CRITICAL FACTORS IN EFFECTIVE CONSTRUCTION WASTE MINIMISATION AT THE DESIGN STAGE: A GAUTENG REGION CASE STUDY.

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A research report submitted to the Faculty of Engineering and the Built Environment, of the University of the Witwatersrand, Johannesburg, in partial fulfillment of the requirements for the MSc. (Building) in Construction Project Management.

Johannesburg, 2014.

DECLARATION

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

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13 January 2015

ABSTRACT

Construction waste minimisation and avoidance at the design stage of a construction project is the most favourable solution in the existing waste management hierarchy triangle. However, there are currently only a limited number of exploratory and context-specific studies that state effective construction waste minimisation factors which can be implemented during the design stage. This can be regarded as a relatively new concept and new research topic, especially as no studies have been done in a South African or a Gauteng region context. This research report aims to address this local knowledge gap.

The research method included an initial conceptual framework of factors (identified from surveying both global and local literature) as a launch pad in order to quantitatively survey design consultants in Gauteng with regards to both the *significance* and *ease of implementation* of the identified factors. The research target population consisted of; architects, architectural technologists, architectural draughtsman, structural engineers, structural technologists, structural draughtsman and finally sustainability consultants. The target population was further narrowed by only including designers who have both attempted to minimise construction on greenfield projects in Gauteng and who have received Green Building Council of South Africa (GBCSA) accreditation on the same project.

This report presents a hierarchical list of twenty-six critical factors that can be implemented during the design stage in order to minimise or avoid construction waste in the context of Gauteng, South Africa. The report further indicates which of these factors will be easier to implement than others. These factors are aimed mainly at clients of construction projects, as they are in essence the stakeholders who will contractually enforce designers to implement these construction waste minimisation factors in order to lower project costs. Furthermore; these factors will also serve as valuable references for the Gauteng Provincial Government as the factors can be utilized in order to drive provincial construction waste regulations and eventually national reform.

This report concludes that the overall most favoured critical factors (which are both *significant* as well as *easy to implement*) in effective construction waste minimisation at the design stage of Gauteng projects are (in order of the most favoured to the least favoured solutions); designers should make use of standardization; designers should specify off-site preparation, pre-assembly, prefabrication & precast components; designers should communicate and co-ordinate efficiently and effectively with other consultants at the design stage; designers should supply adequate information on drawings and avoid lacking or incorrect design and detailing packages; designers should specify re-usable, reclaimed, salvaged or recycled materials and designers should implement Building Information Modelling (BIM) at the design stage.

These factors are most likely to be utilized as part of a context-specific and robust waste minimisation strategy in Gauteng.

DEDICATION

I dedicate this research report to both my parents, Dr. G.A Bezuidenhout & Mr. K.A Eschberger.

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LIST OF SYMBOLS

Meaning	Symbols
Addition	+
Divide	/
Equals	=
Metres Squared	m^2
Percentage	%
Subtraction	-

LIST OF ACRONYMS

Acronyms	Meaning
AEC	Architecture, Engineering & Construction
AECD	Architecture, Engineering, Construction & Design
BIM	Building Information Modelling
BREEAM	Building Research Establishment’s Environmental Assessment Method
CAC	Command & Control
CAD	Computer Aided Design
CBA	Cost & Benefit Analysis
CIDB	Construction Industry Development Board
ECI	Early Contractor Involvement
EI	Economic Instruments
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
GBCSA	Green Building Council South Africa
IEQ	Indoor Environmental Quality
IRP	Incentive Reward Programme
IWMP	Integrated Waste Management Plan
MFR	Mean Factor Rating
NPO	Non-profit Organization
NWMS	National Waste Management Strategy
OPC	Ordinary Portland Cement
RCA	Recycled Coarse Aggregate
RFA	Recycled Fine Aggregate
SA	South Africa
SACAP	South African Council for the Architectural Profession
UAE	United Arab Emirates
UK	United Kingdom
USA	United States of America
VFM	Value for Money
WCWES	Web-based Construction Waste Estimation System
WGBC	World Green Building Council
WMP	Waste Management Plan
WRAP	Waste Resources Action Programme

LIST OF ABBREVIATIONS

Abbreviations	Meaning
1st.	First
2nd.	Second
3D	Three-dimensional
Ch.	Chapter
ed.	Editor
e-journal	Electronic Journal
e-mail	Electronic Mail
et al.	et alia, “and others”
Fig.	Figure
i.e.	id est, “in other words”
n.d	No Date
No.	Number
Pg.	Page
R	Rands (South African Currency)
Vol.	Volume
Wits	University of the Witwatersrand

TABLE OF DEFINITIONS

For clarity in this research report, definitions are defined hereunder. Throughout this document these definitions apply. The definitions are listed in alphabetical order.

Client	The "client" will mean the party engaging with the design practice or professional to perform the full services or any part thereof of the stages as laid out for construction projects (SACAP, 2000: 2).
Construction Waste	Ekanayake & Ofori (2004: 852) defined physical construction waste as "any material apart from earth materials, which needed to be transported elsewhere from the construction site or used on the site itself other than the intended specific purpose of the project due to damage, excess or non-use or which cannot be used due to non-compliance with the specifications, or which is a by-product of the construction process." For the purpose of this study earth materials, specifically soil, will be considered as physical construction waste as excavations and cut & fill processes are seen as construction activities.
Construction Waste minimisation	Keys et al. (2000: 4) defined physical construction waste minimisation as "any technique, process or activity that either avoids, eliminates or reduces waste at its source or allows reuse or recycling of the waste."
Critical factors	Wang, Li and Tam (2014: 1) stated that critical factors are exploratory criteria that can significantly & effectively inform & improve current practices & strategies.
Design stage	The "design stage" will incorporate both the South African Council for the Architectural Profession's Stage two (design concept phase) and Stage three (design development phase). This thus involves the preparation of a design concept in broad outlines which shows space provisions & allocations, space planning relationships, construction materials and specifications to be used. Furthermore it will include how designs are developed in sufficient detail in order to define the construction of the building, spatially co-ordinate the design with other consultants and to ultimately review the design with the relevant local authorities (SACAP, 2000: 3-4).
Designers	"Designers" will encompass any person appointed to provide professional or specialist services with specific reference to the design stage of construction projects (SACAP, 2000: 2). This will thus include architects, architectural technologists, architectural draughtsmen, structural engineers, structural technologists and structural draughtsmen. Sustainability consultants (consultants whose main role is to advise other professions in the built environment) are also included as they provide design guidance to designers within the design stage of projects.
Effectiveness of construction waste management	Yuan (2013b: 477) defined effectiveness of construction waste management as "the degree to which objectives are achieved when implementing construction waste management; where the objectives mainly concern how to simultaneously promote the economic, environmental and social performance of construction waste management activities in the project."

Gauteng	The Gauteng region will be defined with the following geographical borders: its Northern border is the Limpopo province, its southern border is the Vaal River, its western border is the North West province and Mpumalanga borders Gauteng to the east (Gauteng Online, 2014).
Green Buildings	According to the Green Building Council of South Africa; "Green building incorporates design, construction and operational practices that significantly reduce or eliminate the negative impact of development on the environment and people. Green buildings are energy efficient, resource efficient and environmentally responsible" (www.gbcsa.org.za/about/about-green-building/).
Greenfield	Wedding & Crawford-Brown (2007: 484) defined "greenfield" sites as undeveloped parcels of land in an urban context.
Low-cost housing	Le Roux (2011) defined low-cost housing as "housing for people whose combined monthly household incomes are below R3500 per month."
Recycle waste	Yeheyis *et al.* (2013: 82) defined recycling waste as "separating, collecting, processing, marketing and ultimately using a material that would otherwise have been thrown away."
Reduce waste	Yeheyis *et al.* (2013: 82) defined reducing waste as "source reduction or resource optimization. It is a precautionary technique aimed at minimising the waste generated from the source before it becomes a physical problem."
Re-use waste	Yeheyis *et al.* (2013: 82) defined the re-use of waste as "returning a part of the waste stream of a product to be used repeatedly for the same purpose. Effective re-use preserves the present structure of a material or article and does not require additional time or energy for utility."
Sustainable Development	Yates (2013: 283) defined sustainable development as "development that meets the needs of the present without compromising the future generations to meet their own goals."

1. INTRODUCTION

1.1 Construction Waste Context

1.1.1 Global Construction Waste Context

Due to rapid population expansion across the globe, there is an increasing demand for infrastructure, commercial buildings and residential projects. This is particularly noticeable in developing countries, like South Africa, that have been undergoing numerous urbanization and urban renewal programmes in recent years. In combination, these developments lead to a vast amount of construction waste being produced.
It is estimated that about 40% of waste generated globally is as a result of construction activities (Sutrisna, 2012: 135; Yuan, 2013a: 101). Table 1.1 shows the Construction Waste in Million Metric Tons per Year as generated in various global contexts. This construction waste leads to monetary costs and environmental issues, yet construction waste minimisation and avoidance thereof at the design stage of a project is viewed as a relatively new concept or one of low priority by architects and designers globally (Baldwin, et al., 2009: 2067; Nagapan, Rahman & Asmi, 2012: 1, Osmani, 2008: 1156, 1157; Wang, Li & Tam, 2014: 2).

This is unfortunate, as is noted by Osmani (2008: 1147), as approximately one-third of construction waste could essentially accrue from poor or uninformed design decisions. In another study done in Iraq, results showed that construction waste can be reduced by up to 62% by merely making use of a few simple design changes in some of the building practices (Kharrufa, 2007: 2053). By the time that the project reaches the construction phase, majority of the opportunities for waste reduction have already lapsed (Dainty & Brooke, 2004: 22).

It is unfortunate that construction material waste is often seen as “an inevitable by-product of major construction projects” (Dainty & Brooke, 2004: 20). The construction waste rate within the industry is currently estimated to be as high as 10-15% of the total material required for the execution of the project (Dainty & Brooke, 2004: 20). Yeheyis (2013: 81) in turn stated that 75% of construction waste has a residual value and can thus be recycled, salvaged or re-used. Based on this residual value and the construction waste rate, one can thus deduce that 7.5-11.25% of the material costs accrued by the client during the construction project are possibly salvageable.

Table 1.1: Construction Waste in Million Metric Tons per Year in numerous Global Contexts

Context	Construction Waste in Million Metric Tons per Year	Reference
USA	170	Al-Hajj & Hamani (2011)
UK	120	Domingo et al. (2009) & Osmani (2012)
China	100	Wang, Li & Tam (2014)
Germany	59	Jaillon, Poon & Chiang (2009)
Spain	40	Nagapan et al. (2012)
UK	30	Jaillon, Poon & Chiang (2009)
Dubai	28	Al-Hajj & Hamani (2011)
France	24	Jaillon, Poon & Chiang (2009)
Italy	20	Jaillon, Poon & Chiang (2009)
India	14.5	Sutrisna (2012)
Hong Kong	14	Baldwin et al. (2009)
Netherlands	11	Jaillon, Poon & Chiang (2009)
Canada	9	Yeheyis et al. (2013)
Belgium	7	Jaillon, Poon & Chiang (2009)
Austria	5	Jaillon, Poon & Chiang (2009)
Portugal	3	Jaillon, Poon & Chiang (2009)
Denmark	3	Jaillon, Poon & Chiang (2009)
Greece	2	Jaillon, Poon & Chiang (2009)
Sweden	2	Jaillon, Poon & Chiang (2009)

1.1.2 Local Construction Waste Context - Research opportunity identified

Construction Waste in South Africa

Nagapan et al. (2012: 1-2) identified South Africa as a country with "a serious problem" in terms of physical construction waste. Engledow in turn (2010: 17) identified the "low priority status" of physical construction waste management in South Africa together with its "negative impact on the environment and human health."

From a client's perspective; waste generation on site consumes valuable time and effort of the contractor and results in losses in material, project delays, cost over-run and even the execution of non-valuable work performed.

Wang, Li and Tam (2014) noted in a recent study that a research opportunity existed in identifying the factors which will minimise construction waste with specific focus on the design stage. This study resulted in a critical list of factors which will reduce construction waste based specifically on a Chinese context. From the *International Construction Cost Survey 2012* (Turner & Townsend, 2012:14, 30) it can be deduced that South African material costs are approximately double than material costs in China. It can also be deduced that South African labour costs are higher than labour costs in China. Furthermore; in *The Rands and Sense of Green Building* (Milne, 2012: 16) it is stated that the construction and on-going operation of buildings in South Africa generate 40% of waste going to landfill which is double the amount of construction waste going to landfills in China (Baldwin, et al., 2009: 2067). It was thus identified that the South African body of knowledge will greatly benefit from a similar study like Wang, Li and Tam (2014) in a local context, due to the potential higher cost savings on materials, potential higher cost savings on labour as well as potential environmental and social benefits.

Construction Waste in Gauteng

The problem of construction waste in Gauteng is evident in Figure 1.1 and Figure 1.2 which are both office block construction projects in upmarket areas of Johannesburg. The author can thus conclude that due to Gauteng being both the economic and development hub of South Africa (and essentially southern Africa) and since the built environment has expanded rapidly in Gauteng over the past couple of years, construction waste has become an increasing problem, more so than in other provinces in South Africa.

Fig 1.1: [Photograph by Author] ***Hoarding of construction waste on Site "X", which is the construction of a large A-grade high rise office block in Sandton, Gauteng*****.**

Fig 1.2: [Photograph by Author] ***Piled up construction waste on Site "Y", which is the construction of a large low rise office block in Rosebank, Gauteng.***

This is further supported by The Gauteng Provincial Government's *Provincial Building & Demolition Waste Guidelines* (2009: 11) which state that approximately 42% of the overall waste generated in South Africa is from the Gauteng Province and approximately 25% of waste entering landfills in Gauteng are from construction activities.

1.1.3 Construction Project Stakeholders' perspectives on Construction Waste Minimisation

Globally there has been an increase in construction waste disposal and recycling fees which adversely affects the finances of both the client commissioning the construction work as well as the contractor who disposes of the waste. This is the primary reason why construction industry stakeholders should rethink waste management practices and should encourage waste reduction at the source as opposed to merely managing or recycling produced waste. This behavioural mind-shift amongst stakeholders will positively contribute to the construction industry in terms of economic, social & environmental sustainability (Lu & Yuan, 2010: 202; Poon, 2007: 1715).

Osmani (2008: 1147, 1156) noted that construction waste essentially accrues from a lack of awareness during the design stage as "waste reduction is rarely considered during daily life in an architect's office". This is due to architects assuming that waste is mainly produced during construction site operations. This is echoed by quantity surveyors who are of the opinion that there only a "few measures" that could be taken to reduce construction waste (Jacques, 2000: 144). Othman (2011: 337) stated that "in South Africa 76% of design firms indicated that they required contractors' experience in their design because contractors have better knowledge about material availability and appropriate technology that affects design and cost" yet contractors are reluctant to offer pre-construction advice which results in depletion of both their and the client's profits (Oladiran, 2009: 165). Contractors do not feel that waste management is part of their "core responsibilities" and often have poor or untimely communication skills (Dainty & Brooke, 2004: 21; Othman, 2011: 340). Contractors thus miss the golden opportunity to pro-actively address constructability issues during the design stage which will prevent rework on site and thus prevent construction waste. Furthermore contractors do not practice construction waste source separation, source reduction, reuse or recycling on construction sites. This may be due to the potential costs associated with these practices or the lack of knowledge regarding construction waste minimisation (Begum *et al.*, 2009: 326).

Furthermore Domingo *et al*. (2009: 1028) stated that clients do not consider construction waste a priority and see it as the contractor's responsibility, even though they acknowledge that it is an important financial consideration. Osmani *et al*. (2008: 1150, 1151) in turn stated that it is in essence the architect's responsibility to inform the client of the impact of waste reduction as well as the associated costs thereof, yet this is not being implemented in practice enough as the architectural profession is not currently culturally, strategically and logistically focused on construction waste reduction.

This is unfortunate, as if waste minimisation practices is integrated during the design phase of projects amongst all stakeholders, it will reduce construction time, improve quality of construction work and improve productivity of labourers (Othman, 2011: 333). These factors all contribute positively to the government, designers, contractors & clients (Lu & Yuan, 2010: 202).

1.2. Research Problem, Research Question, Delineations, Assumptions & Limitations

1.2.1 Research Problem

> ***Physical construction waste minimisation and waste avoidance is not considered a high priority by architects and designers within the design phase of a construction project. As this is a relatively new concept; critical factors guiding waste minimisation in the Gauteng region do not currently exist. Therefore, the problem to be investigated is the identification of these factors.***

1.2.2 Research Question

> ***What are the critical factors that will minimise physical construction waste production at the design phase of greenfield (undeveloped) construction projects in a Gauteng region context?***

1.2.3 Research Sub-Questions

- How are the identified construction waste minimisation factors within a Gauteng region context ranked in terms *significance*?

- How are the identified construction waste minimisation factors within a Gauteng region context ranked in terms of *ease of implementation*?

1.2.4 Research Delineations

- The resulting critical factors will be limited to design phase factors & strategies only and will therefore not include either the procurement or the construction phase.
- The resulting critical factors will be limited to new builds on Greenfield (undeveloped) sites only and will therefore not include renovation or alteration construction projects.
- The critical factors (which were identified by means of a global literature review) will only be tested and validated within a Gauteng region context. This is due to Gauteng having the majority of the accredited green buildings in South Africa (www.gbcsa.org.za/projects/certified-projects).
- The critical factors which was identified by means of a global literature review will only be tested and validated within the Gauteng region context's designers. This includes architects, architectural technologists, architectural draughtsmen, structural engineers, structural technologists and structural draughtsmen. Sustainability consultants (consultants whose main role is to advise other professions in the built environment) are also included as they provide design guidance to designers within the design stage of projects. Project managers were excluded as they are seen as providing more a managerial role as opposed to having a hands-on approach during the design stage.

1.2.5 Research Assumptions

- Designers are assumed to have the most knowledge regarding construction waste minimisation during the design phase as they are the key stakeholders in this phase of construction projects (SACAP, 2000).
- It is assumed that designers who have worked on Gauteng accredited green buildings will have cutting-edge knowledge about current industry practices and thus carry knowledge about the best contextual practices to minimise construction waste. This is based on the fact that the GBCSA encourages construction waste minimisation by rewarding good practices with points which may ultimately lead to green star ratings (GBCSA, 2008: 31).
- Dainty & Brooke's (2004) study entitled "*Towards improved construction waste minimisation: a need for improved supply chain integration?"* ranked waste producing factors identified in the United Kingdom in order of significance. It is thus assumed that the identified factors in Gauteng region can also be ranked in terms of significance.
- Dainty & Brooke's (2004) study entitled "*Towards improved construction waste minimisation: a need for improved supply chain integration?"* ranked waste producing factors identified in the United Kingdom in order of ease of implementation. It is thus assumed that the identified factors in Gauteng region can also be ranked in terms of ease of implementation.

1.2.6 Research Limitations

- This study will not associate the identified critical factors in effective construction waste minimisation in Gauteng with potential waste volume savings. This is due to every construction project being a unique endeavour.
- The resulting overall solutions in this context-specific study will not be generalizable to any other context.

1.2.7 Research Constraints

Research constraints may include the willingness of respondents to answer online questionnaires due to time constraints in practice and the limit of knowledge that they provide. Some respondents may never have received the questionnaire invitation and other may not give validated, credible and reliable information due to lack of experience on the topic. Constraints can also include how respondents are sampled. This will be discussed further in the research methodology chapter.

1.3 Consequences of the Problem of Construction Waste (Significance of the Study)

1.3.1 Economic & Cost consequences

"Waste costs money" (Baartjies, 2010: 13).

Coventry & Guthrie (1998: 9) identified numerous economic disadvantages in terms of construction waste production by analysing costs arising from the entire life-cycle thereof. The costs in terms of construction waste include the original purchase price, transportation costs to and from the site, the cost of sorting the waste (labour costs), the cost of storing the waste, the cost of disposing of the wastes and finally the loss of revenue from not reclaiming waste materials. These costs may directly and indirectly affect having both lower operations and maintenance costs (Milne, 2012: 136). It can thus be deduced that the client will be the main benefactor of this study as he is ultimately the person who pays for both the operations and maintenance costs as well as the project as a whole and ultimately for all the construction waste which is produced.

Clients have the greatest influence with regards to construction waste as they are in a position of authority to set environmental standards to which the professional team should comply (Dainty & Brooke, 2004: 22). This includes contractually requesting and advising designers to make use of waste minimisation strategies and designers thus become the secondary benefactors of the study.

Dealing with a vast amount of physical construction waste on site may also be a time-consuming task for the contractor and may result in project time over-runs which will adversely affect the client in terms of finances. In literature it is argued that “waste management can act as a profit centre in its own right” and that clients & companies can have a “competitive advantage” by means of adopting waste management & minimisation strategies (Dainty & Brooke, 2004: 20). It can thus be concluded that waste management & minimisation will aid in speedy delivery of building projects at minimum costs, which is ultimately the client’s main goal (Adjei-Kumi & Kpamma, 2011: 102).

1.3.2 Social & Environmental Consequences

Some clients, in particular large corporate companies, consider construction waste minimisation as part of their corporate social responsibility (Sutrisna, 2012: 147). This in turn supports why the client is in essence the stakeholder who will benefit from construction waste minimisation knowledge the most. In Saez *et al.*’s (2013) study in Spain the authors concluded that the main advantage for implementing measures to reduce construction waste was that it improves the corporate image and thus the business reputation of the company. This can be of particular interest to clients in a South African context as the “low priority status of waste management has had a negative impact on the environment and human health within South Africa” (Engledow, 2010: 17).

Environmental consequences include the fact that construction waste occupies landfills which in turn pollutes the environment. This not only endangers the health of human beings, but also negatively effects the natural environment and habitats that all living creatures live in. In the long run this affects climate change and thus the planet’s overall sustainability. (Poon, 2007: 1; Wang, Li & Tam, 2014:1; Yeheyis et al., 2013: 81).

1.4 Objectives of the Research

1.4.1 Primary objective of the study

The primary objective or purpose of this study will be to determine the critical factors in effective physical construction waste minimisation at the design phase of a greenfield (previously undeveloped) construction project in the Gauteng region context. These factors will in turn be ranked in terms of both the *significance* these factors will have in a Gauteng region context and in terms of *ease of implementation* in Gauteng.

This research will therefor aim to add to the current yet limited body of knowledge in South Africa by stating a useful set of overall solutions for effective reduction of physical construction waste.

1.4.2 Literature objective of the study

The Government of South Africa published the *National Environmental Management: Waste Act, Act No. 59 of 2009* in order to reform general waste management policies in South Africa by law (Wiechers, 2010: 25). It is thus crucial to identify critical factors to avoid and minimise the generation of construction waste in order to support the objectives of this Act as this Act does not currently address construction waste separately from municipal waste. The Gauteng Provincial Government's *Provincial Building & Demolition Waste Guidelines* (2009) does however provide some non-legislatory guidelines as to minimise construction waste in South Africa. This is contrary to the United Kingdom's government who has fully committed to sustainable construction strategies and waste minimisation practices (Domingo *et al.*, 2009: 1022-1023).

The findings of this study can thus drive national reform as the criteria may be valuable references for policy makers for the South African government to formulate construction waste minimisation strategies.

1.5 Research Methodology

The research methodology which will be used to investigate this problem will be an emancipatory theory research design method after Creswell (2009: 25). This exploratory research design will firstly incorporate qualitative approaches (deriving a conceptual framework from the current body of knowledge) which in turn will be followed by quantitative techniques (online survey questionnaires which tests the initial conceptual framework in a local context). The results will be statistically analysed and interpreted to produce a set of ranked critical factors for physical construction waste minimisation within a Gauteng region context. In summation the study approach is thus a strategy of inquiry in which current practices are explored in depth in the context of the Gauteng Province. (Creswell, 2009: 30; Saunders *et al*., 2012: 167; 179).

Wang, Li and Tam (2014), who did a similar study within a Chinese context, made use of a similar research design methodology to derive at ranked critical factors that will minimise construction waste at the design stage of Chinese construction projects. This research methodology has complementary strengths as the second part of the research (which encompasses validating the conceptual framework by means of questionnaires) will aid in exploring the applicability and the significance of the initial conceptual framework identified in the literature review. Furthermore and beyond the study of Wang, Li & Tam (2014) this study will also investigate the *ease of implementation* of the identified factors as per Dainty & Brooke's (2004:22) article entitled *Towards improved construction waste minimisation: a need for improved supply chain integration.*

1.6 Structure of the Research Report

This research report consists of multiple preliminaries which includes a list of acronyms, a list of abbreviations and a table of definitions in order to clarify the research. This section also contains a list of figures, a list of tables and a list of graphs which are all listed on conjunction with corresponding page numbers for ease of reference.

Chapter 1 consists mainly of the global and local context and the empirical substantiation of the research problem. This chapter also includes the research problem statement, research question, research sub-questions, delineations, assumptions, limitations, constraints, the consequences of the problem (economic, cost, social & environmental) as well as the objectives of the study. This chapter also briefly states the proposed research methodology, but that is discussed in depth in Chapter 3.

A comprehensive literature review can be found in Chapter 2 in which previous studies of construction waste minimisation were explored in terms of research contexts, research approaches, research methodologies and ultimately research findings. A conceptual framework was derived from the literature review which served as a launch pad for research carried out in the Gauteng region context. The prevalent as well as the non-prevalent factors of this conceptual framework are discussed with specific reference to a Gauteng region context. Furthermore this chapter discusses the adverse effects of construction waste and how context-specific parameters like construction materials, construction method selection, labour, automation & robotics as well as policies and legislation may affect construction waste. The chapter concludes with a discussion on the barriers identified in terms of implementing construction waste minimisation factors as well as the role that the Green Building Council South Africa (GBCSA) plays in Gauteng in terms of construction waste minimisation.

Chapter 3 in this research report discusses the research philosophy, research approach, research methodology and research design incorporated in this report. This includes justification of the research methodology as well as discussions with regards to the online questionnaires sampling techniques utilized in conjunction with ethical considerations. This chapter also discusses validity, constraints & reliability of the research as well as how gathered data will be analysed.

Chapter 4 discusses the research findings within the study. This chapter firstly analyses the response rate of the questionnaires together with the associated confidence level of the study. This is followed by an in-depth analysis of the demographic profile of respondents which is later utilized to potentially identify sub-groups (if any) within the research target population. The remainder of the chapter discusses the processed data obtained form the online questionnaires. This mainly evolves around the ranked *significant* critical factors that will minimise construction waste within the Gauteng region context as well as the ranked *ease of implementation* of these factors. The relationship between the *significance* of the factors as well as the *ease of implementation* of these factors are also explored and conclusions are drawn with regards to the overall favoured waste minimisation solutions in Gauteng. Furthermore this chapter will discuss additional factors identified by the respondents in the questionnaire which were not mentioned in the initial conceptual framework. Potential sub-groups as per demographic profile (role when having worked on green buildings in Gauteng, education level and years of experience when having worked on green buildings in Gauteng) within the research target population are also explored.

