Development of Frameworks for the Management of Materials Procurement and Construction Waste for Nigerian Contractors

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By

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Declaration

The thesis or any part thereof has not been submitted elsewhere for any other degree at any university or place of learning or award for any other candidate. Where other scholars' works are cited in the thesis, they are acknowledged and referenced. I hereby declare that the intellectual content of the work is the result of my own independent investigation and efforts and no other person, and the thesis is submitted in partial fulfilment of the degree of Doctor of Philosophy on the requirements of the University of the West of England, Bristol

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Abstract

Construction is one of the industries that contributes the largest waste on the environment, resulting in pollution and high cost of projects. The industry is faced with waste management challenges undermining its quest for sustainable development. Nigeria is a developing country that needs urgent waste management solutions in construction. Meanwhile, construction waste management practices in the industry are still inefficient, insufficient and poorly organised. However, there is a dearth of literature that provides frameworks to help contractors manage waste effectively. Further, despite that waste can be generated in all construction activities, the existing literature is mainly concerned with providing waste management solutions unilaterally, particularly in the design or construction stage. There is increasing awareness that effort should be made to consider waste management in multiple stages, particularly those with limited attention. Therefore, this study investigates the relevant materials procurement and construction criteria for effective waste management and evaluates the relative priorities of the attributes in contributing to waste minimisation. A quantitative research approach was adopted to achieve the research aim. A comprehensive literature review was used to generate four potential materials procurement criteria, including top management support for procurement, procurement clause, low waste purchase management, and efficient delivery management. Also, top management support in construction, construction clause, site waste management plan and low waste technique were identified as criteria for effective waste management in the construction stage. Additionally, twenty–two attributes were identified and clustered under the materials procurement and construction criteria, respectively. Then, experienced academic experts in construction verified their relevance and suitability in a survey. A questionnaire was designed, pilot–tested and subsequently distributed to experienced construction practitioners in Nigeria through an online platform. The quantitative survey data were analysed using Voting Analytical Hierarchy Process (VAHP) to determine the importance of the criteria and related attributes based on priority weights.

The results of the local weights of the attributes revealed that accurate materials quantification, a take–back clause in suppliers' agreement document, alliance with suppliers and just–in–time delivery of materials is the most important for effective waste management in materials procurement activities. At the same time, senior managers' early commitment to waste minimisation, identifying recyclable materials, adopting prefabricated building components and making subcontractors responsible for their waste are the most important in the construction stage. Further, frameworks to assist Nigerian contractors in managing waste effectively in the materials procurement and construction stages were developed, drawing on the global weights of the attributes and the multi–criteria decision–making concept. The frameworks provided actions that contractors can take to implement effective waste management upon incorporating the criteria in their waste management practices and considering the attributes priorities categorised as high, medium and low. The study, therefore, concludes that positive relationships and cooperation between contractors, subcontractors and suppliers is a requisite for effective waste management in the Nigerian construction industry. This research has contributed to the existing body of knowledge by establishing integrated key criteria that can be adopted to implement effective waste management in materials procurement and construction stages. By recognising the waste management priorities and implementing the actions suggested in the frameworks, Nigerian contractors can substantially minimise waste due to ineffective and unorganised materials procurement and construction activities in collaboration with suppliers and subcontractors. Considering the current waste management challenges confronting the Nigerian construction industry, the study recommends partnership and commitment between contractors, subcontractors and materials suppliers and a top–down management approach for effective waste management in the industry.

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Dedication

To my late mother, Mrs Josephine Chidiobi

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List of Abbreviations

AHP	Analytical Hierarchy Process
BSI	British Standards Institution
BIM	Building Information Modelling
CE	Circular Economy
C&DW	Construction and Demolition Waste
CPIM	Construction Process Improvement Methodology
CBA	Cost–Benefit Analysis
DRIVE	Define, Review, Identify, Verify and Execute
GIS	Geographic Information System
GDP	Gross Domestic Product
IRP	Incentive Reward Program
LCA	Life Cycle Assessment
LE	Linear Economy
MCDA	Multi–Criteria Decision Analysis
MCDM	Multiple–Criteria Decision Making
MSW	Municipal Solid Waste
SWMP	Site Waste Management Plan
SSA	Sub–Saharan Africa
UN	United Nations
VAHP	Voting Analytical Hierarchy Process
WRAP	Waste and Resources Action Programme

