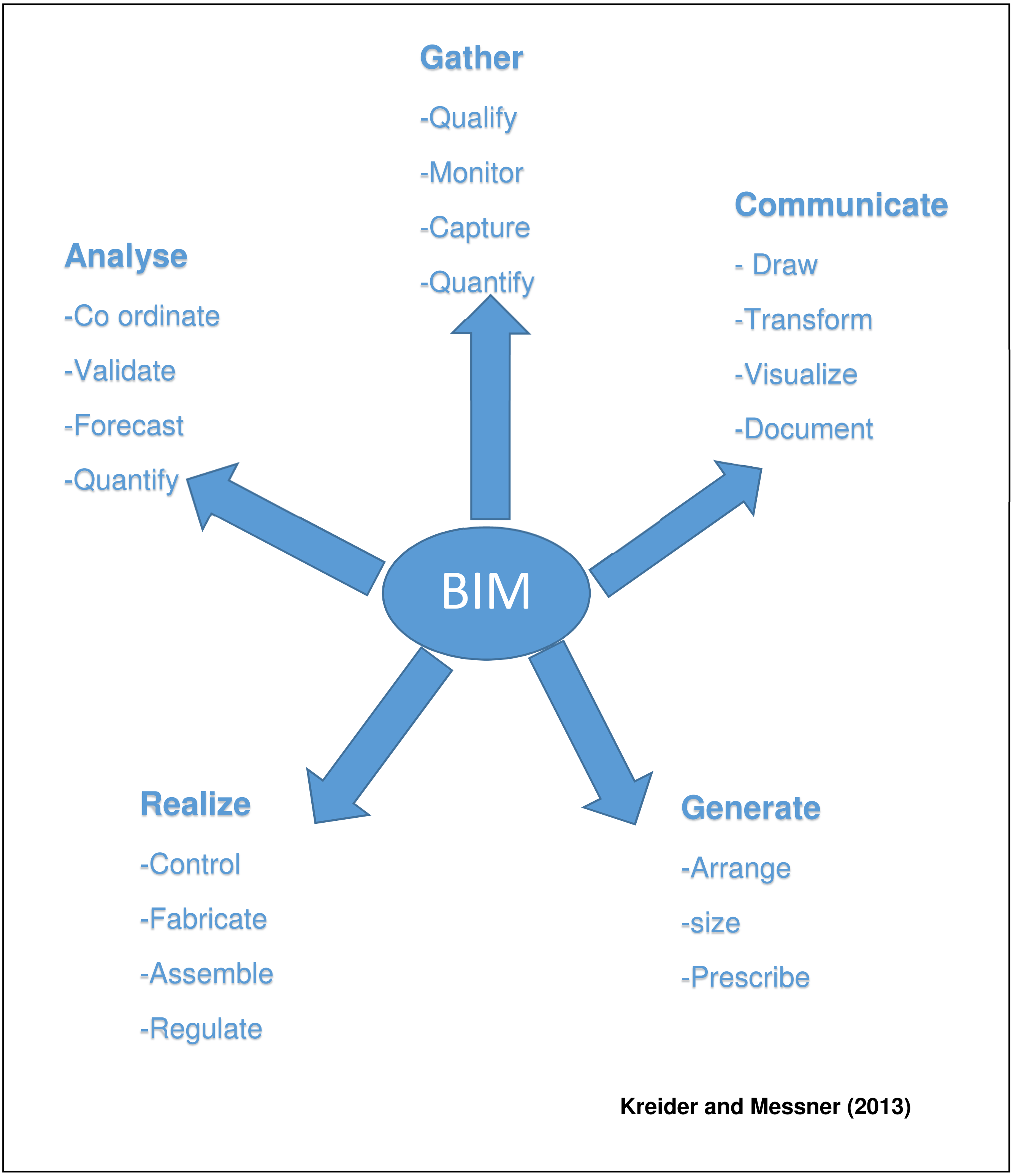


Figure 2.1 BIM Applications

2.13.1. Gather - the objective is to collect project information

BIM is used to collect data about a project at all phases during the project's duration. Whether it is to total the specific amount of a trade or define the status of a project. The sub purpose of BIM includes qualifying, quantifying, monitoring and capturing. The author collects, gathers and organises information about the project. BIM does not define the meaning of the information collated; it focuses on the collection and organisation of information (Eadie *et al*. 2013).

2.13.2. Capture – the objective is to represent the current status of the project

BIM is used to capture geometric and attribute data about a project. This is accomplished by using several methods and at various stages of a project: the elements of the site before the development of a new project or the condition of a current project before refurbishment. A laser scanner is used to capture data or recorded by inputting serial and model numbers into a spreadsheet. The common factor is that data is captured where no data existed before. Although it is not recently generated information it creates a record of the project elements that exist (Cerovskek, 2011).

2.13.3. Quality – express or measure the quantity of a project element

BIM is used for collecting or counting the number of specific project elements. This purpose is used as part of cost forecasting and estimating process. During the design stage of a project, quantities are measured and subjected to change. In the construction phase, quantities can be calculated easily (Ahmad *et al*. 2014).

2.13.4. Monitor – observe the performance of a project and systems

BIM can be used to monitor real-time performance data of project elements and project activities. The purpose of BIM is to understand the performance of particular project processes and elements. For example, in construction, the productivity of the construction process can be monitored by using BIM (Kreider and Messner, 2013).

2.13.5. Qualify – identify project element status

The status of a project is tracked. It includes information such as: does an element exist within a project and how does it work? The BIM purpose tracks project elements over time (Creach, 2013).

2.13.6. Generate – author or create information about a facility

In the project lifecycle, all trades that are involved in a project will produce information about the project. The purpose of BIM is to generate information about the project. This includes arranging, prescribing and sizing project trades to various levels of development. During the design phase, the design team will be the primary contributors of information and while in the construction phase, sub-contractors will generate most of the information. In the operation phase, information generated is by those maintaining the project (Succar *et al*. 2012).

2.13.7. Prescribe – determine the need for specific project elements

The prescribing purpose of BIM is used when the generator defines there is a need for a specific project element. The architect or planner of the project may recommend the need for certain spaces or rooms in the project. While a mechanical engineer may recommend a need for specific heating, ventilation, and air conditioning (HVAC) systems. The contractor determines the need for a temporary construction element like a tower crane, and the operator of the project may recommend a specific replacement part for the project (Bryde *et al.* 2012).

2.13.8. Arrange – determine placement and location of project elements

The arranging purpose of BIM includes uses in which location or arrangement of a project element is determined. During the planning phase of a project's life cycle, this could be the adjacency or arrangement of spaces within a proposed project. In the design phase, it can be the general location of fire protection piping, while in the construction phase it can be the placement of hangers that support the piping. This can be used during the operations phase to determine the location of furniture. In general, at any point a geometric location of an element is determined, it is being arranged (Bryde, 2012).

2.13.9. Size – determine the scale and magnitude of projects elements

The sizing purpose of BIM is when the project magnitude is determined. Some of the elements during design include the shape of steel beams, the size of duct work, and dimensions of spaces. During construction, it could include the thickness of duct insulation or the size of a crane (Kreider and Messner, 2013).

2.13.10. Analyse – study elements of a project to achieve a better understanding of it

Elements of the project require further analysis to determine the practicality of the project. The analysis purpose of BIM includes uses in which the methodical examination of the project elements is needed. This purpose includes forecasting, validating and coordinating. Data is then collated from what was generated or gathered and put into a decision making format (Migilinskas *et al*. 2013).

2.13.11. Coordinate – ensuring the harmony and efficiency of the relationship of facility elements

The purpose is that project elements are analysed to ensure that the relationship with other elements is in harmony and effective. BIM is used for clash detection, avoidance, interference management, design coordination, and collision avoidance among others. Eventually, all of the project elements should work in conjunction with one another. This includes coordinating design intent of various systems during design, installation, fabrication or the coordination of current operations while renovations are underway. This purpose of BIM will ensure that the project will fit together as planned and all the necessary systems have been considered (Volk *et al*. 2014).

2.13.12. Forecast – prediction of the future performance of the project and project elements

This purpose is major and has the most difference in the application from element to element. With this, detail analysis is conducted to foresee the future performance of the project and project elements. The primary performance elements that should be included are energy, flow, temporal, scenario, and finance among others. (Kreider and Messner, 2013).

Forecasting involves:

Energy – the way future energy consumption and flow forecasting predicts performance like air flow or occupant/crowd circulation.

Temporal – Foresees performance of the project over time to include timing for element replacement and building degradation (Kreider and Messner, 2013).

2.13.13. Validate – to check or prove that the project information or accuracy is reasonable and logical

The purpose of BIM is applied to validate project information. This includes checking project information to ensure that it is accurate, reasonable and logical. BIM validation use falls into three areas: functionality, compliance, and prescription validation. The function is to ensure the project is maintainable, practical, and constructible. Will the project be able to accomplish the purpose for which it was designed? Compliance confirms the project's compliance with standards and codes to include in building codes and sustainability standards among others. Prescription ensures the project has the required elements that are specified and programmed in the project including the primary element of project spaces or rooms (Ahmad *et al.* 2014).

2.13.14. Communicate – the representation of information about a project in a way that can be exchanged or shared

The idea of BIM is to communicate project information. BIM's communication purpose is intended to present information about a project in a way that can be exchanged or shared. This is the last step when transformation, drawing, visualisation or a document is created for communication. This is BIM's most valued use. It promotes and increases communication and decreases the time taken to communicate (Hamza and DeWilde, 2014).

2.13.15. Visualize – form a representation of project elements

It is powerful to use BIM to better a project's vision. It assists with those that lack training in the construction and design industry but are crucial in decision making (Cheng and Teizer 2013).

2.13.16. Transform – to adjust and amend information to translate it to be received by another process

With BIM, project information needs to be taken from one form to another so it can be acknowledged and used by another process. The transformation of data allows for interoperability between various systems (Grilo and Jardim-Goncalves, 2010).

2.13.17. Draw – a symbolic representation of the project's elements

BIM improves the ability to enhance drawings with detail. These drawings are created in a parametric method rather than static methods (Kreider and Messner, 2013).

2.13.18. Document- Project information and information for specific project elements is recorded

It is important to record project data in a written description or tabulated format. The document purpose of BIM includes uses in which the project data can be created (Azhar, 2011).

2.13.19. Realize – control or make a physical element using project information

BIM allows the construction industry to remove the contribution of human interaction to develop precise elements of the project. This can assist the project data to control a physical element of the project. The purpose is to give the industry the ability to control, fabricate, regulate and assemble elements of the project. This ability can lead to the improved productivity on operations and construction of the facility (Hergunsel, 2011).

2.13.20. Fabricate – use project elements to manufacture the elements of a project

BIM allows the construction industry to develop project elements that were not possible before the detail product modelling. This use allows project information to manufacture elements of a project (Kreider and Messner 2013).

2.13.21. Assemble – use project information to bring separate elements of a project together

The assembling purpose of BIM is where project information is available to bring together the separate elements of a project. While this is a manual process BIM ensures different systems can be prefabricated, it also has the ability to fit systems together that were traditionally separate (Bew and Underwood, 2010).

2.13.22. Control – use project information to manipulate the operation of executing equipment

BIM has the ability to allow project information to control equipment operations. The controlling aspect of BIM includes a use where project information is used to manipulate the operation of executing equipment (Motawa and Almarshad, 2013).

2.13.23. Regulate – use project information to inform the operation of a facility element

BIM is used to regulate project elements to allow project operators to optimise their operations. This BIM use includes using project information to inform the operation of a project element (Kovacic *et al*. 2013).

2.14. THE INFLUENCE OF BIM ON THE SOUTH AFRICAN CONSTRUCTION INDUSTRY

According to Porwal and Hewage (2012), BIM is a human activity that involves a wide spectrum of change in construction. BIM use is now in demand by a large variety of owners. Several owners have developed contract terms and detailed guides for the construction and design service providers. Globally positive returns on investment values have been reported by construction contractors and design firms, with those that measure return on investments, stated it exceeded their initial investment. In 2007, a survey conducted found that 28 percent of the United States AEC industry used BIM tools; that number has grown to 49 percent in 2009 Azhar (2011).

2.14.1. South Africa's BIM adoption

According to Constructiondigital (2010), for a very long time, CAD systems have been utilised in the South African construction industry but as of recent times, the use of BIM has increased in the civil and structural engineering sector. Further, Autodesk Tekla and BIM software packages have made an impact on the construction industry, for example, in the construction of the stadiums for the 2010 FIFA world cup. The adoption was for interference management and 3D modelling for clash detection. Although the full spectrum of BIM was not realised (Kotze, 2013).

Booyens et al. (2013) stated that BIM in South Africa has been in the spotlight since the new millennium. BIM packages such as “ARCHICAD BIMx”, “TEKLA” and “AUTODESK REVIT” have been used on various projects. The FIFA world cup in South Africa has given the AEC sector an opportunity to examine and implement BIM. Three of the five new venues built for the event were modelled using BIM software and techniques, hence giving South Africa a unique chance in Africa to experience the advantages of BIM (Constructiondigital, 2010 and Kotze, 2013).

To design the steel roof structure of Nelson Mandela Bay Stadium in Port Elizabeth, Steel detailing company CadMax used Tekla structures software of Espoo, Finland to model the roof, said Construct digital web page (2010). The roof consists of Teflon-coated fibreglass, held with 36 steel girders and a combined weight of 2500 tons of curved beams. “One of the most interesting parts of the project was the compression ring. To make the 3D model, we had to duplicate the model and stimulate the deflection so the compression ring could be fitted properly after the girders erection”, said Daniel Barbeau from Canadian steel detailers CadMax (aemag 2010).

The same software produced the existing Royal Bafokeng Stadium and the new Mbombela Stadium in Nelspruit; in both of these projects, visualisation 3D images were used to create timelines, delivery schedules, and shop drawings. According to Risto Räty of TEKLA, “Building the stadiums without the help of 3D BIM software would have been very difficult in an environment in which time was a critical element to the countdown to the opening of the first game*”.*

According to Venkatachalam (2014), South Africa’s BIM adoption is slow due to socio-economic factors. Despite BIM’s many benefits, challenges remain in its implementation (Venkatachalam, 2014). Kiprotich, (2014) discovered that construction firms in South Africa have shown a great interest in BIM since the new millennium. However, contractors are concerned that BIM blurs the difference between design and build Kiprotich, (2014).

2.14.2. Advantages of implementing BIM in the South African construction industry

According to Hergunsel (2011); InfoComm (2011) and Takim *et al.* (2013), implementing BIM can have great advantages for those companies willing to implement it, such as:

- An increase in productivity of professional employees is expected, therefore, reducing professional fees.
- Better quality end product.
- Reduction of wastage, therefore, minimising costs.

The main advantages identified by Kaber, (2010) are improved coordination of documents, improved productivity due to easy access to data, improved visualization, reduced costs, and increased speed of delivery. This is mainly due to the multi-user collaboration abilities as discussed by Davidson, (2009). When each member of the professional team has worked on their preferred programmes (BIM tools), it is then added it to the project database. Due to all tasks being done electronically, it then makes it available at all times for the other members of the professional teams. Furthermore, Kaber, (2010) stated that BIM's ability of embedding and linking of vital data such as the specified location of details, materials, and quantities required for tendering and estimating purposes.

2.15. BIM AND THE QUANTITY SURVEYING PRACTICE

2.15.1. The Role of a Quantity Surveyor

According to Sanders (2008), problems of over/under measurement, material cost and increase in labour in 1800's particularly after the Great Depression of the 1920's and 1930's led to a call for professionals specialise in the measurement of building quantities. Quantity surveyors, in the early days were referred to as 'measurers' or 'surveyors', worked for contractors to measure for payment purposes only (Association of South African Quantity Surveyors, 2011).

A quantity surveyors' service generally includes the preparation of estimates, cost plans, feasibility studies and BOQ's. Quantity surveyors compile and draft documentation for construction contracts and prepare construction contract tenders.

They provide advice on financial management and contractor selection of all construction works and reporting, including planning cost, indexing, and auditing. Services such as construction project management; facilities management, management contracting, value management, and construction dispute resolution among many are rendered (Olatunji *et al*. 2009). According to Masidah and Khairuddin (2005), services carried out by quantity surveyors such as pricing and measuring of construction works, might be unnecessary and undesirable. Further, BIM's potential to generate quantity measurements may decrease a client's requirements for quantity surveyor's services.

The role of quantity surveyors may be viewed as providing the commercial and financial management services on construction projects (Cunningham, 2014). According to Hore, O'Kelly, and Scully (2009), quantity surveyor roles include: advising on contractor claims; adjudication of tenders; valuing work in progress; preparing final accounts; cost planning and value analysis; negotiation of rates; advising on costs and preparing cost reports; advising on procurement options; preparing approximate estimates of costs; preparing BOQ's and other contract documents.

Frei *et al*. (2013) identified several threats to quantity surveyors, such as market/ competition, capability/ capacity, recognition/ relevance and information/ communication/ technology. Threats included the following; continued departure from traditional procurement methods and associated fall in demand for quantity surveying services; relative obscurity of the quantity surveying discipline; blurring of professional boundaries allowing erosion of existing market share by other professionals; shortages of suitably skilled professional and quality graduates threatening long term success of discipline; advances in information technology such as computer-aided drafting (CAD) and BIM threatening the role of quantity surveyors; building market fluctuations; and demise of published scales of fees and resultant levels of fee competition affecting quality of services offered. Several quantity surveyor's services exceed measurements and an assessment of costs facilitated by such data. It is clear that the potential for BIM to influence the quantity surveyor profession is considerable (Olatunji *et al*. 2009).

2.15.2. What does BIM mean for the Quantity Surveyor Profession?

According to RICS (2011), the change towards BIM capabilities and expertise requires quantity surveying practices to reconsider and restructure their business practices. According to Sutrisna *et al*. (2005), conventional construction estimating practices have been criticised because there is hardly an estimate without any peculiarities and current estimating processes are seen by some as too rigid. BIM measurements represent an approach that could have a marked impact on preconstruction processes. This measurement and its link with estimating are real possibilities, but they are significant challenges still to overcome. The most important amongst these is the need to filter BIM data, so they comply with rules prescribed in relevant standard methods of measurement (SMM). SMMs are proliferate throughout the world and several may operate within a single country. For example, in the United Kingdom, the measurement of civil engineering works is under CESSM2 and the measurement of building works is under SMM7. Similarly, in South Africa, the measurement of building and civil works are directed by separate SMM's Sutrisna *et al.* (2005).

2.16. THE USE OF BIM TO AID IN WASTE REDUCTION

The following four processes indicate the current research on construction waste and BIM, BIM improved design waste minimisation, BIM improved demolition waste management, BIM improved coordination to reduce construction waste, and BIM improved on site waste management.

2.16.1. BIM enhanced design waste minimisation

A research case study, undertaken by Porwal and Hewage (2012), developed a tool for engineers to use to minimise bar material use in technical design. A BIM-assisted tool to reduce material wastage was developed, focused specifically on the reduction of structural material, for the structural engineer to apply in the technical design phase. Further, the research lacked investigation on impacts of reducing material waste that is affected by BIM enhanced design activates during early design stages.

According to WRAP (2013a), a case study based on implementing BIM to achieve resource efficiency, proposed the potential of BIM to assist in decreasing material wastage through its implementation at the early design stage. However, it lacked instructions, which have been created for the BIM implementation on reducing material waste during design (WRAP 2013a). A questionnaire survey conducted by O'Reilly (2012) states that BIM could assist architects with reducing material waste by the creation of informed design decisions during the concept and design stages.

2.16.2. BIM improved demolition waste management

A BIM based planning and waste estimation through an API-enhanced (application programming interface) online application for the management of construction waste by planning and waste estimation at the demolition stage was developed by Cheng and Ma (2013). Further, the study focused on demolition waste but lacked ways to indicate the use for the waste estimation system for other project phases such as design.

2.16.3. BIM improved coordination to reduce construction waste

Ahankoob *et al*. (2012) states that BIM performs as a coordination tool to support the project team with reducing construction waste during the construction project. Current methods have not been suggested to aid in reducing waste through BIM enhanced coordination throughout various stages of the construction project.

2.16.4. BIM improvement on site waste management

Porwal and Hewage (2012) propose a probable BIM approach for onsite construction waste management through literature review. This is through a BIM modal driven system for dynamic modelling by using material quantity information. Based on this research Porwal (2013) used three case studies to develop a cost-orientated system approach that specifically focuses on the causes of waste such as design changes by design and construction engineers. Although this study focused on the causes of waste on site, BIM could not help to address other causes of waste on site (i.e. client design changes) that were influenced during design. According to Ningappa (2011), BIM has the ability to assist the onsite project team with reducing waste. Similarly, Sacks *et al.* (2010) proposed that waste could be reduced by implementing BIM-integrated lean in construction. Although, there has been no development based on these studies to assist in reducing waste with the use of BIM.

2.17. POTENTIAL TO MINIMISE WASTE USING BIM

The potential to reduce waste with the aid of BIM focuses on the development of design, specification, coordination and project performance. McGraw-Hill (2010) states that BIM improved design encourages the construction project to take advantage of current construction by removing information from the BIM system such as prefabrication and preassembly, which can assist in accelerating the construction project and making it more competent by avoiding the use of raw materials construction waste generation on site. Further, efforts related to construction waste involved during the design phase could minimise on site rework, which is a major contributor to waste. According to Baldwin *et al.* (2008), this is accomplished through a 3D capacity enhancement within BIM whereby 3D information analysis developments store, retrieve and analyse in-depth building feature information such as doors, windows, and walls.

Eastman et al. (2008) and Love et al. (2013b) state that BIMs' improved coordination through clash detection assists inspection of conflicts prior to construction, such as waste raised from conflicts which will be avoided. Although material waste and waste cost could be reduced by the implementation of BIM during the design and construction stages (Krygiel and Nies, 2008 and Nisbet and Dinesen, 2010) there seems to be a lack of BIM support tools to assist designers to reduce waste during the design stage. According to the UK construction strategy towards 2050 (HM Government, 2013a) and BIM expert and director (Hamil, 2011), it is believed that BIM will have the ability to minimise waste during design and construction.

2.18. CONCLUSION

This chapter has reviewed the literature on waste in the construction industry; sources of material waste such as concrete, reinforcement, tile, timber, pipes, and wires are a major waste contributor on site, the causes of material waste are procurement, operational, design, material handling and storage waste. Waste preventative waste carried out in previous studies were discussed. It further introduces BIM, BIM principles and BIM barriers as a way to reduce waste in the industry and BIMs potential to reduce waste during construction.

CHAPTER 3

RESEARCH METHODOLOGY

3.1. INTRODUCTION

The planning of a research design is significant for the researcher, not only to identify a research problem but also to think of the types of data that an investigation of the problem will require, as well as logical ways of gathering and understanding data (Leedy and Ormrod, 2010). The methodology adopted in this study is described in this chapter. The design of the survey, as well as the respondents for the questionnaire survey, are discussed. The method of research techniques, data collection, population and sampling design employed to carry out the investigation of waste, sources of waste, causes of waste, and the adoption of BIM in the South African construction industry. The study is not only important to the researcher but is also intended to inform others in the construction industry, potential investors in construction projects, and future operators in the Built Environment on reducing material waste with the application of BIM.