Chapter 5 includes the research conclusions and recommendations resulting from the research findings in Chapter 4. It also states unanswered questions beyond the scope of this study and proposes areas for future studies.

This research report is then concluded with a list of references used throughout the report which is finally followed by appendixes which contain additional and supporting information towards the research. The appendixes include; the full list of references for the conceptual framework in Table 2.2, the introductory letter in conjunction with the online questionnaire survey as well as precedents of the chosen data analysis method utilized in this research report.

2. LITERATURE REVIEW

2.1 Objectives of the Literature Review

The primary objective of this literature review is to survey the current global & local body of knowledge with regards to current practices of construction waste minimisation and why these practices should be implemented. These practices will be discussed and compared due to construction material, method & labour costs being different in varying contexts. Global construction waste minimisation factors will be listed together with its relevant context and the statistical frequency of the factors within the literature will be calculated. This thus forms a conceptual framework which acts as a launch pad for further context-specific research. The statistical frequency of factors will later be used in conjunction with other considerations in order for factors to be validated in terms of both *significance* and *ease of implementation* in a Gauteng region context.

This literature review will also include investigating various research methodologies and research techniques used in previous studies which identified critical construction waste minimisation factors globally. This will later serve as justification for the final chosen research design and research methodology as discussed in Chapter 3.

In summation; this literature review aims to prove the research gap of critical construction waste minimisation factors that can be implemented during the design stage of construction projects in Gauteng. It thus shows the current inconclusive state of knowledge regarding construction waste especially amongst Gauteng construction stakeholders. This literature review also explores and discusses current barriers in terms of implementing the identified factors. This research will thus contribute to the limited body of knowledge in Gauteng by addressing both the primary & literature objectives of the study as stated in Chapter 1.

2.2 Adverse effects of Construction Waste

Various categorization models have been applied in the past to classify numerous types of waste globally. Nagapan *et al.* (2012: 2) classified waste into two categories, namely; physical and non-physical waste. Non-physical waste includes time and cost overruns, whereas physical waste includes material waste. This research report deals with physical material waste. Different types of material waste can be classified by their differing states which includes solid, liquid or gaseous states. Material wastes are also classified by their varying characteristics which may include inert, combustible, biodegradable, hazardous or nuclear characteristics. Finally, waste is categorized by its origin which includes processing processes, households, municipal, institutional, emissions, construction activities and energy conversions. Physical construction waste can thus be studied separately from other categories of waste, especially due to its origin (Al-Hajj & Hamani, 2011: 222; Yates, 2013: 291).

Ekanayake & Ofori (2004: 852) defined physical construction waste as “any material apart from earth materials, which needed to be transported elsewhere from the construction site or used on the site itself other than the intended specific purpose of the project due to damage, excess or non-use or which cannot be used due to non-compliance with the specifications, or which is a by-product of the construction process.” For the purpose of this study earth material, specifically soil, will be considered as physical construction waste as excavations and cut & fill processes are seen as construction activities and voluminous excavations should adequately be planned during the design stage.

Construction waste is generally composed of broken or excessive materials which include; concrete, masonry, timber, sand, asphalt, various metals and different types of plastics. It is usually a mixture between inert & organic materials. It has been found that over 75% of what the industry generates as waste has a residual value and can thus be recycled, salvaged or be re-used, yet this is often seen as a burden by both labour workers and contractors (Yeheyis *et al.,* 2013: 81).

It is important to note that physical construction waste can be generated throughout the life-cycle of the construction project, from inception to completion, but the design stage contributes a considerable amount and is also the first stage of the project in which material control can be exerted. Numerous studies have identified physical construction waste as the most critical form of waste, as opposed to labour or machinery waste, due to physical construction waste originating mainly from non-renewable sources. This waste is also bulky, voluminous and difficult to compress or transport and thus time consuming to manage (Osmani, 2012: 38; Osmani *et al.*, 2008: 1149; Sutrisna, 2012: 135; Yeheyis *et al.*, 2013: 83).

Globally the construction industry consumes a vast amount of natural resources and generates large quantities of construction waste. According to Othman (2011:334), the construction industry is responsible for 50% of all material resources taken from nature, 40% of all energy consumption and 50% of total waste generated globally. This waste occupies & pollutes large landfill areas which adversely affects scarce land resources and in turn the global economy. Toxic substances may also be emitted from construction waste which in turn endangers the health of humans as well as the natural environment and habitats therein (Poon, 2007:1; Wang, Li, Tam, 2014:1). Other, more indirect, effects of construction waste include climate change, negative business reputations, effects on tourism and excessive fuel consumption (Yeheyis *et al.*, 2013: 81). Construction waste thus adversely affects economic & social development as well as environmental conditions. It thus adversely affects the "triple bottom line" of the global sustainable development principle without adding value to any of the construction stakeholders (Yuan, 2013b: 476).

Construction waste practices globally have been guided by the three "R's" principle. This is a global principle which hierarchically indicates three desirable strategies in terms of construction waste arranged in order of importance. The three "R's" are reduce, reuse and recycle and is seen in Fig 2.1 below. Research on recycling construction waste has been vastly published, yet less emphasis has been placed on construction waste minimisation or reduction at the source. This is unfortunate as waste thus have to be dealt with during and after the construction phase as opposed to designers having "designed out waste" during the design stage. This may be due to the construction industry's culture of resisting change and stakeholders' misconceptions that waste minimisation is not their responsibility (Baldwin *et al.*, 2009; Lu & Yuan, 2010: 201; Poon, 2007: 1715; Osmani *et al.*, 2008: 1147).

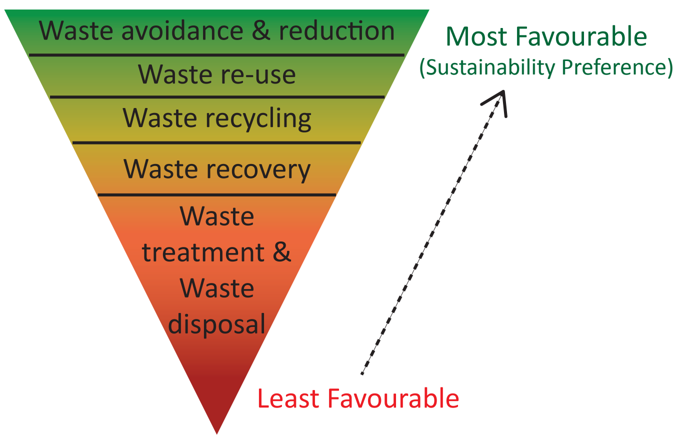


Fig 2.1: [Image by Author] ***Waste Management Hierarchy.***

Image adapted from:
Cornelius, J., 2010. *Integrated Waste Management Facilities.* In: R. Emery, ed. 2010. *The Waste Revolution Handbook South Africa*. 2nd Vol. Johannesburg: Alive2Green. Ch.12, pg. 138.

2.3 Global Research regarding Construction Waste minimisation

Keys *et al.* (2000: 4) defined physical construction waste minimisation as "any technique, process or activity that either avoids, eliminates or reduces waste at its source or allows reuse or recycling of the waste."

Construction waste minimisation can be achieved through various approaches which specifically includes changes in the designs of construction projects. Material selections as well as construction methods will also affect the amount of construction waste being produced on-site. These are generally all decisions made by designers at the design stage of the project and this thus substantiates the research delineation of investigating only the design stage of projects. Furthermore; the approaches towards design, approaches towards labour implementation, legislation, material selections & method of construction differ globally and factors which influence construction waste minimisation are thus seen to be context-specific.

The scientific study of construction waste originated in the United Kingdom in 1963 during exploratory investigations into new forms of tender documents (Ndihokubwayo & Haupt, 2009: 2). Therefor construction waste and the minimisation thereof is by no means a new research area within the global context, however limited studies explore construction waste minimisation at the design stage (at the source) which will result in resource conservation, environmental protection and cost savings for various stakeholders. Prior research cover causes and effects of construction waste, the adverse impact of construction waste on the environment, various stakeholders' perspective on construction waste minimisation and pressures from global evolving legislation & policies.

African studies include studies done in both Ghana (Adjei-Kumi & Zoya Kpamma, 2011) and Nigeria (Oladiran, 2009). The Ghanaian study examined the awareness of sources of construction waste together with local strategies which can be applied to minimise construction waste. The strength of this study is thus its local appeal with regards to context-specific solutions. This is in contrast to the Nigerian study which explored the application of waste management plans to thus examine their effect on construction waste. This Nigerian study found that waste management plans have the greatest effect on physical construction waste production as opposed to equipment waste, labour waste or time waste.

European studies include Spain (Saez *et al.*, 2013) & the United Kingdom (Dainty & Brooke, 2004; Domingo *et al.*, 2009; Osmani *et al.*, 2008 & Osmani, 2012). The Spanish study by Saez *et al.* (2013) aimed to assist various construction stakeholders in making adequate and informed decisions when it comes to construction waste. This is a particularly valuable study as construction stakeholders are in essence the main contributors to construction waste minimisation practices. This was after Osmani *et al*. (2008) conducted a study in the UK entitled *Architects' perspectives on construction waste reduction by design*. Dainty & Brooke (2004: 20), who also conducted their study in the UK, "explored the efficacy of measures used for minimising waste in high-profile United Kingdom based projects." This is similar to what Domingo *et al.*'s (2009) study explored, although Domingo *et al*. (2009) focused on specifically the healthcare industry in the UK. Osmani (2012) followed up on his initial study in 2008 and recently, in 2012, researched waste minimisation drivers and pressures for change within the UK. It can thus be concluded that studies moved from exploring stakeholders' perspectives to exploring waste minimisation guidelines, regulations and legislation that needs to be implemented.

Asian studies, which are by far the most prevalent, include China (Baldwin *et al.*, 2009; Lu & Yuan, 2010; Wang, Li & Tam, 2014 & Yuan, 2013a), Malaysia (Begum *et al.*, 2007), Singapore (Ekanayake & Ofori, 2004), Turkey (Esin & Cosgun, 2007), Iraq (Kharuffa, 2007), United Arab Emirates (Al-Hajj & Hamani, 2011) and India (Rajput, 2012 & Sutrisna, 2012). The amount of Asian studies far surpasses the amount of studies done in Europe or anywhere else globally. This can be due to Asian countries running out of waste disposal sites due to the large amount of construction waste generated (Poon *et al.*, 2004: 461). Baldwin *et al.* (2009) focused on "designing out waste" and Wang, Li & Tam's (2014) study focus on identifying construction waste minimisation factors at the design stage of projects. Ekanayake & Ofori's (2004) study identified a "designed-based tool" for building waste assessment scores. "Designing out waste" is thus an emerging literature topic in the Asian construction industry and Asian studies are thus the front-runners with regards to this topic. The Malaysian study by Begum *et al.* (2007) as well as the Indian study by Sutrisna (2012) both explored implementing waste management in their respective contexts. Asian studies thus comprehensively explored both construction waste factors as well as waste management as a whole.

North American studies cover the United States of America (Yates, 2013) and Canada (Yeheyis *et al*., 2013). Both these recent studies explored construction waste minimisation measures in conjunction with life cycle analysis and the emerging topic of sustainability in the construction industry. This is valuable as construction waste minimisation is thus directly linked to sustainability which involves economic, social & environmental responsibilities.

A study conducted in Australia by Lingard *et al.* (1997) investigated waste management from "a human factors approach." This was a unique study compared to previous studies as it identified "social and psychological factors which may determine behaviour in waste management" (Lingard *et al.*, 1997: 203). This study thus addresses the social aspects of sustainability.

Global studies which include general factors and practices, which are not context specific, have also been published (Keys *et al.*, 2000; Nagapan *et al.*, 2012; Othman, 2011; Poon, 2007 & Yuan, 2013b). Keys *et al.*'s (2000) study explored "designing to encourage waste minimisation" whereas Nagapan et al.'s (2012) study listed both physical and non-physical factors which contribute to the global generation of construction waste. As waste management as become topical, Yuan's (2013b) study was entitled *Key indicators for* *assessing the effectiveness of waste management in construction projects.*

Wang, Li & Tam (2014: 1) stated that identifying critical factors to minimise construction waste is "vitally important" to understand how to "implement efficient waste reduction measures" as it may be contractually required by governments and clients in the future. As most studies are context or region specific, the findings can be quite informative to aid strategic level planning. Context specific studies cannot easily be adapted and applied to other contexts without taking into consideration geographical contextual differences. These studies can however serve as valuable references and points of departures. No studies have currently been done in South Africa and specifically in the Gauteng region to identify the critical factors in effective construction waste minimisation and this study aims to address this research gap.

2.4 Global Research Methodologies used to identify Construction Waste minimisation factors

This section of the report aims to summarize numerous research methodologies that have been utilized in both context-specific as well as global studies which aimed at identifying construction waste minimisation factors.

Table 2.1: Research Methodologies used in previous studies

No.	Author	Context	Research Methodology
1	Osmani et al. (2008)	UK	Sampled Survey Questionnaires (Likert scales) & Open-ended question
2	Al-Hajj & Hamani (2011)	UAE	Sampled Survey Questionnaires (Likert scales) & Interviews & Site Audits
3	Begum et al (2007)	Malaysia	Sampled Survey Questionnaires (Likert scales) & Interviews
4	Dainty & Brooke (2004)	UK	Sampled Survey Questionnaires (Likert scales) & Interviews
5	Lu & Yuan (2010)	China	Sampled Survey Questionnaires (Likert scales) & Interviews
6	Yuan (2013a)	China	Sampled Survey Questionnaires (Likert scales) & Interviews
7	Ekanayake & Ofori (2004)	Singapore	Sampled Survey Questionnaires (Likert scales)
8	Oladiran (2009)	Nigeria	Sampled Survey Questionnaires (Likert scales)
9	Saez et al. (2013)	Spain	Sampled Survey Questionnaires (Likert scales)
10	Wang, Li & Tam (2014)	China	Sampled Survey Questionnaires (Likert scales)
11	Esin & Cosgun (2007)	Turkey	Sampled Survey Questionnaires
12	Kharrufa (2007)	Iraq	Sampled Survey Questionnaires
13	Rajput et al. (2012)	China	Sampled Survey Questionnaires
14	Lingard et al. (1997)	Australia	Interviews & Site audits
15	Adjei-Kumi & Zoya Kpamma (2011)	Ghana	Site audits & Interviews
16	Sutrisna (2012)	India	Case Studies & Interviews
17	Keys et al. (2000)	Global	Site audits
18	Domingo et al. (2009)	UK	Interviews
19	Nagapan et al. (2012)	Global	Interviews
20	Yates (2013)	USA	Interviews
21	Yuan (2013b)	Global	Interviews
22	Osmani (2012)	UK	Desktop Study
23	Poon (2007)	Global	Desktop Study

Wang, Li and Tam (2014) identified critical factors in a Chinese context by means of a twofold research methodology. Firstly; potential factors which can influence construction waste minimisation in China were presented as based on related official guidelines, reports and literature. This is seen as a qualitative interpretivist approach which is useful to formulate a provisional list or a conceptual framework containing potential critical factors. Secondly; sampled institutions (which received Chinese "A" Grade building design certification) was surveyed on the importance of the identified factors by means of quantitative survey questionnaires. Likert scales were optimized in order to identify the significance of the predetermined factors within a Chinese context. From this survey, critical factors were statistically derived and deduced.

Saez *et al.*'s (2013) study in Spain as well as Ekanayake & Ofori's (2004) study in Singapore made use of the exact same research methodology as that of Wang, Li and Tam (2014). The sampled questionnaire methodology incorporated in all these studies is thus seen to be an effective research methodology, particularly in identifying context-specific factors. In general, questionnaires are widely used by researchers within the construction sector (Saez *et al.*, 2013: 53).

Esin & Cosgun (2007), in turn, opted for pure in-depth questionnaire surveys in the context of Turkey. This was the same approach that Kharrufa (2007) utilized in Iraq and Rajput *et al.* (2012) utilized in China. The shortfall of these is that results are thus not as credible as the sequential method approaches utilized by

Ekanayake & Ofori (2004), Saez *et al.* (2013) & Wang, Li & Tam (2014) due to not corroborating the initial findings.

Numerous similar studies, which were also context-specific, have used similar research methodologies as that of Wang, Li & Tam (2014) with slight alterations & variations. This includes Osmani *et al.*'s (2008) study in the United Kingdom in which the survey questionnaires to validate the predetermined factors also included multiple-choice and open-ended questions above the Likert scale rating questions. This study is thus particularly credible, arguable more so than that of Wang, Li & Tam (2014), due to cross-examining answers obtained from the same respondents which thus eliminates respondent errors. Begum *et al.*'s (2007) study in Malaysia implemented a first round of interviews as opposed to making use of an initial extensive literature review like that of Wang, Li and Tam (2014) in order to identify critical factors which were then quantitatively explored by means of Likert rating scales.

In contrast, Domingo *et al*. (2009) used an initial interview which in turn was followed by a full interview to validate their literature review findings in the United Kingdom. Possible weaknesses of only utilizing verbal interviews include how this qualitative data can be quantified in order to statistically establish a set of construction waste minimisation factors. This study was similar to Yates's (2013) study who only interviewed high level construction executives to determine factors in the United States of America, as it was assumed that these executives will be well informed of current contextual construction waste minimisation practices. This assumption by Yates (2013) may have resulted in limited data results as these executives are not necessarily designers in the design stage of construction projects.

In more recent years, more encompassing research studies were implemented. Yuan (2013a) conducted extensive research and validated predetermined factors in a Chinese context by making use of both survey questionnaires & semi-structured interviews prior to determining a final set of critical factors. This is thus a particularly thorough report as it encompassed numerous research method stages. Al-Hajj & Hamani (2011) validated predetermined factors in the United Arab Emirates by means of visiting various construction sites & auditing waste management activities. The results were analyzed in combination with initial literature reviews prior to validating the significance of critical factors by means of quantitative questionnaires. This study can be of particular interest in examining construction waste minimisation practices during the construction phase.

Both Nagapan *et al.* (2012) & Yuan (2013b) conducted global studies and made use of interview sessions to validate the predetermined factors as opposed to Wang *et al.'s* (2014) approach of making use of quantitative questionnaires in a context-specific study. These global studies of Nagapan *et al.* (2012) & Yuan (2013b) have the shortfall of not being generalised to other contexts. This is due to construction methods & design approaches being different in very country. In turn, Lu & Yuan's (2010) study in China validated the factors by making use of both research approaches and included quantitative questionnaires as well as semi-structured interviews to validate predetermined factors in a context-specific study. This triangulation method can be seen as a cross-check to validate data obtained which will "ensure successful competitive performance" (Lu & Yuan, 2013: 203).

Vastly different research methodologies include Osmani's (2012) study in the United Kingdom which consisted of a pure qualitative interpretivist desktop study. This is similar to Poon's (2007) global study which implemented the same methodology and aims at paving the way for more contextual research studies.

Keys *et al.* (2000) made use of on-site observations & site audits where procurement inventories were directly compared to design drawings. This study aimed to determine global factors for construction waste minimisation strategies. This is similar to a Ghanaian study by Adjei-Kumi & Zoya Kpamma (2011) where construction activities on site were closely observed prior to interviewing both clients & contractors. Construction site audits can be particularly useful when researching construction waste practices during the construction phase.

In conclusion, it is evident that the hybrid methodology of incorporating a qualitative literature review followed by sampled questionnaires surveys to validate the initial identified critical factors is by far the most prevalent research methodology utilized, especially for context-specific studies. This is also clearly evident in Table 2.1 (Wang, Li and Tam, 2014; Ekanayake & Ofori, 2004; Saez *et al.*, 2013). It was thus this method which was utilized to identify critical factors in a Gauteng region context. The research design and research methodology is discussed later in the relevant chapter.

2.5 Global Research Findings with regards to Construction Waste minimisation factors

Potential factors which can influence physical construction waste minimisation on greenfield sites in the design phase within various contexts globally was identified by means of qualitatively researching and interpreting various bodies of knowledge. These bodies of knowledge included numerous global academic peer-reviewed journal paper articles and conference papers, which are seen as credible sources due to these sources being refereed. Global reports, design manuals as well as site guides were also surveyed for factors. Book publications and the *Gauteng Provincial Building & Demolition Waste Guidelines* were reviewed from the currently limited South African body of knowledge. This combination of 31 primary & secondary literature sources yielded a positivist conceptual framework of factors identified from 15 different global contexts and is seen in Table 2.2 below.

The frequency of factors within the literature in the current global body of knowledge was determined quantitatively in Table 2.2 and the factors were ultimately ranked from most prevalent to least prevalent. The full referencing for each of these factors can be seen in Appendix A.

Table 2.2: Conceptual Framework of Construction Waste Minimisation Factors (Literature Review Outcomes)

		CONTEXT	Adjei-Kumi & Zoya (2011)	Al-Hajj & Hamani (2011)	Baldwin, Poon et al. (2009)	Begum, Siwar et al. (2007)	Coventry & Guthrie (1998)	Dainty & Brooke (2004)	Domingo, Osmani & Price (2009)	Ekanayake & Ofori (2004)	Esin & Cosgun (2007)	Gauteng Prov. Govt. (2009)	Guthrie et al. (1997)	Keys, Baldwin & Austin (2000)	Kharrufa (2007)	Lingard, Graham et al. (1997)	Lu & Yuan (2010)	Milne (2012)	Nagapan et al. (2012)	Oladiran (2009)	Osmani, Glass & Price (2008)	Osmani (2012)	Othman (2011)	Poon (2007)	Rajput et al. (2012)	Saez et al. (2013)	Sutrisna (2012)	WRAP (2009)	Wang, Li & Tam (2014)	Yates (2013)	Yeheyis et al. (2013)	Yuan (2013a)	Yuan (2013b)	FREQUENCY OF FACTORS
CRITICAL FACTORS IN EFFECTIVE CONSTRUCTION WASTE MINIMISATION AT THE DESIGN STAGE																																		
1	Designers should make use of standardization (standard dimensions, units & structural grids) & modularization in design components	China, UK, Global, Turkey, Australia, Iraq, USA, India			I		I	I	I	I	I			I	I	I					I		I	I	I	I	I	I	I	I			I	19
2	Designers lack knowledge & experience with regards to constructability, materials & material specifications. Ambiguous, wrong, complex, over and under specification result in excessive material cut-offs, maintenance rework & variations. Design management, offering education & training might all be a viable solutions.	UAE, Malaysia, UK, Global, Turkey, Australia, China, Canada, Gauteng		I		I	I	I	I	I	I	I		I		I	I		I	I	I	I	I	I							I			18
3	Designers should specify off-site preparation, pre-assembly, prefabrication & precast components (i.e.; specify precast industrialized concrete components as opposed to wet works)	UAE, China, Malaysia, UK, Global, USA, India		I	I	I	I	I	I					I			I				I		I	I		I	I	I	I	I		I	I	18

		CONTEXT	Adjei-Kumi & Zoya (2011)	Al-Hajj & Hamani (2011)	Baldwin, Poon et al. (2009)	Begum, Siwar et al. (2007)	Coventry & Guthrie (1998)	Dainty & Brooke (2004)	Domingo, Osmani & Price (2009)	Ekanayake & Ofori (2004)	Esin & Cosgun (2007)	Gauteng Prov. Govt. (2009)	Guthrie et al. (1997)	Keys, Baldwin & Austin (2000)	Kharrufa (2007)	Lingard, Graham et al. (1997)	Lu & Yuan (2010)	Milne (2012)	Nagapan et al. (2012)	Oladiran (2009)	Osmani, Glass & Price (2008)	Osmani (2012)	Othman (2011)	Poon (2007)	Rajput et al. (2012)	Saez et al. (2013)	Sutrisna (2012)	WRAP (2009)	Wang, Li & Tam (2014)	Yates (2013)	Yeheyis et al. (2013)	Yuan (2013a)	Yuan (2013b)	**FREQUENCY OF FACTORS**
CRITICAL FACTORS IN EFFECTIVE CONSTRUCTION WASTE MINIMISATION AT THE DESIGN STAGE																																		
4	Designers should avoid frequent & last minute design changes, especially during construction phase.	China, UK, Global, Canada, Ghana, India	I		I			I	I	I				I		I	I		I		I	I		I		I	I		I		I	I	I	18
5	Designers should specify re-usable, reclaimed, salvaged or recycled materials (i.e.; recycled aggregates. In South Africa this can specifically refer to adding flyash (a cheap waste product of smelting plants) to the concrete to reduce the amount of OPC (Ordinary Portland Cement) used.)	UAE, Malaysia, Global, Australia, China, UK, Canada, South Africa, Gauteng, Iraq, USA, India		I		I	I					I	I	I	I	I	I	I			I		I			I	I			I	I		I	17
6	Designers should communicate & co-ordinate efficiently and effectively with other consultants at the design stage. This includes dimensional co-ordination, optimization & co-ordinating with contractors. This particularly involves team problem-solving.	China, UK, Global, Australia, Ghana, India	I		I				I					I			I		I		I	I	I	I		I	I	I						13

		CONTEXT	Adjei-Kumi & Zoya (2011)	Al-Hajj & Hamani (2011)	Baldwin, Poon et al. (2009)	Begum, Siwar et al. (2007)	Coventry & Guthrie (1998)	Dainty & Brooke (2004)	Domingo, Osmani & Price (2009)	Ekanayake & Ofori (2004)	Esin & Cosgun (2007)	Gauteng Prov. Govt. (2009)	Guthrie et al. (1997)	Keys, Baldwin & Austin (2000)	Kharrufa (2007)	Lingard, Graham et al. (1997)	Lu & Yuan (2010)	Milne (2012)	Nagapan et al. (2012)	Oladiran (2009)	Osmani, Glass & Price (2008)	Osmani (2012)	Othman (2011)	Poon (2007)	Rajput et al. (2012)	Saez et al. (2013)	Sutrisna (2012)	WRAP (2009)	Wang, Li & Tam (2014)	Yates (2013)	Yeheyis et al. (2013)	Yuan (2013a)	Yuan (2013b)	FREQUENCY OF FACTORS
CRITICAL FACTORS IN EFFECTIVE CONSTRUCTION WASTE MINIMISATION AT THE DESIGN STAGE																																		
7	Designers should supply adequate information on drawings and avoid lacking or incorrect design & detailing packages.	UK, Global, Australia, Canada, Ghana, India	I				I	I	I					I		I			I		I		I	I			I				I			12
8	Designers should design for future deconstruction & disassembly (Make use of life cycle assessments of materials; i.e.; although solid bricks are more expensive than perforated bricks, solid bricks have a higher chance of being re-used in the future. Minimize types and numbers of fasteners & connectors to ease future re-use.)	UK, Turkey, Global, Gauteng, Iraq, USA					I		I		I	I		I	I						I		I			I		I		I				11
9	Designers should avoid over-designing as well as complex designs & detailing which result in excessive off-cuts.	UK, Global, Australia, USA					I		I	I				I		I			I		I	I	I							I				10