CHAPTER 1: INTRODUCTION

1.1. Background to the Research

Waste of material resources has continued to rise globally, with enormous impacts on the natural environment. A World Bank (2018) report estimated that municipal solid waste (MSW) generation may increase up to 70% by 2050 from 2 billion tonnes in 2016 to 3.40 billion annually due to the increasing population and developmental activities. Disposal of waste to landfill is increasing in many parts of the world, but this is most notable in the developing countries of Sub–Saharan Africa (SSA) (World Bank, 2018).

Unsustainable waste management is amongst the current issues confronting the global community. Without adequate actions for waste minimisation, air and water pollution (Brundtland,1987), flooding (Lamond *et al.,* 2012), energy consumption, land occupation, and harmful gas emissions (Ding *et al.,* 2016) will continue to harm ecosystems. Therefore, there is a need to preserve natural resources through sustainable waste management practices (UNEP, 2015). Such needs require appropriate actions from organisations and countries, particularly in the construction industry that has become a significant waste producer. Confronted by this challenge, the global construction industry is under increasing pressure to contribute to resource–saving through effective and sustainable waste management (Duan *et al*., 2019).

Waste from the construction sector contributes towards solid waste generation and highlights management concerns (UNEP, 2015). Although the industry is hugely important to the economic and social development of many nations (Ofori, 1994; Wang, 2014), it remains one of the world's largest natural resources consumers (World Economic Forum, 2016). Despite widespread efforts, the construction industry exhibits high waste volumes compared to many other industries (Lu *et al.,* 2011; Villoria–Sáez *et al.,* 2011). Evidence indicates that more than 10 billion tonnes of construction and demolition waste (C&DW) are produced worldwide yearly (Wu *et al.,* 2019). This value accounts for about 40% of global solid waste outputs circulating in the society (Esa *et al.,* 2017), much of which is avoidable or salvageable. For instance, large proportions of materials are often wasted in construction projects, and the destination of much C&DW in many countries is disposal (Nagapan *et al*., 2012c; Wang *et al.,* 2021).

Although data is not prepared consistently across nations, indicative values of construction waste generation worldwide are vast. For instance, India is suggested (in 2016) to generate between 112 to 431 million tonnes of construction waste (Jain *et al.,* 2018). Hong Kong generated approximately 22 million tonnes in 2015; with 11% disposed in landfills and 89% used in–filling public areas (Jaillon *et al.,* 2009). The United States Environment Protection Agency (2020) indicates the USA generated 600 million tonnes of C&DW in 2018, which is more than twice the generated MSW. In the UK, waste from the construction industry accounts for 62% of national waste generated (DEFRA, 2020). However, the UK recovery rate is above 70% of the European 2020 minimum target (DEFRA, 2020). Sadly, many low and middle–income countries have not reported similar successes. For instance, Huang *et al*. (2018) show that about 30 to 40% of the total waste produced in China emanates from the construction industry, with an average recovery rate as low as 5%. Elsewhere, in Ondo State, Nigeria, more than 78% of construction waste is indiscriminately disposed or burnt (Adedeji *et al.,* 2013).

While construction waste rate is rising globally, low and middle–income countries' recovery rate is lower than their high–income counterparts (Abarca–Guerrero *et al.,* 2017). Despite this limitation, there is a paucity of research on waste management solutions in low–income countries (Lu and Yuan, 2011; Manowong, 2012). Some scholars suggest that waste from the construction industry has become a more severe issue in these countries (Manowong, 2012; Abarca–Guerrero *et al.,* 2017). This evidence shows that developing countries are slow in moving towards effective and sustainable waste management in the construction sectors. There is a concern that nations may run out of landfill space amidst the increasing population, urbanisation and poor urban planning (Manowong, 2012).