3.2. DEFINITION OF RESEARCH

Research is a process in which information is collected, analysed, and interpreted using a systematic manner to understand a phenomenon that is of interest to the researcher with verifiable facts (Leedy and Ormrod, 2014).

3.3. TYPES OF RESEARCH

There are different types of research. Research may be correlative, exploratory, or descriptive. Aiyetan (2010) is of the view when choosing the correct type of research in attempting to solve a problem, researchers need to be guided by the characteristics of the problem, the knowledge they have at initial stages, the factors that influence change, as well as determine why the investigation is being conducted.

3.4. RESEARCH DESIGN

According to Kumar (2011), a plan, strategy, and structure of investigation that is alleged to attain answers to research problems or questions is known as a research design. The plan will consist of a complete schedule or programme of works, the researcher will outline the study from writing aims, research objectives and operational implications up to the final analysis of the data.

Kumar (2011) further indicates the definition mentioned above states that a research design has two main functions. The first highlights the significance of quality in these procedures to ensure accuracy, objectivity, and validity and the second relates to the identification and development of procedures and logistical arrangements needed to undertake a study.

With a research design, one should be able to:

I. Ensure procedures are adequate to obtain valid objective and accurate answers to research questions.
II. Conceptualise an operational plan to undertake the various procedures and tasks required to complete your study.

Philosophies and paradigms influence a research design because it is almost impossible to separate a researcher's belief, assumptions, and perceptions in which the research is approached (Blaikie, 2010). Therefore, the paradigm, research reasoning, philosophical underpinning, and data are discussed in Figure 3.1.

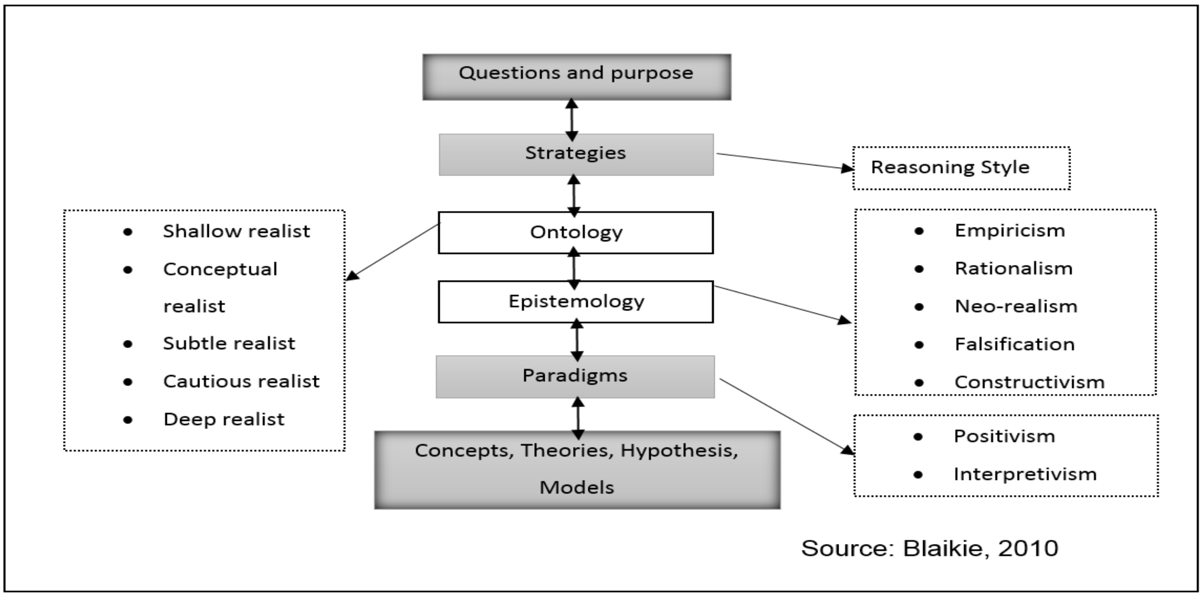


Figure 3.1 Research paradigm

3.4.1. The research philosophy

The philosophical positions inform the choice of research design and the subsequent methods of undertaking research (Alvesson and Willmott, 2012). Furthermore, the research philosophy is related to the improvement of knowledge that contains the vital assumptions that lead up to the views of the research study. There are two significant research philosophy aspects related to social research, these are epistemology and ontology (Dainty 2008; Bryman 2008).

3.4.2. The Ontological background of the research

According to Neumann (2011), ontology in research is described as the study of the concepts of reality and it concerns itself with the reality of being; it questions what really exists and the origin of reality. It considers two interpretations: constructionism and objectivism to the nature of societal entities (Bryman, 2008).

3.4.3. The Epistemological background of the research

Epistemology describes the manner in which knowledge should be achieved and acknowledged (Dancy *et al.* 2010). According to Stone (2008), in research, epistemology is all about knowledge that is sources, concepts, and extent of knowledge; it further concerns itself with the justification and rationale of knowledge. Accordingly, the assumption of the best way of studying by focusing on opinions or facts is an epistemological assumption.

3.4.4. Philosophical position of this research

The research investigated current material waste practices and BIM techniques and tools to develop a BIM flowchart as a way to mitigate waste during construction.
Therefore, the research aimed to reduce waste with the use of BIM. The theoretical generation of waste and BIM based on ontological constructivism, as well as interpretivism leads to theory verification from epistemological positivism providing a philosophical position for the study. Previous research studies have explored the knowledge areas of construction waste and BIM separately, the relationship of construction waste and BIM has not been investigated yet, therefore, the previous studies would not affect the investigation conducted by the research.

3.5. RESEARCH PARADIGMS

According to Creswell (2014), a research paradigm in social science, describes the broad framework of organising and reasoning of observations in research. Paradigms are assumptions and perceptual orientations shared by academic researchers.

3.6. RESEARCH METHOD

The discipline of research or body of knowledge utilises certain established techniques in conducting scientific research. The principles and procedures of the techniques are the research methods (Kinash, 2008). Research data will be collected in the form of questionnaires on issues relating to material waste and BIM. A link to the questionnaire were distributed by email, this method was chosen because it was easier for the researcher and reduces waiting time for responses to be delivered.

3.6.1. Qualitative Research VS Quantitative Analysis

According to Creswell (2007), a qualitative research is understood as an analysis of understanding based on methodological traditions that explore social or human experiences. A qualitative research studies common phenomena within their natural setting, attempting to understand the logic or interpret the phenomena in terms of the importance it brings to them. The qualitative research requires careful thought at commencement, demanding mental alertness and concentration during data collection, calling for progressive skills in data managing and text-driven creativity during analysis and write up (Davies, 2007).

A qualitative study is selected as a research method based on the following situations (Creswell, 2007), these are;

I. Need for a detailed and complex understanding of the issue;
II. The problem or issue that needs to be explored;
III. To understand the framework or setting where the study participants address problems and issues;
IV. The need to empower individuals to hear their voice, share their story and reduce the strong liaison between the researcher and respondents involved in the study;

V. Quantitative research methods and statistical analysis simply do not suit the research problem, whereas qualitative methods fit better.

Further, Bryman (2008) simplified the situations when;

VI. The research concept is analysed on a nominal scale with no clear differentiation involved in exploring behaviour attitudes, or

VII. There is no current research data on the topic and the most appropriate unit of measurement is not certain.

3.6.2. Quantitative Research

According to Fellows and Liu (2008), quantitative research seeks to gather factual data, to study the relationship between facts, theories, and previous research.

Leedy and Ormrod, (2010) indicated that quantitative research is used to answer questions about variables with the purpose of predicting, explaining, and controlling phenomena.

Quantitative research requires discipline and patience at the planning and design stage, data collection may encounter technical problems and require tenacity but it is direct. The data collection task and write up is mostly but not entirely determined by the way the research was set up (Fellows and Liu 2008).

A fundamental difference between qualitative and quantitative research techniques and designs are that the qualitative research designs deal with the 'how' and why of human behaviour as opposed to quantitative research designs, deal with the 'when and what' of knowledge (Fellows and Liu 2008).

According to Kumar (2011), the focus of qualitative research is to understand, explore discover, and explain situations, attitudes, beliefs, values perceptions, and experiences of people. Research plans for qualitative research are, therefore, based on a deductive rather than an inductive logic. The most notable feature of the qualitative research is its adherence to the concept of respondent concordance. In this research approach, the researcher makes every effort to seek the agreement of respondents with regard to the explanation of the situations, presentation, experiences, perceptions, and conclusions (Kumar 2011).

Leedy and Ormrod (2010), explained a quantitative research is focused on measuring quantities and relationships between characteristics by following a set of scientifically

challenging problems. A quantitative research is ideal for conditions where knowledge already exists, this allows for the use of reliable methods of data collection.
Kumar (2011), further states in a qualitative study, there is adequate detail about the study this enables the study to be verified, replicated and reassured.
The aim of a quantitative research is to determine the relationship between one thing (independent variable) and another (dependent variable) in a population.
A quantitative research is either experimental or descriptive. This type of research is about quantifying relationships between variables (Kumar 2011).

3.7. PRIMARY AND SECONDARY SOURCES OF DATA

3.7.1. Primary Sources

Primary data refers to first hand gathering by means of a questionnaire. Questionnaires are normally paper-and-pencil instruments that the respondent finishes. Questionnaires can be managed by means of mail and request the respondents to mail it back or handed out whereby a sample of respondents is requested to complete a survey.

3.7.2. Secondary Sources

The secondary data used in this research were obtained from several South African and international sources, books, conference papers, thesis and the internet. The search for information was undertaken at the Durban University of Technology (DUT) library. The following databases were searched for information and they included: Nexus; EBSCOhost; Emerald and Sabinet reference.

3.8. POPULATION

At the data gathering stage, two categories of respondents were identified. These are:

- Public sector and
- Private sector

The private sector consists of respondents from the Association of South African Quantity Surveyors (ASAQS), Consulting Engineers South Africa (CESA) and South African Council for Project and Construction Management Professions (SACPCMP).

The survey was sent out to all members of the above-mentioned councils, a portion of the responses was selected to represent the entire country as a sample for the study.

3.9. SAMPLING

According to Kumar (2011), Sampling is the process of selecting a few respondents (a sample) from a larger group (the sampling population) to become a basis for estimating or predicting a fact, situation or outcome regarding a larger group. The population of the study is aimed at construction professionals in South Africa, and it is selected for the following reason: it allows the identification of provinces with high construction activity

3.9.1. Sample Frame

The population for the collation of data using the questionnaire aimed at Quantity Surveyors, Engineers and Project managers as shown in Table 3.2.

Table 3. 2 The composition of registered members

Composition	Number
ASAQS (Quantity Surveyors)	**5136**
CESA (Engineers)	**439**
SACPCMP (Project Managers)	**6217**

3.9.2. Sample Size

According to Kumar (2011), the process of selecting a few respondents from a larger group to be the basis for estimating or to predict a situation or outcome is called sampling. According to Walliman (2011), population is defined as a collective term used to describe the total magnitude of cases of the type of respondents, which are subject to study, and a sample is defined as selected as a portion of cases in a population.

Leedy and Ormrod (2010), states researchers should endeavour to maximise the sample size and has provided the following guidelines for sample selection:

I. For smaller populations with fewer than 100 people or other units, there is little point in sampling, survey the entire population;

II. If the population size is around 500, 50% of the population should be sampled;

III. If the population size is around 1 500, 20% should be sampled and

IV. Beyond a certain point (5000 or more), the population size is almost irrelevant and the sample size of 400 should be adequate.

Table 3. 3 Sample size relative to their professions

Profession	Population	No. of Administered Questionnaires	No. of questionnaires received
ASAQS (Quantity Surveyors)	5136	400	32
CESA (Engineers)	439	100	16
SACPCMP (Project Managers)	6207	400	12

Sampling is very important, as it is not possible to examine the entire population. Based on the research guidelines by Leedy and Ormrod (2014) a total of 900 samples were systematically selected for sampling. Systematic sampling is a sample technique that allows a selection of a sample size in sequence. A list of units was made from the population of interest (ASAQS, CESA, and SACMCMP). Every tenth unit on the list was then selected and reconciled with the list to obtain the persons or object to be surveyed. The systematic sampling techniques were carried out as follows

Sample size/population x 100

ASAQS – 5136/400 x 100 = 7

CESA – 100/439 x 100 = 23

SACPCMP – 400/6217 x 100 = 6

This indicates that at every 7th (ASAQS), 23rd (CESA) and 6th (SACPCMP) unit members are selected for the survey.

3.10. Sampling techniques (method of selection of sample)

According to Leedy *et al.* (2010), there are two major sampling approaches: probability and non-probability sampling approaches.

3.10.1. Probability sampling

Probability sampling is the type which allows all the members of a population to be represented in the sample. In this study, samples were chosen from the larger population by a process known as random sampling. This process allows each member of the population to have an equal chance of being selected. The various sampling techniques undertaken in the selection of a probability sample are simple random, stratified random, systematic, and cluster sampling Alvi (2016). Simple random sampling allows the samples to be chosen by simple random selection whereby every member of the population has an equal chance of being selected Alvi (2016). Stratified random sampling happens in populations that consist of different groups. The samples are selected equally from each one of the group to be represented equally Alvi (2016); (Leedy, 2010). Cluster sampling, on the other hand, sub-divides an expansive area into smaller units. A country could be sub-divided into regions and then into towns. The clusters must be as similar to one another as possible, with each cluster containing an equally heterogeneous mix of individuals. A subset of the identified clusters is randomly selected (Alvi 2016).

3.10.2. Non-probability sampling

In non-probability sampling, individual elements of the population are not represented equally and members of the population have little or no chance of being sampled (Alvi 2016).

3.10.3. Proportional stratified sampling

The main characteristic of simple stratified random sampling design is that all the strata of the population are essentially equal in size. Proportional stratified sampling is characterised by a population that contains a definite stratum that appears in different proportions within the population. Therefore, a sample option that will not disadvantage any group is chosen for the selection of sizes. This implies that the member of each group has an equal opportunity of being selected. Selection of sample size is done proportionately (Leedy, 2010).

3.11. Sample selection

All Quantity Surveyors, engineers and architects in the country cannot be surveyed because they constitute a very large sample size in order to achieve a fair and representative sample size a link to the questionnaire was emailed out to members of the ASAQS, CESA and SACCMP.

3.12. Research Instrument

The research instrument for this study is a questionnaire survey. The questionnaire, which comprised three (3) sections were designed and sent out to construction professionals. This questionnaire was constructed using the Likert scale. The Likert scale - a scale that is used to represent people's attitudes towards a topic rated on a scale of 1 – 5, where 1 is minor and 5 is major shown below in Table 3.4
According to Viljoen *et al*. (2011), the advantages of using a Likert scale are;

- It is quick and easy to design
- Each item in the scale meets an empirical test for discriminating ability
- It is undoubtedly more reliable
- It can also be treated as an interval scale

Table 3. 4 Format of table provided for the answering of questions in questionnaires

Materials	Response %							Mean Score	STD DEV	Rank
	Unsure	Does not	Minor…………………………………Major							
			1	2	3	4	5			

3.13. QUESTIONNAIRE DESIGN

A research design verifies that the evidence collected addresses the research questions identified and is required to ensure consistency. Based on the literature reviewed, sub problems associated with the main problem were identified. These problems were identified and structured into questions to address material wastage. The groupings of the problems include:

- Causes of material waste during construction
- Material most prone to waste during construction.
- Factors that are a major contribution to material waste
- Preventive measures of material waste
- Benefits of BIM in the delivery of a project

- Challenges of BIM relative to project delivery

3.14. METHODS OF DATA ANALYSIS

The method of data analysis undertaken in this research comprised statistics. Several analytical techniques were used for data analysis to improve the validity and ease of communicating the results. Based on this the following data analysis methods were employed in the study namely, mean, mean score and frequencies, for the analysis of data from respondents.

3.15. METHOD OF ADMINISTRATION OF RESEARCH INSTRUMENT

To achieve the aim and objectives that have been set out, the questionnaire link for the online survey portal were sent out via email. Questionnaires are one of the most common methods in conducting a survey because it is the most economical method that offers a high validity of results and is most suitable when mass information is required within a short period (Kumar, 2011).

3.16. ETHICAL ISSUES

The Durban University of Technology (DUT) has a clear policy on all research conducted by members of the community. The research is classified as an Expedited review (minimal risk to humans/environment/animals). Each category has a committee, which receives applications from researchers and reviews their submissions prior to issuing the ethics' clearance. The policy stipulates that ethics clearance be sought prior to conducting any research in the named categories. This is to ensure that relevant ethical issues are adequately considered in the research methodology adopted. This policy is in line with conventional research ethics observed by National Institute of Health Office of Extramural Research for "Protecting Human Research Participants". This research has humans as subjects, therefore, all research ethics' protocols of DUT were observed. The University's research policy stipulates that all human survey research must be reviewed and approved by the relevant research committee before its commencement.

3.17. LIMITATIONS OF THE STUDY

Time given to conduct fieldwork is short. There is some limitation when dealing with a questionnaire, as there is no guarantee that the right person stated in the survey form will complete the survey or the respondent may answer questions based on the knowledge of what they hear rather than what they know (Kumar, 2011).

3.18. VALIDITY AND RELIABILITY

Studies, in general, have to be conducted in a valid and logical manner. The basis of the argument and evidence that supports the study should be logical and valid (Aiyetan, 2010). Mouton (2001) states that, to collect data, measuring instruments have to be used. These could be complicated instruments stemming from high-resolution microscopes to gas spectrometers, or instruments such as questionnaires, observation schedules, interviewing schedules and psychological tests. Leedy *et al.* (2014) highlight validity and reliability as two factors that are important when considering the measurement of data: validity is how sound and effective the measuring instrument is. This refers to how the instrument functions and how accurate it is in reading data; and Reliability deals with how accurate the measuring instrument is and how dependable the data read or taken from the instrument is.
The validity of a measurement is tested in many ways. These include:

- Face validity (this is a subjective judgement and is given by the researcher);
- Criterion-related validity (judgement is made of the measurement based on the standards that have been set);
- Content validity (this is the accuracy with which an instrument measures the factors or situations under study);
- Construct validity (this is the extent to which the conclusions reached in a study is free from bias), and
- External validity (this is the extent to which the conclusions reached in a study are generalised and applied to samples in other cases.

Kruger and Welman (2001), agree that there are two types of validity, namely: Construct validity (when a variable is measured with an instrument, the instrument must measure particularly what it is intended to measure) and Criterion-related validity (this refers to the correctness of the result of a measurement to the widely accepted standard result. The validity of the research instrument was determined through face validity and content validity. Respondents in the study confirmed that the instrument could provide adequate data to address the research objectives. The researcher also carried out scrutiny and modification of the research instrument to arrive at a workable questionnaire.

Reliability is the extent to which assessments are consistent. It is concerned with being accurate. Leedy *et al*. (2014) state that the measuring instrument must be consistent; it must yield certain results when the measurement is repeated and show the extent of error of a result. Reliability is about the question: with what accuracy does the measurement test inventory or questionnaire measure what it is intended to measure. In this study, Cronbach's Alpha coefficient was calculated for both questionnaires designed to be responded with Likert scale.

3.19. SUMMARY

The objective of the chapter was to outline the methodology used in the research. The data collected was used to identify trends relating to material wastage with the application of BIM. The feasibility of this chapter can be shown and the conclusions will be analysed in detail in the next chapter.

CHAPTER 4

DATA PRESENTATION AND DISCUSSION

This chapter presents the results of the data analyses and interpretation.

4.1. RESPONSE TO QUESTIONNAIRES

There were two questionnaires for the study that includes one main questionnaire and a validation questionnaire based on a developed flowchart.

4.1.1. Response to main questionnaire

Table 4. 1 Response rate

Province	Sample size	Questionnaires Received	Response Rate (%)
ASAQS	400	32	53.3
CESA	100	16	26.7
SACCMP	400	12	20.0

Questionnaire success rate = Questionnaires received x 100/questionnaires administered - returned questionnaires

$$60 \times 100 / 900 = 6.67\%$$

The questionnaire response rate for phase 1 is 6.67%. Based upon the number of questionnaires received, the response rate can be deemed sufficient for the statistical analyses that are to be conducted (Aiyetan, 2010).

4.1.2. Response rate

The following steps were taken in order to improve the response rate:

- The respondents were assured of their anonymity;
- A humane request was made to respondents by means of a covering letter;
- The questionnaire length was kept to a minimum for the study, and
- Emails were constantly sent to remind respondents about completing the questionnaire.

4.1.3. Missing values

Missing values in questionnaires are expected, though not desirable, as some of the respondents may not understand all the factors. The questionnaire allows a respondent to tick an 'unsure' option rather than to rate a factor incorrectly.

4.2. DEMOGRAPHIC DATA OF RESPONDENTS TO PHASE 1 QUESTIONNAIRE

This section describes the demographics of the respondents involved in the research. It reveals their experience, age, qualification and their status.

4.2.1. Sector

Table 4.2 indicates the sector distribution of the respondents. The majority of respondents belong to the private sector and constitute (96.7%) of the total sample ($p < 0.001$).

Table 4. 2 Sector distribution of respondents

	Frequency	Percent
Private Sector	58	96.7
Public Sector	2	3.3
Total	60	100.0

4.2.2. Province of Origin

The Figure 4.1 indicates the province from which the respondents originated.

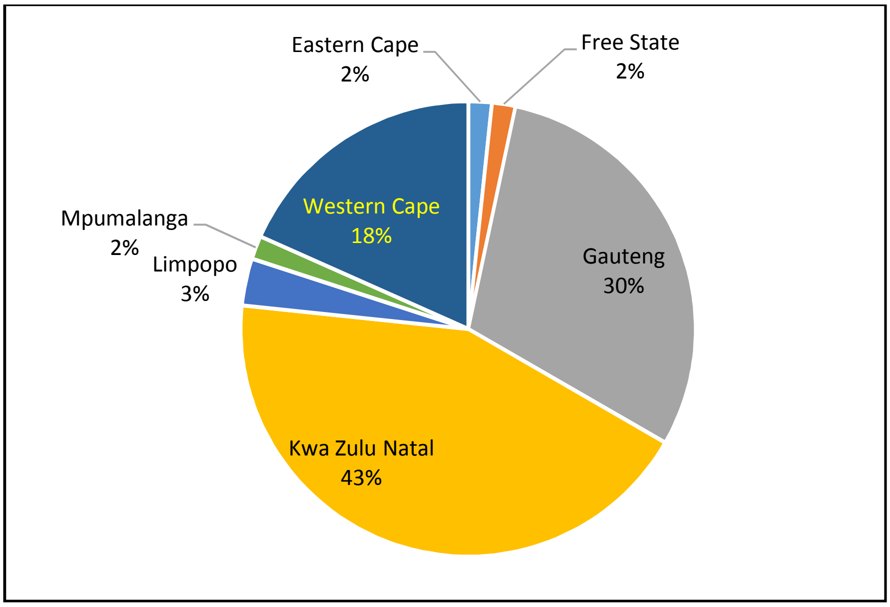


Figure 4.1 Province of Origin

The majority of the respondents were from KZN (43%) with about a third coming from Gauteng (30%) ($p < 0.001$). The least number of respondents were from Mpumalanga, Free State and Eastern Cape (2%).