No.		CONTEXT	Adjei-Kumi & Zoya (2011)	Al-Hajj & Hamani (2011)	Baldwin, Poon et al. (2009)	Begum, Siwar et al. (2007)	Coventry & Guthrie (1998)	Dainty & Brooke (2004)	Domingo, Osmani & Price (2009)	Ekanayake & Ofori (2004)	Esin & Cosgun (2007)	Gauteng Prov. Govt. (2009)	Guthrie et al. (1997)	Keys, Baldwin & Austin (2000)	Kharrufa (2007)	Lingard, Graham et al. (1997)	Lu & Yuan (2010)	Milne (2012)	Nagapan et al. (2012)	Oladiran (2009)	Osmani, Glass & Price (2008)	Osmani (2012)	Othman (2011)	Poon (2007)	Rajput et al. (2012)	Saez et al. (2013)	Sutrisna (2012)	WRAP (2009)	Wang, Li & Tam (2014)	Yates (2013)	Yeheyis et al. (2013)	Yuan (2013a)	Yuan (2013b)	FREQUENCY OF FACTORS
	CRITICAL FACTORS IN EFFECTIVE CONSTRUCTION WASTE MINIMISATION AT THE DESIGN STAGE																																	
10	Designers should implement an organizational culture to waste in their businesses. This can for instance include a waste management report developed during the design stage which will be implemented by the contractor on site during construction. This can also include investing in waste sorting equipment and waste management staff.	Global, Spain, Canada, South Africa, Iraq, UK, India						I							I			I					I		I	I			I		I		I	9
11	Designers should avoid late drawing revisions & submittals which result in over-ordering of materials due to lack of information & time pressures on site	UK, Nigeria, Global, Ghana	I						I										I	I	I	I		I										7
12	Designers should be offered bonuses, rewards or economic incentives for curbing construction waste during the design stage	Malaysia, China, Canada, Global, Iraq, India				I	I								I												I		I		I		I	7

		CONTEXT	Adjei-Kumi & Zoya (2011)	Al-Hajj & Hamani (2011)	Baldwin, Poon et al. (2009)	Begum, Siwar et al. (2007)	Coventry & Guthrie (1998)	Dainty & Brooke (2004)	Domingo, Osmani & Price (2009)	Ekanayake & Ofori (2004)	Esin & Cosgun (2007)	Gauteng Prov. Govt. (2009)	Guthrie et al. (1997)	Keys, Baldwin & Austin (2000)	Kharrufa (2007)	Lingard, Graham et al. (1997)	Lu & Yuan (2010)	Milne (2012)	Nagapan et al. (2012)	Oladiran (2009)	Osmani, Glass & Price (2008)	Osmani (2012)	Othman (2011)	Poon (2007)	Rajput et al. (2012)	Saez et al. (2013)	Sutrisna (2012)	WRAP (2009)	Wang, Li & Tam (2014)	Yates (2013)	Yeheyis et al. (2013)	Yuan (2013a)	Yuan (2013b)	**FREQUENCY OF FACTORS**
CRITICAL FACTORS IN EFFECTIVE CONSTRUCTION WASTE MINIMISATION AT THE DESIGN STAGE																																		
13	Designers should adopt low-waste modern technologies & systems (i.e.; innovative formwork & falsework (use large panel metal formworks), steel structures & drywalls, minimize use of temporary works)	UK, China, Global							I								I						I	I					I				I	6
14	Government legislation, taxation (landfill fees) & policies are lacking or compliance thereto is not enforced. If this was adequate landfilling & incineration of waste may be reduced.	UAE, Turkey, UK, Canada, China, Global		I							I											I									I	I	I	6
15	Designers should receive complete, unambiguous briefings & contract documentation from the client at the design stage	UK, Global, Canada, Ghana	I						I	I									I												I			5
16	Designers lack experience & knowledge with regards to method & sequence of construction which leads to alterations of work	Global, UK, Ghana, India	I							I									I		I				I									5

		CONTEXT	Adjei-Kumi & Zoya (2011)	Al-Hajj & Hamani (2011)	Baldwin, Poon et al. (2009)	Begum, Siwar et al. (2007)	Coventry & Guthrie (1998)	Dainty & Brooke (2004)	Domingo, Osmani & Price (2009)	Ekanayake & Ofori (2004)	Esin & Cosgun (2007)	Gauteng Prov. Govt. (2009)	Guthrie et al. (1997)	Keys, Baldwin & Austin (2000)	Kharrufa (2007)	Lingard, Graham et al. (1997)	Lu & Yuan (2010)	Milne (2012)	Nagapan et al. (2012)	Oladiran (2009)	Osmani, Glass & Price (2008)	Osmani (2012)	Othman (2011)	Poon (2007)	Rajput et al. (2012)	Saez et al. (2013)	Sutrisna (2012)	WRAP (2009)	Wang, Li & Tam (2014)	Yates (2013)	Yeheyis et al. (2013)	Yuan (2013a)	Yuan (2013b)	**FREQUENCY OF FACTORS**
CRITICAL FACTORS IN EFFECTIVE CONSTRUCTION WASTE MINIMISATION AT THE DESIGN STAGE																																		
17	Waste minimisation clauses should be embedded in contractual clauses. Alternatively; building approval departments can establish waste minimisation conditions in order for plans to be approved prior to construction.	UK, Global, Gauteng, India						I	I			I															I	I						5
18	Designers should make use of adaptable & flexible project designs.	UK, China, Global, South Africa							I									I										I				I		4
19	Designers should plan for soil remains (cut & fills) to be used in the same construction site or negotiate with neighbouring sites.	Global, India											I													I	I							3
20	Designers should provide for an adequate space on the construction site where waste quantification, storing and sorting can take place.	Global, India																								I	I						I	3

	CRITICAL FACTORS IN EFFECTIVE CONSTRUCTION WASTE MINIMISATION AT THE DESIGN STAGE	CONTEXT	Adjei-Kumi & Zoya (2011)	Al-Hajj & Hamani (2011)	Baldwin, Poon et al. (2009)	Begum, Siwar et al. (2007)	Coventry & Guthrie (1998)	Dainty & Brooke (2004)	Domingo, Osmani & Price (2009)	Ekanayake & Ofori (2004)	Esin & Cosgun (2007)	Gauteng Prov. Govt. (2009)	Guthrie et al. (1997)	Keys, Baldwin & Austin (2000)	Kharrufa (2007)	Lingard, Graham et al. (1997)	Lu & Yuan (2010)	Milne (2012)	Nagapan et al. (2012)	Oladiran (2009)	Osmani, Glass & Price (2008)	Osmani (2012)	Othman (2011)	Poon (2007)	Rajput et al. (2012)	Saez et al. (2013)	Sutrisna (2012)	WRAP (2009)	Wang, Li & Tam (2014)	Yates (2013)	Yeheyis et al. (2013)	Yuan (2013a)	Yuan (2013b)	FREQUENCY OF FACTORS
21	Designers should design space to be adequate & functional in order to prevent future alterations which result in waste	Turkey, Global									I		I																					2
22	Designers should design in aid of minimizing temporary works	Global					I							I																				2
23	Designers should implement BIM (Building Information Modelling) at the design stage. This will aid in virtually planning for construction materials in order to avoid, prevent or minimize waste.	Canada, India																									I				I			2
24	Designers should take into account the accessibility of construction personnel on site	Global																					I											1
25	Designers should facilitate for construction to be executed with ease during adverse weather conditions.	Global																					I											1
26	Designers should make use of environmental impact assessments during the design stage of the scheme in order to realize where waste reduction potentials are and how materials can be optimized.	UK						I																										1

2.6 Reviewing the Construction Waste minimisation factors

This sections aims to discuss the potential factors which can influence physical construction minimisation within the design stage as identified in the previous section from the global literature survey. Outlying factors (prevalent and non-prevalent) will be explored and discussed in order to clarify why various factors were more prevalent in the literature than others. The relationships & dependencies of factors are also discussed.

2.6.1 Prevalent Factors in Literature

This subsection discusses prevalent factors which are the top five (out of the twenty-six) identified factors from the conceptual framework as seen in Table 2.2.

Designers should make use of Standardization

The literature survey above identified that making use of standardization during the design phase is the most prevalent factor that will minimise construction waste. This includes making use of standard dimensions, standard units & standard structural grids.

It also includes modularization (repetitive structures) in design components which allows components to easily fit together like puzzle pieces. Einstein stated that modularization is “making the bad difficult and the good easy.” This directly links to third most prevalent factor identified from the global literature review, namely that designers should specify precast and prefabricated components. These technologies are discussed below, but it is important to note that a prerequisite of these technologies is standardization.

Poon (2007: 1715) stated that approximately 10% of total construction waste is generated from cut-offs of materials during the construction phase due to designers not opting for standardized material sizes. This is a considerable amount as Dainty & Brooke (2004: 20) stated that 10-15% of the total material required for the execution of projects result in construction waste (Dainty & Brooke, 2004: 20). This also requires a vast amount of labour on site which adversely affects both the client & the contractor financially.

Designers lack knowledge & experience with regards to constructability, materials & material specifications

Designers lacking knowledge & experience with regards to constructability & specifications was identified as the second most prevalent factor from the reviewed global literature. Al-Hajj & Hamani (2011: 221) identified this as the most significant factor in the context of the United Arab Emirates. Ambiguous, wrong, complex, over and under specification result in excessive material cut-offs, maintenance rework, rectifications & constant variations. All these activities are not only extremely time-consuming for the contractor and labour workers (which results in higher labour costs and thus higher project costs), but will also eventually lead to the production of unnecessary physical construction waste.

An example of this includes construction materials ordered, paid and delivered on site which lies on site redundantly due to these materials being ordered from errors in material specifications by the designers. The specification errors can include that the materials are not appropriate or adequate to use on the project due to the project’s geographical context, difficult junctions with other materials, poor material quality or errors in material sizes ordered. These errors or ambiguities are generally as a result of designers not fully understanding or not being familiar with the construction processes and sequences which occur on site (Al-Hajj & Hamani, 2011: 230; Osmani, 2012: 38; Yeheyis et al., 2013: 86). This directly links to another factor, the sixteenth most prevalent factor, which states that designers lack experience & knowledge with regards to method & sequence of construction which leads to alterations of work and thus causes waste.

Design management, quality management, offering education & training might all be viable solutions to address this encompassing issue, but ultimately this can easily be solved by means of team problem solving, communication & co-ordination. Effective communication and co-ordination between all stakeholders during the design stage was identified as the sixth most prevalent factor. Clients should thus incorporate contractual clauses which enforces the contractor to advise and communicate with the designers with regards to the construction sequence and construction method during the design stage. This is known in the industry as ECI (Early Contractor Involvement) (Begum, Siwar et al., 2007: 195; Yeheyis et al., 2013: 86).

This ultimately links to the seventeenth most prevalent factor which states that waste minimisation clauses should be embedded in contractual clauses. It can thus be concluded that designers lacking knowledge & experience with regards to constructability, materials & material specifications is a very inter-dependent factor which can be solved by the implementation of various other factors identified.

Designers should specify off-site preparation, pre-assembly, prefabrication & precast components

The third most prevalent factor from the literature survey is to make use of prefabrication & precasting technologies. This moves the labour intensive construction processes on construction sites to factory production off-site. Wang, Li & Tam (2014) as well as Lu & Yuan (2010) both identified it as the most prevalent factor in their respective studies conducted in China. Baldwin *et al.* (2009) found it applicable especially in high rise and dense residential contexts which is generally in metropolitan cities. In the Gauteng region this can thus be particularly applicable in both the Sandton and Rosebank metropolitan areas.

According to Baldwin *et al.* (2009), 80% of construction waste found on traditional construction projects is as a result of concreting processes and associated wet trades. This can easily be eliminated by opting for precast concrete components to replace cast-in-situ wherever possible, especially as prefabrication is seen as a low level technology (Baldwin *et al.,* 2009: 2067; Lu & Yuan, 2010: 202). This will reduce labour intensive activities on site which in turn provides a safer working environment and reduces labour costs. Baldwin *et al.* (2009: 2069) concluded that an overall manpower saving of 30% in terms of productivity has been found on sites that use precast techniques as opposed to cast-in-situ techniques. This is due to the associated labour force as well as the high supervision staff costs associated with cast-in-situ techniques.

This is thus a very important factor for contexts where labour on site is very expensive or where skilled workers are scarce. It will also be easier to progress with construction during adverse weather conditions as in-situ activities are removed from the critical path in the construction program which in turn will ensure speedy completion of construction projects (Baldwin *et al.*, 2009). This then links with another less prevalent factor (twenty-fifth most prevalent) identified from the global literature survey, namely that designers should design projects that can easily be constructed during adverse weather conditions. Furthermore; quality can be managed easier in prefabrication production plants and quality can thus be ensured in the final construction product. From a social perspective; noise levels will be reduced in the surrounding community.

The downside of precasting and prefabricating design components is possible longer lead times (especially if fabricated internationally), transportation time and costs and storage costs. Good logistical management systems and supervision would need to implemented which render this system as non-feasible for small scale construction projects. Prefabricated design components are also at risk of being damaged during transportation to construction sites. Stakeholders are wary to make use of prefabrication as designers often have the perception that the building’s aesthetic would be compromised. Precasting & prefabrication also requires a multi-disciplinary approach to design in which all consultants communicate & co-ordinate effectively (Baldwin *et al*., 2009: 2068; Poon *et al.*, 2004: 468). This was identified as another prevalent (sixth most prevalent) critical factor as team problem solving in the design stage will eradicate numerous constructability problems once the project hits the construction phase.

In conclusion, Baldwin *et al.* (2009: 2069) stated that a cost saving of 3-5% of the overall project cost can be saved when opting for precast solutions as opposed to cast-in-situ techniques. This calculation included manpower (as opposed to mechanization) and material costs as well as construction waste dumping costs. Although prefabrication & precasting will drastically reduce the required labour on construction sites, this might not be as great an advantage in comparison to other global counterparts due to the current socio-economic climate in South Africa. This is due to the construction industry being a major contributor to the employment sector and thus the financial welfare of society.

Designers should avoid frequent & last minute design changes, especially during construction phase

Last minute design changes due to design errors or to satisfy client requirement result in demolitions, alterations & rework of new construction. This results in construction waste as some construction materials already procured will not be utilized, more materials may have to be obtained for the additional work & demolished works' materials may not be salvageable or reusable. From Ndihokubwayo & Haupt's (2009: 9) study conducted in South Africa one can conclude that both the client and the consultants, as opposed to the contractor, are the waste origin agents in terms of design changes and variations. Construction waste can thus be prevented if adequate design & construction management policies were in place in which design concepts were finalized between the designer and the client prior to construction commencing. This will contractually enforce either the client or the designer to financially take responsibility for the rework of aspects of the project and its associated waste.

Design & construction management policies also include collaborating & co-ordinating design decisions between all consultants involved in the project at the design stage. This was later identified as a separate yet prevalent factor on its own as various stakeholders are involved in the co-ordination of projects (Yeheyis, 2013: 86; Yuan, 2013b: 478). This should, however, be balanced carefully as too much disorganised interaction between consultants may result in confusion.

The effect of frequent & last minute design changes has vastly been published in the reviewed literature as a significant contributing factor to construction waste. Domingo *et al.* (2009) concluded that this factor is the most significant factor in the context of the United Kingdom whereas Nagapan *et al.* (2012) found that this factor is the most significant factor contributing to construction waste globally. This literature review identified frequent & last minute design changes as the fourth most prevalent factor.

Designers should specify re-usable, reclaimed, salvaged or recycled materials

This factor was seen as the fifth most prevalent factor from the reviewed literature and is synonymous with the global three "R's" principle which hierarchically indicates three desirable strategies in terms of construction waste arranged in order of importance. The three "R's" are reduce, reuse and recycle.

"Many countries, including South Africa, have immature recycling markets" which is very unfortunate as "recycling activities can translate into employment and business creation opportunities for [local] communities" (Gauteng Provincial Government, 2009: 2).

In a South African context, it is extremely advisable to make use of both Recycled Coarse Aggregates (RCA) as well as Recycled Fine Aggregates (RFA) in the current prevalent processes of concreting. RCA generally consist of pieces of demolished reinforced concrete structures. RFA includes adding flyash (a cheap waste product of smelting plants) to the concrete to reduce the amount of OPC (Ordinary Portland Cement). A recent study by Ahmed (2013) concluded that concrete containing RCA has improved compressive, flexural, and tensile strengths. Furthermore, the addition of flyash improves the workability as well as the long-term compressive strengths of recycled aggregate concretes (Ahmed, 2013: 1864, 1869). Furthermore, numerous employment opportunities are created at recycling plants which can for instance include separators as well as plant operators. It is thus evident that specifying recycled aggregates in South Africa and in Gauteng will only result in a pure win-win scenario for all stakeholders involved.

Table 2.3 lists more building materials & components which are commonly used in South Africa in conjunction with these materials' potential re-use strategies.

Table 2.3: Common Construction Materials in South African and their potential re-uses. Table adapted from *Green Star SA Office v1 2008.*

BUILDING MATERIALS & COMPONENTS	POTENTIAL RE-USE
Bricks & Concrete	Clean Fill
Salvaged Timber	New Structural Use, Timber waste can be grounded into mulch in order to be re-used as garden compost
Crushed Concrete	Road Base
Crushed Plasterboard	Soil conditioner or as a basis to manufacture new plasterboard
Steel & Aluminium	Recycled to be re-sued as new metal products
Foam insulation & Packaging	Re-use for new insulation or soft structural forms
Pallets	Re-use as is
Clean plastics from packaging	Packaging new materials to be stored
Carpet & Ceiling Tiles	Reconditioning or recycling by manufacturer
Light fixtures	Cleaning & Re-use
Furniture	Re-upholstering & Re-use
Crushed Tiles	Paving or Landscape Decoration

Unfortunately both clients and designers are reluctant to make use of recycled or salvaged building materials due to the misconception that this will yield a lower or inadequate product. This nuance can be addressed by means of creating more awareness in the construction industry as well as awareness in the general public at large. The Gauteng Provincial Government's *Provincial Building & Demolition Waste Guidelines* (2009) does suggest making use of salvageable and recycled construction materials for low-cost housing in South Africa. This can for instance include re-using the timber shuttering of concrete castings of large commercial projects as cladding in low-cost housing. Future legislation can thus also incorporate this factor as Command and Control (CAC) regulations can directly regulate the industry's behaviour by prescribing specific legislation and enforcing compliance thereto by means of economic instruments (EI).

2.6.2 Non-prevalent factors in Literature

This subsection discusses non-prevalent factors which are the bottom six (out of the twenty-six) identified factors from the conceptual framework as seen in Table 2.2.

Designers should provide for an adequate space on the construction site where waste quantification, storing and sorting can take place

Since construction and demolition waste consists of both inert and organic materials, it is imperative to avoid mixing and contaminating numerous wastes in order to optimize the re-use, recycle and disposal potential of the wastes, which is identified as a separate yet prevalent factor (fifth most prevalent). Waste sorting on site is seen as an effective way to increase the rate of both waste reuse and waste recycle. Yuan (2013b) stated that site space was found to be the most important factor in Hong Kong when selecting on-site sorting schemes. Within this study, this factor was the twentieth most important factor and was thus not identified as highly prevalent within a global context. This is unfortunate as without the pre-planned and pre-allocated space on site for waste quantification, waste storing and waste sorting other construction activities might be adversely affected due to site space limitations. This can affect project cost and time overruns which adversely affects the client. Benefits of on site waste sorting include the reduced cost of waste transportation, waste dumping and landfilling. It thus ultimately reduces the impact that construction activities have on the environment (Yuan, 2013b: 482).

Designers should design space to be adequate & functional in order to prevent future alterations

This factor was not extremely prevalent (twenty-first most prevalent) in the reviewed literature, but was found to have made a huge impact in the context of Istanbul, Turkey. A context-specific study conducted by Esin & Cosgun (2007) found that designs of residences in Turkey often do not meet the requirements & expectations of their users & growing families which results in the spaces becoming redundant and underutilized. Residence modification is thus extremely prevalent in Turkey in order to rectify and address these problematic spaces which in turn generates a vast amount of construction and demolition waste. Main reasons for modifications include to improve the quality of materials (due to prolonged deterioration), to improve aesthetics, address difficulties in space usage and to address “insufficient dimensions of space.” This has negatively contributed to the construction waste dilemma in Turkey which particularly involves illegal demolition & illegal dumping of construction waste (Esin & Cosgun, 2007).

This can be solved (amongst other approaches which include efficient designer and client communication, which is the sixth most prevalent factor) by making use of adaptable and flexible project designs. This was identified as another separate yet non-prevalent factor (eighteenth most prevalent) in the reviewed literature. Adaptable & flexible project designs involves the “kit approach” which includes making use of adaptable drywalls (as opposed to fixed internal brick walls) or even drywalls on hinges where spaces within buildings can be interactively modified by the user to his or her needs without causing any material wastage (Domingo, Osmani & Price, 2009: 1027; Poon *et al.*, 2004: 466).

Designers should implement BIM (Building Information Modelling) at the design stage

BIM, a subcategory of CAD (Computer Aided Design), is utilized to manage construction data by means of building a three dimensional virtual project. The objective of information modelling is to properly plan all facets of the project prior to construction commencement. This is usually done by designers, specifically architects, during the design stage of projects. This pre-planning includes spatial co-ordination of materials as well as sequencing of the construction project. This factor thus requires effective communication & co-ordination amongst team members, which was identified as a separate yet prevalent factor (Sixth most prevalent). The three dimensional model can be layered with data to become a four-dimensional model which then includes the element of time. Furthermore, a five-dimensional model will include adding quantities of materials as well as cost of materials to the virtual project. These tools are all useful for effectively planning and thus preventing construction waste (Yeheyis *et al.*, 2013: 87).

This factor was not a prevalent factor (twenty-third most prevalent) as identified from the global literature survey, in fact only two authors mentioned BIM as being a factor at all. This may be due to BIM being a relatively new & emerging technology in the construction industry, yet this should still be investigated within a South African context.

Designers should take into account the accessibility of construction personnel on site

This will allow labour workers adequate space in order to execute construction work safely & efficiently without the chance of injury or rework which will result in both time and physical construction waste. This can also include the ease of accessibility of construction vehicles on site, i.e.: due to a construction truck struggling to enter the construction site, the concrete may set within the truck which results in construction waste.

This factor was identified in a global context by only one author, namely Othman (2011: 336). This is thus not a prevalent factor (twenty-fourth most prevalent) which might be due to various contexts and projects differing in terms of how labour is implemented. Some projects require a vast amount of intensive labour (construction sites might even become crowded) as opposed to projects which mainly incorporate prefabrication and pre-assembly techniques which thus require less labour and more equipment & machinery on site.

This factor may also link to both the second & sixteenth most prevalent factors; namely that designers lack knowledge & experience with regards to constructability and that designers lack knowledge with regards to construction method & sequencing.

Designers should make use of EIAs (Environmental impact assessments)

Designers should make use of environmental impact assessments during the design stage of the scheme in order to pro-actively realize where waste reduction potentials are and how materials can be optimized & utilized (Dainty & Brooke, 2004: 24). This factor was only identified in one study from the reviewed literature and is thus the least most prevalent factor identified, yet majority of the literature stated that construction waste production has adverse effects on the environment. Conducting an environmental impact assessment within a South African context can be extremely applicable as Engledow (2010: 17) stated that construction waste "has had a negative impact on the environment and human health within South Africa."

This factor can be aided by the seventeenth most prevalent factor, namely that waste minimisation clauses should be embedded in contractual clauses.

2.7 Barriers identified in terms of implementing Construction Waste minimisation factors

Unfortunately numerous barriers prevent and inhibit effective construction waste minimisation and reduction globally during all stages of projects, but barriers are especially evident in the design stage. Poon *et al.* (2004: 467) stated that construction method selection, which happens during the design stage, revolves mainly around considerations of construction time, construction cost and familiarity with construction techniques. Physical construction waste reduction is seen as the least important consideration when choosing construction methods. One can thus conclude that the emphasis is placed on lowering costs as opposed to considering the adverse environmental and social impact of construction waste.

Construction stakeholders' perspectives and perceptions have also been identified as barriers. This mainly includes lack of awareness, lack of education or the perception that minimising construction waste would cost more and may cause project time overruns due to additional labour. Clients are generally reluctant to invest additional effort and cost in the early stages of projects as they do not realise the potential cost and time saving in the long run. Furthermore; clients are reluctant to make use of recycled or salvaged building materials due to the misconception that this will yield a lower or inadequate product. On the other hand designers often are of the opinion that low waste technologies (prefabrication, standardization & modularisation) will result in lower aesthetic quality of buildings. Furthermore; lack of mutual respect between designers and contractors inhibit effective communication which can result in preventative construction waste measures (Othman, 2011: 340). The "stakeholder-involved whole life-cycle concept" by Lu & Yuan (2010: 202) should be adopted to cross these barriers.

2.8 Context-specific Construction Parameters which may affect Construction Waste

The construction industry differs internationally in terms of construction methods utilized, materials being used, how labour is implemented, labour costs, automation & robotics and legislation & policies. This section aims to discuss these global international differences in order to shed light on why a context-specific study is necessary within the Gauteng region context.

2.8.1 How the construction industry differs internationally in terms of construction materials & construction material selections

Construction materials account for approximately 50-80% of the total cost of building projects, yet poor material control and management on site which results in construction material waste is a frequent occurrence globally and is often unfortunately seen as inevitable (Poon *et al.*, 2004: 461; Rajput *et al.*, 2012: 70). This subsection will discuss different construction materials in conjunction with their advantages and disadvantages in different contexts.

Prefabrication & precast technologies

The *Construction Industry Development Board* (CIDB) in South Africa (2006: 21) confirmed that steel prefabricated trusses, clay bricks, clay blocks, concrete bricks, concrete blocks and cement are the most utilized construction materials in a South African context. Although clay bricks, clay blocks, concrete bricks and concrete blocks are all considered as prefabricated components as they are fabricated off-site, they still require time-consuming and skilled labour wet trades on-site in order to be assembled to structural components. This is why precasting concrete structural components, i.e. concrete slabs and concrete stairs, is a very viable solution to reduce construction waste in a South African context. The falling exchange rate in South Africa also makes exporting these components a very competitive and lucrative option (Poon *et al.*, 2004: 464; Turner & Townsend, 2013: 44).

Wang, Li and Tam (2014: 4) concluded that making use of prefabricated components is the most effective material utilized to minimise construction waste in a Chinese context. In their report they stated that the use of prefabrication reduces waste from concrete works by up to 51-60%. From the *International*

Construction Cost Survey 2012 (Turner & Townsend, 2012:14, 30) it can be deduced that South African material costs are just about double than material costs in China. This thus highlights the potential higher cost savings that can be achieved in a South African context by opting for prefabrication techniques early on in the design stage.

Potential difficulties of prefabrication include setting up of a fabrication yard which requires high technical skill of on-site workers. Transportation, especially in the vertical axis, might be complicated due to restrictions of machinery and space available on-site. Other potential difficulties include training workers as well as connections between prefabricated components (Wang, Li & Tam, 2014: 4).

The question of waste being produced in a factory which manufactures prefabricated components compared to that of construction waste being produced on-site was answered in a recent study which investigate the whole life-cycle analysis of prefabricated concrete materials. Lu & Yuan (2013:110) concluded that prefabrication of concrete components in a factory environment results in less waste produced than traditional cast-in-situ construction methods.