The life cycle of construction materials impacts the environment from extraction to disposal (Craighill and Powell, 1996). Therefore, sustainable waste management cannot be ignored in construction due to the increasing globalisation and continued demands for natural resources. Sustainability became a watchword after the Brundtland Commission in 1987, demanding sustainable conduct at individual, organisational, national, regional and global levels. Hence, waste management is an integral part of the overall sustainable construction that seeks to meet the need of the current infrastructural development without compromising future demand for natural resources. According to Sev (2009), waste minimisation is one strategy that the construction industry can adopt to contribute towards sustainable development. However, insights suggest waste management has not been given adequate attention in the construction industry, compared to other priorities such as time and cost (Begum *et al.,* 2009). Waste management is at the bottom of the priority list in project decision–making in many countries (Teo and Loosemore, 2001).

Construction waste contributes significantly to Nigeria's growing MSW management problems. Over the last decade, Nigeria has witnessed enormous population growth and, with it, a concomitant expansion in construction activities, particularly building development. Due to these activities, there is a growing environmental concern that waste is littered in many urban areas. Regrettably, there is evidence that waste management is among Nigerian authorities' least priorities (Nkwocha and Okeoma, 2009; Gani and Okojie, 2013). Although national environmental policies deal with solid waste management in Nigeria, their effectiveness is low (Maiyaki *et al.,* 2019). Some limitations include a lack of monitoring and enforcement of the existing regulations (Ayotamuno and Gobo, 2004; Ike *et al.,* 2018). Consequently, there has been a high waste generation rate in the Nigerian construction industry (Afolabi *et al.,* 2018). Further, the poor performance of waste management within the industry makes disposal the commonplace treatment option (Ogunmakinde *et al.,* 2019). Therefore, it is important that Nigerian construction contractors look inward to improve the waste management practices across the industry by adopting and implementing actionable solutions. Adapting a framework with action–oriented techniques to effective waste management can help them achieve waste management objectives for sustainable development.

This study adopts the Multiple–Criteria Decision Making (MCDM) concept as a method that can be used to solve waste management problems (Morrissey and Browne, 2004; Soltani *et al.,* 2015). The method enables the computation of the decision of different interest groups, demonstrating their waste management priorities in decision–making. According to Erol *et al.* (2014), MCDM techniques allow decision–makers to learn about a problem, organisational priorities, and develop objectives to guide them in identifying preferred courses of action. The Voting Analytical Hierarchical Process (VAHP) is chosen as the MCDM tool to develop the proposed frameworks in this research.

1.2. Problem Statement

The Nigerian construction industry contributes significantly to the economic development of the nation. Over the last few years, the industry has outgrown most other local economic sectors (Nigerian National Bureau of Statistics, 2019). The industry serves as an important sector for reducing unemployment and providing the necessary infrastructure to meet the social and economic needs of the people. However, due to the waste of construction materials in projects and their indiscriminate disposal, the industry is considered underperforming in its environmental and waste management (Afolabi *et al.,* 2018).

Currently, Nigeria is the most populous nation in Africa and more construction and civil engineering developments, such as buildings and infrastructure to accommodate the growing population and urban migration, are foreseeable. According to Global Construction (2015), the Nigerian construction market will grow by 160% by 2030, which can add up to US$100bn to the industry's output. This possible growth would result in an upsurge in building and infrastructure developments. However, not all materials supplied on building sites are used during construction, many are wasted and/or unaccounted for (Akinkurolere and Franklin 2005). Consequently, previous studies have expressed concerns about the huge amounts of waste generated in the Nigerian construction sectors and have called for actions towards minimisation (Odusami *et al.,* 2012; Oko and Itodo, 2013; Aiyetan and Smallwood, 2013; Adewuyi *et al.,* 2014; Idris *et al.,* 2015; Aboginije *et al.*, 2021).

Managing waste in the construction industry requires the collaboration of relevant stakeholders such as constructors, subcontractors and suppliers (Dainty and Brooke, 2004). Further, more attention should be given to waste management as one of the key indicators of sustainable development. However, several impediments are militating successful waste management in the Nigerian construction industry. For instance, there is currently no government legislation, particularly for addressing construction waste issues in Nigeria (Adeagbo *et al.,* 2016). In addition, inadequate waste management policies (Nwokoro and Onukwube, 2015; Adeagbo *et al*., 2016) and a lack of consideration of sustainability principles in building construction (Dania *et al.,* 2013), particularly by local construction firms (Dania *et al.,* 2014), have been cited as limitations. Further, while there is a growing need to improve waste management culture in the construction industry (Wong and Yip, 2004; Ajayi *et al.,* 2016a), there is a lack of stakeholder interest in contributing towards effective waste management in Nigeria because of the complexity (Adewuyi and Odesola, 2015). Also, contractor's lack adequate knowledge about waste management strategies (Aboginije *et al.,* 2021), means a lack of waste segregation (Wahab and Lawal, 2011) and poor supervision (Ameh and Itodo, 2013).