4.2.3. Respondents' Gender

Figure 4.2 reveals that the male gender predominated with 85%. This supports the norm that the construction industry is male-dominated.

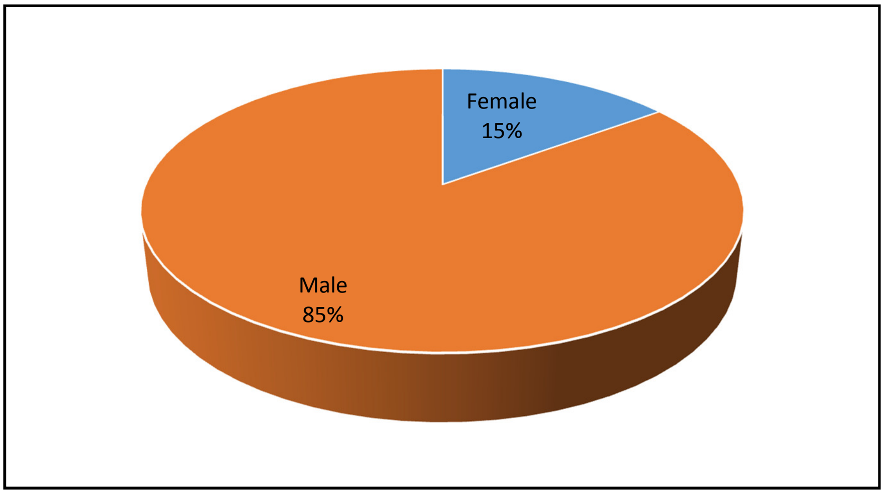


Figure 4.2 Gender distribution of respondents

4.2.4. Age of respondents

Figure 4.3 indicates the frequency of respondents' age. Respondents that are over the age of thirty (30) predominate in the sample investigated. This group of respondents constitutes 31%. Respondents between the ages of forty-one (41) and fifty (50) constitute 27%. It can be concluded that respondents that make up the survey sample are mature, have a high probability if being responsible and experienced.

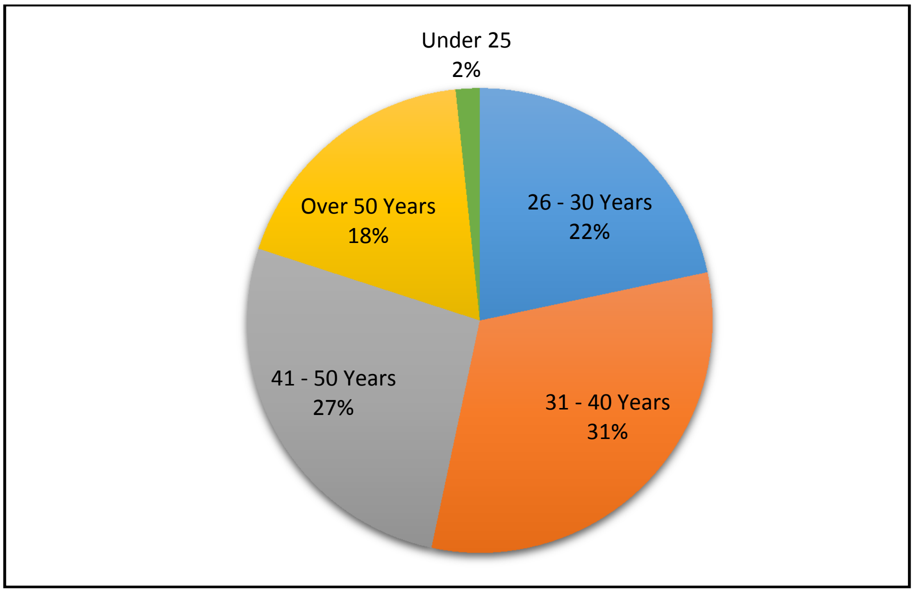


Figure 4.3 Distribution of respondents' age

4.2.5. Category of respondents' qualification

Figure 4.4 indicates the highest academic qualification of the respondents. 42% of the respondents have Bachelors' degrees, and they predominate in the sample. Respondents with Btech qualification rank next to those who have a master's degree in the form of eighteen (18) %. Followed closely are respondents with Diploma qualification totalled at fifteen (15) %. A fraction constituting of the other five (5) % and Matric certificate two (2) % does not have relative construction related qualifications. This analysis indicates that well-qualified personnel is employed in the industry, therefore, the performance is expected to be optimal. It reveals that their perceptions can be relied on.

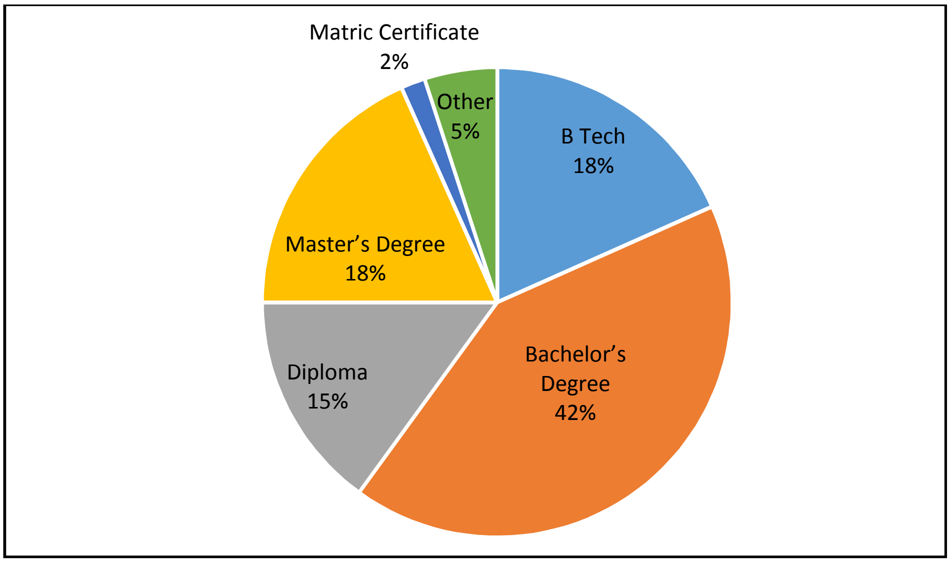


Figure 4.4: Category of respondents' qualification

4.2.6. Status in the organisation

Figure 4.5 indicates that senior staff (40%) predominate among respondents. Followed by junior respondents (20 %) and managers (21.7%). The lowest response is relative to the supervisor and other (1.7 %). Based on the analysis above 70% constitute experienced staff, which indicates the data obtained from these respondents can be relied on.

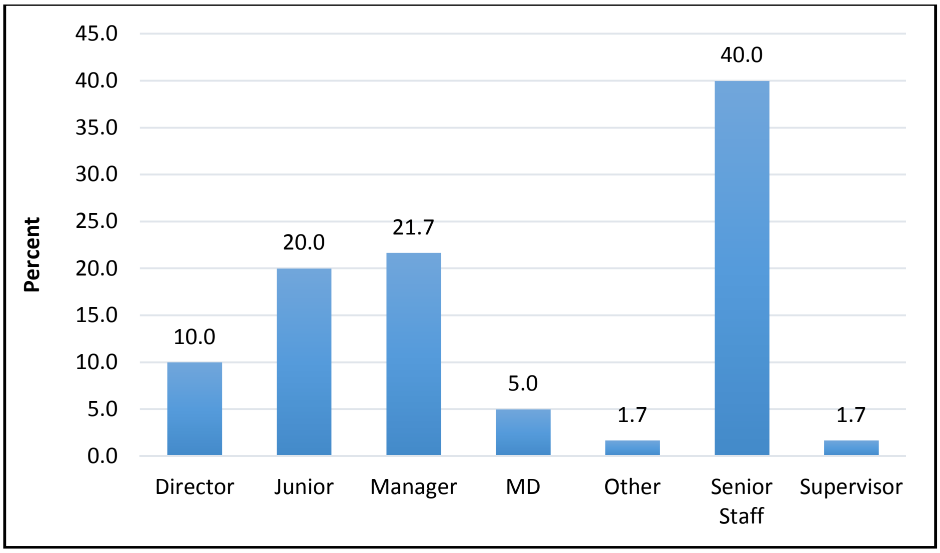


Figure 4.5 Respondents' status in their organisations

4.2.7. Respondents' years of experience

Figure 4.6 indicates that 15 – 30 years (30%) predominates the respondents. Followed closely is over 25 years (21.7%). The following years were 5-10 years (15%) and 0 – 5 years (13.3%) and 20 – 25 years (13.3%). This indicated that most of the respondents have adequate experience to allow them to answer the questions in the questionnaire regarding the industry.

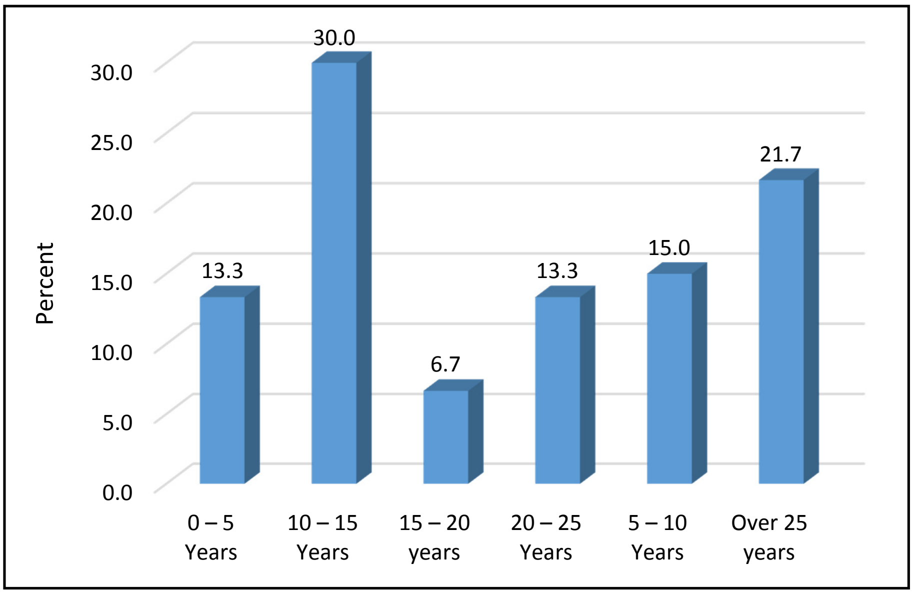


Figure 4.6 Number of respondents' years of experience

4.3. ANALYSIS OF MAIN QUESTION IN PHASE 1 QUESTIONNAIRE

Questionnaires were used in the collection of data. A five-point Likert scale adjoined with 'Unsure' (U) and 'Does not apply' (DN) options were used to measure the views of construction professionals within the construction industry in South Africa. Tables 4.3 to 4.19 indicate the observations of respondents relative to material waste with the aid of BIM in terms of percentage responses to a scale of 1 to 5, and a mean score (MS) ranging between 1.00 and 5.00. MSs were calculated for each statement to enable an interpretation of the percentages relative to each point on the response scale. There are five points on the scale, and that 5 – 1 = 4, the ranges were determined by dividing 4 by 5 which equates to 0.8. Consequently, the ranges and their definitions are as follows:

- > 4.20 ≤ 5.00 between a near major to major/major influence;
- > 3.40 ≤ 4.20 between moderate influence to a near major/near major influence;
- > 2.60 ≤ 3.40 between a near minor to moderate influence/moderate influence;
- > 1.80 ≤ 2.60 between a minor to near minor influence/near minor influence,
- > 1.00 ≤ 1.08 between a minor to near minor influence.

4.3.1. Reliability tests

According to Tavakol and Dennick (2011), the extent to which results are consistent and an accurate representation of the total population under study is known as reliability. The research instrument is considered reliable if the results of the study can be replicated under a similar methodology.

The results of the item analysis conducted to determine the reliability of the combined scores calculated for the various factor categories are reported below. The Item analysis was conducted for the one hundred and fifteen factors in the questionnaire. For each factor, Cronbach's coefficient α was calculated and a factor analysis specifying a one-factor model was conducted.

4.3.1.1 Cronbach's coefficient α test

Tests for the internal reliability of the factors in each category were conducted by determining their Cronbach's coefficient α value. Table 4.3 presents the results:

Table 4. 3 Cronbach's coefficient α value for all factor categories

Factor category	Cronbach's α
Escalation of material price	0.71
Incorrectly placed material	0.82
Lack of material control on site	0.80
Lack of communication leading to mistakes and errors	0.85
Wall tile	0.56
Poor distribution of tiles on site	0.84
Ordering of an additional allowance of concrete	0.86
Short unusable pieces are produced when bars are cut	0.87
Manufacturing defects	0.89
Incorrect storage methods	0.81
Ordering more quantities than what is required	0.83
Proper storage of materials on site	0.85
Improved cost estimating at each project stage	0.94
Lack of skilled personnel	0.86

Cronbach's α value for all (but 1) factor categories were > .70, with the exemption of one, which is regarded as adequate proof of internal consistency. It should be noted that Cronbach's α values of 0.50 to 0.70 are acceptable.

4.3.1.2 Results of factor analysis

Factor analysis was conducted to test the agreement between factors in each category. The results of the analysis are presented in Table 4.4.

Table 4. 4 Summary of factor analysis conducted for item analysis

Causes of Material Waste	Loadings
Procurement	
Escalation of material price	0.913
Substituting a material with an expensive one	0.614
Order errors (too much/too less)	0.822
Material purchased does not comply with the specification	0.786
Unsuitability of material supplied to site	0.804
Operational	
Incorrectly placed material	0.750
Shortage of tools and equipment	0.643
Incorrect construction methods	0.723
Inclement weather	0.913
Damage to work caused by other trades	0.884
Constant breakdown of equipment	0.524
Error by tradesman	0.607
Delays in getting information to the contractor on specification of product to be used	0.785
Incorrect material used and, therefore requires replacing	0.796
Material Handling and Storage	
Lack of material control on site	0.615
Theft	0.712
Poor handling	0.839
Damage of materials on site	0.764
Insufficient handling instructions	0.812
Wrong methods of transport	0.832
Poor methods of storage on site	0.653
Waste from cutting irregular shapes	0.625
Design and Documentation	
Lack of communication leading to mistakes and errors	0.528
Poor site layout	0.861
Incorrect specifications	0.796
Last minute change by client, therefore rework	0.560
Choice of low-quality product	0.803
Poor attention to dimensional coordination of product	0.658
Unclear/lack of information on drawing	0.736

Complex detail on drawing	0.874
Design change whilst in construction	0.822
Materials most prone to waste	
Wall tile	0.513
Floor Tile	0.843
Fresh Concrete	0.778
Reinforcement	0.768
Cement	0.811
Masonry	0.947
Timber	0.798
Tile	
Poor distribution of tiles on site	0.726
Cutting of tiles in great quantities	0.657
Damage during finishing	0.806
Inadequate workers	0.697
Excessive quantities of tile on site	0.613
Damaging of the tile during the necessary cutting process	0.820
Damage during transportation	0.726
Rework as a result of mistakes	0.712
Concrete	
Ordering of an additional allowance of concrete	0.888
Use of inadequate equipment and tools	0.587
Poor performance which leads to rework	0.874
Excessive dimensions of concrete structure	0.881
Inadequate use of vibration which leads to problems in concrete	0.719
Far distance between mixing and casting	0.694
Suppliers delivering quantities of material smaller than what was paid for	0.623
Reinforcement	
Poor handling because its cumbersome to handle due to shape and weight	0.816
Poor structure design in terms of detailing and standardization	0.914
Short unusable pieces are produced when bars are cut	0.813
Using bars that are much longer then what’s required	0.809
Rusting and damage during storage	0.772
Masonry	
Manufacturing defects	0.751
Excessive cutting	0.830
Damage to the unused quantities on site	0.880
Damage during unloading and transportation	0.897
Damage during storage	0.843
Timber	
Incorrect storage methods	0.823
Use of low-quality timber	0.820
Breaking of the timber boards during the removal of frames	0.798
Using the timber for purposes that isn’t required	0.749
Pipes	

Ordering more quantities than what is required	0.775
Poor storage	0.759
Incorrect cutting of pipes	0.909
Theft and Vandalism	0.724
Using pipes that don't comply with the specification	0.714
Waste preventative measures	
Proper storage of materials on site	0.802
Reduce design changes	0.875
Accurate measures of materials	0.577
The use of materials before expiry date	0.828
Promote re use of materials on projects	0.847
Careful handling of tools and equipment on site	0.585
Prompt and early scheduling of deliveries	0.776
Recycling excess waste materials on site	0.701
Vigilance of supervisors	0.899
Construction person undergoing courses (Training)	0.563
Constant training and education on handling of materials	0.709
The use of Building Information Modelling (BIM)	0.612
BIM Benefits	
Improved cost estimating at each project stage	0.733
Improved productivity of estimator in quantity take-off	0.752
Easier quantity take-off	0.892
Reduced cost from health and safety issues	0.817
Reduced overall project cost	0.609
Increased speed of delivering projects	0.691
Reduced overall project duration	0.706
Improved design quality	0.593
Reduced safety risks	0.847
Reduced redesign issues	0.708
Fewer change orders at the construction stage	0.550
Improved site analysis	0.711
Improved communication among various divisions of the same company	0.658
Improved documents management	0.640
Potentially Improved maintenance of the facility due to the as-built model	0.717
Enhanced work coordination with subcontractors	0.611
Greater predictability of project time and cost	0.536
Improved conflicts detection	0.870
Improved human resources management	0.857
BIM Challenges	
Lack of skilled personnel	0.558
Inadequate support available to the supply chain	0.599
People refusal/reluctance to learn	0.752
The unsuitability of some projects to the adoption of BIM	0.486
Client limitation due to high cost	0.706
Cost of training existing staff	0.653

Cost of new software and updates	0.676
Time required to produce the models	0.818
Time required to train existing staff	0.813
Time taken to implement BIM	0.791
Restructuring of organisation to accommodate BIM	0.768

Based upon the factor analysis loadings obtained for factors, the majority are greater than 0.60, There are some factors which have loadings a little lower than .60. These are Inadequate support available to the supply chain (.599), Use of inadequate equipment and tools (.587), Careful handling of tools and equipment on site (.585), Accurate measures of materials (.577), Construction person undergoing courses (Training) (.563), Last minute change by client, therefore rework (.560), Lack of skilled personnel (.558), Fewer change orders at the construction stage (.550), Greater predictability of project time and cost (.536), Lack of communication leading to mistakes and errors (.528), Constant breakdown of equipment (.524), Wall tile (.513) and The unsuitability of some projects to the adoption of BIM (.486) It can be deemed that the items for all factor categories have good agreement. This means that the factors adequately describe these categories. Some of the factors loaded perfectly along a single component whilst others split along 2, 3 or 4 components.

4.4. MAIN QUESTIONNAIRE ANALYSIS

Table 4. 5 Causes of Material Waste: Procurement factors

S/ No	Procurement Factors	Response (%)							Mean Score	Rank
		Unsure	Does not apply	Minor...............................Major						
				1.00	2.00	3.00	4.00	5.00		
1	Order errors (too much/too less)	1.7	1.7	10.0	18.3	28.3	30.0	10.0	3.12	1
2	Material purchased does not comply with the specification	0.0	1.7	15.0	13.3	40.0	20.0	10.0	2.97	2
3	Unsuitability of material supplied to site	0.0	0.0	13.3	25.0	35.0	16.7	10.0	2.85	3
4	Substituting a material with an expensive one	0.0	8.3	20.0	41.7	15.0	11.7	3.3	2.31	4
5	Escalation of material price	3.3	18.3	21.7	20.0	28.3	8.3	0.0	2.30	5

Table 4.5 presents the respondents' rating of the influence of procurement factors on the causes of material waste. It is notable that all factors in the category have MSs > 2.30 ≤ 3.20, which indicates that the factors have between a near minor to moderate/ moderate influence to material waste. The results above from respondents are in line with the literature (Nagapan *et al*. 2012 and Osmani, 2013).

The factor with the most significant influence is order errors (too much/too less) (MSs 3,12). The inadequacies originating from the design stage leads to incorrect quantities if too much material is ordered there is excess and this leads to the costs being covered by the contractor. When too little material is ordered this results in delays during construction.

Following this factor is material purchased does not comply with the specification (MSs 2.97). When details are not adequately expressed or easily accessible to any member of the design team, specifications pertaining to a particular project are not analysed.

The least significant factor is an escalation of material price (MSs 2.30). The price is not determined by any member of the design team. An increase in prices is allowed for at tender stage. These are the reasons why the factor may be the least influential.

Table 4. 6 Causes of material waste: Operational factors

S/ No	Operational Factors	Response (%)							Mean Score	Rank
		Unsure	Does not apply	Minor...................................Major						
				1.00	2.00	3.00	4.00	5.00		
1	Damage to work caused by other trades	0.0	1.7	3.3	10.0	25.0	28.3	31.7	3.76	1
2	Delays in getting information to the contractor on specification of product to be used	1.7	5.0	8.3	8.3	8.3	41.7	26.7	3.75	2
3	Incorrectly placed material	1.7	1.7	5.0	13.3	25.0	20.0	33.3	3.66	3
4	Error by tradesman	0.0	0.0	3.4	13.8	20.7	39.7	22.4	3.64	4
5	Incorrect material used and therefore requires replacing	0.0	0.0	10.2	8.5	27.1	25.4	28.8	3.54	5
6	Incorrect construction methods	0.0	1.7	0.0	21.7	26.7	33.3	16.7	3.46	6
7	Shortage of tools and equipment	3.4	3.4	11.9	20.3	32.2	15.3	13.6	2.98	7
8	Constant breakdown of equipment	1.7	3.3	15.0	23.3	21.7	23.3	11.7	2.93	8
9	Inclement weather	0.0	5.0	21.7	31.7	23.3	13.3	5.0	2.46	9

Table 4.6 presents the respondents' rating of the influence of operational factors on the causes of material waste. It is notable that all factors in the category have MSs > 3.40 ≤ 4.20 between moderate influence to a near major/near major influence to material waste. The results above from respondents are in line with the literature (Nagapan *et al*. 2012 and Osmani, 2013).

The factor with the most significant influence is damage to work caused by other trades (MSs 3.76). The poor coordination of machinery, equipment, and other trades lead to disorder and confusion on sites. These all have an effect on creating material waste due to rework.

Following this factor is delays in getting information to the contractor on the specification of the product to be used (MSs 3.75). Delayed information to the contractor will obstruct the smooth flow of operations on site, therefore, inducing delay to the project completion date.