Masonry Work & Drywalling

As mentioned above, clay bricks, clay blocks, concrete bricks and concrete blocks can all be seen as prefabricated components which require high labour, specialized skill and a lot of time to construct. This is considered masonry work and is a very popular construction technique, especially in South Africa where wet trades are readily utilized. It is also readily implemented in Hong Kong as well as in Iraq.

It is interesting to note that in the 1990s, clay brick walls used to me made as solid single modular components (See Fig 2.1). Factories later opted for fabricating small, modular loose bricks with holes in them (See Fig 2.2). This was done to reduce the amount of material per brick which reduces the overall material costs. It also makes it easier and lighter to transport and allowed for a more design options. Although this seemed as an initial viable solution, problems arose when considering the whole life-cycle of these bricks. The perforated bricks broke when buildings were altered or demolished. None of the perforated bricks could thus be salvaged or re-used. With regards to buildings opting for solid bricks (which are currently actually cheaper than perforated bricks), these components were easily extracted and re-used. Although the perforated bricks are still readily used in a South African context, clients will have to consider the whole life-cycle of materials in future projects and aim at constructing buildings for future deconstruction & disassembly. The negative side of opting for building deconstruction & disassembly is that it may take longer than demolition processes as this method can be extremely labour (and thus time & cost)

Fig 2.2: Kharuffa, S., 2007. [Photograph] *Solid bricks. Can mostly be extracted and reused after demolition.*

In: Kharrufa, S., 2007. Reduction of building waste in Baghdad, Iraq. Building & Environment, [e-journal] 42(2053-2061). Available through: University of the Witwatersrand Library Website <http://www.wits.ac.za/library> [Accessed 11 March 2014]

Fig 2.3: Kharuffa, S., 2007. [Photograph] *Perforated bricks. Break when wall is demolished. Cannot be reused.*

In: Kharrufa, S., 2007. Reduction of building waste in Baghdad, Iraq. Building & Environment, [e-journal] 42(2053-2061). Available through: University of the Witwatersrand Library Website <http://www.wits.ac.za/library> [Accessed 11 March 2014] intensive (Kharuffa, 2007: 2059, 2060; Poon *et al.*, 2004: 464).

Masonry work should be utilized in conjunction with internal drywall partitioning. Although drywall partitioning is about 80% higher in costs than conventional brick walls or concrete block walls, the cost can be offset against plastering, high construction time and high labour costs. It is approximated that opting for drywall partitioning can reduce construction time by 70% (which lowers labour costs) and can increase the usable floor area by up to 8% due to drywall partitioning being thinner than conventional masonry walls. This is of particular interest in offices as well as shopping centres where every square metre is imperative to the client's return on investment. By utilizing internal drywall partitions, which are usually modular and standardized components, less waste will be produced on-site which will save costs later down the line in terms of waste transportation, incineration & landfilling (Poon *et al.*, 2004: 464).

Timber formwork in aid of casting concrete

In both Asia and in South Africa, timber formwork in aid of casting concrete is a very popular construction material. This is because it is relatively inexpensive, light in weight and has a high load bearing capacity. Furthermore; it is easily cut and quite pliable. The downside of this material is that due to its relatively low durability and low re-usability it results in a vast amount of construction waste being produced. In the Hong Kong study conducted by Poon *et al*. (2004: 463) it has been concluded that timber formwork is the highest contributor to construction waste on-site. In fact, approximately 30% of construction waste produced on sites in Hong Kong is as a result of timber formwork. As all the formwork will have to eventually be discarded and replaced, timber formwork in its whole life-cycle results in 100% waste after several construction cycles (Poon *et al*., 2004).

This can easily be replaced by alternative formwork technologies which usually involves metal formwork. Although this requires a high initial cost, it will be balanced out in the long term with the savings that will be made in terms of the alternative formwork technologies requiring less labour. The concrete products cast within the metal formwork will also be of a higher and more consistent quality and concrete surfaces will be immediately suitable for applying both paintwork and tiling (Poon *et al.*, 2004: 464). Due to the time, material and cost savings associated with modern formwork technologies as opposed to timber formwork, the construction industry internationally is adopting these alternative techniques.

Construction material differences conclusions

In conclusion, Poon *et al.* (2004: 467) listed the factors that affect the selection of construction materials. These factors, in order from highest influential factor to lowest influential factor are; material cost, client's requirements, material availability, efficiency of construction, ease of construction, availability of equipment, site space and labour available. It is thus evident that costs in conjunction with client's requirements are the main drivers of material selection whereas construction waste production or designing for future disassembly or deconstruction is not even under consideration.

2.8.2 How the construction industry differs internationally in terms of labour costs

The construction industry's labour force plays a vital role in all countries' economies, especially that of developing economies in which rapid housing & infrastructure developments are taking place. These developments in turn also create a vast amount of secondary employment opportunities, i.e.: labour workers at construction material fabrication sites.

The construction sector is the largest industrial employer in Europe as it employs more than 7% of Europe's workforce. In the United States of America, the construction labour force accounts for 8% of total employment. Furthermore construction labour accounts for 20-50% of the total costs of a construction project and is thus seen as the highest risk taken on by the contractor due to potential productivity issues which will result in project and thus cost overruns (Kazaz & Ulubeyli, 2004: 93).

From the *International Construction Cost Survey 2013* (Turner & Townsend, 2013:11) it can be deduced that South African labour costs are higher than labour costs in China, India & Qatar. Construction labour costs in Eastern countries are extremely low, in the EC Harris *International Construction Cost Report* (2012: 8) it is stated that labour costs in Eastern countries are about a third of labour costs in the United Kingdom.

Labour costs in South Africa are similar to that of labour costs in Singapore, Hong Kong, Malaysia and the

United Arab Emirates. Poon *et al.* (2004: 469) found that in Hong Kong labour is more expensive than the construction materials and the contractors on-site would therefor not focus on reducing construction waste, but rather on keeping the labour force productive.

Labour costs in the United Kingdom, Canada and in Australia are significantly higher than labour costs in South Africa. In turn, clients and contractors in Europe as well as the United Kingdom have problems securing access to a sufficient volume of labour capacity, especially skilled labour forces. This is due to recent economic slowdown and labourers having moved into other more job-secure markets. The United States of America currently has the highest construction labour costs globally due to their construction industry being heavily unionised (EC Harris Research, 2012: 13; Turner & Townsend, 2013:11).

The opportunity to optimize intercontinental trading of labour has thus emerged due to varying labour costs in different countries. It is important to note that the *International Construction Cost Survey 2013* (Turner & Townsend, 2013:11) identified South Africa as the country with the greatest risk in terms of labour cost escalation, namely a prediction of a 9% cost escalation by the end of 2014. This is due to labour strikes in which workers demand wage increases above the currently high inflation rate (Turner & Townsend, 2013: 44). It will thus be imperative to minimise labour costs in a South African context in order to minimise the overall construction costs of projects.

In Al-Hajj & Hamani's (2011) study conducted in the United Arab Emirates, it was identified that the main cause of construction waste is labourers' lack of awareness and more importantly labourers' attitudes. Labour workers often see waste segregation, waste reuse or recycling and waste prevention as a workload burden or outside their scope of employment. It was Chen, Li & Wong (2002: 525) who stated that "without careful control and rewarding systems, construction workers may become careless in handling construction materials." It can thus be concluded that labour skill, labourers' behaviour and awareness (which all fall under the contractor's responsibility) directly influence the amount of construction waste produced on construction sites. This is directly supported by Lingard *et al.*'s (1997) study conducted in Australia which was entitled *Waste Management in the Australian Construction industry: A Human factors approach.*

2.8.3 How the construction industry differs internationally in terms of automation and robotics

"Intelligent building and construction automation has been, in one form or another, instrumental for decades and yielding many benefits" (Zavadskas, 2010: 286). An example of this is the international emerging robotic technologies in terms of prefabrication of design components. These technologies can yield highly-individualized building elements and components of very complex geometries with consistent quality and producing only a small, if any, amount of construction waste. Due to the benefits of speed, accuracy and consistency of these machines, robotics has to some extent replaced construction labour workers. However, the high cost of automation, robotics and new machinery still encourages most clients to opt for lower level technologies and more traditional low-waste construction methods. This partially contributes to the international problem of huge amounts of construction waste produced annually (Chen, Li & Wong, 2002: 522).

Due to the South African construction industry employing a large number of labour workers, there are obviously concerns about mechanization, automation & robotics entering the industry and pushing out the workforce. The perception that all construction automation & robotic systems will eventually replace construction labour workers is luckily untrue.

In some instances the advent of automation & robotic technologies in the construction industry can create additional employment opportunities in the long run. This is evident in the *bar-code technique* which is used to facilitate the effective management of construction materials on large construction sites. This construction materials management technique provides instant and up-to-date information of quantities of construction materials exchanged between the *storage keeper* and the *group leaders* of construction workers on site. This technique is thus a group-based incentive reward programme (IRP) which encourages all construction labour workers to minimise avoidable wastes of construction materials by rewarding the labourers according to the amounts of construction material that they have saved. This system creates employment opportunities in the aspects of designing, implementing and monitoring the system. Additional employment opportunities include *storage keepers* as well as individuals who constantly bar-code every construction material. In turn, this system encourages construction labourers to use materials sparingly, to save material by reducing operational mistakes and by returning unused or inadequate materials for future reuse or recycling (Chen, Li & Wong, 2002: 521, 522, 525, 528).

This *bar-code technique* can be utilized in conjunction with a *Web-based Construction Waste Estimation System* (WCWES). As the WCWES is an online system, stakeholders should consider the online trading of re-usable and recyclable construction wastes between vicinity sites. It will thus be the perfect example of all construction stakeholders collaborating with each other, in some instances even across projects to neighboring sites. This will in essence not only be environmentally sustainable, but will also potentially save clients a lot of unnecessary material costs.

The above-mentioned systems in conjunction with designers utilizing BIM from the design stage onwards can in conjunction reduce construction waste considerably in any context.

2.8.4 How the construction industry differs internationally in terms of policies, legislation & guidelines

After World War II most developed nations implemented regulations in terms of construction waste management. The main objective of these regulations was to reduce the environmental impact of construction waste to in turn promote sustainable development. Heavy taxation as well as penalties were incorporated by numerous municipalities to discourage landfilling and incineration of construction waste. The main focus of these waste management plans is to firstly avoid waste altogether and secondly to minimise waste by means of recycling & re-using. Waste disposal should only be seen as a last resort (Yeheyis *et al.*, 2013: 81).

In Canada numerous municipalities have by-laws in place which outlaws the landfilling of specific types of construction waste, yet there is currently no Canadian legislation in place to reduce construction waste at source. This is contrary to the Hong Kong government which has promulgated extensive regulations for promoting effective and holistic construction waste management (Yuan, 2013a: 102; Yeheyis *et al.*, 2013: 84). In order contexts, like Shenzhen city in China, it was identified that governmental regulation is the single most important factor for managing construction waste. This finding was echoed by Osmani *et al.* (2008) who stated that architects perceive regulation to be the most important incentive that will drive construction waste reduction during the design stage (Yuan, 2013b: 478). In turn, Osmani (2012) stated that legislative and other fiscal measures are undoubtedly the major drivers for construction waste minimisation in the United Kingdom.

The Government of South Africa published the *National Environmental Management: Waste Act, Act No. 59 of 2009* in order to reform waste management policies in South Africa by law. This Act is in turn supported by South Africa's *National Waste Management Strategy* (NWMS) (Wiechers, 2010). Unfortunately, this Act does not currently address construction waste directly and separately, but addresses waste management in general with specific focus on municipal waste. This is thus a causative factor of the continuous problem of construction waste in South Africa. The Gauteng Provincial Government's *Provincial Building & Demolition Waste Guidelines* (2009) does, however, provide some non-legislatory guidelines as to minimise construction waste in the Gauteng province. These guidelines form part of an *Integrated Waste Management Plan* (IWMP) which will be combined into the *Provincial Management Plan.* Barriers of implementing these plans in South Africa include limited human and resource capacities as well as financial constraints. As it is extremely challenging for rural municipalities in South Africa to implement these plans; informal & unlicensed construction waste disposal fee practices may result.

This is contrary to the United Kingdom's government who has fully committed to sustainable construction strategies and waste minimisation practices (Domingo *et al.*, 2009: 1022-1023). The United Kingdom has utilized a combination of regulation, economic instruments and voluntary agreements to meet targets of social, ethical and environmental performance in driving the waste management agenda. The United Kingdom's *Strategy for Sustainable Construction* which was published in 2008 called for zero construction waste to landfill in 2020. In addition to this, the current exorbitant taxation of waste disposal fees to landfill as well as compulsory construction waste management plans for larger projects in the UK pushes the industry towards a closed loop production system (Osmani, 2012: 38).

Gauteng Provincial Government's *Building & Demolition Waste Guidelines* (2009)
As mentioned above, certain non-legislatory guidelines as to minimise construction waste in South Africa currently exist in the form of the Gauteng Provincial Government's *Provincial Building & Demolition Waste Guidelines* (2009). The primary aim of these guidelines are to guide the user in terms of selecting an appropriate building and demolition waste minimisation option.

These guidelines, with specific reference to the design stage guidelines, are currently very limited and include only the following:

- Make use of lasting construction materials in order to reduce maintenance frequency and thus waste (2009: 34).
- Design for future building disassembly. This includes re-using and recycling construction materials especially for low-cost housing in South Africa (2009: 34).
- Planning departments (which include both local & provincial authorities) should make use of the condition that when authorising building plans, construction materials and waste is sufficiently considered (2009: 34, 35).
- A registry for professional Waste Management practitioners and Waste managers should be established in order to uphold certain ethics & professional standards. This will also aid in awareness and will support the already established voluntary Institute of Waste Management of South Africa (2009: 34, 35).

As these guidelines are extremely limited, it is evident that the construction industry in Gauteng can benefit from a more comprehensive set of critical factors that will minimise construction waste produced during the design stage.

Construction Waste Disposal Tariffs in South Africa
The City of Cape Town (Western Cape Province) in South Africa has recently introduced tariffs at construction waste disposal sites in order to promote other means of "disposing" waste. This was after the *Environmental Management Plan of the Western Cape* identified that 80% of construction waste that goes to landfills can be recycled. This "waste" thus has a residual value which can be utilized elsewhere in Cape Town or in the Western Cape Province (Emery & Manson-Kullin, 2010: 77; Environmental Waste Management Plan of the Western Cape, 2008).

Cape town is thus a front-runner in South Africa in terms of construction waste management and it will thus be expected that other large metropolitan areas like Durban and Johannesburg will follow suit.

Construction Waste Reduction Clauses
Apart from government regulation and legislation as mentioned above, the client can also contractually stipulate waste reduction clauses, strategies and waste management plans. This involves designing for waste efficient procurement and penalising poor waste performance on the overall project. There should thus be clear & accurate records of material purchased, payed, delivered and used in order for construction waste audits to be implemented. Due to this directly affecting the contractor financially, one can assume this approach to be very effective (Al-Hajj & Hamani, 2011; Dainty & Brooke, 2004: 23; Domingo, Osmani & Price, 2009: 1026; Gauteng Provincial Government, 2009: 34; Poon *et al.*, 2004: 468; Sutrisna, 2012: 148; WRAP, 2009: 24).

2.9 The role of the GBCSA (Green Building Council South Africa) in Gauteng in terms of construction waste minimisation
The GBCSA is a local and independent Non-Profit Organization (NPO) that was formed in 2007 in order to lead the South African construction industry in terms of sustainable development. This includes utilizing resources more efficiently as well as creating healthier and more productive environments for South Africans. The GBCSA is one of 92 international members of the World Green Building Council (WGBC).

The GBCSA promotes Green Buildings mainly by establishing a common language of measurement coined the *Green Star SA Rating tools* by which projects are measured and in turn certified (https://www.gbcsa.org.

za/about/).

Credits for obtaining GBCSA Green Building accreditation can be scored in all of the following categories:
- Management
- Indoor Environmental Quality (IEQ)
- Energy
- Transport
- Innovation
- Water
- Materials
- Land Use & Ecology
- Emissions

(GBCSA, 2008: 2-4).

Within the above categories, various rating points can be specifically allocated to construction waste minimisation. These categories are discussed hereunder in conjunction with their possible rating point allocations.
- Management
    - Environmental Management (2 points are available if a comprehensive & project-specific Environmental Management Plan (EMP) is provided and consistent and ongoing compliance thereof is adhered to.)
    - Waste Management (3 points are available if the contractor implements a Waste Management Plan (WMP), retains adequate waste records, issues quarterly reports and a percentage of all construction waste is thus ultimately reused or recycled)
- Materials
    - Recycling Waste Storage (2 points are available when a storage space that facilitates the recycling of resources used within buildings are incorporated which will ultimately reduce waste going to disposal)
- Land Use & Ecology
    - Topsoil (1 point available if you preserve the ecological integrity of topsoil)

(GBCSA, 2008: 2-4, 28, 31, 279).

From the above it is evident that the GBCSA is creating awareness in South Africa with regards to construction waste minimisation. Furthermore Gauteng is the province in South Africa which by far has the most accredited GBCSA Green Buildings (www.gbcsa.org.za/projects/certified-projects). It is thus evident that the GBCSA has vastly influenced the construction industry in Gauteng to reform to not only more sustainable design solutions, but also in terms of holistically minimising & managing construction waste.

2.10 Literature Review Conclusions

Factors which influence construction waste during the design stage have been identified internationally by means of a global literature survey. The prevalency of the factors within the literature was statistically determined and factors were ranked in terms of global significance. This is thus a conceptual framework which will be utilized as a launch pad in the research methodology chapter hereafter.

As the identified factors are all from various contexts, these factors can not necessarily be limited to a short list prior to being validated by means of online quantitative questionnaires in a South African context. It can thus be concluded that all twenty-six factors as listed above will be investigated in a South African context in order to test both the *significance* and the *ease of implementation* of each factor.

The literature review revealed that economic performance and corporate image, especially from the client's perspective, is still the foremost objective of construction waste minimisation and management as opposed to environmental & social aspects which is considered as being of a lower priority in the industry. (Yuan, 2013b: 476.) This is noteworthy as economic incentives, rewards and penalties can thus be seen as the driving solution to overcome waste management & waste minimisation barriers.

Some of the identified factors were found to be interlinked and interdependent on one another. It can thus be concluded that construction waste management and waste minimisation should be approached holistically and factors can not be implemented in a piecemeal or segregated approach. Some critical factors will be implemented by default if other factors are in place. In conclusion; there is a pressing need for an integrated waste reduction approach in South Africa (this can fall in place once critical factors are identified) which combines waste management mechanisms, waste management technologies, local green star rating systems and legislation in a rational and pragmatic way (Yeheyis, 2013: 85). With this considered; some factors will be more of a "quick win" as opposed to others, especially in varying contexts. Therefor the research in this study will not only explore the significance of the identified factors contextually in Gauteng, but it will also be of value to research various factors' ease of implementation. This is discussed further in the research methodology chapter.

3. RESEARCH METHODOLOGY

3.1 Research Objective

The primary objective or purpose of this study will be to determine the critical factors in effective physical construction waste minimisation at the design phase of a greenfield (previously undeveloped) construction project in the Gauteng region context. These factors will in turn be ranked in terms of both the *significance* these factors will have in a Gauteng region context and in terms of *ease of implementation.*

3.2 Research Approach

The main research approach utilized within this report is the collection of causality data about construction waste within the specific context of the Gauteng region by utilizing predetermined & highly structured data techniques. This technique is utilized as data collection was used to explore the phenomena of construction waste and a conceptual framework (Table 2.2) was thus formed. This conceptual framework utilized 31 recent sources in order to list 26 waste minimisation factors from 15 different global contexts. Factors from global contexts were also included in order to derive a holistic framework. This research report will build on this conceptual framework by means of generalizing these factors in the Gauteng region context.

3.3 Research Methodology & Research Design

The research methodology which will be used to investigate the research problem will be an emancipatory theory research design method after Creswell (2009: 25) as the research aims to eventually empower the respondents of the study. The Gauteng designers may use the identified waste minimisation critical factors in future construction projects. This exploratory research design will firstly incorporate qualitative approaches which in turn will be followed by quantitative techniques as described in the research method below. The results will be statistically analysed and interpreted to produce a set of critical factors for physical construction waste minimisation within the Gauteng region context. In summation; the study approach is thus a strategy of inquiry in which current design and construction waste minimisation practices are explored in depth within the context of the Gauteng Province (Creswell, 2009: 30; Saunders *et al.*, 2012: 167; 179).

Wang, Li and Tam (2014), who did a similar study within a Chinese context, made use of a similar research design methodology to derive at critical factors that will minimise construction waste at the design phase of Chinese construction projects. This research report is partially a replicative study of the work of Wang, Li & Tam (2014) within a South African context and thus leans strongly on their research method. This report's research method is further strengthened by the approach of Dainty & Brooke (2004) as discussed below.

This research methodology thus has complementary strengths as the second part of the research, which will encompass validating questionnaires within the Gauteng region context, will aid in exploring the applicability as well as the significance of the initial conceptual framework identified in the literature review.

3.4 Research Method & Research Strategy

The research process in this study was as follows: firstly; potential factors which can influence physical construction waste minimisation on greenfield sites (previously undeveloped) in the design phase within various contexts globally was identified by means of qualitatively researching and interpreting various bodies of existing knowledge. These bodies of knowledge included numerous global academic peer-reviewed journal paper articles and conference papers, which are seen as credible sources due to these sources being refereed. Global reports, design manuals as well as site guides were also surveyed for factors. Book publications and the *Gauteng Provincial Building & Demolition Waste Guidelines* were reviewed from the currently limited South African body of knowledge. This combination of primary & secondary literature sources yielded a positivist conceptual framework of factors identified from a global context. This conceptual framework can be seen in Table 2.2.

The frequency of factors within the literature in the current global body of knowledge was determined quantitatively and factors were ranked from the most prevalent to the least prevalent. It was then identified that due to the factors being from varying contexts, it will be appropriate to test the significance of all the factors identified within the Gauteng region context.

Secondly; sampled architects and designers will be surveyed in-depth by means of positivist quantitative digital questionnaires. Within these online questionnaires which are utilized as a research strategy, Likert scales will reveal the significance rating of the previously identified factors within the Gauteng region context. The Likert scales will also be implemented to measure the *ease of implementation* of the identified factors (Dainty & Brooke, 2004: 22).

From these quantitative online surveys, the South African critical factors of construction waste minimisation will be derived and interpreted. The research methodology thus elaborates and expands on the initial research method, which then ultimately results in an Interpretivist research solution (Creswell, 2009: 31). The final critical factors will be an important contribution to the South African body of knowledge.

3.4.1 *Qualtrics Survey Software* & Digital Survey Questionnaires

Deduction is utilized as a research approach as digital survey questionnaires will be used as a data collection technique in order to evaluate the predetermined conceptual framework (Table 2.2) within the Gauteng region context (Saunders et al., 2012: 144).

Saez *et al.* (2013: 54) as well as Wang, Li & Tam (2014: 2) noted in their respective studies that the questionnaire methodology has been vastly implemented in previous context-specific studies with regards to identifying factors that will minimise construction waste. This includes Osmani et al.'s (2008) study in the United Kingdom, Begum *et al.*'s (2007) study in Malaysia as well as Lu & Yuan's (2010) study in China. This study will opt for online questionnaires due to the assumption that target population of professional designers will all have access to internet and can thus partake in the online survey questionnaire within their own time and in a physical environment that they will feel comfortable in.

The *Qualtrics Survey Software* tool will be utilized as this can be accessed from the University of the Witwatersrand.

The online questionnaire in this study will consist of three parts as discussed below.

Questionnaire Part One

The survey kicks off with an introduction and information with regards to the research study. This followed by the first questions which will determine whether the respondents have worked on certified Green Buildings in the Gauteng region. Thereafter, the questions in part one will evolve around the demographics of the respondents. This demographics section will include the employment role of the respondents when having worked on Green Buildings in Gauteng (see population of designers below), number of years of experience in the Green Building industry in Gauteng and the highest level of education of the respondents.

Questionnaire Part Two

The second part will include all the factors identified from the conceptual framework in the literature review (Table 2.2) which respondents should rate by means of Likert scales in terms of both *significance* as well as *ease of implementation* in the Gauteng region context.

Questionnaire Part Three

The third part of the questionnaire will include an optional space for respondents to suggest factors that had not been covered in the second part of the questionnaire.

The online questionnaire in conjunction with the introductory letter can be found in Appendix B.

3.4.2 Likert Scales

Likert scales have been prevalently implemented in similar studies globally. This is evident in Table 2.1 which summarizes numerous research methodologies that has been utilized in both context-specific as well as global studies which all aimed at identifying construction waste minimisation factors.

Wang, Li & Tam (2014) as well as Lu & Yuan (2010) both incorporated Likert scales in their respective studies which identified critical factors for construction waste minimisation in a Chinese context whereas Osmani *et al.* (2008) made use of the same approach when conducting a study in the United Kingdom. Saez et al. (2013) made use of Likert scales in a Spanish context and Ekanayake & Ofori (2004) implemented Likert scale techniques in a Singapore study. Within an African context; Oladiran (2009) opted for Likert scales in a Nigerian context.

It is thus a prevalent approach in the construction industry to contextually identify critical factors that will affect construction waste minimisation.

Five-point Likert Scales

The five-point Likert scale technique, as adopted from Wang, Li & Tam (2014), will thus be utilized as a research instrument in order for respondents to rate the various factors' *significance* in Gauteng. This Gauteng specific study will also include rating the *ease of implementation* of the identified factors and thus takes Wang, Li & Tam's (2014) approach further. This additional approach of rating the "ease of implementation" of factors is based on a similar study's research methodology, namely: Dainty & Brooke's (2004: 22) article entitled *Towards improved construction waste minimisation: a need for improved supply chain integration?* The "ease of implementation" scores will reveal the factors that will be "most likely to be utilized as part of a robust waste minimisation strategy" in the Gauteng region and is seen as a research sub-question (Dainty & Brooke, 2004: 25).

On five-point this Likert scale;

- 5 is denoted as being extremely significant or extremely easy to implement
- 4 is denoted as being important or easy to implement
- 3 is denoted as neutral
- 2 is denoted as unimportant or difficult to implement and
- 1 is denoted as negligible or impossible to implement

3.4.3 Research Sampling, Research Population & Contacting the Population

It is crucial to make use of appropriate research sampling in order to obtain effective and valuable information from the relevant population. The main target population for this study are designers, as they are the key stakeholders in the design stage and are thus seen as the gatekeepers of knowledge.

Sampled AEC (architecture, engineering & construction) designers for the online survey questionnaire will be targeted based on the following criteria:

- Designers who have attempted to minimise waste on greenfield (previously undeveloped) sites in the design stage AND
- Designers who have achieved Green Building Council of South Africa (GBCSA) certification as a result thereof AND
- These projects should be Green buildings located in the Gauteng region of South Africa only. (This will ensure a context specific study.)

Data obtained from the surveyed designers will only be processed if the respondents have met all of the above criteria.