Sustainable construction depends on how well the industry manages its waste generation (Sev, 2009). Effective waste management in the industry requires a good understanding of the requisite criteria and methods. However, waste management knowledge amongst Nigerian construction practitioners is limited. Hence, limited knowledge of waste management strategies and how they can be implemented exists (Aderibigbe *et al.,* 2017). Compounding this problem is the perceived lack of consensus of what should be understood as key criteria for effective waste management in the industry due to a lack of collaboration (Oladiran *et al.,* 2019).

Up to 21–30% of a project cost overrun in Nigeria is attributed to materials waste (Oko and Itodo, 2013). The rate of materials wastage in the industry incurs significant cost overruns and usually outweighs the recovery rate (Saidu and Shakantu, 2017). Also, additional costs to projects due to waste of materials often impairs clients' and contractors' partnerships in Nigeria, limiting contractors' chances of winning further projects (Aiyetan and Smallwood, 2013). Besides the environmental and social implications, cost overrun due to waste is usually undesirable to contractors or clients responsible for additional costs.

Aboginije *et al.* (2021) recommend upgrading the approaches and methods of application of waste management strategies to deal with some of these problems. Successful waste management requires identifying and integrating criteria or factors on which assessment of successful waste management should be based. Therefore, there is a need to investigate waste management criteria and how defining the attributes' priorities in a framework can help contractors plan and make the appropriate decision to implement effective waste management. Findings from this research can help increase construction professionals' awareness of the important criteria required to assess the success or failure of waste management at the company and project levels. Also, the study can enable and enhance construction waste reduction, reuse, and recycling, by discouraging disposal for the environmental, social, and economic benefits.

1.3. The Knowledge Gap

Comparatively few studies have focused on construction waste management for Nigeria, and several research gaps exist in the current literature. The existing studies have mainly concentrated on the causes of waste generation (Wahab and Lawal, 2011; OKo and Itodo, 2013; Aiyetan and Smallwood, 2013; Adewuyi *et al.,* 2014; Idris *et al.,* 2015; Adeagbo *et al.,* 2016), while the possible solutions, in the form of frameworks, are limited (Oladiran *et al.,* 2019). However, this study recognised the contributions of two studies that created frameworks for waste management in the construction industry. Oladiran *et al.* (2019) developed a framework for materials waste minimisation on Nigerian building projects using define, review, identify, verify and execute (DRIVE) and construction process improvement methodology (CPIM) techniques. In addition, Ogunmakinde (2019) developed a waste minimisation framework based on the circular economy (CE) concept. While these studies have made significant contributions to knowledge, framework based on a multicriteria decision–making method for waste management (Hung *et al.,* 2007; Coronado *et al.,* 2011; Coban *et al.,* 2018) has not been developed for Nigerian construction contractors. Developing such a framework can allow construction contractors to explicitly structure waste management solutions and evaluate multiple criteria to understand stakeholders' priorities for planning and facilitating effective waste management in their companies. However, the frameworks developed in previous studies does not allow contractors to identify, select and incorporate necessary criteria for managing construction waste regarding multiple stakeholders' priorities.

The VAHP, a simplified Analytic hierarchy process (AHP) method (Saaty, 1980) has an important feature for quantifying the objective or subjective judgements made by decision–makers by assigning corresponding mathematical values to issues under consideration regards to their relative priority weights (Liu and Hai, 2005). Therefore, none of these studies had tried to unveil the possibility of the MCDM models, particularly the VAHP model, in providing construction waste management solutions for Nigeria.

There is limited knowledge of the important criteria for assessing successful waste management, the key attributes and actions to enable effective waste management in the industry. Therefore, current studies on Nigeria construction waste management have failed to provide contractors with comprehensive and straightforward management frameworks that incorporate key criteria to direct waste management operations. These limitations justify the need to identify and integrate waste management criteria in a framework applicable to construction companies.