The least significant factor is inclement weather (MSs 2.46). Although this factor is least influential and it is allowed for in the project programme, it does not imply that this factor is negligible as it has a time delay.

Table 4. 7 Causes of material waste: material storage and handling

S/ No	Material storage and handling factors	Response (%)							Mean Score	Rank
		Unsure	Does not apply	Minor......................................Major						
				1.00	2.00	3.00	4.00	5.00		
1	Lack of material control on site	0.0	1.8	3.5	5.3	19.3	42.1	28.1	3.88	1
2	Damage of materials on site	0.0	1.8	1.8	8.9	14.3	51.8	21.4	3.84	2
3	Waste from cutting irregular shapes	0.0	0.0	1.7	15.0	21.7	28.3	33.3	3.77	3
4	Poor methods of storage on site	0.0	0.0	5.0	11.7	16.7	51.7	15.0	3.60	4
5	Poor handling	0.0	0.0	0.0	15.8	31.6	47.4	5.3	3.42	5
6	Theft	0.0	1.8	3.5	19.3	40.4	21.1	14.0	3.23	6
7	Wrong methods of transport	1.7	1.7	3.4	20.3	35.6	28.8	8.5	3.19	7
8	Insufficient handling instructions	1.7	0.0	10.2	13.6	40.7	28.8	5.1	3.05	8

Table 4.7 presents the respondents' rating of the influence of material storage and handling on the causes of material waste. It is notable that all factors in the category have MSs > 3.40 ≤ 4.20 between moderate influence to a near major/near major influence to material waste. The results above from respondents are in line with the literature (Kofoworola and Gheewala, 2009 and Patel and Vyas, 2011).

The factor with the most significant influence is the lack of material control on site (MSs 3.88). Supervisor's lack adequate training and contractors fail to develop new material control procedures.

Following this factor is damage of materials on site (MSs 3.84). The probable reason for this is materials are ordered to early and poor storage facilities on sites results deterioration

The least significant factor is insufficient handling instructions (MSs 3.05). Although this factor has a minimal contribution to waste, time must be taken to research material specifications and their correct handling instructions in the planning phase.

Table 4. 8 Causes of material waste: Design and documentation

S/ No	Design and documentation Factors	Response (%)							Mean Score	Rank
		Unsure	Does not apply	Minor.............................Major						
				1.00	2.00	3.00	4.00	5.00		
1	Last minute change by client, therefore rework	0.0	1.7	3.3	6.7	13.3	41.7	33.3	3.97	1
2	Design change whilst in construction	0.0	0.0	3.3	8.3	13.3	43.3	31.7	3.92	2
3	Lack of communication leading to mistakes and errors	0.0	1.7	0.0	18.3	16.7	36.7	26.7	3.73	3
4	Unclear/lack of information on drawing	1.7	0.0	11.7	11.7	28.3	30.0	16.7	3.29	4
5	Incorrect specifications	0.0	3.3	10.0	13.3	35.0	28.3	10.0	3.16	5
6	Complex detail on drawing	0.0	1.7	13.8	15.5	24.1	32.8	12.1	3.14	6
7	Poor site layout	0.0	0.0	6.7	26.7	26.7	28.3	11.7	3.12	7
8	Poor attention to dimensional co-ordination of product	1.7	1.7	8.5	18.6	35.6	23.7	10.2	3.09	8
9	Choice of low-quality product	0.0	0.0	6.7	23.3	41.7	16.7	11.7	3.03	9

Table 4.8 agrees with the literature that explains the waste causes due to design and documentation. It is notable that all factors in the category have MSs $> 3.40 \leq 4.20$ which indicate that the factors between moderate influence to a near major/near major influence on waste contribution (Babatunde, 2012 and Osmani, 2013).

The factor that has a significant influence is last minute change by the client, therefore rework. It is not compulsory for the client to be knowledgeable in construction or else there would be no need for contractors, therefore, it is wise for the design team to advise the client prior to construction to prevent demolition and rework.

The following factor is design change whilst in construction. When there is a change whilst in construction it causes a delay to all trades involved in the project

The least significant factor is the choice of low-quality product. Although this factor contributes to waste, a low-quality product is occasionally chosen due to cost constraints.

Table 4. 9 Material most prone to waste during construction

S/ No	Factor	Response (%)							Mean Score	Rank
		Unsure	Does not apply	Minor...................................Major						
				1.00	2.00	3.00	4.00	5.00		
1	Floor Tile	3.4	0.0	8.6	6.9	15.5	32.8	32.8	3.77	1
2	Fresh Concrete	3.6	0.0	10.7	3.6	17.9	30.4	33.9	3.76	2
3	Cement	0.0	0.0	10.3	15.5	20.7	5.2	48.3	3.66	3
4	Masonry	1.8	0.0	5.3	10.5	21.1	42.1	19.3	3.61	4
5	Reinforcement	0.0	0.0	3.5	17.5	19.3	35.1	24.6	3.60	5
6	Timber	1.7	0.0	6.9	13.8	39.7	29.3	8.6	3.19	6
7	Wall tile	6.3	6.3	6.3	25.0	18.8	31.3	6.3	3.07	7
8	Pipes	0.0	1.7	12.1	31.0	36.2	17.2	1.7	2.65	8

The results presented in Table 4.9 agree with the literature which explains materials that contribute to waste. It is notable that all factors in the category have MSs > 3.40 ≤ 4.20 which indicate that the factors between moderate influence to a near major/ near major influence on waste contribution (Nagapan *et al*. 2012 and Kareem and Pandey, 2013). The material with the most significant contribution to waste is floor tile, followed by fresh concrete and lease significant is pipes.

Table 4. 10 Factors as they contribute to material waste: Tile

S/ No	Factor	Response (%)							Mean Score	Rank
		Unsure	Does not apply	Minor.......................................Major						
				1.00	2.00	3.00	4.00	5.00		
1	Rework as a result of mistakes	1.7	1.7	0.0	5.2	17.2	48.3	25.9	3.98	1
2	Damaging of the tile during the necessary cutting process	1.7	1.7	3.4	6.8	11.9	45.8	28.8	3.93	2
3	Cutting of tiles in great quantities	1.7	1.7	3.4	6.8	18.6	37.3	30.5	3.88	3
4	Damage during finishing	1.7	1.7	3.4	8.6	22.4	39.7	22.4	3.71	4
5	Excessive quantities of tile on site	1.7	1.7	5.1	13.6	22.0	42.4	13.6	3.47	5
6	Inadequate workers	3.4	1.7	6.8	27.1	13.6	30.5	16.9	3.25	6
7	Damage during transportation	1.7	1.7	15.3	11.9	15.3	44.1	10.2	3.23	7
8	Poor distribution of tiles on site	1.7	1.7	15.3	16.9	16.9	28.8	18.6	3.19	8

The results presented in Table 4.10 agree with the literature that explains that tile is a major waste contributor. It is notable that all factors in the category have MSs > 3.40 ≤ 4.20 which indicate that the factors between moderate influence to a near major/ near major influence on waste contribution.

The factor that has a significant influence is rework as a result of mistakes. An error during the design process can lead to waste. Unclear instructions and poor distribution of specifications lead to rework as a result of mistakes.

The following significant factor is damaging of the tile during the necessary cutting process. Abnormal designs require cutting at irregular shapes. Poor planning also contributes to waste pieces are cut and left aside before it is needed.

The least significant factor is poor distribution of tiles on site. This may occur if the project programme is not carefully planned out or persons responsible for material distribution is not fully trained.

Table 4. 11 Factors as they contribute to material waste: concrete

S/ No	Factor	Response (%)							Mean Score	Rank
		Unsure	Does not apply	Minor......................................				..Major		
				1.00	2.00	3.00	4.00	5.00		
1	Ordering of an additional allowance of concrete	0.0	1.7	10.0	6.7	16.7	46.7	18.3	3.58	1
2	Poor performance which leads to rework	0.0	1.7	1.7	23.3	23.3	30.0	20.0	3.44	2
3	Excessive dimensions of concrete structure	1.7	3.3	10.0	13.3	16.7	38.3	16.7	3.40	3
4	Inadequate use of vibration which leads to problems in concrete	0.0	1.7	11.9	18.6	22.0	30.5	15.3	3.19	4
5	Suppliers delivering quantities of material smaller than what was paid for	1.7	8.3	18.3	16.7	16.7	25.0	13.3	2.98	5
6	Use of inadequate equipment and tools	0.0	3.3	10.0	23.3	31.7	25.0	6.7	2.95	6
7	Far distance between mixing and casting	1.7	3.4	10.2	30.5	23.7	18.6	11.9	2.91	7

The results presented in Table 4.11 agree with the study by Kareem and Pandey (2013) that concrete allowance contributes to waste. It is notable that all factors in the category have MSs > 3.40 ≤ 4.20 which indicate that the factors between moderate influence to a near major/near major influence on waste contribution.

The factor that has a significant influence is the ordering of an additional allowance of concrete. Incorrectly measured quantities will result in extra material being stored on site that may never be used.

The following significant factor is poor performance which leads to rework. Rework occurs when there is minimal curing time. Poor planning results in accelerated work subsequently leading to rework

The least significant factor is the far distance between mixing and casting. The ease of access of materials to the construction site is directly proportional to how fast the project can be completed.

Table 4. 12 Factors as they contribute to material waste: reinforcement

S/ No	Factor	Response (%)							Mean Score	Rank
		Unsure	Does not apply	Minor..Major						
				1.00	2.00	3.00	4.00	5.00		
1	Rusting and damage during storage	0.0	13.3	0.0	5.0	6.7	8.3	66.7	4.58	1
2	Short unusable pieces are produced when bars are cut	1.7	3.3	11.7	8.3	21.7	20.0	33.3	3.58	2
3	Poor handling because it is cumbersome to handle due to shape and weight	0.0	5.2	22.4	5.2	6.9	29.3	31.0	3.44	3
4	Poor structure design in terms of detailing and standardization	1.7	1.7	20.3	3.4	13.6	37.3	22.0	3.39	4
5	Using bars that are much longer then what's required	0.0	1.7	13.6	13.6	23.7	18.6	28.8	3.36	5

The results presented in Table 4.12 agree with the study by Agyekum, (2012) that explains that the storage of reinforcement has a significant influence on waste. It is notable that all factors in the category have MSs > 4.20 ≤ 5.00 between a near major to major/major influence on waste contribution.

The factor that has a significant influence is rusting and damage during storage. An excess in quantity of reinforcement bars results in unwanted material being left aside. The material in due course deteriorates due to inclement weather.

The following significant factor is short unusable pieces are produced when bars are cut. Irregular building designs lead to trimming and cutting of bars. Reinforcement bars come in set sizes with is meant to be used all at once.

The least significant factor is using bars that are much longer than what is required. It is least because though reinforcement bars are of an incorrect length it can still be used.

Table 4. 13 Factors as they contribute to material waste: masonry

S/ No	Factor	Response (%)							Mean Score	Rank
		Unsure	Does not apply	Minor...Major						
				1.00	2.00	3.00	4.00	5.00		
1	Damage to the unused quantities on site	1.8	1.8	3.5	12.3	21.1	31.6	28.1	3.71	1
2	Excessive cutting	1.8	1.8	3.5	10.5	26.3	38.6	17.5	3.58	2
3	Damage during unloading and transportation	1.7	1.7	8.6	12.1	25.9	27.6	22.4	3.45	3
4	Damage during storage	1.7	1.7	13.8	12.1	12.1	43.1	15.5	3.36	4
5	Manufacturing defects	1.8	1.8	24.6	15.8	24.6	22.8	8.8	2.75	5

The results presented in Table 4.13 agree with the study by Agyekum, (2012) which identified that there is significant damage to unused material on site. It is notable that all factors in the category have MSs > 4.20 ≤ 5.00 between a near major to major/ major influence on waste contribution (Agyekum, 2012).

The factor that has a significant influence is damage to the unused quantities on site. Purchasing an excess quantity of masonry results in the unused quantities being damaged due to continuous work and weather conditions.

The following significant factor is Excessive cutting. This occurs when there are uncommon building designs. The material is cut to accommodate the design, which results in wastage.

The least significant factor is manufacturing defects. Although this is the least significant factor and contributes to waste a contractor has no control over rectifying defects.

Table 4. 14 Factors as they contribute to material waste: timber

S/ No	Factor	Response (%)							Mean Score	Rank
		Unsure	Does not apply	Minor.....................................major						
				1.00	2.00	3.00	4.00	5.00		
1	Breaking of the timber boards during the removal of frames	3.3	5.0	10.0	18.3	15.0	35.0	13.3	3.25	1
2	Using the timber for purposes that isn't required	1.7	3.3	13.3	16.7	25.0	26.7	13.3	3.11	2
3	Incorrect storage methods	1.7	1.7	6.8	33.9	13.6	30.5	11.9	3.07	3
4	Use of low-quality timber	1.7	3.3	15.0	21.7	23.3	30.0	5.0	2.88	4

The results presented in Table 4.14 agree with the study by Agyekum, (2012) explains that incorrect removal of timber after use contributes to waste, this can have a significant effect on the cost as timber can be reused. It is notable that all factors in the category have MSs > 2.60 ≤ 3.40 between a near minor to moderate influence/ moderate influence on waste contribution.

The factor that has a significant influence is breaking of the timber boards during the removal of frames. This occurs when a project is behind the project completion date. Another reason for the breaking of boards is employees are not properly trained in ways to minimise waste.

The following significant factor is using the timber for purposes that are not required. When there is a lack of material control, the material on site is easily accessible to any trade.

The least significant factor is the use of low-quality timber, although this factor is least significant, the use of low-quality timber deteriorates at a much quicker rate than a much higher quality timber. The reason for low-quality is mainly due to cost constraints.

Table 4. 15 Factors as they contribute to material waste: pipes

S/ No	Factor	Response (%)							Mean Score	Rank
		Unsure	Does not apply	Minor.......................................Major						
				1.00	2.00	3.00	4.00	5.00		
1	Ordering more quantities than what is required	0.0	5.1	11.9	22.0	18.6	23.7	18.6	3.16	1
2	Incorrect cutting of pipes	0.0	1.7	3.4	32.8	25.9	25.9	10.3	3.07	2
3	Using pipes that don't comply with the specification	0.0	5.2	15.5	12.1	32.8	20.7	13.8	3.05	3
4	Poor storage	0.0	5.1	10.2	25.4	20.3	28.8	10.2	3.04	4
5	Theft and Vandalism	0.0	3.4	11.9	18.6	32.2	22.0	11.9	3.04	5

The results presented in Table 4.15 agree with the study by Agyekum, (2012) explaining that ordering more quantity than what is required for pipes has a significant influence on material waste. It is notable that all factors in the category have MSs > 2.60 ≤ 3.40 between a near minor to moderate influence/moderate influence on waste contribution.

The factor that has a significant influence is ordering more quantities than what is required. The most probable reason for this is incorrect measures taken which results in extra leftover material.

The following significant factor incorrect cutting of pipes. Lack of training of employees under a specific trade will result in work being carried out incorrectly.

The least significant factor is theft and vandalism. Although this factor contributes to waste, however, with the correct security measure it can be prevented.

Table 4. 16 Preventative measures of material waste

S/ No	Factor	Response (%)							Mean Score	Rank
		Unsure	Does not apply	Minor....................................Major						
				1.00	2.00	3.00	4.00	5.00		
1	Proper storage of materials on site	0.0	0.0	0.0	5.1	13.6	30.5	50.8	4.27	1
2	Vigilance of supervisors	0.0	0.0	0.0	1.7	18.3	40.0	40.0	4.18	2
3	Construction person undergoing courses (Training)	0.0	0.0	0.0	5.3	21.1	36.8	36.8	4.05	3
4	The use of Building Information Modelling (BIM)	5.0	0.0	3.3	3.3	10.0	48.3	30.0	4.04	4
5	Accurate measures of materials	0.0	0.0	0.0	3.3	26.7	46.7	23.3	3.90	5
6	Constant training and education on handling of materials	0.0	0.0	1.7	5.1	30.5	28.8	33.9	3.88	6
7	Prompt and early scheduling of deliveries	0.0	0.0	3.4	0.0	31.0	36.2	29.3	3.88	7
8	Reduce design changes	0.0	0.0	3.3	1.7	18.3	58.3	18.3	3.87	8
9	Recycling excess waste materials on site	0.0	0.0	3.3	1.7	31.7	31.7	31.7	3.87	9
10	Careful handling of tools and equipment on site	0.0	1.7	3.3	6.7	16.7	45.0	26.7	3.86	10
11	Promote re use of materials on projects	0.0	1.7	5.1	6.8	15.3	40.7	30.5	3.86	11
12	The use of materials before expiry date	1.7	0.0	8.3	13.3	31.7	23.3	21.7	3.37	12

The results above in Table 4.16 that explains current measures that are used to prevent waste. It is notable that all factors in the category have MSs > 2.60 ≤ 3.40 between a near minor to moderate influence / moderate influence on waste contribution. The factor that has the most significant influence is the proper storage of materials on site. Storing materials in correct conditions away from weather damage, in the correct temperature and away from traffic will allow the use of extra material to be used for another construction project.

Ranked second is the vigilance of supervisors. The supervision and availability of supervisors to assist all trades including the contractor and subcontractors in order to correctly manage materials. Ranked third is a construction person undergoing courses (Training). When employees undergo training, they understand the need to prevent waste. It also enables employees to provide better-reducing measures to contractors as they are directly involved in construction.

Ranked fourth is the use of Building Information Modelling (BIM). This new technology updates the BIM model, whenever there is a design change that is accessible to all trades involved in a project. It provides the correct quantities, therefore, reducing rework and notifies when the material is needed.

Ranked fifth is accurate measures of materials. The correct measuring of materials will reduce the extra material purchased and wasted

Ranked twelfth is the use of materials before the expiry date. Using material before the expiry of its shelf life will prevent purchasing the material again.

Table 4. 17 Benefits of BIM in the delivery of a project

S/ No	Factor	Response (%)							Mean Score	STD Dev	Rank
		Unsure	Does not apply	Minor.............................Major							
				1.00	2.00	3.00	4.00	5.00			
1	Improved cost estimating at each project stage	1.7	0.0	0.0	6.8	5.1	40.7	45.8	4.28	0.85	1
2	Improved communication among various divisions of the same company	3.4	0.0	0.0	6.8	8.5	39.0	42.4	4.21	0.88	2
3	Easier quantity take-off	1.7	0.0	3.4	8.5	5.1	28.8	52.5	4.21	1.10	3
4	Improved documents management	1.7	0.0	0.0	8.6	6.9	39.7	43.1	4.19	0.91	4
5	Potentially Improved maintenance of the facility due to the as-built model	3.4	0.0	0.0	6.8	10.2	45.8	33.9	4.11	0.86	5
6	Increased speed of delivering projects	1.7	5.1	8.5	3.4	10.2	22.0	49.2	4.07	1.27	6
7	Improved conflicts detection	3.4	1.7	0.0	10.3	13.8	29.3	41.4	4.07	1.02	7
8	Fewer change orders at the construction stage	5.2	0.0	1.7	6.9	12.1	36.2	37.9	4.07	1.00	8
9	Enhanced work coordination with subcontractors	1.7	1.7	3.4	5.1	11.9	37.3	39.0	4.07	1.03	9
10	Reduced overall project cost	3.4	1.7	5.1	3.4	10.2	40.7	35.6	4.04	1.06	10
11	Reduced redesign issues	1.7	0.0	0.0	10.2	10.2	44.1	33.9	4.03	0.94	11
12	Improved productivity of estimator in quantity take-off	1.7	0.0	3.4	6.8	8.5	47.5	32.2	4.00	1.01	12
13	Improved design quality	3.4	0.0	5.1	6.8	8.5	39.0	37.3	4.00	1.12	13
14	Improved site analysis	1.7	0.0	1.7	5.1	11.9	54.2	25.4	3.98	0.87	14
15	Greater predictability of project time and cost	5.1	1.7	1.7	8.5	11.9	40.7	30.5	3.96	1.00	15
16	Reduced overall project duration	1.7	0.0	8.5	5.1	22.0	40.7	22.0	3.64	1.15	16
17	Reduced safety risks	3.4	0.0	8.5	6.8	25.4	40.7	15.3	3.49	1.12	17

18	Reduced cost from health and safety issues	5.1	0.0	8.5	11.9	22.0	40.7	11.9	3.38	1.14	18
19	Improved human resources management	3.4	1.7	3.4	16.9	35.6	18.6	20.3	3.38	1.12	19

The results present in table 4.17 that explains the benefits of BIM. It is notable that all factors in the category have MSs > 4.20 ≤ 5.00 between a near major to major/major influence on waste contribution. The survey results are in line with the literature identified in chapter 2 (Farnsworth et al. 2014; Parvan, 2012; Lindblad, 2013; Holness 2006).

The factor that has a significant influence is improved cost estimating at each project stage. Compared to traditional quantity take-offs and cost estimation that occurs late in the design stage, BIM updates at every change.

Ranked second is improved communication among various divisions of the same company. BIM's communication purpose is used to present information about the project in a way that can be accessible to any member of the construction project. It reduces response time as each member can update the model.

Ranked third is easier quantity take-off. The model is constantly updated with revision changes for accuracy.

Ranked fourth is improved documents management. The model is an electronic version of the project from start to completion and therefore, all documents are electronic that can be accessed at any time.

Ranked fifth is potentially improved maintenance of the facility due to the as-built model. Once construction is complete, the model can be kept and monitored for maintenance, refurbishments, and even demolition.

Ranked sixth is the increased speed of delivering projects. A BIM project is linked and functions as a single unit. This means information is easily accessible and at any point in time, Clash detection schedules, design change, and quantities are updated instantly.

Ranked seventh is improved conflicts detection. In the design stage, prior to construction, the model assist in conflict resolution and therefore, reducing design errors.

Ranked eighth is fewer change orders at the construction stage. With the majority of changes occurring at the design stage, the construction stage has minimal changes that do not have a significant impact on the project.

Ranked ninth is enhanced work coordination with subcontractors. BIM's enhanced coordination provides a detailed programme and gives subcontractors access to the model to update if there is a design change.

Ranked tenth is reduced overall project cost. Material cost, plant cost and standing time can be significantly reduced with BIM by providing the contractor with information to avoid error as well as rework.

The least significant factor is improved human resources management. Although BIM assists with construction resource as well as labour there is no significant tool to assist with human resources. Probably the reason as to why this is the least significant factor.