This approach to research can be seen as "advocacy" or "participatory" research after Creswell (2009: 25, 27) and was chosen as respondents (designers) can collaboratively advance an agenda for change which will ultimately benefit the South African body of knowledge.

It is assumed that designers who have worked on Gauteng accredited green buildings will have cutting-edge knowledge about current industry practices and thus carry knowledge about the best contextual practices to minimise construction waste. This is based on the fact that the GBCSA encourages construction waste minimisation by rewarding good practices with points which may ultimately lead to green star ratings.

In the *Green Star SA Office v1 2008* publication by the GBCSA, which is the publication that guides green star ratings for offices, they state that:

"Up to three points are awarded where:

- *The contractor implements a Waste Management Plan (WMP), retains waste records and*
- *issues quarterly reports to the building owner; AND*
- *A percentage (by mass) of all demolition and construction waste is reused or recycled as follows:*
    - *One point for 30% of the waste;*
    - *Two points for 50% of waste; and*
    - *Three points for 70% of waste."*

(GBCSA, 2008: 31).

Research Target Population

The *Green Building Council of South Africa* (GBCSA) has up until the second quarter of 2014 published 26 certified projects as *Green Buildings* in the Gauteng region alone and this number is constantly growing (www.gbcsa.org.za/projects/certified-projects).

Table 3.1 lists GBCSA certified Green Buildings in Gauteng & Professional Consultants Associated with these Buildings. These are thus the firms whose employees may form part of the research target population. As can be deduced from Table 3.1; there are certain companies who are front-runners when it comes to Green Buildings in Gauteng as they have been involved in multiple of these projects.

Table 3.1: Certified Green Buildings in Gauteng & Professional Consultants Associated with these Buildings - Research Target Population.
Data summated from: www.gbcsa.org.za/projects/certified-projects

No.	Green Building Name & Location	Architects	Structural Engineers	Sustainability Consultants
1	102 Rivonia Rd, Johannesburg	Boogertman & Partners	Aurecon	WSP Group Africa
2	Nedbank Menlyn Maine Falcon Building, Pretoria	Boogertman & Partners	WSP Structures	WSP Green by Design
3	Sage VIP Menlyn Maine, Pretoria	Boogertman & Partners	WSP Structures	WSP Green by Design
4	Department of Environmental Affairs	Boogertman & Partners	PD Naidoo & Associates Consulting Engineers	PD Naidoo & Associates Consulting Engineers
5	Alexander Forbes, 115 West Street, Sandton	Paragon Architects	Sotiralis Consulting Engineers	PJ Carew Consulting
6	Eastgate 20, Sandton, Johannesburg	Paragon Architects	Sotiralis Consulting Engineers	PJ Carew Consulting
7	Alice Lane Building 1, Sandton, Johannesburg	Paragon Architects	L&S Consulting	Solid Green Consulting
8	Alice Lane Building 2, Sandton, Johannesburg	Paragon Architects (Amir Livneh)	L&S Consulting (Kevin van Aart)	Solid Green Consulting, Marloes Reinink
9	Group 5 Head Office, Waterfall Estate	LYT Architects	L&S Consulting	
10	37 Melrose Boulevard, Melrose Arch, Johannesburg	LYT Architects	Sutherland Engineers	Solid Green
11	90 Grayston Drive, Sandton, Johannesburg	GLH Architects	Sutherland Engineers	WSP Green by Design
12	DStv City, Randburg, Johannesburg	GLH Architects	PURE Consulting	Solid Green Consulting, Marloes Reinink
13	Standard Bank, Rosebank	GLH Architects	PURE Consulting	WSP Green by Design
14	Nedbank Head Office Phase 2	GLH Architects & Terra Ether Architects	WSP Structures	WSP Green by Design
15	Vodafone Site Solution Innovation Centre	GLH Architects	WSP Structures	WSP Green by Design
16	Aurecon Centre, Lynnwood Bridge	Barnes Van der Walt Architects & Studio 3 Architects	Aurecon	Aurecon
17	Aurecon Tshwane Head Office	Barnes Van der Walt Architects	Aurecon	Aurecon, Martin Smith
18	Sanral Corporate Head Office, Pretoria	Activate PTY Limited (Edward Brooks & Robert Serman)	Civil Concepts (T.S. Kruger)	Activate PTY Limited (Edward Brooks)
19	Hyundai Automotive Head Office, Bedfordview, Johannesburg	HLA Architects	Aurecon	Aurecon
20	Absa Towers West, Main & Marshall streets, Johannesburg	Poloko JV	WSP Structures	WSP Green by Design & PJ Carew Consulting
21	Agrivaal Building, Pretoria	PKA International	WSP Structures	WSP Green by Design
22	Lakeside Office Park, Block 3	AMA Architects	PD Naidoo & Associates Consulting Engineers	Aurecon
23	40 on Oak, Melrose Arch, Johannesburg	Osmond Lange Architects	PURE Consulting	Solid Green
24	Tshedimosetso House, Pretoria	Urban Concept Architects & ADO Architects	EDS	Aurecon
25	Upper Grayston Block E, Sandton	BroMag Architect	MVW Consulting Engineers	Solid Green Consulting
26	Villa Mall, Pretoria	Osglo Architects	Laubscher Engineers Africa	WSP Green by Design

In summation from Table 3.1;

- 17 Architecture firms,
- 11 Structural Engineering firms and
- 6 Sustainability Consulting firms are noted

The population of designers, as identified above, can further be divide into various stratified groups which all need to be presented in this research report. These groups include; architects, architectural technologists, architectural draughtsmen, structural engineers, structural technologists and structural draughtsmen. Sustainability consultants (consultants whose main role is to advise other professions in the built environment) are also included as they provide design guidance to designers within the design stage of projects. Project managers were excluded as they are seen as providing more a managerial role as opposed to having a hands-on approach in the design stage.

Of the 26 certified GBCSA projects in Gauteng (as seen in Table 3.1) all the projects are office blocks with the exception of two projects, namely; *40 on Oak* (a residential project) and *Villa Mall* (a retail complex). Office blocks are thus seen as being the most prominent architectural typology of green buildings in Gauteng. As based on the GBCSA case study of the Green Building *Alice Lane Building 2* in Sandton (an office block), we can assume that each Green Building in Gauteng's team consists of;

- 1 Architect
- 2 Architectural Technologists
- 2 Architectural Draughtsmen
- 1 Structural Engineer
- 2 Structural Technologists
- 1 Structural Draughtsmen
- 1 Sustainability Consultant

(www.gbcsa.org.za/projects/certified-projects).

This will yield 10 professionals per project which will consist of;

- 5 Architectural consultants
- 4 Engineering consultants and
- 1 Sustainability consultant per project.

If one were to further assume that each firm only consists of either 5 architectural consultants or 4 engineering consultants or 1 sustainability consultant that work on Green Building projects due to the current low number of accredited Green Building projects in Gauteng, we can attempt to calculate the research target population number as follows:

(5 Architectural consultants per project x
17 Architectural firms in Gauteng who have worked on Green Buildings)
+
(4 Engineering consultants per project x
11 Engineering firms in Gauteng who have worked on Green Buildings)
+
(1 Sustainability consultant per project x
6 Sustainability Consulting firms in Gauteng who have worked on Green Buildings)
= 85 + 44 + 6
= 135 People as the Research Target Population Estimation

Required Response Rate & Confidence Level

According to Nulty (2008: 310), a response rate of 87% is required for the target population size of 135 people in order to have a 95% confidence level. Previous yet similar studies' target population in conjunction with questionnaire response rates received are listed in Table 3.2. The actual response rate of this study in conjunction with the final confidence level is discussed in Chapter 4.

Table 3.2: Previous Studies' Target Population in Conjunction with Questionnaire response rates received

No.	Author	Context	Research Methodology	Target Population	Number of Questionnaires Distributed	Questionnaire Response Rate
1	Osmani et al. (2008)	UK	Sampled Survey Questionnaires (Likert scales) & Open-ended question	UK top Architectural practices.	100	40%
2	Al-Hajj & Hamani (2011)	UAE	Sampled Survey Questionnaires (Likert scales) & Interviews & Site Audits	Medium & Large contractors in UAE.	120	46%
3	Dainty & Brooke (2004)	UK	Sampled Survey Questionnaires (Likert scales) & Interviews	Key stakeholders of five BREEAM rated buildings in the UK.	45	60%
4	Lu & Yuan (2010)	China	Sampled Survey Questionnaires (Likert scales) & Interviews	Project managers, structural engineers, supervision engineers, researchers & government officials.	51	68%
5	Yuan (2013a)	China	Sampled Survey Questionnaires (Likert scales) & Interviews	Site Engineers, Project Managers, Supervisory Engineers, Professors and Associate Professors in China. All experts in Construction Waste.	282	28%
6	Ekanayake & Ofori (2004)	Singapore	Sampled Survey Questionnaires (Likert scales)	Large contractors in Singapore	145	32%
7	Saez et al. (2013)	Spain	Sampled Survey Questionnaires (Likert scales)	Construction companies in Madrid	82	71%
8	Wang, Li & Tam (2014)	China	Sampled Survey Questionnaires (Likert scales)	Architects, Structural and Mechanical designers and Project Managers who have all received Grade A building design certification in Shenzhen, China.	142	61%
9	Rajput et al. (2012)	China	Sampled Survey Questionnaires	Construction agencies in China	40	68%
AVERAGE RESPONSE RATE:						**53%**

Contacting the Research Target Population

As the questionnaires are based online, potential respondents will be invited via e-mail. These e-mail addresses will be obtained from the online database of the *Green Building Council of South Africa* where you can browse by province (this report focuses on Gauteng region only) as well as by profession. Potential respondents from this database will be identified via their firm affiliations as is seen in Table 3.1. This selection is done as not all persons that are registered with the GBCSA in Gauteng have necessarily worked on green buildings.

3.5 Proposed Research Data Analysis

The data from the online questionnaires will be analysed in numerous ways as discussed below in order to create lists and graphs from which conclusions and recommendations can be drawn.

Calculating means of the identified factors in order to rank factors

Determining the mean values from data gathered by utilizing Likert scales has been prevalently done in the construction industry in the past. Wang, Li & Tam (2014) as well as Dainty & Brooke (2004) both calculated means of the identified factors that will minimise construction waste in their respective studies conducted in China and in the UK (This is attached in Appendix C). Wang, Li & Tam (2014) utilized the means in order to rank identified *significant* factors, whereas Dainty & Brooke (2004) went a step further and mapped the relationships between the *impact* and the *ease of implementation* of the factors utilizing means. This is seen in Graph 3.1.

Cross-tabulated lists

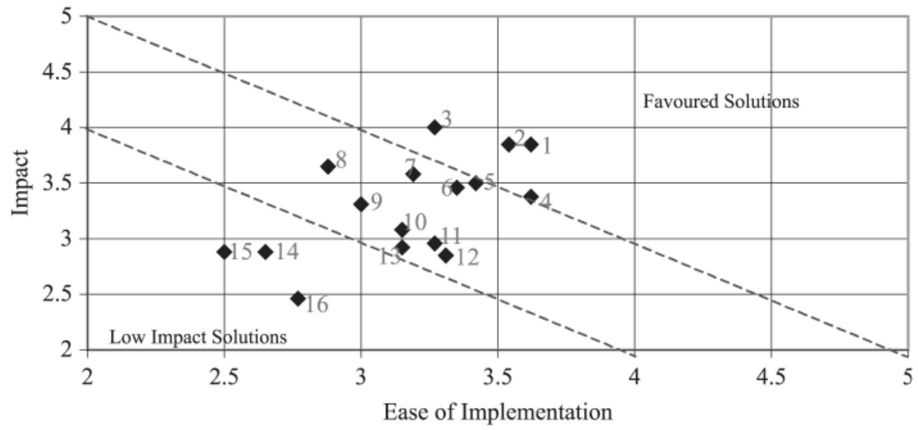
In this study, descriptive statistics will be utilized as the means of the five-point Likert scale answers from the online questionnaire will be utilized in order to create two ranked lists, namely;

- a list of the critical factors in terms of *significance*, ranked from most frequent to least frequent
- a list of the critical factors in terms of *ease of implementation*, ranked from most frequent to least frequent

The above two lists will also be tabulated next to each other in order to reveal the factors' relationships with one another.

Mean Factor Rating Graphs

Graph 3.1: Dainty, A.R.J & Brooke, R.J., 2004. Assessment of Waste management measures identified.



In: Dainty, A.R.J. & Brooke, R.J., 2004. *Towards improved construction waste minimisation: a need for improved supply chain integration?* Structural Survey, [e-journal] 22(1)(20-29). Available through: University of the Witwatersrand Library Website <http://www.wits.ac.za/library> [Accessed 13 March 2014]

A similar graph as above will be utilized in this study in order to map the relationship between the *significance* and the *ease of implementation* of the means of the identified factors in Gauteng. The one axis will map the means of the *significance* of factors whereas the other axis will map the means of the *ease of* *implementation* of factors. From this graph, favoured and high impact solutions can be concluded.

These conclusion will in turn be supported by Table 3.3 which generalizes mean values to a scoring system for prioritisation. This table was adapted from Barry *et al.* (2008) who in turn adapted it from Jillson (1975).

Table 3.3: Scoring System for prioritisation of Mean Values

Mean Value	Significance	Ease of Implementation
Less than 1.8	Negligible	Impossible to implement
Less than 2.6 and equal to or greater than 1.8	Unimportant	Difficult to implement
Less than 3.4 and equal to or greater than 2.6	Neutral	Neutral
Less than 4.2 and equal to or greater than 3.4	Important	Easy to Implement
Greater than 4.2	Extremely significant	Extremely easy to implement

As adapted from: Barry, M., Steyn, H. & Brent, A., 2008. Determining the most important factors for sustainable energy technology selection in Africa: Application of the Delphi Technique. In: International Association for Management of Technology Conference, 2008. Available at: Google Scholar <http://scholar.google.co.za/> [Accessed 16 April 2014]

Analysing Respondent Demographics in Conjunction with Findings

The data obtained will be analysed in conjunction with demographics to potentially identify sub-groups. The aim of this will be to investigate if there is a correlation between data given by respondents and either their role when having worked on green buildings, years of experience or their level of education.

Additional factors

The questionnaire will provide respondents an opportunity to list additional factors which will minimise construction waste in Gauteng which were not mentioned in the survey. These factors will be investigated in order to see if a research gap existed in the initial conceptual framework and if there are unanswered questions beyond the scope of this study.

3.6 Validity, Constraints, Reliability & Generalisability of the Research

The conceptual framework as identified from the existing body of knowledge (Table 2.2) can be seen as valid as multiple sources of evidence which included both primary & secondary sources were utilized. In turn; the final set of critical factors within the Gauteng region, that were identified by means of Likert scales, were thus credibly triangulated from this initial conceptual framework (Saunders *et al.*, 2012: 82).

Constraints within the study include the limit in number of digital survey questionnaires responses received. This can be as a result of time constraints of designers practicing in the industry and some designers not having access to internet facilities. There is also the risk of questionnaires never having reached potential respondents via e-mail.

Reliability concerns with regards to the online survey questionnaire include respondent error as well as respondent biases. Respondent error includes any factors which adversely effects the manner in which a respondent performs in order to answer the questionnaire. This can happen due to respondents being unfamiliar with the way the online survey is set up or being unfamiliar with technology in general. Respondent biases are generally false responses on the questionnaires which may be as a result of fear of their anonymity not being protected or respondents answering questions as they assume these are the answers the researchers are after (Saunders *et al.*, 2012: 192).

As generalisability refers to the extent to which the findings of a research study are applicable to other settings, this study's direct results are not very generalisable. This is due to the study focusing particularly on the context of the Gauteng region. It is, however, possible for the conceptual framework (which includes global construction waste minimisation factors as identified from global literature) to be utilized as a launch pad for other context-specific studies (Sanders *et al.*, 2012: 382).

3.7 Research Ethical Considerations

The ethical concerns relevant to this study would mainly include confidentiality with regards to how data will be collected by means of in-depth Interpretivist online survey questionnaires. This includes the ethics around sampling a small group of willing respondents (who were all provided with respondent information within the cover e-mail) (see Appendix B) and ultimately how gathered data will be stored and destroyed upon completion of the study.

The e-mail addresses of potential respondents will be obtained from the online database of the *Green Building Council of South Africa.* This online database reveals e-mail addresses of members of the GBCSA in conjunction with geographical locations & firm affiliations. As this database is openly accessible online, there are no ethical concerns in this regard. The questionnaire will however have a tick a box where the person completing it gives there approved consent for their data to be used. (see Appendix B)

The raw data gathered from the online survey questionnaires will be kept until the end of April 2015 on the online *Qualtrics Survey Software* database which only I have the access password for. As this software will act as an intermediary between researcher and respondent, anonymity and confidentiality is guaranteed. This is due to the fact that *Qualtrics Survey Software* does not reveal a respondent's identity to the researcher, but merely reveals their digital IP address. The raw data will however be discarded eventually to prevent the information from falling into the hands of researchers who might misappropriate it.

As respondents might benefit from the knowing the most effective construction waste minimisation factors in Gauteng, the processed data will be published online in the final research report on the University of the Witwatersrand's website. The survey contains a declaration by myself which states that the data will not be used for commercial purposes in which I will have a competitive advantage due to the information gathered.

The target population is a specialized group of people and have most likely been used previously in research studies, but participation in this study is completely voluntary and respondents will be allowed to withdraw from the research at any time without any form of penalty.

3.8 Research Methodology Conclusions

The research design in this study starts with a qualitative conceptual framework (Table 2.2) for exploratory purposes regarding global construction waste minimisation factors. This was followed by quantitative online questionnaire surveys within a selected sampled population so that the initial factors identified can be generalized to the Gauteng region context. This methodology was chosen as numerous similar studies in other contexts made use of the same research approach to identify context-specific factors. A summarized flow diagram of the research methodology can be seen in Figure 3.1.

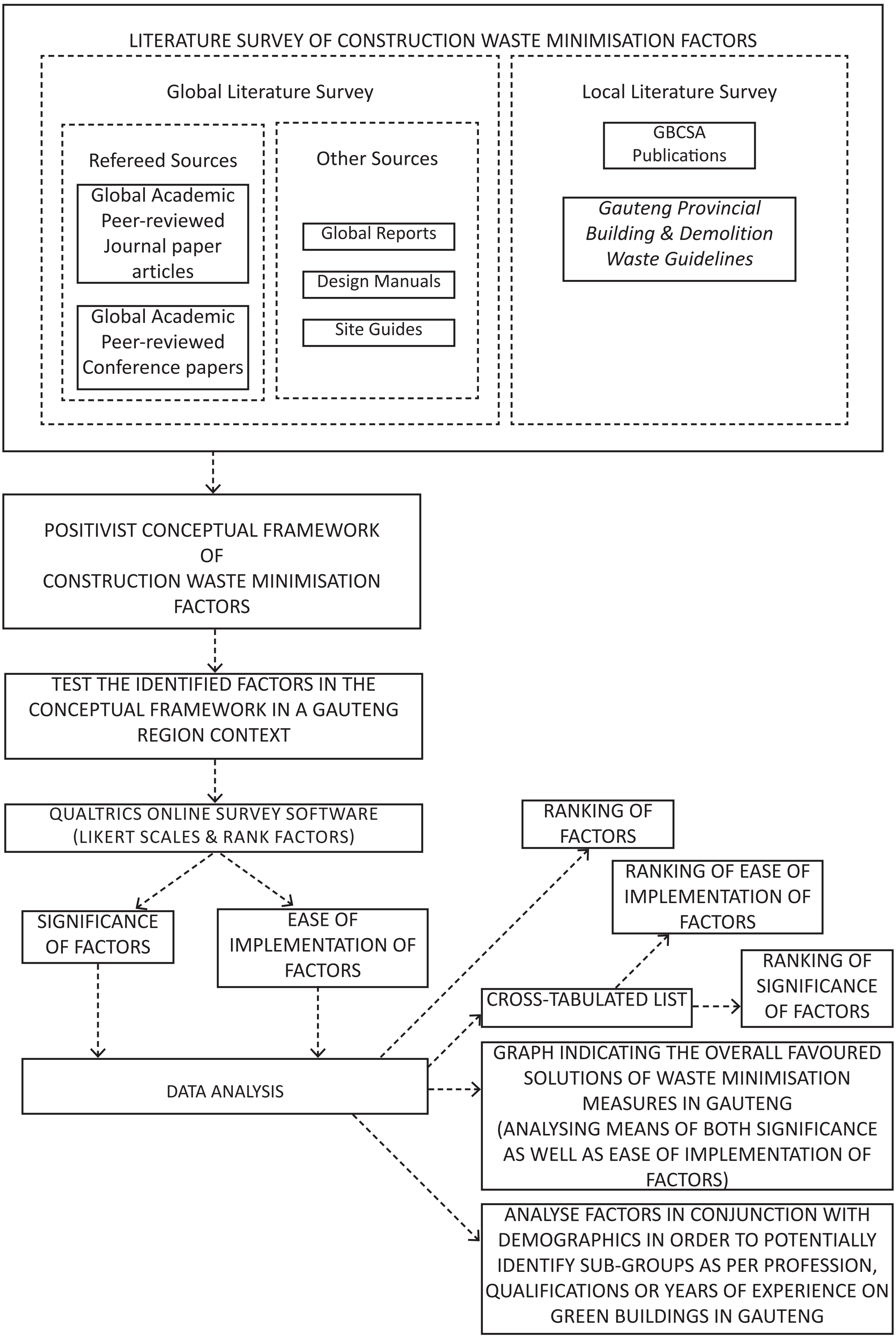


Fig 3.1: [Diagram by Author] ***A summarized flow diagram of the Research Methodology.***

4. RESEARCH FINDINGS

4.1 Response Rate of Questionnaires & Confidence Level

The online questionnaire survey was officially launched on 14 May 2014 after ethics clearance was obtained from *the School of Construction Economics & Management* at Wits. In total, 138 individual invitations to the Online Questionnaires was sent out via e-mail. This is on par with the initial target population estimation of 135 individuals.

Individual invitations were sent in aid of personalizing the questionnaires as potential respondents' full names and surnames were available in conjunction with their e-mail addresses on the GBCSA website. (The questionnaire and the introductory e-mail are both available in Appendix B.)

A valid response is a response which has adhered to ***all*** of the following criteria:

- The respondents must have given approved consent that their data may be utilized for the purpose of this study
- The respondents must have answered all questions in the survey as opposed to "dropping-out" during the process (This also aids in cleaning up the raw data obtained.)
- The respondents must have attempted to minimise waste on greenfield (previously undeveloped) sites during the design stage
- The respondents must have achieved GBCSA certification for the project in which they have attempted to minimise waste
- These projects should be Green buildings located in the Gauteng region of South Africa only. (This will ensure a context specific study.)

An invalid response will thus be a response which does not adhere to all of the above criteria.

After the first two weeks of launching the questionnaire, on 28 May 2014, 47 valid responses were received. A reminder invitation was then sent out to all potential respondents (the survey is anonymous and there is no way of knowing who has already responded) in order to attempt to increase the response rate and thus the overall credibility of this study. (The cover letter of this reminder e-mail reminder is available in Appendix B.) On 4 June 2014, a week after the first reminder e-mail was sent, an additional 14 valid responses were received which brought the total number of valid responses up to 61. A second reminder was then sent out on the same day. On 7 June 2014, three days after the second reminder was sent out, an additional 9 valid responses were received which brought the total number of valid responses up to 70 and the survey was officially closed. The survey was thus open for approximately 4 weeks.

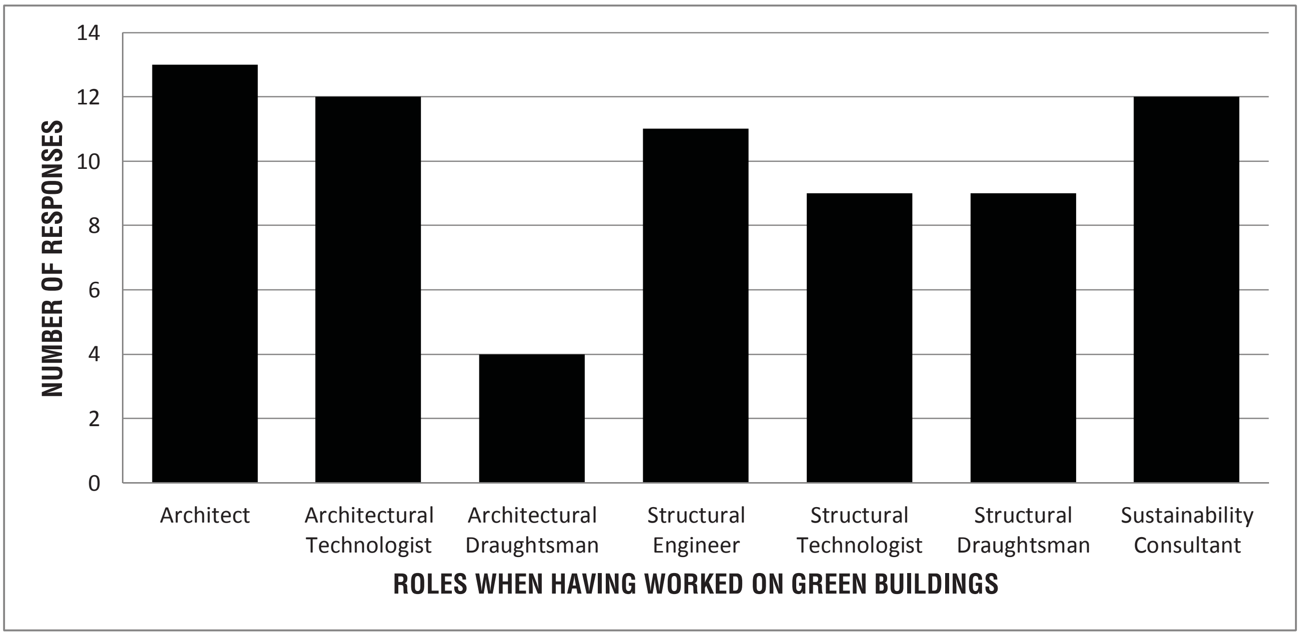
There were thus 70 valid responses (out of the 138 census population) received in total which yields a 50.7% response rate. The associated confidence level of this response rate is 80% in conjunction with a 10% sampling error as per Nulty (2008: 310). Table 3.2 (above) shows Previous Studies' Target Population in Conjunction with questionnaire response rates received. This table indicates an average response rate of 53%. Although this study has a slightly lower response rate than the average of 53%, this study is on par with the typical response rate of similar construction waste minimisation studies.

Unfortunately 7 invalid responses were received. These responses were not considered in any of the data processing as most of these responses were either too incomplete to be utilized and some respondents were not serious when answering the questionnaire.

4.2 Demographic profile of Respondents

Fortunately, the respondents covered the whole spectrum of design-roles (architectural, structural & sustainability consultants), years of experience and various levels of education. This wide overall spectrum of respondents has aided in obtaining more credible results as the whole AECD (architecture, engineering, construction & design) industry in Gauteng who has contributed to Green Buildings was thus represented. The following graphs will describe the demographics of the respondents in more depth.