Further, previous studies have noted the impact of materials procurement activities on waste generation; however, this important aspect of the construction delivery process has received less attention in waste management research compared to design and construction stages (Ajayi *et al.,* 2017b). Also, most literature in construction waste management is concerned with managing waste at the construction stage (Lu and Yuan, 2011). However, rather than focusing solely on one stage, there is increasing awareness that effort should be made to consider waste management in multiple stages (Ekanayake and Ofori, 2004), particularly those with limited attention, such as materials procurement. Moreover, managing waste in these important construction activities needs to be more comprehensive; therefore, adequate information should be provided to contractors for better waste management. Without adequate knowledge of criteria for managing waste during materials procurement and construction activities and the realisation of the attributes' priorities, Nigerian contractors would continue to face waste management challenges, thus, leaving a significant research gap that needs to be filled.

This research sets out to address these gaps by investigating what constitutes the criteria for determinants of successful waste management in the materials procurement and construction activities and defining the priorities of the attributes according to practitioners' perceptions. This will aid the development of the proposed frameworks to enable contractors to identify and select criteria they need to incorporate into their waste management practices.

Meanwhile, MCDM has not been tested as a construction waste minimisation strategy in Nigeria, even though it has been shown to be an effective technique for reducing MSW. Thus, by involving multiple stakeholders whose actions or inaction can result in waste generation and analysing their priorities, the poor culture of waste management in the industry can be tackled. Accordingly, to fill these gaps, the research intends to answer the following questions.

1.4. Research Questions

1. Considering materials procurement and construction activities, what are the key criteria and attributes that can influence effective waste management in the construction industry?
2. What are the relative weights/priorities of the attributes?
3. How can contractors implement the attributes in each criterion to minimise waste in their materials procurement and construction activities?

1.5. Aim

This research aims to develop frameworks for the management of materials procurement and construction waste for Nigerian construction contractors. The frameworks will support contractors to identify, select and incorporate key criteria in their waste management practices to minimise waste in their materials procurement and construction stages. The following objectives will be followed to achieve the aim.

1.5.1. Objectives

1. To review the extent literature and understand the current state of the art in waste management in the construction industry.
2. To identify criteria and attributes factors that influence waste management in materials procurement and construction activities.
3. To undertake a comprehensive review of literature on waste management decision–making models and understand the concept of MCDM for the development of the proposed frameworks.
4. To gauge stakeholder opinions on materials procurement and construction waste management in Nigeria.

5. To conduct a computational analysis of stakeholder survey responses and establish waste management criteria and related attributes' priority weights.
6. To Develop and validate frameworks for the management of materials procurement and construction waste for Nigerian construction contractors.

1.6. Overview of the Research Approach

Literature reviews and questionnaire surveys are used to fulfil the first research objectives, and follow-up interviews are adopted to validate the proposed frameworks.

The literature review is used to retrieve existing information on construction waste management studies and decision–making models to achieve objectives one, two and three, respectively. Therefore, the fundamental waste management criteria, attributes and other information relevant for achieving the above objectives were documented. Further, selected Nigerian academic construction experts were consulted to confirm the criteria and attributes identified. Then a structured online questionnaire survey (after piloting) was shared with Nigerian-based industry practitioners to gauge their opinions on materials procurement and construction waste management (Objective four). VAHP computational analysis was applied to the survey responses to establish the criteria and related attributes priority weights (Objective five). Finally, the findings are used to aid the development of two frameworks using the basic MCDM concept. Further, the research results were subjected to validation to assess the usability in Nigerian construction companies. The validation was to inquire about the practitioners' view of the framework's contents, including the criteria, attributes and priorities, and the proposed actions for effective waste management. The validation strengthens the study's overall outcome by considering practitioners' viewpoints on the above issues (Objective six). Finally, conclusions and recommendations are presented (Objective seven). Figure 1.1 shows the overall research design and structure of the study.