Table 4. 18 Challenges of BIM relative to delivery of a project

S/ No	Factor	Response (%)							Mean Score	STD Dev	Rank
		Unsure	Does not apply	Minor......................................Major							
				1.00	2.00	3.00	4.00	5.00			
1	Lack of skilled personnel	3.3	0.0	0.0	3.3	8.3	36.7	48.3	4.34	0.78	1
2	Client limitation due to high cost	3.3	0.0	0.0	10.0	8.3	36.7	41.7	4.14	0.96	2
3	Cost of training existing staff	3.4	1.7	1.7	3.4	23.7	30.5	35.6	4.00	0.97	3
4	Inadequate support available to the supply chain	3.3	0.0	0.0	6.7	15.0	50.0	25.0	3.97	0.84	4
5	Cost of new software and updates	3.4	0.0	3.4	1.7	22.4	36.2	32.8	3.96	0.99	5
6	Time taken to implement BIM	3.4	0.0	3.4	10.2	11.9	37.3	33.9	3.91	1.11	6
7	Time required to train existing staff	3.4	0.0	1.7	5.1	23.7	35.6	30.5	3.91	0.97	7
8	People refusal/reluctance to learn	0.0	1.7	6.7	8.3	16.7	26.7	40.0	3.86	1.24	8
9	Restructuring of organisation to accommodate BIM	0.0	1.7	1.7	10.3	24.1	29.3	32.8	3.82	1.07	9
10	Time required to produce the models	5.1	0.0	3.4	5.1	23.7	39.0	23.7	3.79	0.97	10
11	The unsuitability of some projects for the adoption of BIM	5.1	0.0	3.4	8.5	25.4	30.5	27.1	3.73	1.09	11

The results presented in Table 4.18 that explains the challenges of BIM. It is notable that all factors in the category have MSs > 4.20 ≤ 5.00 between a near major to major /major influence on waste contribution.

The factor that has a significant influence is the lack of skilled personnel. BIM requires fully trained personnel to understand the programme and model to use it to its full potential.

Ranked second is client limitation due to the high cost. A high start-up cost to implement BIM can be a probable reason as to why clients reluctance to adopt a BIM project.

Ranked third is the cost of training existing staff. Since the software is relatively new in South Africa, initial training can be costly for a company.

Ranked fourth is inadequate support available to the supply chain. Limited support is due to the BIM's slow adoption however with more projects wanting to save cost, the support will increase.

Ranked fifth is the cost of new software and updates. The BIM software is constantly being updated to meet the needs of the construction industry, therefore, a cost is involved to update.

The least significant factor is the unsuitability of some projects for the adoption of BIM. Some projects are not designed to suit BIM but with the change and rapid growth of the construction industry projects are now becoming more BIM friendly.

Table 4. 19 Ranking of Factors' of the causes of material waste according to their MSs

S/ No	Factor	Valid Number	Std. Dev	Mean	Rank
1	Last minute change by client, therefore rework	59	1.03	3.97	1
2	Design change whilst in construction	60	1.05	3.92	2
3	Lack of material control on site	56	1.01	3.88	3
4	Damage of materials on site	55	0.94	3.84	4
5	Waste from cutting irregular shapes	60	1.13	3.77	5
6	Damage to work caused by other trades	59	1.12	3.76	6
7	Delays in getting information to the contractor on specification of product to be used	56	1.22	3.75	7
8	Lack of communication leading to mistakes and errors	59	1.06	3.73	8
9	Incorrectly placed material	58	1.24	3.66	9
10	Error by tradesman	58	1.09	3.64	10
11	Poor methods of storage on site	60	1.04	3.60	11
12	Incorrect material used and therefore, requires replacing	59	1.28	3.54	12
13	Incorrect construction methods	59	1.02	3.46	13
14	Poor handling because its cumbersome to handle due to shape and weight	55	1.57	3.44	14
15	Wrong methods of transport	57	0.99	3.19	15
16	Incorrect specifications	58	1.12	3.16	16
17	Complex detail on drawing	57	1.25	3.14	17
18	Order errors (too much/too less)	58	1.14	3.12	18
19	Poor site layout	60	1.16	3.12	19
20	Poor attention to dimensional coordination of product	57	1.11	3.09	20
21	Insufficient handling instructions	58	1.03	3.05	21
22	Theft and Vandalism	57	1.19	3.04	22
23	Choice of low-quality product	60	1.07	3.03	23
24	Shortage of tools and equipment	55	1.22	2.98	24
25	Material purchased does not comply with the specification	59	1.17	2.97	25
26	Constant breakdown of equipment	57	1.28	2.93	26
27	Unsuitability of material supplied to site	60	1.16	2.85	27
28	Inclement weather	57	1.15	2.46	28
29	Substituting a material with an expensive one	55	1.07	2.31	29
30	Escalation of material price	47	1	2.30	30

Table 4.19 presents thirty factors, which signify the causes of material waste: Last minute changes by the client, therefore rework has the highest MS of 3.97. This means that design changes by the client have the most contribution to waste.

Design change whilst in construction (MS = 3.92), a design change causes delay and rework. Lack of material control on site is ranked third (MS = 3.88), supervisors lack sufficient training on material control procedures. Damage of materials on site is ranked fourth (MS = 3.84), materials are ordered too early and poor storage facilities are provided on site. Waste from cutting irregular shapes is ranked fifth (MS = 3.77), irregular design causes significant waste due to unique shapes.

Damage to work caused by other trades is ranked sixth (MS = 3.76), poor planning causes many trades to work at once, therefore due to high traffic on site, damages occur on finished work. Delay in getting information to the contractor on the specification of the product to be used is ranked seventh (MS = 3.75), delaying information to the contractor will have an effect on the overall project completion. Lack of communication leading to mistakes and errors is ranked eight (MS = 3.73), when valuable information is not correctly distributed to members of the project errors can occur. Incorrectly placed material is ranked ninth (MS = 3.66), poor communication on site leads to incorrect setting out. Error by tradesman is ranked tenth (MS = 3.64), tradesmen require training from the main contractor to minimise any risks or errors.

5.1 Testing of hypotheses

Table 4.20: Summary of p-value tests conducted on the hypotheses

Null hypotheses	Test of means against reference constant (value)			
	Valid Numbers	Mean	Standard deviation	p-value
There are significant causes of waste in construction	58	3.27	1.106	0.0682
There are significant sources of waste in construction	56	3.29	1.207	0.0784

The following are the conditions governing the testing:

The significance level α = 5% (0.05), and

The confidence level is at 95%.

Null (μ) = 3 and alternative μ > 3, where μ = mean = 3.

First Hypothesis

The null hypothesis states that:

H_o = There are significant causes of waste in construction.

The alternative hypothesis states that:

H1 = There are no significant causes of waste during construction processes on construction sites.

Decision rule

If p – value < 0.05, then H_o is rejected, but the average p – value = 0, 0682 p > 0.05

Therefore, H_o There are significant causes of waste in construction accepted since p > 0.05

Second Hypothesis

The null hypothesis states that:

H_o = There are significant sources that contribute to waste in construction.

The alternative hypothesis states that:

H1 = There are no significant sources that contribute to waste during the construction of a project.

Decision rule

If p – value < 0.05, then H_o is rejected, but the average p – value = 0, 0784 p > 0.05

Therefore, H_o there are significant sources that contribute to waste in construction is accepted since p > 0.05.

CHAPTER 5

DEVELOPMENT OF A FLOWCHART

5.1 INTRODUCTION

This research has explored the use of BIM as a method during construction to reduce material waste. Based on the causes of waste discussed in the previous chapter and findings from the questionnaire (Table 6.1). It has been established that material is a major contribution to waste in construction. Therefore, BIM will be used as a way to mitigate the waste.

5.2 APPLICATION OF BIM RELATIVE TO MATERIAL WASTE REDUCTION

This research has not only added value to existing knowledge by improving the understanding of how BIM can be used in construction to reduce material waste with the use of a flowchart (Figure 5.1) with the aid of processes such as clash detection, detailing, coordination and communication, and visualisation and simulation. The following steps are proposed before starting a BIM project;

5.2.1 The BIM Process

The recommended BIM process is as follows;

A. *Design Phase*

I. People involved in the design team include; engineers, architects, and surveyors. If the design team is identified at an early stage, key decisions involving collaboration and interoperability can be taken.

II. A contract is drawn up by the BIM manager based on BIM requirements and objectives. The BIM model requirements must be presented in all design contracts:
    - Identify the exchange of file methods and formats.
    - Identify the development level required at each stage
    - Identify and define key moments when the models are frozen (Collaboration, Clash detection)

- The specifications have to be taken into account as early as possible to improve the exchange process.

III. Coordination and grid lines are identified, set out and sent to all members who are part of the design team.

IV. If there is an addition to the design team at a later stage, the following is communicated:
   - A detailed explanation of BIM's explanations
   - The exchange process is communicated and explained
   - A contact list of the design team
   - A detailed list of software products used

B. Tender Phase

V. A BIM project tender documents in addition to the general tender requirements contain:
   - A BIM model from each sector (Structural and Architectural).
   - A coordinated BIM design model
   - A document indicating the BIM requirements of a contractor
   - A document indicating the software used.

VI. A copy of the document is saved and kept by each member of the design team.

VII. A signed off document containing a list of all exchanged documents is provided.

C. Building Phase

A BIM contract clearly indicating the BIM duties is signed once a contractor is appointed. The contractor has to:

- Receive a contact list
- Receive a list of software products
- Understand the exchange process
- Understand BIMs aims

5.3 THE MODEL FLOWCHART

For the purpose of this study and to avoid the complexity of a flowchart, an approach aimed at the contractor (quantity surveyors, engineers, project manager and construction managers employed by contractors) was designed and presented in Figure 5.1, which represents the components and description of BIM's advanced tools to aid in waste minimisation.

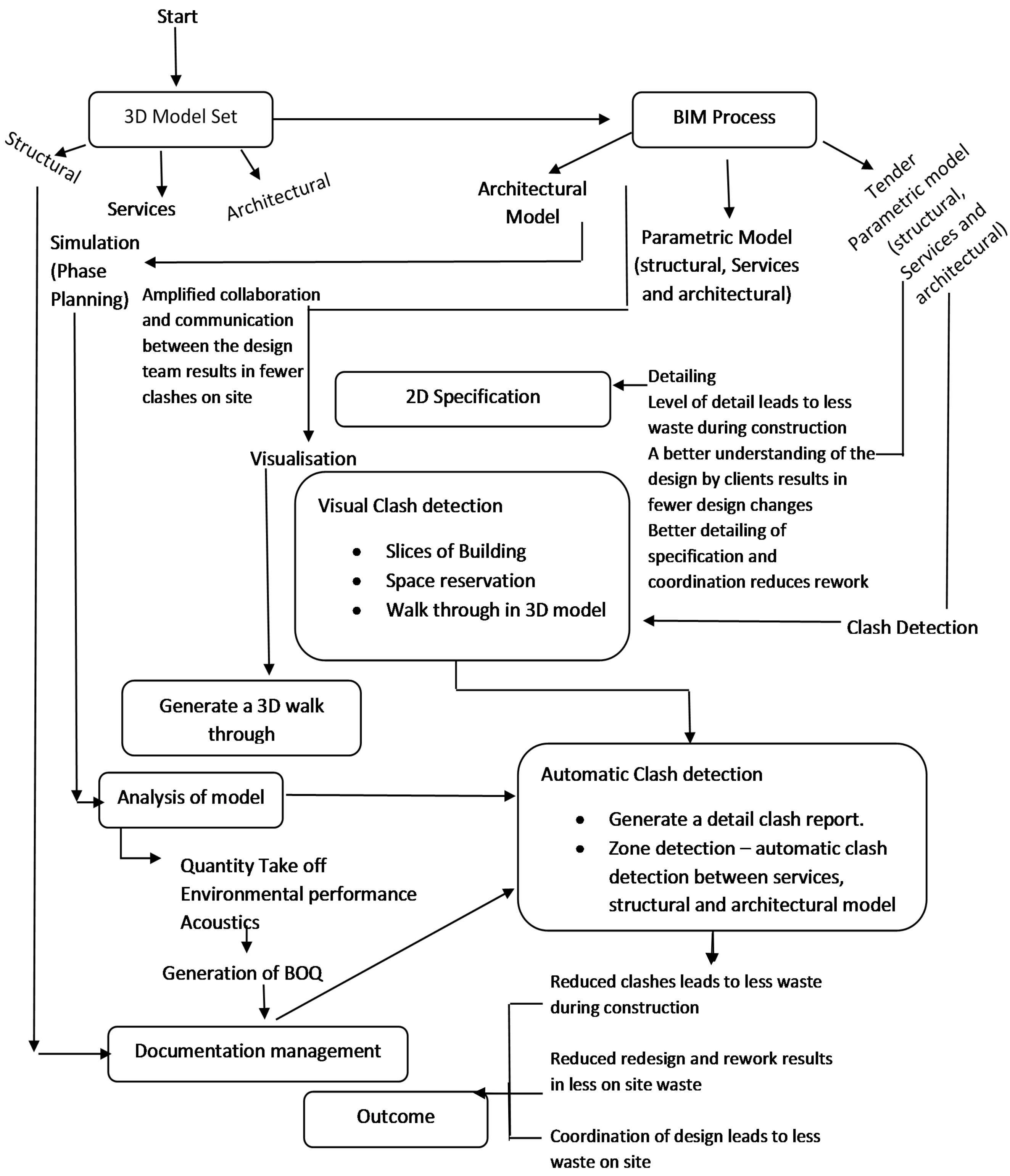


Figure: 5.1 Model for BIM waste reduction

The BIM process enhances the efficiency of the structural, service and architectural design for virtual waste minimisation. BIM's multi design specification, communication, and coordination tools are used to aid in waste minimisation.

Architectural, structural and service components of each design are created through the use of a simple model for accurate dimensional coordination.

The Flowchart Process

Stage one – Information is captured into the program by the design team; Architect for layout information and design specification, Engineers for elevation detail, service detail.

Stage Two – The program combines all the information provided in the process above to create individual models.

The models are combined and compared known as Simulation (phase planning), based on the integration of a schedule provides a plan indicating the construction sequence and space requirements. The BIM model allows for the planning of materials, equipment, and labour to resolve workspace conflicts prior to the construction process.

Stage Three - Each member of the design team captures specifications relative to their process in great detail. This includes material specifications, plant specifications, and resource schedules.

Stage Four, Five and Six - The clash detection process compares 3D models of the building and eliminates any conflicts with trades involved in the project prior to construction. A detail clash report is generated that indicates task clashes, programme clashes, clashes between different trades and clash of services to name a few. A change in drawing revisions during construction will raise a flag to all members of the design team prior to the occurrence of the event.

Stage Seven – the model is rectified and created. A 3D walk through model is now accessible to members of the construction project. Documents are kept electronically and are easily accessible to any member. A BOQ is generated and updated with each revision change. Quantity take-offs are provided by the program as well as a detail list of when materials are required. Material waste during construction is generated because of poor planning and procurement procedures. BIM aids in a quantity take off as it accurately estimates the amount of raw materials required during construction.

5.4 BIM FLOWCHART VALIDATION

Based on the responses, participants defined ways in which BIM can be used to reduce waste. It has been identified that BIM is implemented through each stage to create a 3D model with the ability to aid construction activities with amplified scheduling and sequencing focused in the construction phase. The aim of the flowchart validation was to examine the appropriateness of the BIM framework and identify the implementation procedure. The BIM flowchart validation contained a validation questionnaire.

5.5 BIM FLOWCHART VALIDATION RESULTS

The validation questionnaire was sent out to the sixty (60) respondents from the main questionnaire, the participants of the validation questionnaire were requested to comment on each level of the BIM flowchart across the following aspects:

- Clarity of flow
- Clarity of structure
- Suitability of content

The data below represents the results and analysis of the validation questionnaire.

5.5.1 Respondents' Gender

Figure 5.1 reveals that the male gender predominated with 68% and the female population made up 32%.

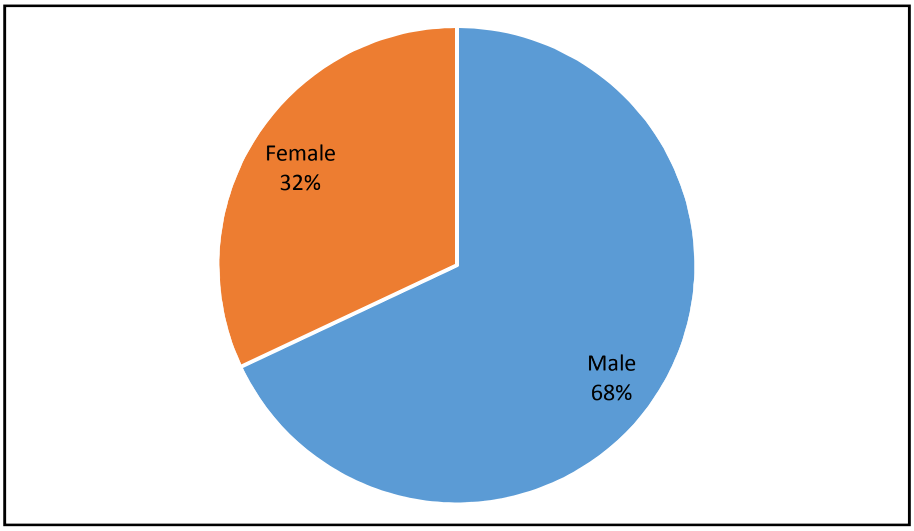


Figure 5.2 Gender distribution of respondents

5.5.2 Age of respondents

Figure 5.2 indicates the frequency of respondents' age. Respondents that are over the age of twenty-five (25) predominate in the sample investigated. This group of respondents constitutes 32%. Respondents between the ages of thirty-one (31) and forty (40) constitute to 24%.

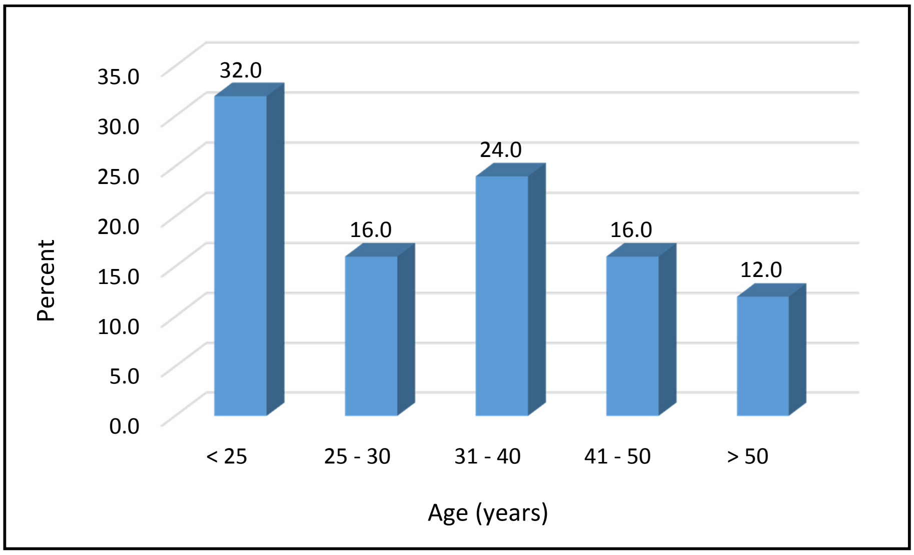


Figure 5.3 Age of respondents'

5.5.3 Category of respondents’ qualification

Figure 5.3 indicates the highest academic qualification of the respondents. 44% of the respondents have Bachelors’ degrees, and they predominate in the sample. Respondents with Btech qualification rank 32%. Followed closely are respondents with Masters Degrees at 24%. This analysis indicates that well-qualified personnel is employed in the industry, therefore, the performance is expected to be optimal. It reveals that their perceptions can be relied on.

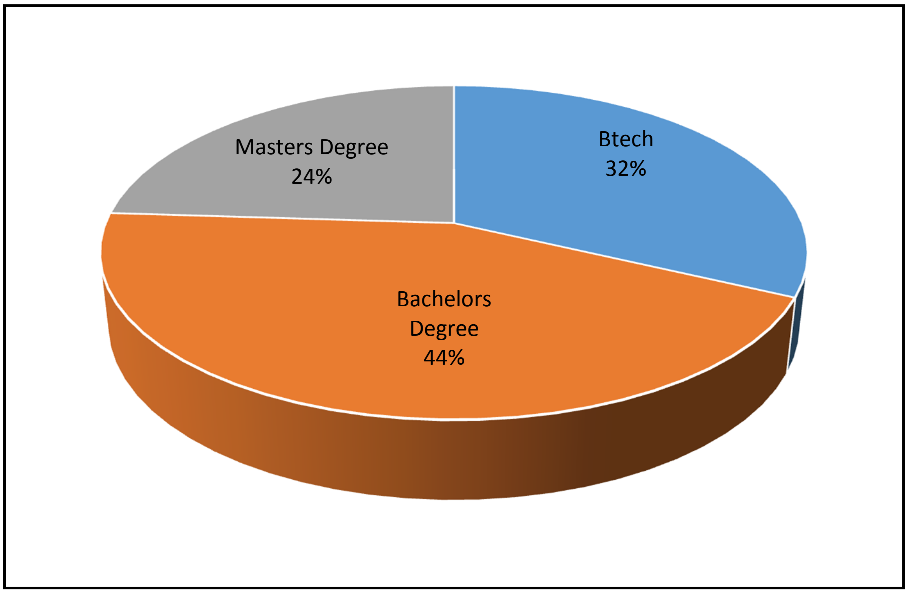


Figure 5.4 Respondents’ qualification

5.5.4 Cronbach’s coefficient α test

Table 5. 1 Cronbach’s coefficient α value for validation data

Stages in the BIM lifecycle	
Cronbach's Alpha	N of Items
0.621	2

The reliability value is within the accepted normality (α > 0.6) for a newly developed questionnaire.

5.5.5. Results of factor analysis

Factor analysis was conducted to test the agreement between factors in each category. The results of the analysis are presented in Table 5.2.

Table 5. 2 Summary of factor analysis conducted for item analysis

Stages of BIM	Loadings
Capture Architectural/ Structural and service data	0.861
BIM model is created using the input of the required data	0.698
Detail input of material specifications relative to BIM model	0.591
Reports of Visual/Automatic clash detection	0.876
Clashes sent back to the design team for correction and model update	0.503
Clashes rectified in the model and waste is eliminated	0.839
3D model walk through is created	0.837

Based upon the factor analysis loadings obtained for factors, the majority is greater than 0.60. There are some factors which have loadings a little lower than .60. These are Detail input of material specifications relative to BIM model (.591) and Clashes sent back to the design team for correction and model update (.503). It can be deemed that the items for all factor categories have good agreement. This means that the factors adequately describe these categories.

Table 5. 3 Respondents perspective on BIM stages

S/ No	Factor per category	Does not apply	Responses (%)					Mean score	Rank
			SD	D	N	A	SA		
1	3D model walk through is created	0.0	0.0	0.0	24.0	36.0	40.0	4.16	1
2	Capture Architectural/ Structural and service data	0.0	0.0	0.0	44.0	16.0	40.0	3.96	2
3	Clashes sent back to the design team for correction and model update	0.0	0.0	16.0	24.0	24.0	36.0	3.80	3
4	Clashes rectified in the model and waste is eliminated	0.0	8.0	4.0	28.0	28.0	32.0	3.72	4
5	Detail input of material specifications relative to BIM model	0.0	4.0	4.0	56.0	28.0	8.0	3.32	5
6	Reports of Visual/Automatic clash detection	8.0	4.0	4.0	56.0	16.0	12.0	3.30	6
7	BIM model is created using the input of the above data	4.0	0.0	12.0	64.0	20.0	0.0	3.08	7

Table 5.3 presents the respondents' rating of waste minimisation by following the stages of BIM. It is notable that all factors in the category have MSs > 3.40 ≤ 4.20

between moderate influence to a near major/near major influence in the reduction of construction waste.