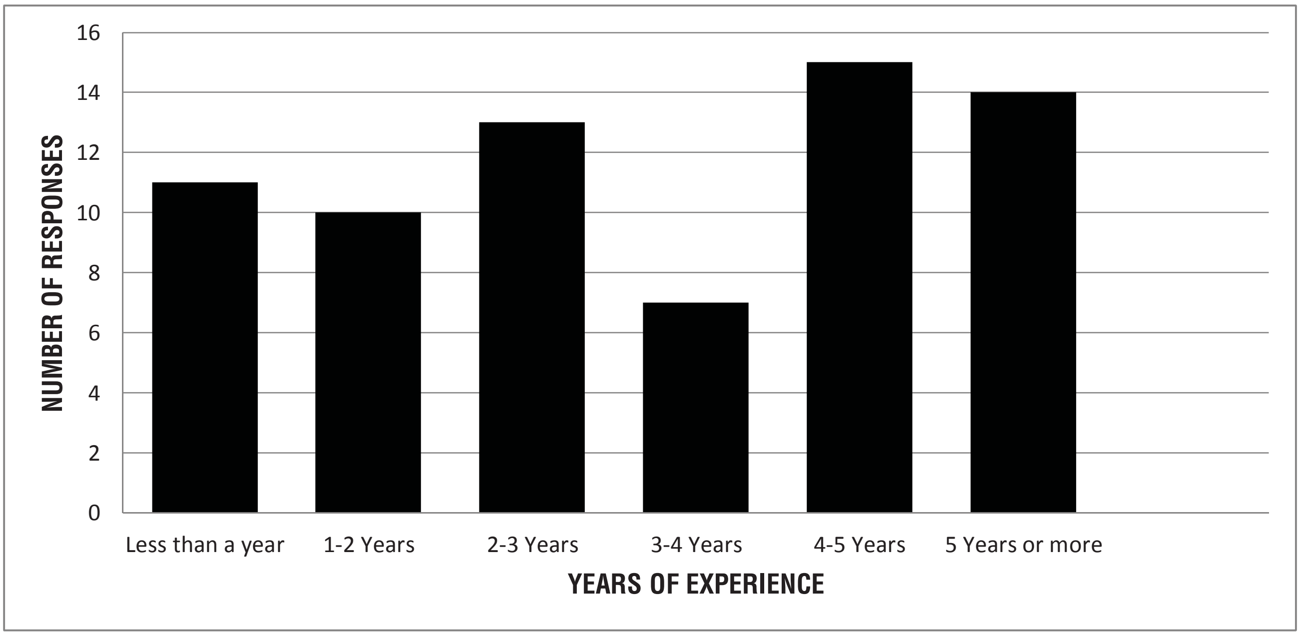
Graph 4.1: Graph indicating Respondents' Roles when having worked on Green Buildings in Gauteng



From Graph 4.1 it can be concluded that the whole spectrum of design-roles in Gauteng has been represented in this study. The architectural profession (architects, architectural technologists & architectural draughtsman) as well as the structural engineering profession (structural engineers, structural technologists & structural draughtsman) are both equally represented. Sustainability consultants are the respondents who are the least represented in this study.

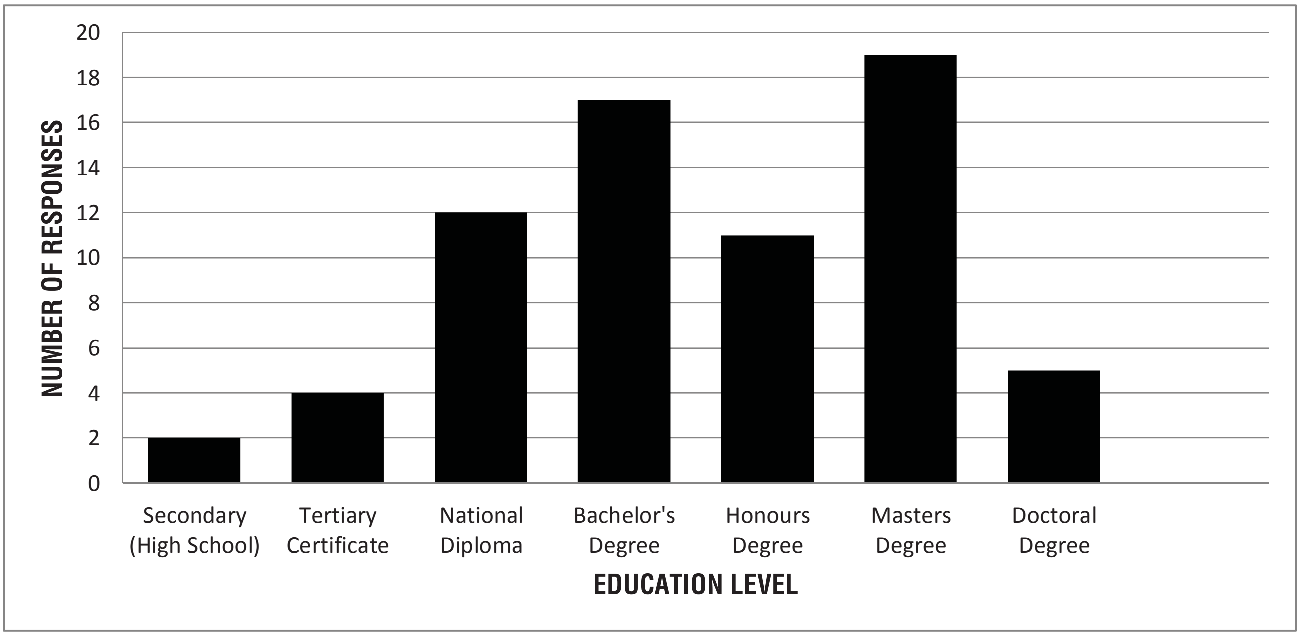
The diversity of roles of respondents when having worked on green buildings contributes to the representativeness of the target population.

Graph 4.2: Graph Indicating Respondents' Years of Experience Working on Green Buildings in Gauteng



From Graph 4.2 it can concluded that respondents with various levels of experience working on green buildings in Gauteng has been represented in this study. It is evident that most respondents have either 4-5 years of experience or 5 years or more. This group of respondents with a high level of experience will later be investigated as a potential sub-group within the study. The diversity of the various levels of experience of respondents contributes to the representativeness of the target population.

Graph 4.3: Graph Indicating Respondents' Level of Education



From Graph 4.3 it can be concluded that the whole spectrum of level of education has been represented in this study. It is also evident that most respondents hold either a masters or a bachelor's degree. The diversity of the levels of education of respondents contributes to the representativeness of the target population.

4.3 Exploring Construction Waste minimisation Factors in Gauteng in terms of Significance & Ease of Implementation

This subsection will list and discuss the *significant* construction waste minimisation factors identified in Gauteng as well as the *ease of implementation* of these factors. This is followed by a cross-tabulated list of the factors identified which shows the relationship between the factors' s*ignificance* & *ease of implementation.*

4.3.1 Significance of Construction Waste Minimisation factors in Gauteng

Table 4.1 lists the critical waste minimisation factors in Gauteng in terms of *Significance*, ranked from most frequent to least frequent as per mean factor rating score. These context-specific factors in comparison with the initial conceptual framework (Table 2.2) which indicates the prevalency of factors from global literature is very comparable, with the exception of the implementation of BIM being found as being very significant in Gauteng. This may be due to BIM being a relatively new concept and was thus not discussed prevalently as a waste minimisation factor in global literature.

4.3.2 Ease of implementation of Construction Waste Minimisation factors in Gauteng

Table 4.2 lists the critical waste minimisation factors in Gauteng in terms of *Ease of Implementation*, ranked from most frequent to least frequent as per mean factor rating score. These context-specific factors in comparison with the initial conceptual framework (Table 2.2) which indicates the prevalency of factors from global literature is comparable for the most part, with a few exceptions.

The implementation of BIM was found as being very easy to implement in Gauteng and the avoidance of frequent and last minute design changes were found to be much more difficult to manage in Gauteng as opposed to a global context. This table furthermore indicates that designers being offered bonuses, rewards or economic incentives for curbing construction waste during the design stage as well as implementing and enforcing government legislation, taxation (landfill fees) & policies are much harder in a Gauteng region context as opposed to the global context.

4.3.3 Exploring relationships between Significance and Ease of Implementation of Factors

Table 4.3 cross-tabulates the ranked critical factors in Gauteng in terms of *Significance* as well as *Ease of implementation*. From this table is evident that certain factors are both highly significant as well as easy to implement in Gauteng. These factors will thus be the overall favoured solutions in Gauteng.

Table 4.1: A list of the critical waste minimisation factors in Gauteng in terms of Significance, ranked from most frequent to least frequent.

RANKING IN GAUTENG	No. AS PER CONCEPTUAL FRAMEWORK	***SIGNIFICANCE*** **OF FACTORS IN EFFECTIVE CONSTRUCTION WASTE MINIMISATION AT THE DESIGN STAGE - A GAUTENG REGION CASE STUDY**	MEAN FACTOR RATING (MFR)
1	6	Designers should communicate & co-ordinate efficiently and effectively with other consultants at the design stage.	4.6
2	3	Designers should specify off-site preparation, pre-assembly, prefabrication & precast components.	4.47
3	7	Designers should supply adequate information on drawings and avoid lacking or incorrect design & detailing packages.	4.47
4	1	Designers should make use of standardization.	4.44
5	2	Designers lack knowledge & experience with regards to constructability, materials & material specifications.	4.39
6	4	Designers should avoid frequent & last minute design changes, especially during construction phase.	4.34
7	5	Designers should specify re-usable, reclaimed, salvaged or recycled materials.	4.34
8	23	Designers should implement BIM (Building Information Modelling) at the design stage.	4.3
9	11	Designers should avoid late drawing revisions & submittals.	4.19
10	9	Designers should avoid over-designing as well as complex designs & detailing which result in excessive off-cuts.	4.09
11	14	Government legislation, taxation (landfill fees) & policies are lacking or compliance thereto is not enforced.	4.09
12	12	Designers should be offered bonuses, rewards or economic incentives for curbing construction waste during the design stage.	3.94
13	10	Designers should implement an organizational culture to waste in their businesses.	3.9
14	8	Designers should design for future deconstruction & disassembly.	3.86
15	15	Designers should receive complete, unambiguous briefings & contract documentation from the client at the design stage.	3.83
16	17	Waste minimisation clauses should be embedded in contractual clauses.	3.73
17	13	Designers should adopt low-waste modern technologies & systems.	3.63
18	16	Designers lack experience & knowledge with regards to method & sequence of construction which leads to alterations of work.	3.4
19	18	Designers should make use of adaptable & flexible project designs.	3.33
20	19	Designers should plan for soil remains (cut & fills) to be used in the same construction site or negotiate with neighbouring sites.	3.26
21	21	Designers should design space to be adequate & functional in order to prevent future alterations which result in waste.	3.16
22	20	Designers should provide for an adequate space on the construction site where waste quantification, storing and sorting can take place.	3.13
23	22	Designers should design in aid of minimizing temporary works.	3.03
24	25	Designers should facilitate for construction to be executed with ease during adverse weather conditions.	2.97
25	26	Designers should make use of environmental impact assessments during the design stage of the scheme in order to realize where waste reduction potentials are and how materials can be optimized.	2.94
26	24	Designers should take into account the accessibility of construction personnel on site.	2.81

Table 4.2: A list of the critical waste minimisation factors in Gauteng in terms of Ease of implementation, ranked from most frequent to least frequent.

RANKING IN GAUTENG	No. AS PER CONCEPTUAL FRAMEWORK	*EASE OF IMPLEMENTATION* OF FACTORS IN EFFECTIVE CONSTRUCTION WASTE MINIMISATION AT THE DESIGN STAGE - A GAUTENG REGION CASE STUDY	MEAN FACTOR RATING (MFR)
1	1	Designers should make use of standardization.	4.13
2	3	Designers should specify off-site preparation, pre-assembly, prefabrication & precast components.	4.03
3	5	Designers should specify re-usable, reclaimed, salvaged or recycled materials.	3.74
4	23	Designers should implement BIM (Building Information Modelling) at the design stage.	3.71
5	6	Designers should communicate & co-ordinate efficiently and effectively with other consultants at the design stage.	3.6
6	7	Designers should supply adequate information on drawings and avoid lacking or incorrect design & detailing packages.	3.57
7	10	Designers should implement an organizational culture to waste in their businesses.	3.4
8	2	Designers lack knowledge & experience with regards to constructability, materials & material specifications.	3.26
9	8	Designers should design for future deconstruction & disassembly.	3.17
10	9	Designers should avoid over-designing as well as complex designs & detailing which result in excessive off-cuts.	3.14
11	17	Waste minimisation clauses should be embedded in contractual clauses.	3.11
12	11	Designers should avoid late drawing revisions & submittals.	3.09
13	15	Designers should receive complete, unambiguous briefings & contract documentation from the client at the design stage.	3
14	13	Designers should adopt low-waste modern technologies & systems.	2.99
15	19	Designers should plan for soil remains (cut & fills) to be used in the same construction site or negotiate with neighbouring sites.	2.97
16	18	Designers should make use of adaptable & flexible project designs.	2.9
17	16	Designers lack experience & knowledge with regards to method & sequence of construction which leads to alterations of work.	2.89
18	20	Designers should provide for an adequate space on the construction site where waste quantification, storing and sorting can take place.	2.83
19	22	Designers should design in aid of minimizing temporary works.	2.79
20	4	Designers should avoid frequent & last minute design changes, especially during construction phase.	2.74
21	26	Designers should make use of environmental impact assessments during the design stage of the scheme in order to realize where waste reduction potentials are and how materials can be optimized.	2.7
22	21	Designers should design space to be adequate & functional in order to prevent future alterations which result in waste.	2.64
23	24	Designers should take into account the accessibility of construction personnel on site.	2.63
24	12	Designers should be offered bonuses, rewards or economic incentives for curbing construction waste during the design stage.	2.57
25	14	Government legislation, taxation (landfill fees) & policies are lacking or compliance thereto is not enforced.	2.47
26	25	Designers should facilitate for construction to be executed with ease during adverse weather conditions.	1.9

Table 4.3: A cross-tabulated list of the critical factors in Gauteng in terms of Significance & Ease of implementation.

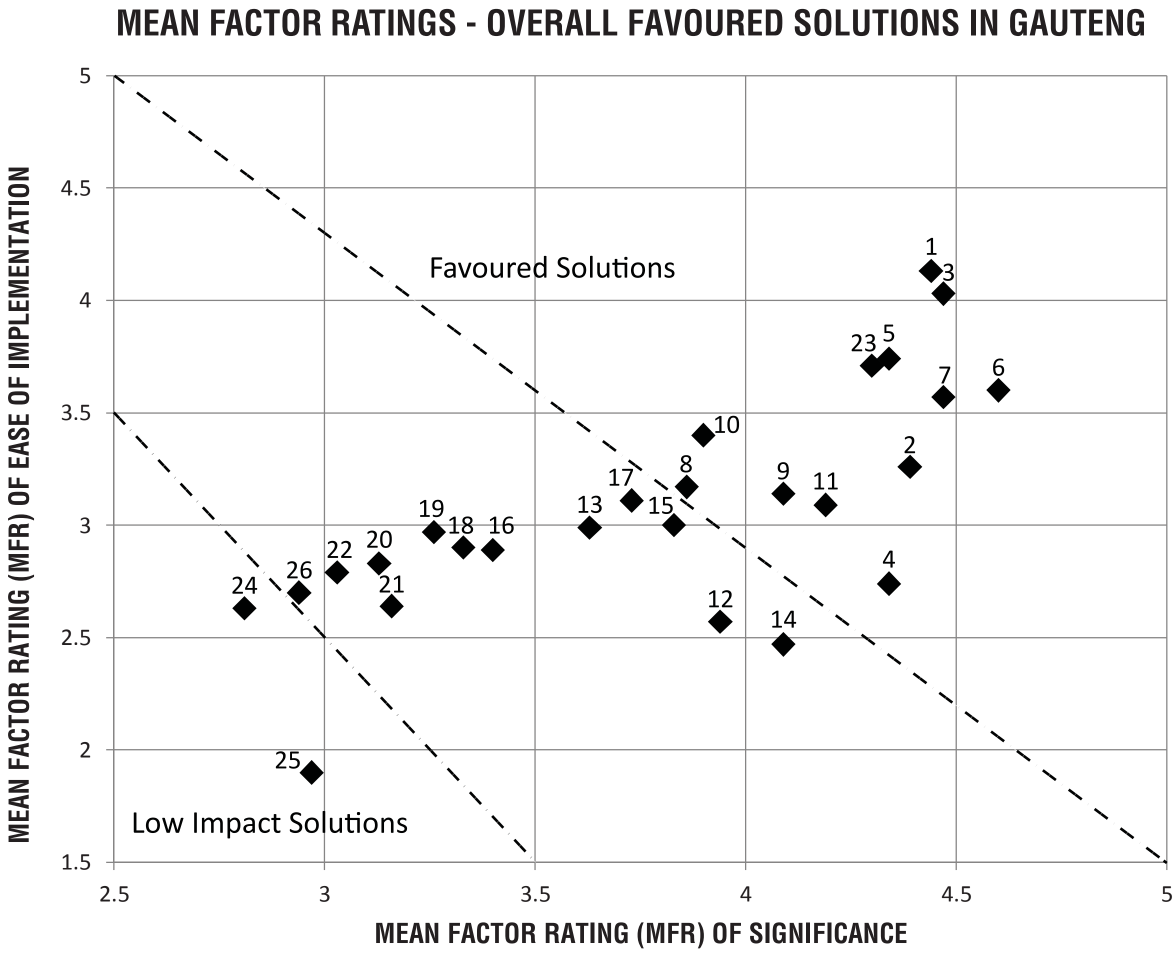
RANKING IN GAUTENG	***SIGNIFICANCE*** **OF FACTORS IN EFFECTIVE CONSTRUCTION WASTE MINIMISATION AT THE DESIGN STAGE - A GAUTENG REGION CASE STUDY**	***EASE OF IMPLEMENTATION*** **OF FACTORS IN EFFECTIVE CONSTRUCTION WASTE MINIMISATION AT THE DESIGN STAGE - A GAUTENG REGION CASE STUDY**
1	Designers should communicate & co-ordinate efficiently and effectively with other consultants at the design stage.	Designers should make use of standardization.
2	Designers should specify off-site preparation, pre-assembly, prefabrication & precast components.	Designers should specify off-site preparation, pre-assembly, prefabrication & precast components.
3	Designers should supply adequate information on drawings and avoid lacking or incorrect design & detailing packages.	Designers should specify re-usable, reclaimed, salvaged or recycled materials.
4	Designers should make use of standardization.	Designers should implement BIM (Building Information Modelling) at the design stage.
5	Designers lack knowledge & experience with regards to constructability, materials & material specifications.	Designers should communicate & co-ordinate efficiently and effectively with other consultants at the design stage.
6	Designers should avoid frequent & last minute design changes, especially during construction phase.	Designers should supply adequate information on drawings and avoid lacking or incorrect design & detailing packages.
7	Designers should specify re-usable, reclaimed, salvaged or recycled materials.	Designers should implement an organizational culture to waste in their businesses.
8	Designers should implement BIM (Building Information Modelling) at the design stage.	Designers lack knowledge & experience with regards to constructability, materials & material specifications.
9	Designers should avoid late drawing revisions & submittals.	Designers should design for future deconstruction & disassembly.
10	Designers should avoid over-designing as well as complex designs & detailing which result in excessive off-cuts.	Designers should avoid over-designing as well as complex designs & detailing which result in excessive off-cuts.
11	Government legislation, taxation (landfill fees) & policies are lacking or compliance thereto is not enforced.	Waste minimisation clauses should be embedded in contractual clauses.
12	Designers should be offered bonuses, rewards or economic incentives for curbing construction waste during the design stage.	Designers should avoid late drawing revisions & submittals.
13	Designers should implement an organizational culture to waste in their businesses.	Designers should receive complete, unambiguous briefings & contract documentation from the client at the design stage.
14	Designers should design for future deconstruction & disassembly.	Designers should adopt low-waste modern technologies & systems.
15	Designers should receive complete, unambiguous briefings & contract documentation from the client at the design stage.	Designers should plan for soil remains (cut & fills) to be used in the same construction site or negotiate with neighbouring sites.
16	Waste minimisation clauses should be embedded in contractual clauses.	Designers should make use of adaptable & flexible project designs.
17	Designers should adopt low-waste modern technologies & systems.	Designers lack experience & knowledge with regards to method & sequence of construction which leads to alterations of work.
18	Designers lack experience & knowledge with regards to method & sequence of construction which leads to alterations of work.	Designers should provide for an adequate space on the construction site where waste quantification, storing and sorting can take place.
19	Designers should make use of adaptable & flexible project designs.	Designers should design in aid of minimizing temporary works.
20	Designers should plan for soil remains (cut & fills) to be used in the same construction site or negotiate with neighbouring sites.	Designers should avoid frequent & last minute design changes, especially during construction phase.
21	Designers should design space to be adequate & functional in order to prevent future alterations which result in waste.	Designers should make use of environmental impact assessments during the design stage of the scheme in order to realize where waste reduction potentials are and how materials can be optimized.
22	Designers should provide for an adequate space on the construction site where waste quantification, storing and sorting can take place.	Designers should design space to be adequate & functional in order to prevent future alterations which result in waste.
23	Designers should design in aid of minimizing temporary works.	Designers should take into account the accessibility of construction personnel on site.
24	Designers should facilitate for construction to be executed with ease during adverse weather conditions.	Designers should be offered bonuses, rewards or economic incentives for curbing construction waste during the design stage.
25	Designers should make use of environmental impact assessments during the design stage of the scheme in order to realize where waste reduction potentials are and how materials can be optimized.	Government legislation, taxation (landfill fees) & policies are lacking or compliance thereto is not enforced.
26	Designers should take into account the accessibility of construction personnel on site.	Designers should facilitate for construction to be executed with ease during adverse weather conditions.

Table 4.4: Key for Graph 4.4, Graph 4.5, Graph 4.6, Graph 4.7, Graph 4.8 & Graph 4.9

No. (AS PER CONCEPTUAL FRAMEWORK)	FACTORS
1	Designers should make use of standardization.
2	Designers lack knowledge & experience with regards to constructability, materials & material specifications.
3	Designers should specify off-site preparation, pre-assembly, prefabrication & precast components.
4	Designers should avoid frequent & last minute design changes, especially during construction phase.
5	Designers should specify re-usable, reclaimed, salvaged or recycled materials.
6	Designers should communicate & co-ordinate efficiently and effectively with other consultants at the design stage.
7	Designers should supply adequate information on drawings and avoid lacking or incorrect design & detailing packages.
8	Designers should design for future deconstruction & disassembly.
9	Designers should avoid over-designing as well as complex designs & detailing which result in excessive off-cuts.
10	Designers should implement an organizational culture to waste in their businesses.
11	Designers should avoid late drawing revisions & submittals.
12	Designers should be offered bonuses, rewards or economic incentives for curbing construction waste during the design stage.
13	Designers should adopt low-waste modern technologies & systems.
14	Government legislation, taxation (landfill fees) & policies are lacking or compliance thereto is not enforced.
15	Designers should receive complete, unambiguous briefings & contract documentation from the client at the design stage.
16	Designers lack experience & knowledge with regards to method & sequence of construction which leads to alterations of work.
17	Waste minimisation clauses should be embedded in contractual clauses.
18	Designers should make use of adaptable & flexible project designs.
19	Designers should plan for soil remains (cut & fills) to be used in the same construction site or negotiate with neighbouring sites.
20	Designers should provide for an adequate space on the construction site where waste quantification, storing and sorting can take place.
21	Designers should design space to be adequate & functional in order to prevent future alterations which result in waste.
22	Designers should design in aid of minimizing temporary works.
23	Designers should implement BIM (Building Information Modelling) at the design stage.
24	Designers should take into account the accessibility of construction personnel on site.
25	Designers should facilitate for construction to be executed with ease during adverse weather conditions.
26	Designers should make use of environmental impact assessments during the design stage of the scheme in order to realize where waste reduction potentials are and how materials can be optimized.

4.4 Overall Favoured solutions in Gauteng

Graph 4.4: Graph Indicating Mean Factor Ratings of the Overall Favoured Solutions in Gauteng (See Table 4.4 as Graph Key)



Graph 4.4 shows the distribution of waste minimisation factors according to their mean factor rating (MFR) in terms of the *significance* and *ease of implementation* measures. Those above the higher line are seen as being extremely *significant* or extremely *easy to implement* in Gauteng. They represent the favoured waste minimisation factors in Gauteng and comprise of those factors most likely to be utilized as part of a context-specific and robust waste minimisation strategy. Those below the lower line were seen as unimportant or negligible and having a lower overall impact. (The generalization of these means values are summated in Table 3.3 which shows a scoring system for prioritisation of mean values.)

Graph 4.4 thus indicates that the following factors are the overall favoured waste minimisation factors in Gauteng, ranked from the most favoured solutions to the least favoured solutions;

- Designers should make use of standardization.
- Designers should specify off-site preparation, pre-assembly, prefabrication & precast components.
- Designers should communicate & co-ordinate efficiently and effectively with other consultants at the design stage.
- Designers should supply adequate information on drawings and avoid lacking or incorrect design & detailing packages.
- Designers should specify re-usable, reclaimed, salvaged or recycled materials.
- Designers should implement BIM (Building Information Modelling) at the design stage.
- Designers lack knowledge & experience with regards to constructability, materials & material specifications. Education & training will address this issue.