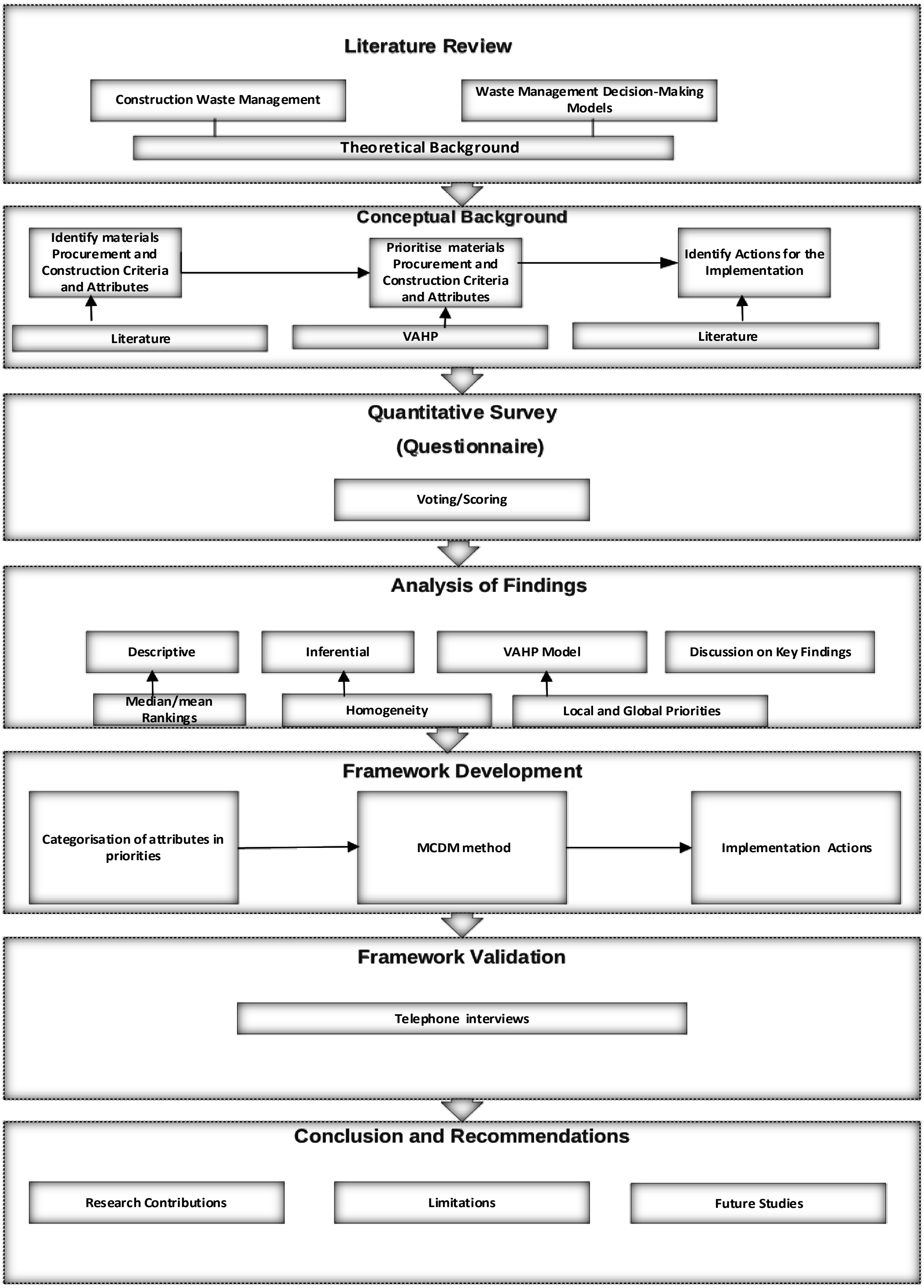

Figure 1.1: Research design and structure of the study.

1.7. Research Scope

This thesis reflects upon construction waste generation to pursue solutions for waste minimisation in materials procurement and construction activities. The following boundaries are defined to narrow the study for a logical conclusion.

Construction projects are categorised as buildings and other infrastructure facilities. Other infrastructure facilities may include roads, railways, airports, seaports, dams, highways, and bridges. This study focuses on building construction due to the increasing housing development in Nigerian cities such as Abuja, Lagos (Obia, 2016) and others. The research can be applied to residential, commercial and institutional buildings, provided contractors can identify and incorporate the criteria necessary to improve their waste management practices. Also, it can be adapted by a variety of construction organisations, from small to large enterprises.