Respondents agree (MS=4.16) that this stage of the BIM flowchart reduces waste; 3D model walk through is created. The probable reason for this is the 3D model is a visual representation of the building enabling members of the construction team to modify, correct, and change the design prior to construction.

Followed closely respondents agreed with Architectural/ Structural and service data (MS=3.96). This factor reduces documentation delays since all drawings, elevations, and layouts are available electronically once the responsible personnel has captured it.

The third most influential factor is clashes sent back to the design team for correction and model update (MS=3.80). The most effective way to make corrections to a design is electronically. BIM combines all structures virtually and generates a schedule indicating corrections required, these corrections can be missed due to human error if done manually.

The fourth most influential factor in the BIM process that assists in reducing waste is clashes rectified in the model and waste is eliminated (MS=3.72). Correcting design defects before construction aids in reducing time delays, it reduces rework, and reduces material waste, as well as wastage of equipment and labour.

The following factor; detail input of material specifications relative to BIM model (MS=3.32) has been agreed by respondents as a way to minimise waste. The purpose of this task is the model will generate exact quantities for each material and it will further indicate when it will be needed, as well as if the material is suitable.

Respondents further rated visual/automatic clash detection (MS=3.30), the model will assist the contractor to manage his subcontractors, this reduces delays as there will not be many trades working at once and reduces rework due to damages from subcontractors.

A factor that aids in waste minimisation although rated the least is BIM model created (MS=3.08) using the input of the above data. The most probable reason for this is the programme creates the model and requires no input once all data has been captured.

The stages by which BIM can be applied to reduce waste where MSs 4.16 is the highest and MSs 3.08 is the lowest which implies BIM has the ability to reduce waste.

5.5.6. Link between findings of main study and validation

Findings from the main study reveals that: Order errors (too much/too less) (MSs 3.76) has the most influence relative to material waste on site. BIM's quantity take off technology provides a complete BOQ as well as a take-off list for the specification and quantity of materials required and presents this to the user with accurate quantities of materials relative to each trade, which ultimately eliminates order errors. Damages to work caused by other trades (MSs 3.76) has a significant influence on material waste. BIM's clash detection technology provides a comprehensive programming report that enables fewer trades to work in a specific area therefore reducing damages to work completed. Lack of material control on site (MSs 3.88) has a great influence on material waste. BIM's programming presents a timeline schedule to the user to purchase materials only when it is required for each specific trade. This assists in reducing waste because; construction sites have poor storage areas, some materials need to be stored at a specific temperature to prevent degrading and damages can occur on if there are too many materials stored together. Last minute changes by client therefore rework (MSs 3.97) has a high contribution to material waste. With BIM's innovative 3D walk through model a client is able to view the complete model prior to construction, this can reduce the number of changes as the client has a visual idea of each detail in the project, changes can be made on the model prior to construction. This will help reduce waste as materials are purchased in advance, if there is a design change the materials are now redundant and goes to waste.

5.5.7. Conclusion

It has been verified that material waste in construction is due to poor planning and procurement, constant design changes, improper design and poor material handling. It has been discovered that material waste can be reduced by clash detection, simulation, communication and coordination, and quantity take off. It has further been identified that the minimised waste can be monitored by BIM waste management planning and execution.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1. INTRODUCTION

The chapter provides a summary of the findings and conclusions of the study. It further provides recommendations for future studies relative to the research objectives outlined. The purpose of the study was to identify the causes and sources of waste on construction sites and with the aid of BIM, mitigate waste.

6.1.1 Discussion on results of main study

The questionnaire findings (see section 4.1) are discussed below:

Order errors (too much/too less) has the most significant influence on procurement waste. The study of Lu and Yuan, “A framework for understanding waste management studies in construction waste management” (2011). Gamage et al., *“An investigation into the impact of procurement systems on waste generation: the contractors' perspective”* (2009) and Nagapan et al., “Identifying the Causes of Construction Waste” (2012) have all indicated that during the construction process, poor procurement procedures causes delays stemming from insufficient quantities ordered. Further, the final cost of a project is adversely affected, when materials are surplus. Respondents have agreed with literature as order errors (too much/too less) has been ranked the highest with regard to procurement waste.

Damage to work caused by other trades has the most significant influence on operational waste. Nagapan et al., “*Identifying the Causes of Construction Waste”* (2012) indicated that poor project planning results in too many trades working in a specific area at once that causes damages to the work completed. Poor operational procedures results in rework that adversely affects the cost of the project that cannot be recovered by the client as damages is a cost to the contractor. Respondents have agreed with literature as damage to work caused by other trades has been ranked the highest with regard to operational waste.

Lack of material control on site has the most significant influence on material handling and storage waste. In a study undertaken by Patel and Vyas, “*Construction Materials Management on Project sites*” (2011), poor material control leads to theft, degrading of material as well as the incorrect distribution of material to various trades of the project. Respondents have agreed with literature Lack of material control on site has been ranked the highest with regard to material handling and storage waste.

Last minute change by client therefore rework has the most significant influence on design waste. Osmani, *"Design waste mapping: a project life cycle approach"* (2013) concluded that there is limited understanding by designers on the causes of design waste and the negative effect it has on the overall cost of the project. Respondents have agreed with literature as last minute change by client therefore rework has been ranked the highest with regard to design waste.

With regard to materials that are most prone to waste, floor tile has the most significant influence on waste. In a study undertaken by Adewuyi and Otali, *"Evaluation of Causes of Construction Material Waste"* (2013), the main cause of tile waste is cutting the material into various sizes and uneconomical shapes, further cut pieces are and left as debris when the work crew moves to the next task. This affects the cost, as the pieces can no longer be used. Respondents have agreed with literature as tile have been ranked the highest with regard to material waste.

6.1.2. Conclusions relative to findings

Based on the analysis of data obtained, the following conclusions have been reached:

- Factors identified for each sub problem are described by the value of the loading obtained for each category, which was greater than 0.60 in most cases.
- Poor supervision and site procedures negatively influence cost and productivity and have an overall effect on project delivery time.
- Material handling and storage factors such as lack of material control on site, damage of materials on site and waste from cutting irregular shapes increased project costs that are irrecoverable.
- Last minute changes by clients necessitate design change during construction and a breakdown in communication leads to mistakes related to design and documentation factors
- Damage of work caused by other trades, delays in getting information to the contractor on specification, and unsuitability of material supplied to site relates to operational factors on construction sites can result in waste and have a negative effect on project delivery and increase costs.

- Procurement factors related to waste include material purchased that does not comply with the specification, and unsuitability of material supplied to the site has a direct effect on project cost.
- Material waste such as reinforcement, tile, masonry, concrete, timber, and pipes negatively affects project costs.

6.1.3. Conclusions relative to the main questionnaire

i. Identify the types and causes of material waste on construction sites.

The first task was to review existing literature on the causes and sources of material waste on construction sites. This was carried out through the literature review and questionnaire in Chapters 2 and 4. Chapter 2 identified and classified the types and causes of waste in line with procurement, design and documentation, material handling and storage and operations. Fulfilling the first objective was the basis for further investigation of material waste causes during construction and how these causes could be minimised with the use of BIM.

The study has identified the main sources and causes of material waste in the South African construction industry. Construction professional respondents agree that operational factors, material handling factors, and design and documentation factors have a significantly high contribution to the generation of waste on construction sites. Procurement factors were, however, not relevant to respondents since they believed these problems could easily be eliminated if corrective actions are undertaken.
Reinforcement, tile, masonry, and concrete are the main materials wasted on construction sites. The results have shown that all the materials with the exclusion of timber and pipes have a very high contribution of waste on construction sites.

ii. Identify barriers to the successful application of BIM in the South African construction industry.

Barriers to the successful implementation of BIM were reviewed through literature and a questionnaire. Factors in the questionnaire identified by construction professionals of South Africa as potential barriers to the implementation of BIM. Respondents ranked lack of skilled personnel, client limitation due to the high cost and cost of training existing staff as the greatest challenge. The reason for this is the limited knowledge that professionals in South Africa have of BIM or the high initial cost that is required to start up a BIM project.

iii. The ability to minimise material wastage through the application of BIM in the construction industry with the aid of a flowchart.

The development of a flowchart was accomplished through design and validation presented in Chapter 5. The aim of the BIM flowchart is to assist the construction industry to reduce material waste through all stages of the project. The development of the framework was based on key findings that emerged from the research.

6.1.4 Conclusions relative to the hypotheses

6.1.4.1 First hypothesis

There are significant causes of waste that can negatively affect a cost of a project during construction. The factors associated with this problem indicate that they do support the hypothesis. Based upon the results respondents agree that in construction there are significant causes of waste that can have an effect on the cost of a project. Further indicated by research undertaken by Lu and Yuan, 2011; Nagapan et al. 2012; Patel and Vyas, 2011 and Babatunde 2012 the causes of waste during construction has a negative effect on the cost.

6.1.4.2 Second hypothesis

There are significant sources of waste that can negatively affect a cost of a project during construction. The factors associated with this problem indicate that they do support the hypothesis. Based upon the results respondents agree that in construction there are significant sources during construction that contribute to waste generation. Further indicated by research undertaken by Kareem and Pandey (2013); Napier, (2012); Adewuyi and Otali, (2013) and Agyekum, (2012) the sources of waste during construction negatively affects the cost of a project.

6.2. CONCLUSIONS BASED ON VALIDATION QUESTIONNAIRE

The average MSs on the various stages of a BIM flowchart application project is 3.61. This falls within the range of > 3.40 ≤ 4.20 indicating moderate influence to a near major/near major influence on a construction project. It indicates that respondents are of the opinion that the use of BIM during a construction project could assist the industry by eliminating material waste, design changes, rework, clashes of trades, and delays in the delivery of a project.

The MS of 4.16 falls within the range > 3.4 ≤ 4.20 between moderate influence to a near major/near major influence reducing material waste in the delivery of a construction project.

It reveals that respondents agree that a BIM 3D model applied to a project could have a positive impact on the construction project. It does not only give you a clear visualisation of the completed project but allows you to verify designs and to identify if the project is economical to construct
Based on the literature reviewed and the findings from the respondents, BIM is a new technology that can be used to assist the construction industry to minimise waste. The use of BIM in the South African construction industry relative to the delivery of a project can have a positive impact on the industry. The most likely reasons are that BIM assists a project in waste reduction, reduced timelines, and reduced rework. It has further been identified that BIM assists a project with planning, design, construction, and maintenance throughout the project lifecycle.

6.3. RECOMMENDATIONS

The recommendations for this study are divided into two sections, namely recommendations stemming from the questionnaire and the validation questionnaire.

6.3.1. Recommendations from questionnaires

Based on the conclusions reached from the data analysis, the following recommendations have been made;

- Correct site and waste management procedures, as well as detailed material specifications, are recommended as measures to be undertaken in waste minimisation.
- Contractors should provide or price into their tender waste reduction training to increase awareness.

- Incentives are given by private organisations who collects material waste for recycling and re-use, this act should be promoted.
- The lack of material control on site contributes to waste, based on this it is recommended that a delegated person should be directly involved in the receiving of materials and handling and storage of materials.
- A contractor should be directly involved in the project lifecycle from the design stage up until completion.
- Members of the professional team need to constantly go for BIM training to utilise BIM to its full potential
- The government should assist companies and encourage the adoption of BIM.

6.3.2. Recommendations from the validation of the model

- It is recommended in order to utilise BIM to its full potential, BIM should be used from the start of a project till completion.
- During a construction project, all members involved should go for BIM training regardless of whether BIM is used individually by companies.

6.3.3. Recommendations for further studies

A study should be conducted to identify the cost analysis of waste on a conventional construction project versus waste on a BIM construction project.

REFERENCES

Abbasnejad, B. and Moud, H.I, (2013), BIM and Basic Challenges Associated with its Definitions, Interpretations and Expectations. International Journal of Engineering Research and Applications (IJERA), Vol 3: No. 2, pp. 287-294

Adewuyi, T. O. and Otali, M. (2013). Evaluation of Causes of Construction Material Waste: Case of River State, Nigeria. Ethiopian Journal of Environmental Studies and Management, 6, 746-753

Ahmad, A. M., Kystallis, I., Deiman, P. K. and Price, A. (2014) "Using Building Information Modelling (BIM) to Design Flexible Spaces with Design Standards in Healthcare Facilities." Journal of Civil Engineering and Architecture Research. 1(5). pp. 312-326

Ahmad, A. M., Demian, P., and Price A. D (2012). BIM implementation plans: a comparative analysis. *Smith, S. Proceedings of 28th Annual ARCOM*. Edinbrugh, UK: Association of Researchers in Construction.

Aiyetan, A.O. 2010. Influences on Construction Project Delivery Time, PhD, Nelson Mandela Metropolitan University, Port Elizabeth.

Agyekum, K. (2012). Minimizing material wastage at the construction stage of a project through the implementation of lean construction, Masters' Thesis, Kwame Nkrumah University of Science and Technology. Ghana.

Ahankoob, A., Khoshnava, S. M., Rostami, R. and Preece, C. (2012). "BIM perspectives on construction waste reduction", Management in Construction Research Association (MiCRA) Postgraduate Conference, pp. 195-199.

AIA. (2007). Integrated project delivery: a guide, [Online]. Available: http://www.aia.org/groups/aia/documents/pdf/aiab083423.pdf [2011, 17 Jan].

Alan, M. (2009). "Who is making money out of waste?" Article published on Loughborough University, Department of Civil and Building Engineering, UK.

Al-Hajj, A. and Hamani, K. (2011). "Material Waste in the UAE Construction Industry: Main Causes and Minimisation Practices", Architectural Engineering and Design Management, vol. 7, no. 4, pp. 221-235.,

Al-Maghony, S. S. (2006). "Managing and Minimizing Construction Waste in Gaza Strip." Master Thesis. The Islamic University of Gaza, Palestine.

Alvesson, M. & Willmott, H., 2012. Making sense of management: A critical introduction, 2nd edition. London: SAGE.

Alvi, M. (2016). A Manual for Selecting Sampling Techniques in Research. University of Karachi, Iqra University.

Alwi, S., Hampson, K. and Mohamed, S. (2002). "Waste in the Indonesian Construction Project". Proceedings of the 1st International Conferences of CIB W107

– Creating a Sustainable Construction Industry in Developing Countries, pp. 305-315, November 2002, South Africa.

Alwisy, A. Al-Hussein, M. and Al-Jibouri, S. H. (2012). “BIM Approach for Automated Drafting and Design for Modular Construction Manufacturing”. In Computing in Civil Engineering, 17-20 June 2012, Reston, Virginia, USA.

Arayici, Y., Khosrowshahi, F., Ponting, A, M., and Mihindu, S. (2009). Towards implementation of building information modelling in the construction industry. *Proceeding of the Fifth International Conference on Construction in the 21st Century “collaboration and integration in Engineering, Management and Technology*.” Istanbul, Turkey: Middle East Technical University and Florida International University.

Arayici, Y., Egbu, C. and Coates, P. (2012). Building Information Modelling (BIM) Implementation and Remote Construction Projects: Issues, Challenges, and Critiques. Information Technology in Construction, 17(Special Issue), 75-92.
Ashcraft H. W. (2008). Building information modelling: a framework for collaboration. *Construction Lawyer*, Vol. 28.

Augustine, S. (2011). Managing Waste in Construction industry: A case study of the road construction industry. An MBA thesis submitted to the Institute of Distance Learning, Kwame Nkrumah University of Science and Technology, Ghana.

Autodesk. (2011). Building Information Modelling [online]. Available; http://usa.autodesk.com/building-information-modeling/about-bim [2016, 19 May].

Azhar, S. and Brown, J. (2009). “BIM for Sustainability Analyses”. International Journal of Construction Education and Research, vol. 5, pp. 276-292.

Azhar, S. (2011). “Building Information Modelling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry”. Leadership and Management in Engineering, vol. 11, pp. 241-252.

Azhar, S. Nadeem, A. Mok, Y. N. and Leung, H. Y. (2008). “Building Information Modelling (BIM): A New Paradigm for Visual Interactive Modelling and Simulation for Construction Projects”. First International Conference on Construction in Developing Countries (ICCIDC–I), August 4-5, Karachi, Pakistan.

Azis, A., Memon, A. H., Rahman, I. A., Nagapan, S., and Latif, Q. B. A. I. 2012.Challenges faced by construction industry in accomplishing sustainability goals.In Business, Engineering and Industrial Applications (ISBEIA), 2012 IEEE Symposium on: 630-634.

Babatunde, S. O. (2012). “Quantitative Assessment of Construction Materials Wastage in the Nigerian Construction Sites”. Journal of Emerging Trends in Economics and Management Sciences, vol. 3, no. 3, pp. 238-241.

Babbie, E. 2005. The basics of social research. New York: Thompson Wadsworth.

Baldwin, A.N., Poon, C., Shen, L., Austin, S. and Wong, I. (2009b). "Designing out waste in high-rise residential buildings: Analysis of precasting methods and traditional construction", Renewable Energy, vol. 34, no. 9, pp. 2067-2073.

Baldwin, A.N., Shen, G.Q. and Brandon, P. (2009a). "Collaborative construction information management - evolution and revolution" in Collaborative Construction Information Management, eds. G.Q. Shen, P. Brandon and A. Baldwin, Spon press, New York, pp. 1-17.

Baldwin, A.N., Shen, L.Y., Poon, C.S., Austin, S.A. and Wong, I. (2008). "Modelling design information to evaluate pre-fabricated and pre-cast design solutions for reducing construction waste in high rise residential buildings", Automation in Construction, vol. 17, no. 3, pp. 333-341.

Barlish, K., Chair, K., Kashiwagi, D., and Badger, W. (2011). How to measure the benefits of BIM — A case study approach. Automation in Construction.

Begum, R.A., Siwar, C., Pereira, J.J and Jaafar, A.H. (2009). “Attitude and behavioural factors in waste management in the construction industry of Malaysia”, Resources, Conservation and recycling.

Bew, M., & Underwood, J. 2010, "Delivering BIM to the UK Market", In J. Underwood & I. Umit (Eds.), Handbook of Research on Building Information Modeling and Construction Informatics: Concepts and Technologies, IGI Global, pp. 30-64

Blaikie N. (2010). Designing Social Research, 2nd ed. Polity Press. Cambridge

Burcin, B, G. Jazizadeh, F. Li, N and Calis, G. (2012). "Application Areas and Data Requirements for BIM-Enabled Facilities Management", Journal of Construction Engineering and Management.

Booyens, D., Bouwman, H., Burger, M. (2013) “The status of building image modelling in the South African construction industry”. The 2nd year of Advanced Research in Scientific Areas proceedings, 2-6 December, Pretoria.

Bowling A, Ebrahim S (2005). Handbook of health research methods: Investigation, Measurement and Analysis. Open University Press Maidenhead.

Branco, C.R. (2007). An effective way to reduce residential construction waste. A thesis submitted to the office of Post graduate studies of Texas AandM University.

Bryde, D., Broqueatas, M. and Volm, J. M. (2012) “The project benefits of Building Information Modelling (BIM).” International Journal of Project Management.

Bryman, A. (2008) "Research methods and methodology", Qualitative Research in Organizations and Management: An International Journal, Vol. 3 Issue: two, pp.159-168, BuildingSmart, 2012. International Home of openBIM [online] Available at: http://www.buildingsmart.com/> [2016, 18 August].

CBS, PBL, Wageningen UR (2012a). Ecological sustainability of bottom fishing in the North Sea p. 1-2.

Cerovsek, T. (2011) “A review and outlook for a ‘Building Information Model’ (BIM): A multi-standpoint framework for technological development.” Advanced engineering informatics. 25(2). pp. 224-244.

Cheng, C. P. and Ma, Y.H. (2013). “A BIM-based system for demolition and renovation waste estimation and planning”. Waste Management, vol.33, no. 6, pp. 1539-1551.

Cheng, T. and Teizer, J. (2013). "Real-time resource location data collection and visualization technology for construction safety and activity monitoring applications", Automation in Construction, vol. 34, pp. 3-15.

Charted Institute of Building, (2010). CIOB’s Professionalism: An Inclusive Definition of Construction Management. Ascot: The Chartered Institute of Building.

Cunningham, T. (2014). The Work and Skills Base of the Quantity Surveyor in Ireland – An Introduction, Dublin Institute of Technology.

Creswell, J.W. (2007). Qualitative inquiry and research design: choosing among five traditions, Sage Publications, Thousand Oaks, CA.

Creswell, J.W. (2009). Research design: Qualitative, quantitative, and mixed methods approaches, 3rd ed. SAGE Publication, Inc.

Creswell, J. W., 2014. Research design: Qualitative, quantitative, and mixed methods approaches, 4th edition. Thousand Oaks, CA: Sage.

Dancy, J., Sosa, E. & Steup, M. Eds., 2010. A companion to epistemology, 2nd edition. West Sussex: John Wiley & Sons.

Dainty, A. (2008). "Methodological Pluralism in Construction Management Research" in Advanced Research Methods in the Built Environment, eds. A. Knight and L. Ruddock, Blackwell Publishing Ltd, , pp. 1-13.

Davidson, A. R. (2009). ‘A study of the development and impact of building information modelling software in the construction industry’.

Davies, M.B. (2007). Doing a successful research project: Using qualitative or quantitative methods, Palgrave Macmillan, New York.

Davis, K. A. (2008). “Assessing individuals’ resistance prior to its implementation in the AEC industry”. CIB W78 2008: International Conference on Information Technology in Construction, Santiago, Chile.

Desta, S. (2006). An investigation into the practice of Project Management Office concept in the German developer, contractor and project management sectors. Unpublished MSc degree research report. Cape Town University.
Dowsett, R.M., Harty, C., 2013. Evaluating the benefits of BIM for sustainable design: a review, in: Proceedings 29th Annual ARCOM Conference. Presented at the Association of Researchers in Construction Management, ARCOM.

Dzambazova, T., Krygiel, E., and Demchak, G. (2009). Introducing Revit Architecture 2010 "BIM for beginners," 1st Edition.

Eadie, R., Odeyinka, H., Browne, M., Keown, C. and Yohanis, M. (2013) "An analysis of the drivers for adopting Building Information Modelling." Journal of Information in Technology in Construction. 18. pp.338-352.

Eastman, C., Teicholz, P., Sacks, R and Liston, K., (2011). BIM handbook: A guide to building information modelling for owners, managers, designers, engineers and contractors.

Eastman, C., Teicholz, P., Sacks, R. and Liston, K. (2008). BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors, John Wiley and Sons, Inc., Canada.