4.5 Analysing Respondent Demographics in Conjunction with Findings

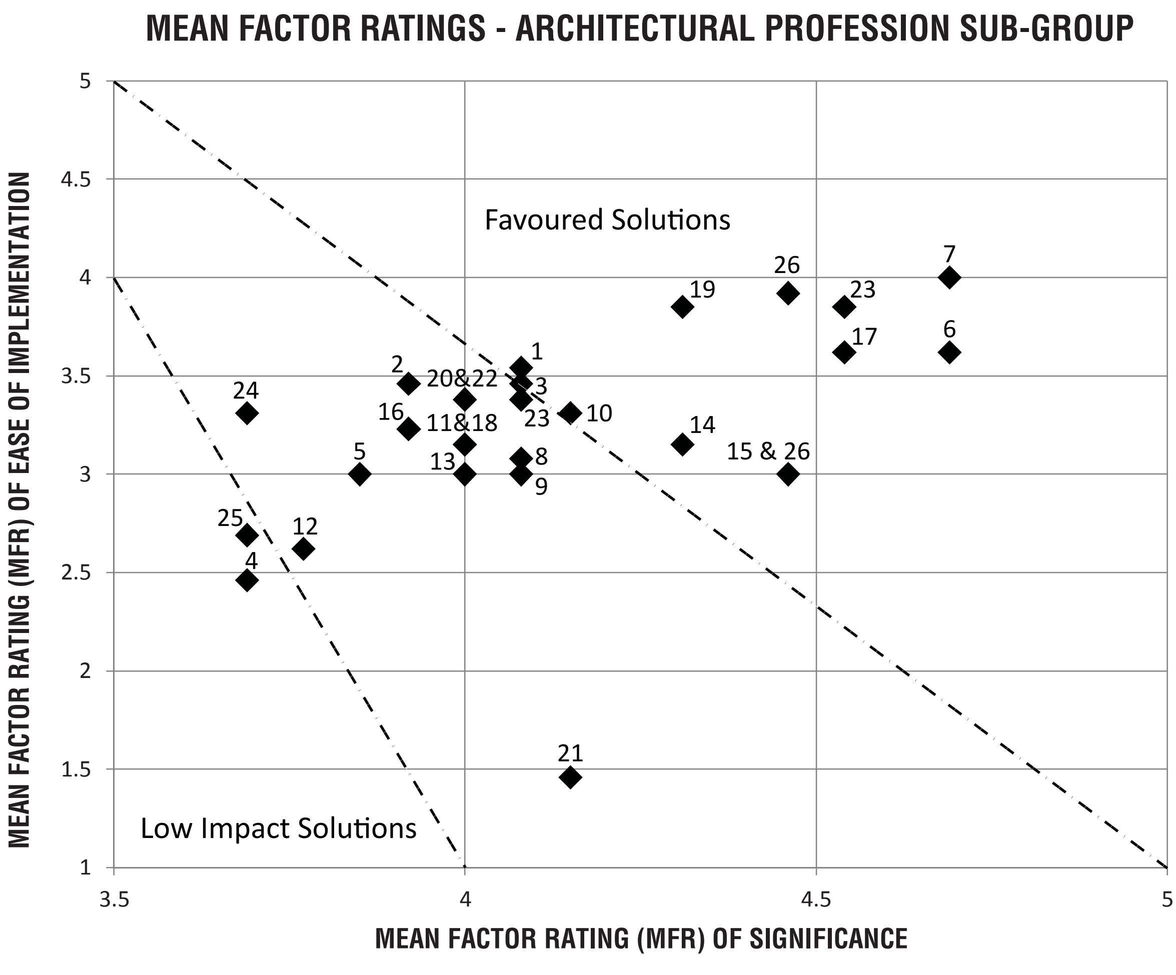
The data obtained was analysed in conjunction with demographics to potentially identify sub-groups, if any are present. The aim of this was to investigate if there is a correlation between data given by respondents and either their role when having worked on green buildings, years of experience working on Green Buildings in Gauteng or their level of education.

The following potential sub-groups were investigated:

- Respondents who are in the architectural profession
- Respondents who are in the engineering profession
- Respondents who are sustainability consultants
- Respondents whose highest level of qualification is either a masters or a doctoral degree (Highly educated)
- Respondents who has five years or more of experience on Green Buildings in Gauteng (Highly experienced on Green Buildings in Gauteng)

4.5.1 The Architectural Profession Sub-group

Graph 4.5: Graph Indicating Mean Factor Ratings as per Architectural Profession Sub-group (See Table 4.4 as Graph Key)



Graph 4.5 indicates that the following factors are the overall favoured waste minimisation factors by the architectural profession in Gauteng, ranked from the most favoured solutions to the least favoured solutions;

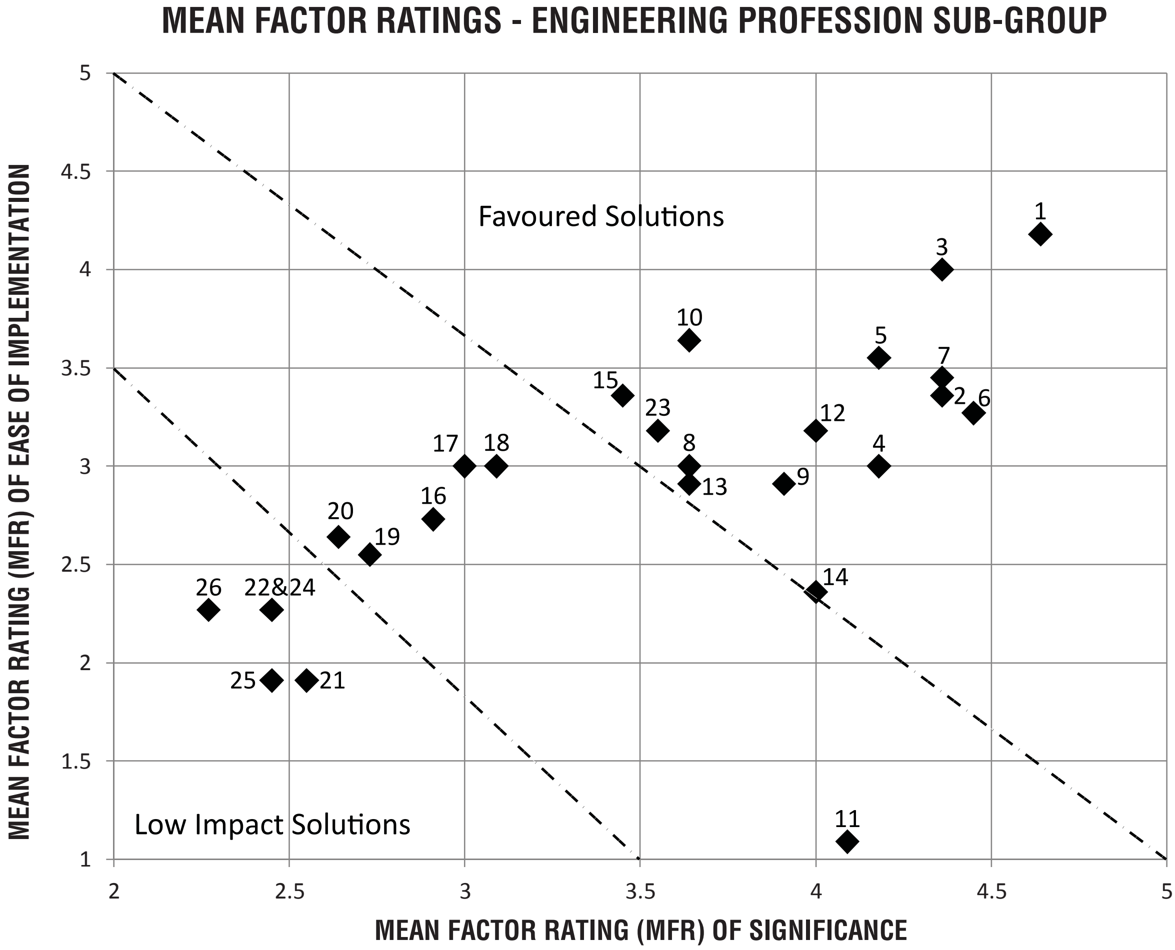
- Designers should supply adequate information on drawings and avoid lacking or incorrect design & detailing packages
- Designers should communicate & co-ordinate efficiently and effectively with other consultants at the

design stage
- Designers should implement BIM (Building Information Modelling) at the design stage
- Designers should make use of environmental impact assessments during the design stage of the scheme in order to realize where waste reduction potentials are and how materials can be optimized
- Waste minimisation clauses should be embedded in contractual clauses.

The first four factors as identified solely by the architectural profession sub-group are factors that can directly be implemented by this sub-group during the design stage which could be the reason why this sub-group placed emphasis on these factors. Furthermore, the overall favoured solutions by the architectural profession sub-group are quite different from the overall favoured solutions in Gauteng. It can thus be concluded that the architectural profession is a sub-group within the initial research target population.

4.5.2 The Engineering Profession Sub-group

Graph 4.6: Graph Indicating Mean Factor Ratings as per Engineering Profession Sub-group (See Table 4.4 as Graph Key)



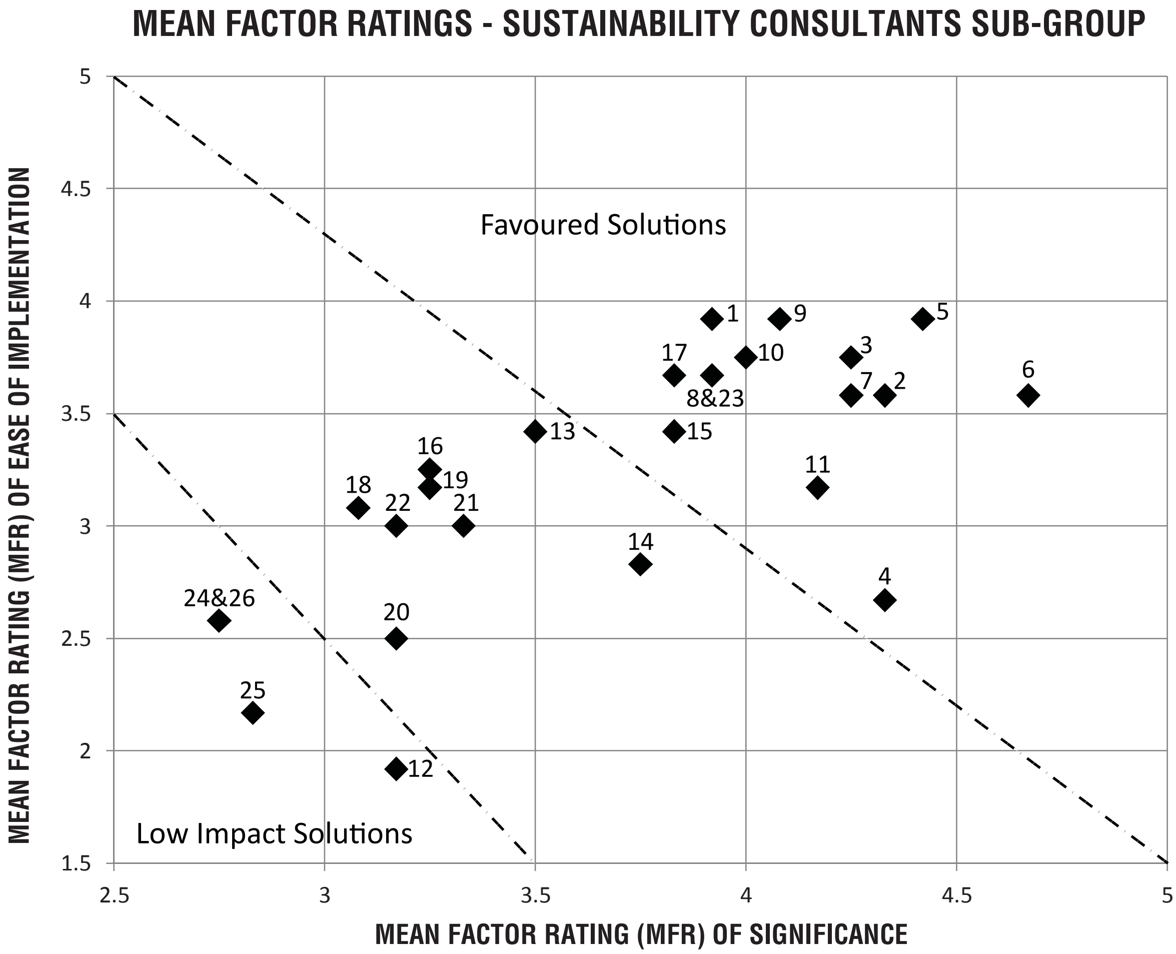
Graph 4.6 indicates that the following factors are the overall favoured waste minimisation factors by the engineering profession in Gauteng, ranked from the most favoured solutions to the least favoured solutions;
- Designers should make use of standardization.
- Designers should specify off-site preparation, pre-assembly, prefabrication & precast components.
- Designers should supply adequate information on drawings and avoid lacking or incorrect design & detailing packages.
- Designers should communicate & co-ordinate efficiently and effectively with other consultants at the design stage.
- Designers lack knowledge & experience with regards to constructability, materials & material specifica-

tions.
- Designers should specify re-usable, reclaimed, salvaged or recycled materials.

The above factors as identified by the engineering profession sub-group are extremely similar to the overall favoured solutions in Gauteng. Similarly to the overall favoured solutions in Gauteng, this sub-group also identified the implementation of BIM as being more significant than identified by the initial conceptual framework in Table 2.2. It can thus be concluded that the engineering profession is not a sub-group within the initial research target population.

4.5.3 The Sustainability Consultants Sub-group

Graph 4.7: Graph Indicating Mean Factor Ratings as per Sustainability Consultants Sub-group (See Table 4.4 as Graph Key)



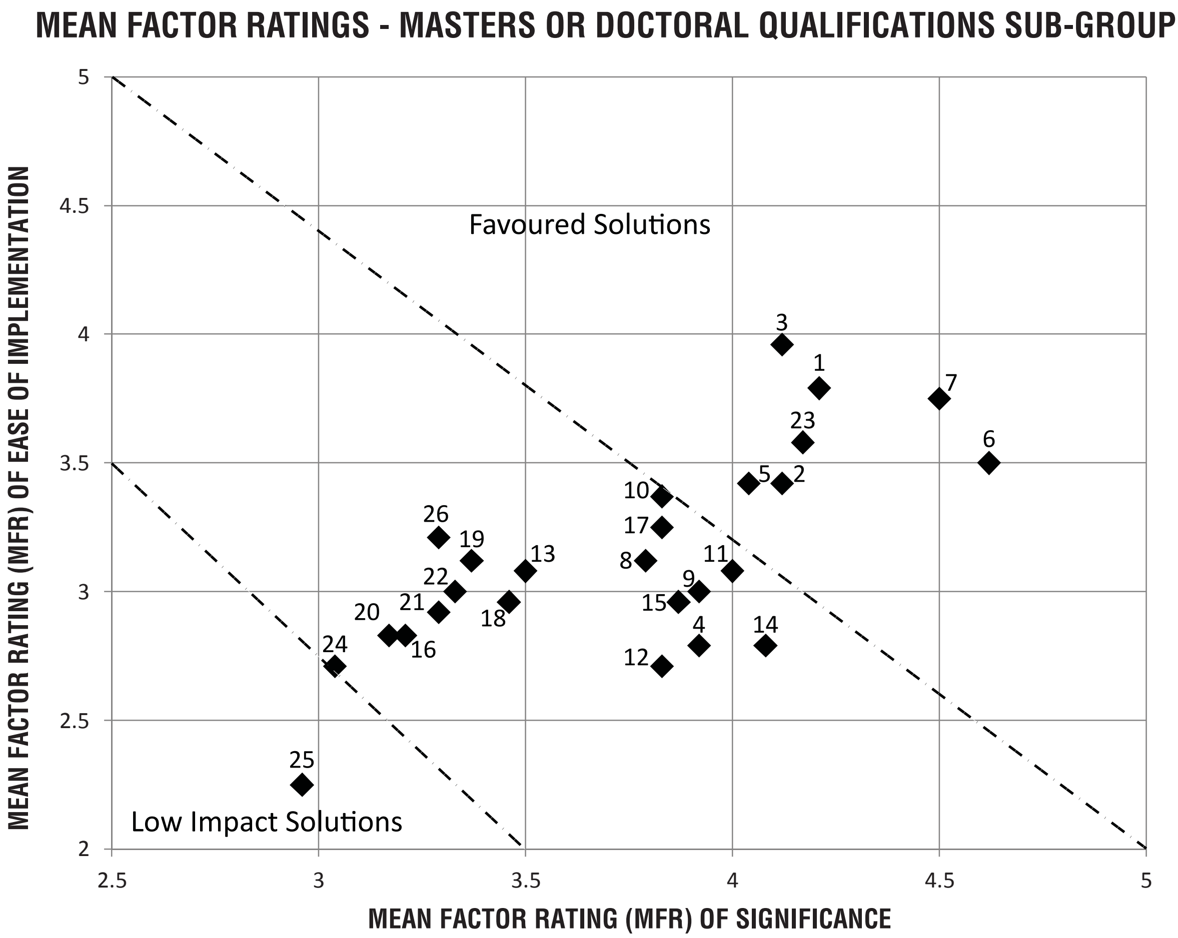
Graph 4.7 indicates that the following factors are the overall favoured waste minimisation factors by the sustainability consultants in Gauteng, ranked from the most favoured solutions to the least favoured solutions;
- Designers should specify re-usable, reclaimed, salvaged or recycled materials.
- Designers should communicate & co-ordinate efficiently and effectively with other consultants at the design stage.
- Designers should specify off-site preparation, pre-assembly, prefabrication & precast components.
- Designers lack knowledge & experience with regards to constructability, materials & material specifications.
- Designers should avoid over-designing as well as complex designs & detailing which result in excessive off-cuts.
- Designers should supply adequate information on drawings and avoid lacking or incorrect design &

detailing packages.

The above factors as identified solely by the sustainability consultants sub-group are extremely similar to the overall favoured solutions in Gauteng. Similarly to the overall favoured solutions in Gauteng as well as the engineering profession sub-group, this sub-group also identified the implementation of BIM as being more significant than identified by the initial conceptual framework in Table 2.2. It can thus be concluded that the sustainability consultants sub-group is not a sub-group within the initial research target population.

4.5.4 Masters or Doctoral Qualifications Sub-group

Graph 4.8: Graph Indicating Mean Factor Ratings as per Masters or Doctoral Qualifications Sub-group (See Table 4.4 as Graph Key)



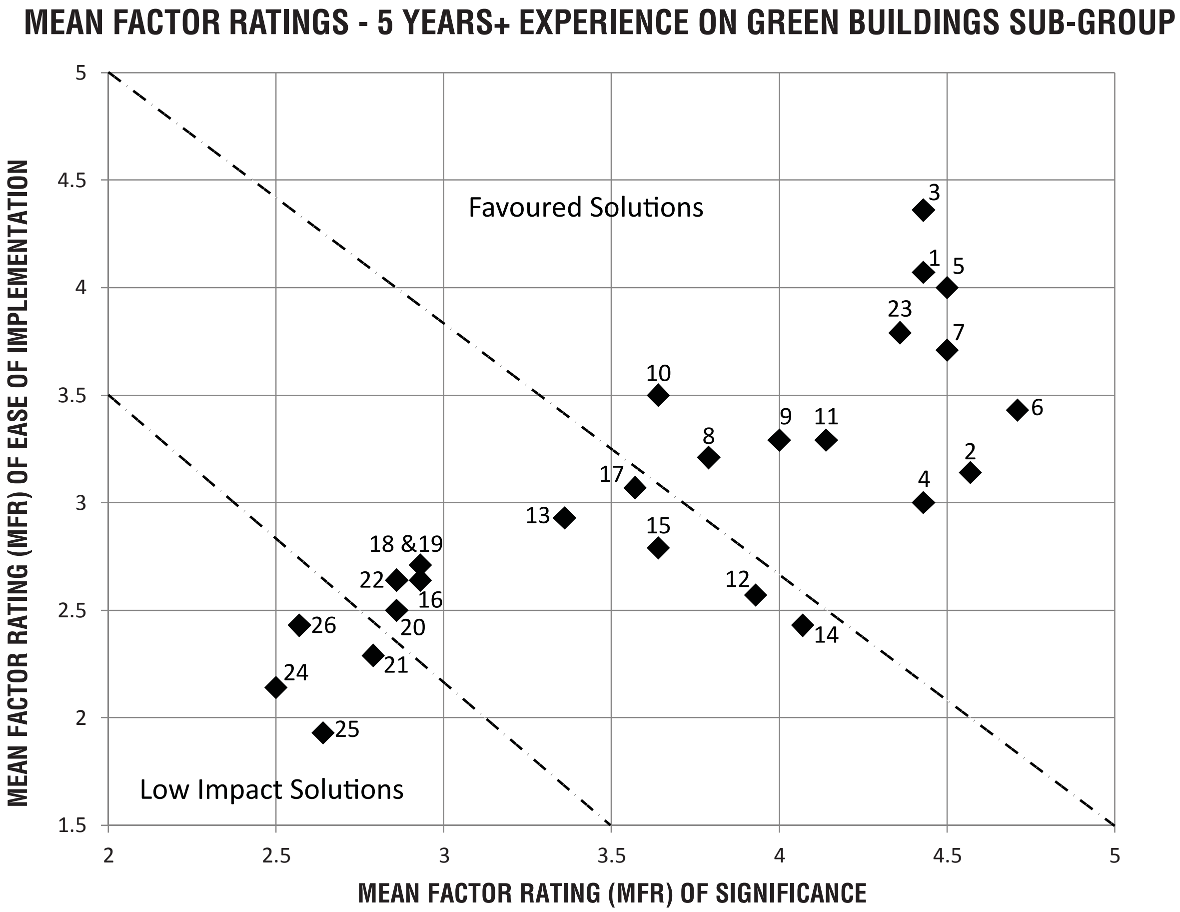
Graph 4.8 indicates that the following factors are the overall favoured waste minimisation factors by the respondents who hold either a masters or a doctoral degree in Gauteng, ranked from the most favoured solutions to the least favoured solutions;

- Designers should supply adequate information on drawings and avoid lacking or incorrect design & detailing packages.
- Designers should communicate & co-ordinate efficiently and effectively with other consultants at the design stage.
- Designers should specify off-site preparation, pre-assembly, prefabrication & precast components.
- Designers should make use of standardization.
- Designers should implement BIM (Building Information Modelling) at the design stage.
- Designers lack knowledge & experience with regards to constructability, materials & material specifications.

The above factors as identified solely by the respondents who hold either a masters or a doctoral degree sub-group are extremely similar to the overall favoured solutions in Gauteng. Similarly to the overall favoured solutions in Gauteng as well as the engineering profession sub-group, the sustainability consultants sub-group and the masters or doctoral qualification sub-group, this sub-group also identified the implementation of BIM as being more significant than identified by the initial conceptual framework in Table 2.2. It can thus be concluded that the respondents who have 5 years or more experience on green buildings in Gauteng is not a sub-group within the initial research target population.

4.5.5 Five years or more experience on Green Buildings in Gauteng Sub-group

Graph 4.9: Graph Indicating Mean Factor Ratings as per Five years or more experience on Green Buildings in Gauteng Sub-group (See Table 4.4 as Graph Key)



Graph 4.9 indicates that the following factors are the overall favoured waste minimisation factors by the respondents who have 5 years or more experience on green buildings in Gauteng, ranked from the most favoured solutions to the least favoured solutions;

- Designers should specify off-site preparation, pre-assembly, prefabrication & precast components.
- Designers should specify re-usable, reclaimed, salvaged or recycled materials.
- Designers should make use of standardization.
- Designers should supply adequate information on drawings and avoid lacking or incorrect design & detailing packages.
- Designers should communicate & co-ordinate efficiently and effectively with other consultants at the design stage.
- Designers should implement BIM (Building Information Modelling) at the design stage.

The above factors as identified solely by the respondents who have 5 years or more experience on green buildings in Gauteng are extremely similar to the overall favoured solutions in Gauteng. Similarly to the overall favoured solutions in Gauteng as well as both the engineering profession and sustainability consultants sub-groups, this sub-group also identified the implementation of BIM as being more significant than identified by the initial conceptual framework in Table 2.2. It can thus be concluded that the respondents who hold either a masters or a doctoral qualification sub-group is not a sub-group within the initial research target population.

4.6 Additional factors identified by respondents in the questionnaire

The online questionnaire provided respondents an opportunity to list additional factors which will minimise construction waste in Gauteng which were not mentioned in the survey. This question was only answered by 25 respondents. Of the answers obtained, the following answers were factors outside of the initial conceptual framework (Table 2.2):

- Designers should specify locally manufactured products which allows for easier recycling of potential construction waste. Designers should also advise utilizing locally supplied construction equipment. This will simultaneously stimulate the Gauteng employment markets. (This factor links to factor 2 in the conceptual framework which states that designers lack knowledge with regards to specifications.)
- The government should incorporate operational incentives for minimising waste on construction sites. This can include reducing rates & taxes of a property for a set period of time and thus increasing that property's land valuation. (This factor links to factor 12 in the conceptual framework which states that designers should be offered bonuses, rewards or economic incentives for curbing construction waste during the design stage.)
- Quantity surveyors should be consulted during the design stage in order to survey construction materials and thus to prevent potential construction waste. These consultants will also be able to inform the client about potential cost savings. (This factor links to factor 6 in the conceptual framework which states that designers should communicate & co-ordinate efficiently and effectively with other consultants at the design stage.) One can thus conclude that the effective communication & co-ordination should not merely be amongst designers, but actually amongst the project team as a whole.
- Designers should avoid the fast-paced design and build construction techniques in Gauteng. It is more advisable to sign off smaller, packaged segments of a construction project in order to have better overall control of the project which will aid in minimising construction waste.
- Numerous respondents noted that construction should preferably be on brownfield sites as opposed to greenfield sites. Designers can thus optimize what is already there and this will potentially result in less construction waste. (This study was scoped to investigate greenfield sites only, but future studies may investigate brownfield sites' construction waste minimisation factors.)

5. CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusions

Although the overall consensus from both global and local literature states that a substantial amount of construction waste is as a result of poor or uninformed design decisions during the design stage, there is currently a research gap in the current body of knowledge with regards to the effective critical factors that will minimise construction waste during the design stage in specifically the Gauteng region context.

This study's aim or objective was thus to address the above mentioned research gap from both an academic as well as a practical perspective as it has identified effective critical factors that will minimise construction waste during the design stage in a Gauteng region context. This was done by analysing both global and local literature and thus establishing an initial conceptual framework of twenty-six factors. This conceptual framework was further investigated, explored and tested in order to answer the research question by means of quantitatively surveying sampled designers in Gauteng in order to determine which of these factors were the most contextually significant. This data was analysed and the study ranked the factors separately in terms of both *significance* as well as *ease of implementation* in order to answer the research sub-question which ultimately analyzes both sets of factors in conjunction to determine the overall most favoured critical factors in Gauteng.

The top overall most favoured critical factors (which are both *significant* as well as *easy to implement*) in effective construction waste minimisation at the design stage of Gauteng projects are (ranked from the most favoured to the least favoured solutions); designers should make use of standardization, designers should specify off-site preparation, pre-assembly, prefabrication & precast components, designers should communicate & co-ordinate efficiently and effectively with other consultants at the design stage, designers should supply adequate information on drawings and avoid lacking or incorrect design & detailing packages, designers should specify re-usable, reclaimed, salvaged or recycled materials, designers should implement BIM (Building Information Modelling) at the design stage and designers lack knowledge & experience with regards to constructability, materials & material specifications.

From the above overall contextual findings it is evident that the most effective solutions to minimise waste during the design stage in Gauteng are those solutions which seek to develop alliances and working relationships with manufacturers, suppliers, other consultants and recycling companies. The top overall favoured factor in Gauteng, namely: designers should make use of standardization, will improve the buildability for the contractors and will significantly reduce the quantity of construction waste material off-cuts. In conjunction the above identified solutions can practically be implemented in order to reduce the amount of construction waste going to landfills in Gauteng which in turn will address the social an economic consequences of the problem of construction waste.

Potential sub-groups were explored and investigated in Chapter 4 in order to identify if there is a correlation between data obtained from respondents and either their role when having worked on green buildings in Gauteng, years of experience working on Green Buildings in Gauteng or their highest level of education.