Elmualim, A., and Gilder, J. (2013). BIM: innovation in design management influences and challenges of implementation. Architectural Engineering and design management, Vol. 10: No. 1080, pp 1745-2007.

Enshassi, A., Mohamed, S. and Abushaban, S. (2009). Factors Affecting the Performance of Construction Projects in the Gaza Strip. Journal of Civil Engineering and Management, 15(3): 269–280.

Environment Agency. (2003). Sustainable Construction: Position Statement.

Fellows, R & Liu, A. 2008. Research Methods for Construction. Oxford: Wiley-Blackwell

Fernández-Solis and Rybkowski, (2015). Fernández-Solis, J., and Rybkowski, Z. K. 2015. A theory of waste and value.

Formoso, C.T., Lucio Soibelman, M., De Cesare, C and Isatto, E.L (2002). Materials Waste in Building Industry: Main causes and prevention.

Foster, L.L., (2008). Legal Issues and Risks Associated with Building information modelling technology. [online] master's thesis, university of Kansas.

Gamage, I.S.W., Osmani, M. and Glass, J. (2009). "An investigation into the impact of procurement systems on waste generation: the contractors' perspective". In: DAINTY., A., Proceedings of 25th Annual ARCOM Conference, 7-9 September 2009, Nottingham, UK, Association of Researchers in Construction Management, pp.1031-1040.

Ghaffarianhoseini, A., Tookey, J., Naismith, N., Azhar, S., Efimova, O. and Raahemifar, K. 2017;2015;2016;, "Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges", Renewable & sustainable energy reviews.

Giel, B.K., and Issa, R.R.A, (2013). Return on Investment Analysis of Using Building Information Modeling in Construction. Journal of Computing in Civil Engineering.

Grilo, A. & Jardim-Goncalves, R. 2010, "Building information modelling and collaborative working environments", Automation in Construction, vol. 19, no. 5, pp. 521-521.

Haile, M.T and Hartono, Y.D, (2017). Current Practices of Construction and Demolition Waste Management (CDWM): Based on Observations at Swedish Construction Site

Hamil, S. (2011). Design and Specification. Retrieved 3 January 2013, from http://www.thenbs.com/topics/DesignSpecification/articles/nbsCreate.asp

Hamza, N. & DeWilde, P. 2014, "Building simulation visualization for the boardroom: an exploratory study". Journal of Building Performance Simulation, vol. 7, no. 1, pp. 52-67.

Han, S. Lee, S. Fard, M.G and Pena-mora, F. (2007). Modelling and Representation of non-value adding activities due to errors and changes in design and construction projects.

Hardin, B. (2009). BIM and construction management: proven tools, methods, and workflows, 1st ed. Wiley Publish, Inc., Canada.

Harris, F. and McCaffer. R., (2001). Modern Construction Management, 5th Edition Black well Science Ltd, Malden USA

Hergunsel, M. F. (2011). Benefits of building information modelling for construction managers and BIM based scheduling.

Hjelseth, E. (2010). "Exchange of Relevant Information in BIM Objects Defined by the Role- and Life-Cycle Information Model", Architectural Engineering and Design Management, vol. 6, no. 4, pp. 279-287.

HM Government. (2013a). Construction 2025: Industrial Strategy: government and industry in partnership [Online]. Available: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/210099/bis- 13-955-construction-2025-industrial-strategy.pdf [2013, 22 September].

Holness, G. V. (2006). Future direction of the design and construction industry.

Hosseini, S. A. Abbasian, A. Nikakhtar, K. Y. Wong, and A. Zavichi. (2012) "Implementing Lean Construction Theory into Construction.

Hore, A., O'Kelly, M. and Scully, R. (2009). Seeley and Winfield's Building Quantities Explained – Irish Edition, Palgrave MacMillan, Houndsmills, Basingstoke, Hampshire.

Howard, R. and Björk, B.C., (2008). Building Information Modelling Experts' views on standardisation and industry deployment. Advanced Engineering Informatics. http://www2.wrap.org.uk/downloads/Reducing_Material_Wastage_in_Construction.6 bf74 95b.4711.

Huovinen, P. (2010). Enhancement of Business Management for a Better Construction World: A Review of a 62-Concept Population Published between 1990-2009 P. Barrett, D. Amaratunga, R. Haigh, K. Keraminiyage, C. Pathirage (Eds.), Proceedi ngs of CIB 2010 World Building Congress. CIB, 2010, University of Salford, Salford UK (2010), pp. 1-12 10-13 May

IAI. (2010). 23 July-last update, Model - Industry Foundation Classes (IFC) [Homepage of Alliance for Interoperability], [Online]. Available: http://www.buildingsmart.com/bim [2010, 02 November].

Ibrahim, A.Z., Roy, M.H., Ahmed, Z.U. and Imtiaz, G., (2010). Analysing the dynamics of the global construction industry: Past, present and future.

InfoComm. (2011). Building Information Modeling (BIM) Guide. Infocomm home.

Innes, S. (2004). "Developing tools for designing out waste pre-site and on-site", Proceedings of Minimising Construction Waste Conference: Developing Resource Efficiency and Waste Minimisation in Design and Construction, New Civil Engineer, London.

Isikdag, U, Underwood, J and Aoud, G.F (2008). 'An investigation into the applicability of Building Information Models in geospatial environment in support of site selection and fire response management process'.

Jayamathan, J. and Rameezdeen, R. (2014). Influence of Labour Arrangement on Construction Material Waste Generation. Structural Survey, 32(2): 76-88

Kaber, R. (2010), Will the implementation of Building Information Modelling be advantageous to the South African construction industry?

Kareem, K. R., and Pandey, R. K. 2013. Study of Management and Control of Waste Construction Materials in Civil Construction Project. International Journal of Engineering and Advanced Technology (IJEAT).

Keegan, C.J. (2010). Building information modelling in support of space planning and renovation in colleges and universities. MSc Thesis, Construction project Management, Faculty of Worcester Polytechnic Institute (WPI) USA.

Keller, T. and Tergan, S.O. (2005). "Visualizing knowledge and information: an introduction". Knowledge and Information Visualization, vol. 3426, pp. 1-23.

Khosrowshahi, F. and Alani, A. (2011). “Visualisation of impact of time on the internal lighting of a building”, Automation in Construction, vol. 20, no. 2, pp. 145-154.

Kiprotich, C. J. K (2014). An Investigation on Building Information Modelling In Project Management: Challenges, Strategies and Prospects in the Gauteng Construction Industry, South Africa.

Koskela, L. (1992). Application of the New Production Philosophy to Construction, CIFE Technical Report.

Koskela, L. (2000). An Exploration towards a Production Theory and Its Application to Construction.

Kofoworola, O. F, and Gheewala, S.H. (2009). “Estimation of Construction Waste Generation and Management in Thailand”, Journal, Waste Management, Elsevier, 29 (731-738)

Kovacic,I., Oberwinter,L., Müller, C. & Achammer, C. 2013, “The “BIM-sustain” experiment – simulation of BIM-supported multi-disciplinary design”. Visualization in Engineering, vol. 1, no. 1, Article.13, DOI:10.1186/2213-7459-1-13.

Kreider, R. and Messner, N. (2013). The uses of BIM: Classifying and selecting BIM uses. Version 0.9.

Krygiel, E., Nies, N. and McDowell, S. (2008). Green BIM: Successful Sustainable Design with Building Information Modeling. Wiley Publishing, Indianapolis.

Ku, K. and Taiebat, M. (2011), “BIM Experiences and Expectations: The Constructors'.

Kulatunga, U., Amaratunga, D., Haigh, R. and Rameezden, R. (2006). "Attitudes and Perceptions of construction workforce on Construction Waste in Sri Lanka", Management and Environmental Quality: An International Journal, Emerald Group Publishing Limited, United Kingdom. Vol 17, No. 1, pp. 57-72.

Kumar, R. (2011). Research Methodology. A step by step Guide for beginners.

Kotze, C. (2013) BIM technology uptake increasing in SA. [Online] Available from: http://www.engineeringnews.co.za/print-version/bim-technology-uptakeincreasing-in-sa-2013-06-14.

Lawal, A.F and Wahab, A.B., (2011). An Evaluation of Waste Control Measures in Construction Industry in Nigeria. Available online at http://www.academic journals.org/AJEST

Lee, J., Min, K., Lee, Y., Kim, J. and Kim, J. (2008). “Building ontology to implement the Bim (building information modelling) focused on Briefing stage”. The 25th International Symposium on Automation and Robotics in Construction, Vilnius, Lithuania.

Leedy P.D. & Ormrod J.E. (2010) Practical Research: Planning and Design. (9th ed). Pearson Educational International, Boston

Leedy, P.D, and Omrod, J.E. (2014). Practical Research: planning and design, 11th Edition, Upper Saddle River. NJ: Merrill Prentice Hall.

Lemon, A., O'Meara and Winchester, B. (2004) Microsoft Encarta Encyclopaedia. [(RD Rom]. New York: Microsoft Corporation.

Lihua, F., Wenxia, B., Ying, Z., Haijun, G., Duofei, P., and Yu, L. 2013. Practice and Exploration of Environmental Supervision to Pollution Project.

Lindblad, H. (2013). "Study of the implementation process of BIM in construction projects".

Lorimer, J. (2011). *Building information modelling: Why do we need BIM?* From NBS. Available at: http://www.thenbs.com/topics/bim/articles/whyDoWeNeedBIM.asp

Love, P. E., Lopez, R. and Edwards, D. J. 2013b, "Reviewing the past to learn in the future: making sense of design errors and failures in construction". Structure and Infrastructure Engineering: Maintenance, Management, Life-Cycle Design and Performance, vol. 9, no. 7, pp. 675-688.

Love, P. E., Lopez, R. and Kim, J. T. (2013a). "Design error management: interaction of people, organisation and the project environment in construction", Structure and Infrastructure Engineering: Maintenance, Management, Life-Cycle Design and Performance, DOI:10.1080/15732479.2013.767843.

Lu, W. and Yuan, H., (2011). A framework for understanding waste management studies in construction waste management.

Lu, W., and Tam, V. W. 2013. Construction waste management policies and their effectiveness in Hong Kong: A longitudinal review. Renewable and Sustainable Energy Reviews, 23, 214-223.

Ma, Z., Wei, Z. and Zhang, X. (2013). "Semi-automatic and specification-compliant cost estimation for tendering of building projects based on IFC data of design model", Automation in Construction, vol.30, pp. 126-135.

Macozoma, D.S. (2004). International report - construction site waste management and minimisation. 2004, International Council for Research and Innovation in Building and Construction (CIB): South Africa.

Madhav, N, Stab-French, S, and Pottinger, R. (2012). "Providing Query Support to Leverage BIM for Construction", Construction Research Congress 2012,

Mah, D., Manrique, J. D., Yu, H., Al-Hussein, M. and Nasseri, R. (2011). "House construction CO2 footprint quantification: a BIM approach". Construction innovation, vol. 11, no. 2, pp. 161-178.

Malkin, R. (2010). "Building information modelling (BIM) for efficient sustainable design". ARCHITECTURE AUSTRALIA, vol. 99, no. 5, pp. 105-107.

Mansi, J., (2012). Economic Aspects of Construction Waste Materials in Building Industry:-Main Causes and Prevention. National Conference on Recent Trends in Engineering and Technology.

Manthe, M.F.(2008). The appropriateness of tertiary built environment education.

Memon, A.H. Abdul-Rahman, I. and Memon, I. (2014). Rule Based DSS in Controlling Construction Waste. Life Science Journa,l 11 (6), 417-424.

Mahesh D. Meghani (2011). "A Study on Basic Material Waste in Building Industry: Main causes and Prevention", B.V.M. Engineering college, Gujarat Technological University, Vallabh Vidhayanagar, India.

McGraw-Hill (2007). Interoperability in the construction industry, McGraw-Hill Construction, New York.

McGraw-Hill (2008). Building Information Modeling (BIM): Transforming Design and Construction to Achieve Greater Industry Productivity, McGraw-Hill Construction, New York.

McGraw-Hill (2010). Green BIM Smart Market Report: How Building Information Modeling is Contributeing to Green Design and Construction, McGraw-Hill construction, New York.

Migilinskas, D., Popov, V., Juocevicius, V. and Ustinovichius, L. (2013) "The benefits, obstacles and problems of practical BIM implementation." Procedia Engineering. 57. pp.767-774.

Mitchell, D., and Lambert, S. (2013). BIM: rules of engagement. CIM World Building Congress (Bib Bc13). Brisbane, Australia.

Mocozoma, D.S (2002). "Construction Site Waste Management and Minimisation international report".

Morrison, P.D., Roberts, J.H. and Midgley, D.F. (2004). "The Nature of Lead Users and Measurements of Leading Edge Status, Research Policy.

Motawa, I. & Almarshad, A. 2013, "A knowledge-based BIM system for building maintenance", Automation in Construction, vol.29, pp. 173-182.

Mutai, B. K. (2000) How to Write Quality Research Proposal: A Complete Simplified Recipe. Mysore: Thalley Publications.

Nagapan, S., Rahman, I. A., Asmi, A., Memon, A. H., and Latif, I. 2012. Issues on construction waste: The need for sustainable waste management. In Humanities, Science and Engineering (CHUSER), 2012 IEEE Colloquium on (pp. 325-330). IEEE.

Nagapan, S. Abdul-Rahman, I. Asmi, A. and Hameed, A. (2012). Identifying the Causes of Construction Waste-Case of Central. International Journal of Integrated Engineering, 4(2), 22-28.

Nassar, K. (2010). “A model for assessing occupant flow in building spaces”. Automation in Construction, vol.19, pp. 1027-1036.

Neuman, W.L. (2006). Social Research Methods: Qualitative and Quantitative Approaches, 6th ed. Pearson Education, Boston

Nguyen, H.T. (2016). Integration of BIM and IoT to improve the building performance for occupants’ perspective A case study at Tyréns headquarter building in Stockholm.

Ningappa, G. (2011), "Use of Lean and Building Information Modeling (BIM) in the Construction Process; Does BIM make it Leaner?" Master degree thesis, Georgia Institute of Technology.

Nisbet, N. and Dinesen, B. (2010). Building information modelling: construction the business case, British Standards Institution, London.

Okorafor, C and Mwanumo, E.M., (2012). A Perspective on Causes of Material waste in Tshwane.

Olatunji, O, A., W. D. Sher (2009). Legal implications of BIM: Model ownership and Other Matters Arising, School of Architecture and Build Environment, University of Newcastle, Callagham.

O'Reilly, A. (2012). “Using BIM as a tool for cutting construction waste at source”. CIOB Construction Research and Innovation, vol. 3, no. 1, pp. 28-31.

Osmani, M. (2013). "Design waste mapping: a project life cycle approach", Proceedings of the ICE - Waste and Resource Management, vol. 166, no. 3, pp. 114-127.

Osmani, M. Glass, J. and Price, A. D. F. (2006). “Architect and contractor attitudes to waste minimization‟, Institution of Civil Engineers. Waste and Resource Management, Vol. 159, pp. 65-72.

Osmani, M., Glass, J. and Price, A.D.F. (2008). "Architects' perspectives on construction waste reduction by design", Waste Management, vol. 28, no. 7, pp. 1147-1158. Perspective”. International Journal of Construction Education and Research.

Patel, K. V., and Vyas, C. 2011. Construction Materials Management on Project sites. In National Conference on Recent Trends in Engineering and Technology.

Polat, G. and Ballard, G. (2004). "Waste in Turkish construction: need for lean construction techniques", 12th Annual Conference on lean construction, Denmark, IGLC, Copenhagen, Denmark.

Poon, C.S., Yu, A.T.W. & Jaillon, L. 2004, "Reducing building waste at construction sites in Hong Kong", Construction Management and Economics, vol. 22, no. 5, pp. 461-470.

Poon, C.S. and Jaillon, L. (2010). "Designing for Waste Minimization in High-Density Cities" in Designing High-Density Cities: For Social and Environmental Sustainability, ed. E. Ng, Earthscan, London, pp. 195-207.

Poon, C.S. (2007). "Reducing construction waste", Waste Management, vol. 27, no. 12, pp. 1715-1716.

Porwal, A. and Hewage, K. N. (2012). “Building Information Modeling–Based Analysis to Minimize Waste Rate of Structural Reinforcement”. Journal of construction engineering and management, vol.138, pp. 943-954.

Porwal, A. and Hewage, K. N. (2013) “Building Information Modelling (BIM) partnering framework of public construction projects.” Automation in Construction. 31. pp.204-214.

Razavi, S. N. and Haas, C. T. (2010). “Multisensor data fusion for on-site materials tracking in construction”, Automation in Construction, vol. 19, no. 8, pp. 1037-1046.

Rekola, M., Kojima, J. and Mäkeläinen, T. (2010). “Towards Integrated Design and Delivery Solutions: Pinpointed Challenges of Process Change”, Architectural Engineering and Design Management, vol. 6, no. 4, pp. 264-278.

Sacks, R., L. Koskela, B. Dave and R.L. Owen (2010). "The interaction of lean and building information modeling in construction." Journal of Construction Engineering and Management 136 (9): 968-980.

Sanders, T. L. (2008). The History of Quantity Surveying in Australia, ACT, Australia, AIQS.

Schade, J., Olofsson, T. and Schreyer, M. (2011). “Decision‐making in a model‐based design process”, Construction Management and Economics, vol. 29, no. 4, pp. 371-382.

Scherer, R.J. and Schapke, S. E. (2011). “A distributed multi-model-based Management Information System for simulation and decision-making on construction projects”, Automation in Construction, vol. 25, pp. 582-599.

Shen, L.Y. and Tam, V.W.Y. (2002). "Implementation of environmental management in the Hong Kong construction industry", International Journal of Project Management, vol. 20, no. 7, pp. 535-543.

Shen, L.Y., Tam, V.W.Y and Tam, C.M., (2002). Assessing the level of Material wastage affected by sub-contracting relationships and projects types with their correlations.

Shen, L.Y., Tam, V.W.Y., Tam, C.M. and Drew, D. (2004). "Mapping approach for Examining waste management on construction sites", JOURNAL OF CONSTRUCTION ENGINEERING AND MANAGEMENT, vol. 130, pp. 472-481.

Shen, W., Hao, Q. and Xue, Y. (2012b). “A loosely coupled system integration approach for decision support in facility management and maintenance”. Automation in Construction, vol.25, pp. 41-48.

Shen, W., Shen, Q. and Sun, Q. (2012a). “Building Information Modeling-based user activity simulation and evaluation method for improving designer–user communications”. Automation in Construction, vol.21, pp. 148-160.

Shen, W., Zhang, X., Shen, G. Q. and Fernando, T. (2013). “The User Pre-Occupancy Evaluation Method in designer–client communication in early design stage: A case study”, Automation in Construction, vol. 32, pp. 112-124.

Singh, V. Gu, N. and Wang, X. (2011) “A theoretical framework of a BIM-based Multi-disciplinary collaboration platform.” Automation in Construction. 20. pp.134-144.

Smith, D. (2007). AIA: An Introduction to Building Information Modelling (BIM), Journal of Building Information Modelling.

Smith, D.K. and Tardif, M. (2009). Building information modelling: a strategic implementation guide for architects, engineers, constructors, and real estate asset managers, John Wiley and Sons, Inc., Canada

Smith, J., O’Keeffee, N., Georgiou, J., and Love, P. E. (2004). Auditing construction costs during building design; a case study of cost planning in action

State of Ohio. (2010). *State of Ohio Building Information Modelling protocol.* Ohio: Ohio department of administrative services.

Steel, J., Drogemuller, R. and Toth, B. (2012). “Model interoperability in building information modelling”. Software and Systems Modelling, vol. 11, no. 1, pp. 99-109.

Succar, B. (2009). "Building information modelling framework: A research and delivery foundation for industry stakeholders", Automation in Construction, vol. 18, no. 3, pp. 357- 375.

Succar, B., Sher, W. and Williams, A. (2012) “Measuring BIM performance: Five metrics.” Architectural Engineering and Design Management. 8(2). pp. 120-142.

Sutrisna, M., Buckley, K., Potts, K and Proverbs, D. (2005). A decision support tool for the valuation of variations on civil engineering products. RICS research papers.

Tam, V.W.Y., and Tam, C.M. (2006). “A review on the viable technology for construction waste recycling”. Resources, Conservation and Recycling, vol.47, no. 3, pp. 209-221.

Tam, V.W.Y., Tam, C.M. & Ng, W.C.Y. 2007, "On prefabrication implementation for different project types and procurement methods in Hong Kong", Journal of Engineering, Design and Technology, vol. 5, no. 1, pp. 68-80.

Takim, R., Harris, M., Nawawi, A. H. (2013). 'Building information modelling (BIM): A new paradigm for quality of life within architectural, engineering and construction (AEC) industry'.

Tavakol, M. & Dennick, R., 2011. Making sense of Cronbach's alpha. International Journal of Medical Education, 22011, pp. 53-55.

UK Green Building Council. (2013). Key Statistics. Retrieved 14/01/2013, 2013, from http://www.ukgbc.org/content/key-statistics-0

Urio, A.F. and Brent, A. C. (2006). Solid Waste Management Strategy in Botswana: A focus on the Reduction of Construction Waste. Masters dissertation. Department of Engineering and Technology Management, University of Pretoria.

Venkatachalam, S (2014). A Study on the various possible policy frameworks for the effective adoption of Building Information Modelling (BIM) in South African Architectural Engineering and Construction (AEC) sector. In Proceedings of the 8th Built Environment Conference, Durban, South Africa, pp. 144-154.

Volk, R., Stengel, J. and Schultmann, F., 2014. Building Information Modeling (BIM) for existing buildings—Literature review and future needs. Automation in construction.

Wong, J. K.W., Li, H., Wang, H., Huang, T., Luo, E. and Li, V. (2012). "Toward low-carbon construction processes: the visualisation of predicted emission via virtual prototyping technology", Automation in Construction, vol.33, pp. 72-78.

WRAP. 2007a, Reducing material wastage in construction [Online]. Available: http://www2.wrap.org.uk/downloads/Reducing_Material_Wastage_in_Construction.6 bf74 95b.4711.pdf [2016, 19 May].

WRAP. (2008). TRUE COST of waste in whole life costing, [Online]. Available: http://www.wrap.org.uk/sites/files/wrap/True%20Cost%20of%20Waste%20in%20Wh ole %20Life%20Costing%20report.pdf [2013, 22 September].

WRAP. (2009). Designing out Waste: a design team guide for buildings, [Online]. Available:http://www.wrap.org.uk/content/designing-out-waste-design-team-guide-buildings.

WRAP. (2010). WRAP SWMP Tracker, [Online]. Available: http://swmptracker.wrap.org.uk/.[2016, 12 March].

WRAP. (2011). Welcome to WRAP's Waste forecasting tools, [Homepage of Waste and Resources Action Programme], [Online]. Available: http://nwtool.wrap.org.uk/.[2016, 12 March].