The architectural profession was identified as the only sub-group as the data obtained from this group (see Graph 4.5) differed vastly from the identified overall favoured waste minimisation solutions in Gauteng (see Graph 4.4). The overall favoured solutions as identified solely by the architectural profession sub-group are factors that can directly be implemented by this sub-group during the design stage which could potentially be the reason why this sub-group placed emphasis on these factors. These factors include supplying adequate information on drawings, avoiding lacking or incorrect design and detailing packages and communicating and co-ordinating efficiently and effectively with other consultants during the design stage. The architectural profession sub-group is also the only group who highly values the use of environmental impact assessments during the design stage of the scheme in order to realize where waste reduction potentials are and how materials can be optimized.

The largest deviation of the overall favoured waste minimisation solutions in Gauteng in comparison to the initial conceptual framework (Table 2.2) is that the majority of the Gauteng region's respondents (including all potential sub-groups investigated) placed great value on the implementation of BIM (Building Information Modelling) at the design stage in Gauteng. It is thus evident that the industry sees this technological advancement as being imperative to construction waste minimisation during the design stage. It is also important to note that it is possible that this factor was not prevalent in the initial conceptual framework as the literature sources may not be as current as industry practices, especially seeing as technology is constantly and rapidly evolving.

Furthermore, majority of respondents within the whole research target population concluded that facilitating for construction to be executed with ease during adverse weather conditions is generally a lower favoured or low impact solution in terms of waste minimisation.

The ranked critical factors identified in this study was discussed in the literature review in Chapter 2 in terms of their inter-relationships, inter-dependencies as well as their potential advantages and drawbacks. This knowledge in conjunction with the overall research findings as discussed above should be utilized by construction stakeholders in order to make decisions between the vast array of construction waste minimisation options available. This will in essence ensure a sustainable waste management procedure in Gauteng and will thus promote the ideal of zero waste generation buildings in South Africa.

Research Limitations experienced

The limitations experienced during this study include the current limited literature on construction waste minimisation practices in Gauteng. The international body of knowledge was thus surveyed in-depth and correlations to Gauteng were investigated. Another limitation experienced was the initial low response rate by respondents which in turn was mitigated by means of sending out two reminder e-mails which ultimately brought up the number of valid responses received.

5.2 Recommendations

The ranked factors and overall contextual waste minimisation solutions identified in this study serve as a valuable reference for the *Gauteng Provincial Government* as the factors can be utilized in order to drive provincial construction waste regulations and to thus eventually drive national reform. Local municipalities (initially Gauteng municipalities only, but eventually all national municipalities) should ideally enforce these critical factors by means of incorporating the factors as a separate category of application for building plan approvals. Furthermore, municipalities can enforce the submittal of a 3D (three-dimensional) building information model which explores and showcases where waste reduction potentials are and how these potentials are utilized in order to both minimise waste and thus save costs to the client.

The main concern to be overcome by designers in Gauteng is the widely held misconception that construction waste is inevitable on construction projects. This misconception can be overcome by embedding the importance of waste minimisation as a key performance criterion throughout the supply chain of the project as a whole.

5.3 Unanswered questions beyond the scope of this study

This research report explored the *significance* as well as the *ease of implementation* of critical waste minimisation factors in Gauteng. It is important to note that this study did not investigate the Value For Money (VFM) or Cost & Benefit Analysis (CBA) notion of these identified factors. This unanswered question was identified as respondents stated that not all waste minimisation factors will be viable to implement on all projects Gauteng. A working example of this will include if off-site preparation & prefabrication workshops are logistically located very far away from the construction site, the petrol of the vehicles (and its adverse environmental effects) as well as the time spent in terms of transportation will not necessarily outweigh the potential waste minimisation benefits.

Another unanswered question beyond the scope of this study may include how different architectural building typologies (physical classification) will benefit more from certain factors than from others. It may be more appropriate to make use of prefabrication and precasting processes for rural low-cost housing in Gauteng than it would be for a church in a dense urban environment. This is due to low-cost housing being repetitive in nature and often needs to be constructed within a very strict time-frame whereas a church building may require more unique architectural and spatial components within a lesser strict time-frame. With this in mind, it is important to note that there are indeed underlying and holistic principles of effective waste management and waste minimisation which this study has identified contextually.

5.4 Areas for future study

Future studies can include exploring critical factors that will reduce construction waste minimisation during either the procurement or the construction phase. Studies can also explore construction waste minimisation factors on renovation or alteration construction projects (brownfield sites) as opposed to merely exploring greenfield sites. Furthermore; conducting studies from various stakeholders' perspective might be informative as to address barriers and misconceptions currently in the industry.

The conceptual framework within this study can also be transferred and replicated in order to test its significance in other contexts. This can include global as well as local contexts. In South Africa, this specifically includes the other large metropolitan areas like Cape Town and Durban as these areas are also undergoing rapid expansion and urbanization.

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APPENDIX A

References of Factors as Identified in Table 2.2

For ease of reference, the factors are listed hereunder in the same order as they are found in Table 2.2 above (from most to least prevalent):

1. Designers should make use of standardization (standard dimensions, units & structural grids) & modularization in design components (Baldwin, Poon *et al.*, 2009: 2072; Coventry & Guthrie, 1998: 14; Dainty & Brooke, 2004: 23; Domingo, Osmani & Price, 2009: 1025; Ekanayake & Ofori, 2004: 855; Esin & Cosgun, 2007: 1673; Keys, Baldwin & Austin, 2000: 8; Kharuffa, 2007: 2058; Lingard, Graham *et al.*, 1997: 205; Osmani, Glass & Price, 2008: 1150, 1151; Othman, 2011: 335; Poon, 2007: 1715; Rajput *et al.,* 2012: 71; Saez *et al.*, 2013: 54, 55; Sutrisna, 2012: 135; WRAP, 2009: 23; Wang, Li & Tam, 2014: 5; Yates, 2013: 289, 291, 294; Yuan, 2013b: 478).

2. Designers lack knowledge & experience with regards to constructability, materials & material specifications. Ambiguous, wrong, complex, over and under specification result in excessive material off-cuts, maintenance rework & variations. Design management, offering education & training might all be a viable solutions (Al-Hajj & Hamani, 2011: 221, 223, 228, 230; Begum *et al.*, 2007: 195, 196; Coventry & Guthrie, 1998: 12, 13; Dainty & Brooke, 2004: 21-23; Domingo, Osmani & Price, 2009: 1026; Ekanayake & Ofori, 2004: 855; Esin & Cosgun, 2007; Gauteng Provincial Government, 2009: 34; Keys, Baldwin & Austin, 2000; Lingard, Graham *et al.*, 1997: 205; Lu & Yuan, 2010: 204; Nagapan *et al.*, 2012; Oladiran, 2009: 168; Osmani, Glass & Price, 2008: 1149, 1151; Osmani, 2012: 38, 39; Othman, 2011: 335, 336, 340; Poon, 2007; Yeheyis *et al.*, 2013: 86).

3. Designers should specify off-site preparation, pre-assembly, prefabrication & precast components (i.e.; specify precast industrialized concrete components as opposed to wet works) (Al-Hajj & Hamani, 2011: 224; Baldwin, Poon *et al*., 2009: 2067; Begum *et al*., 2007: 200; Coventry & Guthrie, 1998: 12, 14; Dainty & Brooke, 2004: 24; Domingo, Osmani & Price, 2009: 1027; Keys, Baldwin & Austin, 2000: 8; Lu & Yuan, 2010: 202; Osmani, Glass & Price, 2008: 1150, 1151; Othman, 2011: 336; Poon, 2007: 1715; Saez *et al*., 2013: 54, 55; Sutrisna, 2012: 135; WRAP, 2009: 20; Wang, Li & Tam, 2014: 5; Yates, 2013: 291, 296; Yuan, 2013a: 103, 104; Yuan, 2013b: 477).

4. Designers should avoid frequent & last minute design changes, especially during construction phase (Adjei-Kumi & Zoya, 2011: 103; Baldwin, Poon *et al*., 2009: 2068; Dainty & Brooke, 2004: 22; Domingo, Osmani & Price, 2009: 1026; Ekanayake & Ofori, 2004: 855; Keys, Baldwin & Austin, 2000; Lingard, Graham *et al.*, 1997: 204; Lu & Yuan, 2010: 204, 208; Nagapan *et al*., 2012: 4-6; Osmani, Glass & Price, 2008: 1149; Osmani, 2012: 38, 39; Poon, 2007: 1715; Saez *et al*., 2013: 54; Sutrisna, 2012: 148; Wang, Li & Tam, 2014: 5; Yeheyis *et al*., 2013: 86; Yuan, 2013a: 103; Yuan, 2013b: 477, 482).

5. Designers should specify re-usable, reclaimed, salvaged or recycled materials (i.e.; recycled aggregates. In South Africa this can specifically refer to adding flyash (a cheap waste product of smelting plants) to the concrete to reduce the amount of OPC (Ordinary Portland Cement) used) (Al-Hajj & Hamani, 2011: 224, 232; Begum *et al*., 2007: 201; Coventry & Guthrie, 1998: 12; Gauteng Provincial Government, 2009: 34; Guthrie *et al*., 1997: 7; Keys, Baldwin & Austin, 2000: 8; Kharuffa, 2007: 2058; Lingard, Graham *et al*., 1997: 205; Lu & Yuan, 2010: 202; Milne, 2012: 20, 39; Osmani, Glass & Price, 2008: 1150; Othman, 2011: 338; Saez *et al.*, 2013: 54, 55; Sutrisna, 2012: 135; Yates, 2013: 288, 294, 293; Yeheyis *et al*., 2013; Yuan, 2013b).

6. Designers should communicate & co-ordinate efficiently and effectively with other consultants at the design stage. This includes dimensional co-ordination, optimization & co-ordinating with contractors. This particularly involves team problem-solving (Adjei-Kumi & Zoya, 2011: 103, 110; Baldwin, Poon *et al.,* 2009: 2072; Domingo, Osmani & Price, 2009: 1026, 1029; Keys, Baldwin & Austin, 2000: 8; Lu & Yuan, 2010: 206; Nagapan *et al*., 2012: 5; Osmani, Glass & Price, 2008: 1149; Osmani, 2012: 38, 39; Othman, 2011: 335, 339, 346; Poon, 2007; Saez *et al.*, 2013; Sutrisna, 2012: 148; WRAP, 2009).

7. Designers should supply adequate information on drawings and avoid lacking or incorrect design & detailing packages (Adjei-Kumi & Zoya, 2011: 103, 105; Coventry & Guthrie, 1998: 13; Dainty & Brooke, 2004: 21, 22; Domingo, Osmani & Price, 2009: 1026; Keys, Baldwin & Austin, 2000: 9; Lingard, Graham *et al.*, 1997: 204; Nagapan *et al.*, 2012: 5; Osmani, Glass & Price, 2008: 1149; Othman, 2011: 335; Poon, 2007: 1715; Sutrisna, 2012: 148; Yeheyis *et al*., 2013: 86).

8. Designers should design for future deconstruction & disassembly (Make use of life cycle assessments of materials; i.e.; although solid bricks are more expensive than perforated bricks, solid bricks have a higher chance of being re-used in the future. Minimise types and numbers of fasteners & connectors to ease future re-use) (Coventry & Guthrie, 1998: 12; Domingo, Osmani & Price, 2009: 1027; Esin & Cosgun, 2007: 1673; Gauteng Provincial Government, 2009: 34; Keys, Baldwin & Austin, 2000: 8; Kharuffa, 2007: 2053, 2058, 2059; Osmani, Glass & Price, 2008: 1150, 1151; Othman, 2011: 338; Saez *et al.*, 2013: 54, 55; WRAP, 2009: 18, 27; Yates, 2013: 289).

9. Designers should avoid over-designing as well as complex designs & detailing which result in excessive off-cuts (Coventry & Guthrie, 1998: 17; Domingo, Osmani & Price, 2009: 1026; Ekanayake & Ofori, 2004: 855; Keys, Baldwin & Austin, 2000: 8; Lingard, Graham *et al.*, 1997: 205; Nagapan *et al*., 2012: 5; Osmani, Glass & Price, 2008: 1149, 1150; Osmani, 2012: 38, 39; Othman, 2011: 336; Yates, 2013).

10. Designers should implement an organizational culture to waste in their businesses. This can for instance include a waste management report developed during the design stage which will be implemented by the contractor on site during construction. This can also include investing in waste sorting equipment and waste management staff (Dainty & Brooke, 2004: 23; Kharuffa, 2007: 2058; Milne, 2012: 25; Othman, 2011: 346; Rajput *et al*., 2012: 77; Saez *et al*., 2013: 52, 55; Wang, Li & Tam, 2014: 5; Yeheyis *et al*., 2014: 86; Yuan, 2013b: 477, 482).

11. Designers should avoid late drawing revisions & submittals which result in over-ordering of materials due to lack of information & time pressures on site (Adjei-Kumi & Zoya, 2011: 103; Domingo, Osmani & Price, 2009: 1026; Nagapan *et al*., 2012: 5; Oladiran, 2009: 168; Osmani, Glass & Price, 2008: 1149, 1150; Osmani, 2012; Poon, 2007).

12. Designers should be offered bonuses, rewards or economic incentives for curbing construction waste during the design stage (Begum, Coventry & Guthrie, 1998: 14; Kharuffa, 2007: 2061; Siwar *et al.*, 2007: 196; Sutrisna, 2012: 135; Wang, Li & Tam, 2014: 5; Yeheyis *et al*., 2013: 81; Yuan, 2013b: 477).

13. Designers should adopt low-waste modern technologies & systems (i.e.; innovative formwork & falsework (use large panel metal formworks), steel structures & drywalls, minimise use of temporary works) (Domingo, Osmani & Price, 2009: 1027; Lu & Yuan, 2010: 204, 206 & 208; Othman, 2011: 337; Poon, 2007: 1715; Wang, Li & Tam, 2014: 5; Yuan, 2013b: 477, 482).

14. Government legislation, taxation (landfill fees) & policies are lacking or compliance thereto is not enforced. If this was adequate landfilling & incineration of waste may be reduced (Al-Hajj & Hamani, 2011: 230; Esin & Cosgun, 2007: 1673; Osmani, 2012: 40; Yeheyis *et al*., 2014: 81; Yuan, 2013a: 102; Yuan, 2013b: 477, 482).

15. Designers should receive complete, unambiguous briefings & contract documentation from the client at the design stage (Adjei-Kumi & Zoya, 2011: 103; Domingo, Osmani & Price, 2009: 1026; Ekanayake & Ofori, 2004: 855; Nagapan *et al.*, 2012: 5; Yeheyis *et al*., 2013: 86).

16. Designers lack experience & knowledge with regards to method & sequence of construction which leads to alterations of work (Adjei-Kumi & Zoya, 2011: 103, 111; Ekanayake & Ofori, 2004: 855; Nagapan *et al.*, 2012: 5; Osmani, Glass & Price, 2008: 1149; Rajput *et al.*, 2012: 71).

17. Waste minimisation clauses should be embedded in contractual clauses. Alternatively; building approval departments can establish waste minimisation conditions in order for plans to be approved prior to construction (Dainty & Brooke, 2004: 23; Domingo, Osmani & Price, 2009: 1026; Gauteng Provincial Government, 2009: 34; Sutrisna, 2012: 148; WRAP, 2009: 24).

18. Designers should make use of adaptable & flexible project designs (Domingo, Osmani & Price, 2009: 1027; Milne, 2012: 131; WRAP, 2009; Yuan, 2013a: 104).

19. Designers should plan for soil remains (cut & fills) to be used in the same construction site or negotiate with neighbouring sites (Guthrie *et al.,* 1997: 22, 32; Saez *et al*., 2013: 55; Sutrisna, 2012: 148).

20. Designers should provide for an adequate space on the construction site where waste quantification, storing and sorting can take place (Saez *et al.*, 2013; Sutrisna, 2012: 149; Yuan, 2013b: 477, 482).

21. Designers should design space to be adequate & functional in order to prevent future alterations which result in waste (Esin & Cosgun, 2007: 1673; Guthrie *et al.*, 1997).

22. Designers should design in aid of minimizing temporary works (Coventry & Guthrie, 1998: 12; Keys, Baldwin & Austin, 2000).

23. Designers should implement BIM (Building Information Modelling) at the design stage. This will aid in virtually planning for construction materials in order to avoid, prevent or minimise waste (Sutrisna, 2012: 149; Yeheyis *et al*., 2014: 86).

24. Designers should take into account the accessibility of construction personnel on site (Othman, 2011: 336). This will allow labour workers adequate space in order to execute construction work adequately without the chance of rework which will result in construction waste.

25. Designers should facilitate for construction to be executed with ease during adverse weather conditions (Othman, 2011: 336).

26. Designers should make use of EIAs (Environmental impact assessments) during the design stage of the scheme in order to realize where waste reduction potentials are and how materials can be optimized (Dainty & Brooke, 2004: 24).

APPENDIX B

Introductory Letter in E-mail

Dear Colleague

I am conducting research regarding Construction Waste minimisation at the design stage of construction projects in Gauteng. Please spend 15 minutes of your time to complete the online survey questionnaire by clicking on the link below.

The questionnaire consists mainly of ranking factors that will minimise construction waste during the design phase.

I assure you that all data collected in this survey will be kept anonymous. Data will only be presented in a processed and anonymous format. Demographic data collected will only be used for the purposes of identifying subgroups (if needed) and will not be used to identify individuals.

Please click on the link to participate in the survey: (insert link)

Kind regards

Anine Eschberger Wortmann

Introductory Letter in E-mail (Reminder)

Please note that this is a reminder. If you have already completed the online survey we appreciate it and apologise for the inconvenience. The use of an intermediary survey software to assist in assuring anonymity means that I cannot resend to only those respondents who have not yet completed the survey.

Dear Colleague

I am conducting research regarding Construction Waste minimisation at the design stage of construction projects in Gauteng. Please spend 15 minutes of your time to complete the online survey questionnaire by clicking on the link below.

The questionnaire consists mainly of ranking factors that will minimise construction waste during the design phase.

I assure you that all data collected in this survey will be kept anonymous. Data will only be presented in a processed and anonymous format. Demographic data collected will only be used for the purposes of identifying subgroups (if needed) and will not be used to identify individuals.

Please click on the link to participate in the survey: (insert link)

Kind regards

Anine Eschberger Wortmann

Online Questionnaire Survey

Block 01 - Demographics

1. Dear Colleague

I am busy conducting research regarding Construction Waste. We are all aware that this is an increasing problem and that there are certain factors that can be implemented to either reduce or avoid Construction Waste. As part of this study I will be exploring critical factors in effective physical construction waste minimisation at the design phase of construction projects in Gauteng. These factors will also be explored in terms of ease of implementation.

You have been selected due to your knowledge with regards to green buildings in Gauteng.

I assure you that all data collected in this survey will be kept confidential and that the data will be kept securely. Data will only be presented in a processed and an anonymous format. Demographic data will only be utilized for the purpose of identifying different research subgroups (if needed) and will not be used in any way to identify individuals.

I appreciate your time. The research report emanating from this part of the study will be available at the end of the academic year and a follow-up e-mail with the online link to the report will be sent once the final thesis document is available on the University's website.

By completing & submitting this questionnaire, your participation in the research is assumed.

I hereby declare that any data collected will not be used for commercial purposes in which I may have a competitive advantage due to information collected.

Thank you

For any queries contact:

Anine Eschberger Wortmann
0701162P@students.wits.ac.za

Q1.1. I, the respondent in this questionnaire, hereby give approved consent that data I provide may be used in this study. Note: All responses are anonymous.

- Yes
- No

Q1.2. Have you attempted to minimise Construction Waste during the design stage of greenfield (undeveloped) projects in Gauteng?

- Yes
- No

Q1.3. Have these projects (in which you have attempted to minimise Construcion Waste in Gauteng) received Green Building Council of South Africa accreditation?

- Yes
- No

Q1.4. Which of the following best suits your role when having been in involved with Green Buildings in Gauteng?

- Architect
- Architectural Technologist
- Architectural Draughtsman
- Structural Engineer
- Structural Technologist
- Structural Draughtsman
- Sustainability Consultant (advise other professions in the built environment)

Q1.5. How many years of experience do you currently have with regards to working on Green Buildings in Gauteng?

- Less than a year
- 1-2 Years
- 2-3 Years
- 3-4 Years
- 4-5 Years
- 5 Years or more

Q1.6. Which of the following best suits your current level of education?

- Secondary (High School)
- Tertiary Certificate
- National Diploma
- Bachelor's Degree
- Honours Degree
- Masters Degree
- Doctoral Degree

Block 02 - Factors

2. Please rank the following Construction Waste Minimisation factors in terms of Significance & Ease of Implementation in a Gauteng region

Q2.1. Designers should make use of standardization (standard dimensions, units & structural grids) & modularization in design components.

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.2. Designers lack knowledge & experience with regards to constructability, materials & material specifications.

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.3. Designers should specify off-site preparation, pre-assembly, prefabrication & precast components

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.4. Designers should avoid frequent & last minute design changes, especially during construction phase.

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.5. Designers should specify re-usable, reclaimed, salvaged or recycled materials

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.6. Designers should communicate & co-ordinate efficiently and effectively with other consultants at the design stage

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.7. Designers should supply adequate information on drawings and avoid lacking or incorrect design & detailing packages

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.8. Designers should design for future deconstruction & disassembly

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.9. Designers should avoid over-designing as well as complex designs & detailing which result in excessive off-cuts.

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.10. Designers should implement an organizational culture to waste in their businesses. This can for instance include a waste management report developed during the design stage which will be implemented by the contractor on site during construction.

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.11. Designers should avoid late drawing revisions & submittals which result in over-ordering of materials

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.12. Designers should be offered bonuses, rewards or economic incentives for curbing construction waste

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.13. Designers should adopt low-waste modern technologies & systems

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.14. Government legislation, taxation (landfill fees) & policies are lacking or compliance thereto is not enforced

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.15. Designers should receive complete, unambiguous briefings & contract documentation from the client at the design stage

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.16. Designers lack experience & knowledge with regards to method & sequence of construction

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.17. Waste minimisation clauses should be embedded in contractual clauses.

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.18. Designers should make use of adaptable & flexible project designs.

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.19. Designers should plan for soil remains (cut & fills) to be used in the same construction site or negotiate with neighbouring sites.

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.20. Designers should provide for an adequate space on the construction site where waste quantification, storing and sorting can take place.

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.21. Designers should design space to be adequate & functional in order to prevent future alterations which result in waste.

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.22. Designers should design in aid of minimizing temporary works.

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.23. Designers should implement BIM (Building Information Modelling) at the design stage.

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.24. Designers should take into account the accessibility of construction personnel on site.

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.25. Designers should facilitate for construction to be executed with ease during adverse weather conditions.

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Q2.26. Designers should make use of EIAs (Environmental impact assessments) during the design stage of the scheme in order to realize where waste reduction potentials are and how materials can be optimized.

	Extremely Significant or Easy to Implement	Important or Easy to Implement	Neutral	Unimportant or Difficult to Implement	Negligible or Impossible
Significance in Gauteng					
Ease of Implementation in Gauteng					

Block 03 - Additional Factors

Q3. Please list any other factors that will minimise construction waste during the design stage in the Gauteng region which are not listed above.

Block 04 - Thank you

4. Thank you for participating in this survey - it is appreciated!

For any queries or further information, please contact:

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APPENDIX C

Previous study's data analysis methods - Calculating means of Likert Scale data - Precedent 01

Table I Ranking of waste measures identified

Rank	Potential waste measure	Implementation	Impact	Average
1	Supply chain alliances with suppliers/recycling companies	3.6	3.9	3.8
2	Increased off-site prefabrication to control waste and damage	3.5	3.9	3.7
3	Standardisation of design to improve buildability and reduce the quantity of off-cuts	3.3	4.0	3.7
4	Stock control measures to avoid the over ordering of materials	3.6	3.4	3.5
5	Improved education of the workforce	3.4	3.5	3.5
6	Provision of waste skips for specific materials	3.4	3.5	3.5
7	Just-in-time delivery strategy	3.2	3.6	3.4
8	Dedicated site team or specialist sub-contract package for on-site waste management	2.9	3.7	3.3
9	Contractual clauses to penalise for poor waste performance	3.0	3.3	3.2
10	Design management to prevent the over specification of materials	3.2	3.1	3.2
11	Additional tender premiums where waste initiatives are to be implemented	3.3	3.0	3.2
12	Waste auditing to monitor and record environmental performance on-site	3.3	2.9	3.1
13	On-site materials compactors	3.2	2.9	3.1
14	Educate clients about measures to reduce waste levels	2.7	2.9	2.8
15	Supplier flexibility in providing small quantities of materials	2.5	2.9	2.7
16	Environmental impact assessments of the scheme during the design phase	2.8	2.5	2.7

Table 6.1: Dainty, A.R.J & Brooke, R.J., 2004. Assessment of Waste management measures identified.

In: Dainty, A.R.J. & Brooke, R.J., 2004. *Towards improved construction waste minimisation: a need for improved supply chain integration?* Structural Survey, [e-journal] 22(1)(20-29).
Available through: University of the Witwatersrand Library Website <http://www.wits.ac.za/library>
[Accessed 13 March 2014]

Previous study's data analysis methods - Calculating means of Likert Scale data - Precedent 02

Survey results on mean importance ratings and hypothesis testing.

Variables	U	Rank	S	t value	Sig
Architectural technologies					
Large panel metal formworks	3.326	6	1.034	2.920	*
Steel scaffolding	3.023	19	1.029	0.210	
Metal hoarding	3.140	9	0.935	1.384	
Prefabricated components	3.767	1	1.037	6.865	*
Architectural design					
Design for hanging cradles	3.047	16	1.217	0.355	
Design for thinner internal walls and floor slabs	3.070	13	1.309	0.494	
Fewer Design modifications	3.512	3	1.003	4.731	*
Design for recycled materials such as recycled aggregates	3.093	12	1.343	0.642	
Modular design	3.419	5	0.901	4.311	*
External mechanism					
Construction waste regulation	3.116	11	0.975	1.106	
Waste reduction investment	3.535	2	1.048	4.732	*
Market-stimulating system	3.058	15	0.925	0.583	
Regulation implement supervision	3.070	14	0.837	0.773	
Designer's capacity					
Educational background	3.151	8	1.203	1.165	
Work experience	3.163	7	1.105	1.367	
Designer's behavior and attitude					
Environmental awareness	3.035	17	1.034	0.313	
Design strategy training	3.140	10	1.031	1.255	
Economic incentive	3.442	4	1.069	3.832	*
Waste minimization culture within institution	3.035	18	0.846	0.382	

* t-Value is larger than $t_{(85,0.05)}$, which is 1.6627.

Table 6.2: Wang, J., Li, Z. and Tam, V.W.Y., 2014. Survey results on mean importance ratings and hypothesis testing.

In: Wang, J., Li, Z. and Tam, V.W.Y., 2014. *Critical factors in effective construction waste minimization at the design stage: A Shenzhen case study, China*. Resources, Conservation and Recycling, [e-journal] 82(1-7). Available through: University of the Witwatersrand Library Website <http://www.wits.ac.za/library> [Accessed 31 January 2014]