WRAP. (2013). Review of the factors causing waste soil to be sent to landfill, 2007 to 2011[Online]. Available: http://www.wrap.org.uk/sites/files/wrap/CIS101 301%20Final%20Report%20final%2017%20april%2013.pdf. [2017, 20 April].
WRAP. (2013a). BIM (Building Information Modelling) utilisation to achieve resource efficiency in construction: Leeds Arena [Online]. Available: http://www.wrap.org.uk/sites/files/wrap/Leeds_Arena_FINAL.pdf. [2016, 12 March].

WRAP. (2013b). What is Halving Waste to Landfill? [Online]. Available: http://www.wrap.org.uk/content/what-halving-waste-landfill. [2016, 12 March].

WRAP. (2013c). Construction procurement guidance, [Online]. Available: http://www.wrap.org.uk/content/procurement-guidance 13. [2016, 21 March].

WRAP. (2013d). 2013 update, BIM and Resource Efficiency, WRAP, [Online]. Available: http://www.wrap.org.uk/content/bim-and-resource-efficiency. [2016, 26 April].

Yahya, K. & Boussabaine, A.H. 2006, "Eco-costing of construction waste", Management of Environmental Quality: An International Journal, vol. 17, no. 1, pp. 6-19.

Yan H and Damian P (2008). Benefits and barriers of building information modelling. Proceedings of 12th International Conference on Computing in Civil and Building Engineering, Beijing.

Zhang, J. and Li, D. (2010). “Research on 4D virtual construction and dynamic management system based on BIM”. Proceedings of the international conference on computing in civil and building engineering.

http://www.constructiondigital.com/sectors/constructionproducts/bim-world-stage-world-cup-2010

http://www.tekla.com/international/Pages/Default.aspx

https://aecmag.com/case-studies-mainmenu-37/373-tekla-shoots-for-goal-at-the-fifa-world-cup

APPENDIX 1 : QUESTIONNAIRE ONE

Appendix I

28 February 2017

Dear Sir/ Madam

Re: Reducing Material Waste with the Application of Building Information Modelling

The questionnaire survey is part of a research project aimed at meeting the requirements for Master of Technology (Quantity Surveying) at the Durban University of Technology, carried out to:

Assess the causes of material waste during construction
Assess materials most prone to waste during construction.
Assess factors that are a major contribution to material waste
Asses preventive measures of material waste
Assess Benefits of BIM in the delivery of a project
Assess Challenges of BIM relative to project delivery

We would be grateful if you would complete the accompanying questionnaire. Please note your anonymity is assured. The use of BIM to reduce material waste will be assessed from your response and enhance the reliability of the research findings.

We would be grateful if you would endeavour to complete the questionnaire and return it by 28th April 2017 to:

1 Gary Frost Road
Bayhead
Durban
Or per email to ayesha.mall14@yahoo.com
Should you have any queries please do not hesitate to contact Miss A Mall at 083 231 5223.
Thanking you in anticipation of your response.

A Mall
MBE (Quantity Surveying) student

Dr. A.O Aiyetan, PHD
(Construction Management)
Supervisor
Department of Construction Management and Quantity Surveying

QUESTIONNAIRE TYPE I

Section 1: DEMOGRAPHIC DATA

A. ORGANISATIONAL

1. In what sector do your work?

Private Sector		**Public Sector**	

2. Please indicate your province …………………………………………………………………………………………

3. Name of organisation ……………………………………………………………………………………………………

4. Please indicate the number of years your organisation has been involved in construction

……………………………………..

B. PERSONAL

5. Please indicate your gender

Female		Male	

6. Please indicate your age

Under 25		31 – 40 years		Over 50 years	
25 – 30 years		41 – 50 years			

7. Please indicate your highest formal qualification

Matric Certificate		Diploma		Bachelor's Degree	
B Tech		Master's Degree		Doctoral Degree	
Other					

8. Please indicate the category of construction profession you belong to:

Architect		Engineer		Builder	
Project Manager		Client		Quantity Surveyor	
Construction Manager		Other		Client	

9. Please indicate your status in the organisation

MD		Supervisor		Director		Manager	
Senior Staff		Junior		Intern		Other	

10. Please indicate your actual years of experience in the construction industry

0 – 5 Years		10 – 15 Years		20 – 25 Years	
5 – 10 Years		15 – 20 years		Over 25 years	

SECTION 2: QUESTIONNAIRE

11. On a scale of 1 (Minor) to 5 (Major), kindly rate these causes of material waste during construction relative to your perception on *material waste* (Please note the 'Unsure' and 'Does not Apply' options)

Causes of Material Waste	Unsure	Does not Apply	Minor ……….Major				
			1	2	3	4	5
Procurement	U	DN	1	2	3	4	5
Escalation of material price	U	DN	1	2	3	4	5
Substituting a material with an expensive one	U	DN	1	2	3	4	5
Order errors (too much/too less)	U	DN	1	2	3	4	5
Material purchased does not comply with the specification	U	DN	1	2	3	4	5
Unsuitability of material supplied to site	U	DN	1	2	3	4	5
Operational	U	DN	1	2	3	4	5
Incorrectly placed material	U	DN	1	2	3	4	5
Shortage of tools and equipment	U	DN	1	2	3	4	5
Incorrect construction methods	U	DN	1	2	3	4	5
Inclement weather	U	DN	1	2	3	4	5
Damage to work caused by other trades	U	DN	1	2	3	4	5
Constant breakdown of equipment	U	DN	1	2	3	4	5
Error by tradesman	U	DN	1	2	3	4	5
Delays in getting information to the contractor on specification of product to be used	U	DN	1	2	3	4	5
Incorrect material used and therefore requires replacing.	U	DN	1	2	3	4	5
Material Storage and Handling	U	DN	1	2	3	4	5
Lack of material control on site	U	DN	1	2	3	4	5
Theft	U	DN	1	2	3	4	5
Poor handling	U	DN	1	2	3	4	5
Damage of materials on site	U	DN	1	2	3	4	5
Insufficient handling instructions	U	DN	1	2	3	4	5
Wrong methods of transport	U	DN	1	2	3	4	5
Poor methods of storage on site	U	DN	1	2	3	4	5
Waste from cutting irregular shapes	U	DN	1	2	3	4	5
Design and Documentation	U	DN	1	2	3	4	5
Lack of communication leading to mistakes and errors	U	DN	1	2	3	4	5
Poor site layout	U	DN	1	2	3	4	5
Incorrect specifications	U	DN	1	2	3	4	5
Last minute change by client therefore rework	U	DN	1	2	3	4	5
Choice of low quality product	U	DN	1	2	3	4	5

Poor attention to dimensional co-ordination of product	U	DN	1	2	3	4	5
Unclear/lack of information on drawing	U	DN	1	2	3	4	5
Complex detail on drawing	U	DN	1	2	3	4	5
Design change whilst in construction	U	DN	1	2	3	4	5

12. **On a scale of 1 (Minor) to 5 (Major), kindly rate the *material most prone to waste during construction*. (Please note the 'Unsure' and 'Does not Apply' options)**

Materials	**Unsure**	**Does not Apply**	**Minor ……….Major**				
			1	2	3	4	5
Tile	U	DN	1	2	3	4	5
• Wall tile	U	DN	1	2	3	4	5
• Floor Tile	U	DN	1	2	3	4	5
Fresh Concrete	U	DN	1	2	3	4	5
Reinforcement	U	DN	1	2	3	4	5
Cement	U	DN	1	2	3	4	5
Masonry	U	DN	1	2	3	4	5
Timber	U	DN	1	2	3	4	5
Pipes	U	DN	1	2	3	4	5

13. **On a scale of 1 (Minor) to 5 (Major), kindly rate these *factors that are a major contribution to material waste*. (Please note the 'Unsure' and 'Does not Apply' options)**

Factor	**Unsure**	**Does not Apply**	**Minor ……….Major**				
			1	2	3	4	5
Tile							
1. Poor distribution of tiles on site	U	DN	1	2	3	4	5
2. Cutting of tiles in great quantities	U	DN	1	2	3	4	5
3. Damage during finishing	U	DN	1	2	3	4	5
4. Inadequate workers	U	DN	1	2	3	4	5
5. Excessive quantities of tile on site	U	DN	1	2	3	4	5
6. Damaging of the tile during the necessary cutting process	U	DN	1	2	3	4	5
7. Damage during transportation	U	DN	1	2	3	4	5
8. Rework as a result of mistakes	U	DN	1	2	3	4	5
Concrete							
1. Ordering of an additional allowance of concrete	U	DN	1	2	3	4	5

2. Use of inadequate equipment and tools	U	DN	1	2	3	4	5	
3. Poor performance which leads to rework	U	DN	1	2	3	4	5	
4. Excessive dimensions of concrete structure	U	DN	1	2	3	4	5	
5. Inadequate use of vibration which leads to problems in concrete	U	DN	1	2	3	4	5	
6. Far distance between mixing and casting	U	DN	1	2	3	4	5	
7. Suppliers delivering quantities of material smaller than what was paid for	U	DN	1	2	3	4	5	
Reinforcement								
1. Poor handling because its cumbersome to handle due to shape and weight	U	DN	1	2	3	4	5	
2. Poor structure design in terms of detailing and standardization	U	DN	1	2	3	4	5	
3. Short unusable pieces are produced when bars are cut	U	DN	1	2	3	4	5	
4. Using bars that are much longer then what’s required	U	DN	1	2	3	4	5	
5. Rusting and damage during storage	U	DN	1	2	3	4	5	
Masonry								
1. Manufacturing defects	U	DN	1	2	3	4	5	
2. Excessive cutting	U	DN	1	2	3	4	5	
3. Damage to the unused quantities on site	U	DN	1	2	3	4	5	
4. Damage during unloading and transportation	U	DN	1	2	3	4	5	
5. Damage during storage	U	DN	1	2	3	4	5	
Timber								
1. Incorrect storage methods	U	DN	1	2	3	4	5	
2. Use of low quality timber	U	DN	1	2	3	4	5	
3. Breaking of the timber boards during the removal of frames	U	DN	1	2	3	4	5	
4. Using the timber for purposes that isn’t required	U	DN	1	2	3	4	5	
Pipes								
1. Ordering more quantities than what is required	U	DN	1	2	3	4	5	
2. Poor storage	U	DN	1	2	3	4	5	
3. Incorrect cutting of pipes	U	DN	1	2	3	4	5	
4. Theft and Vandalism	U	DN	1	2	3	4	5	
5. Using pipes that don’t comply with the specification	U	DN	1	2	3	4	5	

14. **On a scale of 1 (Not effective) to 5 (Major effect), kindly rate these *preventive measures of material waste according to their effectiveness on waste reduction*. (Please note the 'Unsure' and 'Does not Apply' options)**

Waste Preventive Measures	**Unsure**	**Does not Apply**	**Not Effective ………. Major effect**				
			1	2	3	4	5
Proper storage of materials on site	U	DN	1	2	3	4	5
Reduce design changes	U	DN	1	2	3	4	5
Accurate measures of materials	U	DN	1	2	3	4	5
The use of materials before expiry date	U	DN	1	2	3	4	5
Promote re use of materials on projects	U	DN	1	2	3	4	5
Careful handling of tools and equipment on site	U	DN	1	2	3	4	5
Prompt and early scheduling of deliveries	U	DN	1	2	3	4	5
Recycling excess waste materials on site	U	DN	1	2	3	4	5
Vigilance of supervisors	U	DN	1	2	3	4	5
Construction person undergoing courses (Training)	U	DN	1	2	3	4	5
Constant training and education on handling of materials	U	DN	1	2	3	4	5
The use of Building Information Modelling (BIM)	U	DN	1	2	3	4	5

SECTION 3: QUESTIONNAIRE

15. **Please indicate your actual years of experience using BIM**

0 – 5 Years		10 – 15 Years		20 – 25 Years	
5 – 10 Years		15 – 20 years		Over 25 years	

16. **Please indicate the number of BIM projects worked on**

0 – 5		5 – 10	

17. **Please indicate if you are aware of BIM and its benefits?**

Extremely Aware		Very Aware		Moderately Aware		Slightly Aware		Not At All Aware	

18. **Based on the benefits of BIM do you believe clients will increasingly insist on BIM usage?**

Strongly Agree		Agree		Neutral		Disagree		Strongly Disagree	

19. Please indicate if additional BIM training is necessary for the use of BIM tools?

Strongly Agree		Agree		Neutral		Disagree		Strongly Disagree	

20. On a scale of 1 (Not Effective) to 5 (Major Effect), kindly rate the *benefits of BIM in the delivery of a project*. (Please note the 'Unsure' and 'Does not Apply' options)

BIM Benefits	Unsure	Does not Apply	Not Effective ………. Major effect				
			1	2	3	4	5
Improved cost estimating at each project stage	U	DN	1	2	3	4	5
Improved productivity of estimator in quantity take-off	U	DN	1	2	3	4	5
Easier quantity take-off	U	DN	1	2	3	4	5
Reduced cost from health and safety issues	U	DN	1	2	3	4	5
Reduced overall project cost	U	DN	1	2	3	4	5
Increased speed of delivering projects	U	DN	1	2	3	4	5
Reduced overall project duration	U	DN	1	2	3	4	5
Improved design quality	U	DN	1	2	3	4	5
Reduced safety risks	U	DN	1	2	3	4	5
Reduced redesign issues	U	DN	1	2	3	4	5
Fewer change orders at the construction stage	U	DN	1	2	3	4	5
Improved site analysis	U	DN	1	2	3	4	5
Improved communication among various divisions of the same company	U	DN	1	2	3	4	5
Improved documents management	U	DN	1	2	3	4	5
Potentially Improved maintenance of the facility due to the as-built model	U	DN	1	2	3	4	5
Enhanced work coordination with subcontractors	U	DN	1	2	3	4	5
Greater predictability of project time and cost	U	DN	1	2	3	4	5
Improved conflicts detection	U	DN	1	2	3	4	5
Improved human resources management	U	DN	1	2	3	4	5

21. **On a scale of 1 (Minor) to 5 (Major), kindly rate the challenges of BIM relative to project delivery. (Please note the 'Unsure' and 'Does not Apply' options)**

BIM Challenges	**Unsure**	**Does not Apply**	**Minor ……….Major**				
			1	2	3	4	5
Lack of skilled personnel	U	DN	1	2	3	4	5
Inadequate support available to the supply chain	U	DN	1	2	3	4	5
People refusal/reluctance to learn	U	DN	1	2	3	4	5
The unsuitability of some projects to the adoption of BIM	U	DN	1	2	3	4	5
Client limitation due to high cost	U	DN	1	2	3	4	5
Cost of training existing staff	U	DN	1	2	3	4	5
Cost of new software and updates	U	DN	1	2	3	4	5
Time required to produce the models	U	DN	1	2	3	4	5
Time required to train existing staff	U	DN	1	2	3	4	5
Time taken to implement BIM	U	DN	1	2	3	4	5
Restructuring of organization to accommodate BIM	U	DN	1	2	3	4	5

Please record your details below to facilitate contacting you, in the event that a query should arise.

Please note that the data provided in this questionnaire will be treated in the strictest confidence.

ORGANISATION ______________________________

ADDRESS ______________________________

____

____

____

CONTACT PERSON ______________________________

PHONE ______________________________

FAX ______________________________

MOBILE ______________________________

E-MAIL ______________________________

Thank you for your contribution to efforts directed towards reducing material waste with the application of BIM.

APPENDIX 2 : QUESTIONNAIRE TWO

Appendix 2

01 November 2017

Dear Sir/ Madam

Re: Validation of Reducing Material Waste with the Application of Building Information Modelling

The flowchart is the completion of the research into reducing material waste in the construction industry with the application of BIM.

The flowchart has been developed by assisting the construction industry with necessary steps to reduce material waste with the aid of BIM

We would be grateful if you would complete the accompanying questionnaire. Please note your anonymity is assured. The use of BIM to reduce material waste will be assessed from your response and enhance the reliability of the research findings.

We would be grateful if you would endeavor to complete the questionnaire and return it by 30th November 2017 to:

1 Gary Frost Road
Bayhead
Durban
Or per email to Ayesha.mall14@yahoo.com

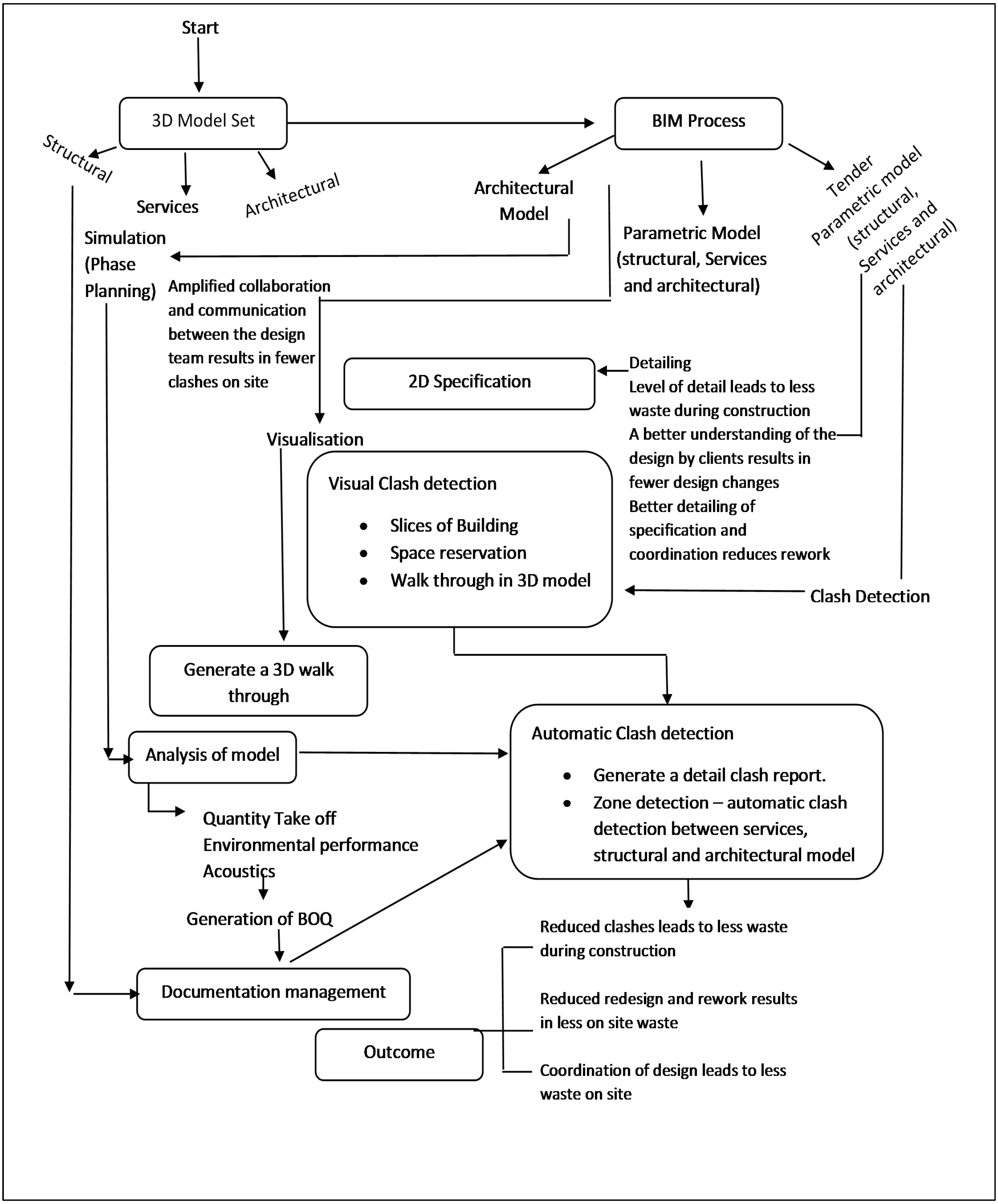
Should you have any queries please do not hesitate to contact Miss A Mall at 083 231 5223. Thanking you in anticipation of your response.

____

A Mall
MBE (Quantity Surveying) student

____

Dr. A.O Aiyetan, PHD (Construction Management)
Supervisor
Department of Construction Management and Quantity Surveying


Start
3D Model Set
BIM Process
Structural
Services
Architectural
Architectural Model
Parametric Model (structural, Services and architectural)
Tender Parametric model (structural, Services and architectural)
Simulation (Phase Planning)
Amplified collaboration and communication between the design team results in fewer clashes on site
2D Specification
Detailing
Level of detail leads to less waste during construction
A better understanding of the design by clients results in fewer design changes
Better detailing of specification and coordination reduces rework
Visualisation
Visual Clash detection
Slices of Building
Space reservation
Walk through in 3D model
Clash Detection
Generate a 3D walk through
Analysis of model
Automatic Clash detection
Generate a detail clash report.
Zone detection – automatic clash detection between services, structural and architectural model
Quantity Take off
Environmental performance
Acoustics
Generation of BOQ
Documentation management
Outcome
Reduced clashes leads to less waste during construction
Reduced redesign and rework results in less on site waste
Coordination of design leads to less waste on site

QUESTIONNAIRE TYPE I

Section 1: DEMOGRAPHIC DATA

C. ORGANISATIONAL

22. Name of organization ……….

D. PERSONAL

23. Please indicate your gender

Female		Male	

24. Please indicate your age

Under 25		25 – 30 years		31 – 40 years	
41 – 50 years		Over 50 years			

25. Please indicate your highest formal qualification

Matric Certificate		Diploma		B Tech	
Bachelor's Degree		Master's Degree		Doctoral Degree	
Other					

26. Please indicate the category of construction profession you belong to:

Architect		Engineer		Builder	
Project Manager		Client		Quantity Surveyor	
Construction Manager		Other			

SECTION 2: QUESTIONNAIRE

With reference to the flowchart attached, kindly indicate on a scale of 1 (Strongly Disagree) to 5(Strongly Agree), the statements relative to BIM in the minimization of construction waste. (Please note the 'Unsure' and 'Does not Apply' options)

Stages relative to BIM waste minimisation	**Unsure**	**Does not Apply**	**Strongly Disagree… Strongly agree**				
			1	2	3	4	5
Stage One							
Capture Architectural/ Structural and service data	U	DN	1	2	3	4	5
Stage Two							
BIM model is created using the input of the above data	U	DN	1	2	3	4	5
Stage Three							
Detail input of material specifications relative to BIM model	U	DN	1	2	3	4	5
Stage Four							
Reports of Visual/Automatic clash detection	U	DN	1	2	3	4	5
Stage Five							
Clashes sent back to the design team for correction and model update	U	DN	1	2	3	4	5
Stage Six							
Clashes rectified in the model and waste is eliminated	U	DN	1	2	3	4	5
Stage Seven							
3D model walk through is created	U	DN	1	2	3	4	5

Please record your details below to facilitate contacting you, in the event that a query should arise.

Please note that the data provided in this questionnaire will be treated in the strictest confidence.

ORGANISATION ______________________________

ADDRESS ______________________________

____

____

____

CONTACT PERSON ____

PHONE ____

FAX ____

MOBILE ____

E-MAIL ____

Thank you for your contribution to efforts directed towards reducing material waste with the application of BIM.