Ekanayake and Ofori (2000) classified construction waste into three main types – waste of time, machinery, and materials. The study is intended to help minimise materials waste due to the obvious environmental impacts in Nigeria (Ogunmakinde, 2019). Therefore, in this study, 'waste' can be defined as tangible materials procured and intended for use in building projects, but are not fit for purpose, damaged, or was not used due to overordering and cannot be returned to suppliers. Therefore, waste of materials due to overuse of materials in projects is excluded in this study.

Construction waste management research is usually considered in project stages to help the audience understand the scope (Lu and Yuan, 2011). This study covers the materials procurement and construction stages due to the traditional procurement dominance in the Nigerian construction sector (Oladirin *et al.,* 2013). Hence, contractors who do not have direct involvement in projects design can improve waste management by collaborating with subcontractors and suppliers to help reduce waste output in the industry. While government intervention is important to waste minimisation in construction, the study mainly covers internal stakeholders (contractors, subcontractors and suppliers) interventions for effective waste management because of their direct involvement in construction activities. Data for the study were retrieved from the global and relevant construction waste management literature. Although data collection was targeted at construction practitioners across Nigeria, those in Abuja, Port–Harcourt, and Lagos were particularly targeted to represent three major cities in Nigeria with significant construction activities.

1.8. Significance of the Study

As an empirical contribution, this research provides insight into how to improve waste management by identifying key criteria determinants for effective waste management in materials procurement and construction activities. The results will demonstrate the priorities that most practitioners attach to waste management strategies to help contractors implement actions to minimise waste by focusing on good waste management practices. In that regard, contractors can consider incorporating vital criteria in their waste management objectives to improve practices. Also, practitioners can learn about waste management problems to guide decision–making and course of action at company or projects levels. Thus, to drive the idea of (reduce reuse and recycle) agenda in the industry using the VAHP–MCDM method, novel for construction waste management in Nigeria. The study will be valuable for future studies and contribute to construction waste management solutions in developing countries, particularly in the SSA region, where waste management solutions are underdeveloped.

1.9. Organisation of Chapters

This thesis consists of 8 chapters, spanning from the introduction to the conclusion. The organisation of the chapters is presented in Figure 1.2, which also demonstrates how the study objectives accord with the organisation of the thesis chapters.

Chapter 1: Presented the research background and highlights a need for the current research and its justifications. It presented the research questions, aim and objectives, an overview of the study's methods, scope, and significance.

Chapter 2: The chapter highlights the overview of the construction industry. It provides a general background to construction waste management, such as causes of waste generation, the impacts, and the existing management strategies and others. Finally, an overview of the Nigerian construction industry and its solid waste management challenges alongside the stakeholders' roles towards effective waste management are presented.

Chapter 3: The chapter discussed frameworks for effective construction waste management strategies. Accordingly, a framework is generated showing the position of the current research in the construction waste management literature. Further, as the conceptual background of the study, key criteria and attributes influencing effective materials procurement and construction waste management were identified. Therefore, the chapter presented the research conceptual framework to guide its development.

Chapter 4: This chapter presents a comprehensive literature review of waste management decision–making models to reveal their basic applications, strengths, and limitations. Further, it discussed the suitability of the VAHP technique for the data analysis and the basic concept of MCDM to develop the proposed frameworks.

Chapter 5: The chapter provides a detailed methodological outline for achieving the research objectives. It presents the justification for choosing a quantitative survey as the research design and the VAHP computational analysis.

Chapter 6: Presents the research data analysis: the Kendal coefficient of concordance and Kruskal Wallis (H) test results. Further, it presents the VAHP results based on the participants' ranking of the criteria and the attributes. Finally, the chapter discussed the research key findings; thus, the materials procurement and construction criteria alongside their highest–ranked attributes.

Chapter 7: Presents the proposed frameworks: developed based on the basic MCDM model mentioned earlier. From the survey findings and the literature review, the criteria' attributes are prioritised, and actions for effective waste management are provided. Also, the chapter presents the outcome of the validation of the frameworks' contents using the results of the telephone interviews.

Chapter 8: This chapter provides the research conclusions, including the objectives and practical and theoretical contributions to knowledge. Also, the research limitations and several recommendations for future research were highlighted.

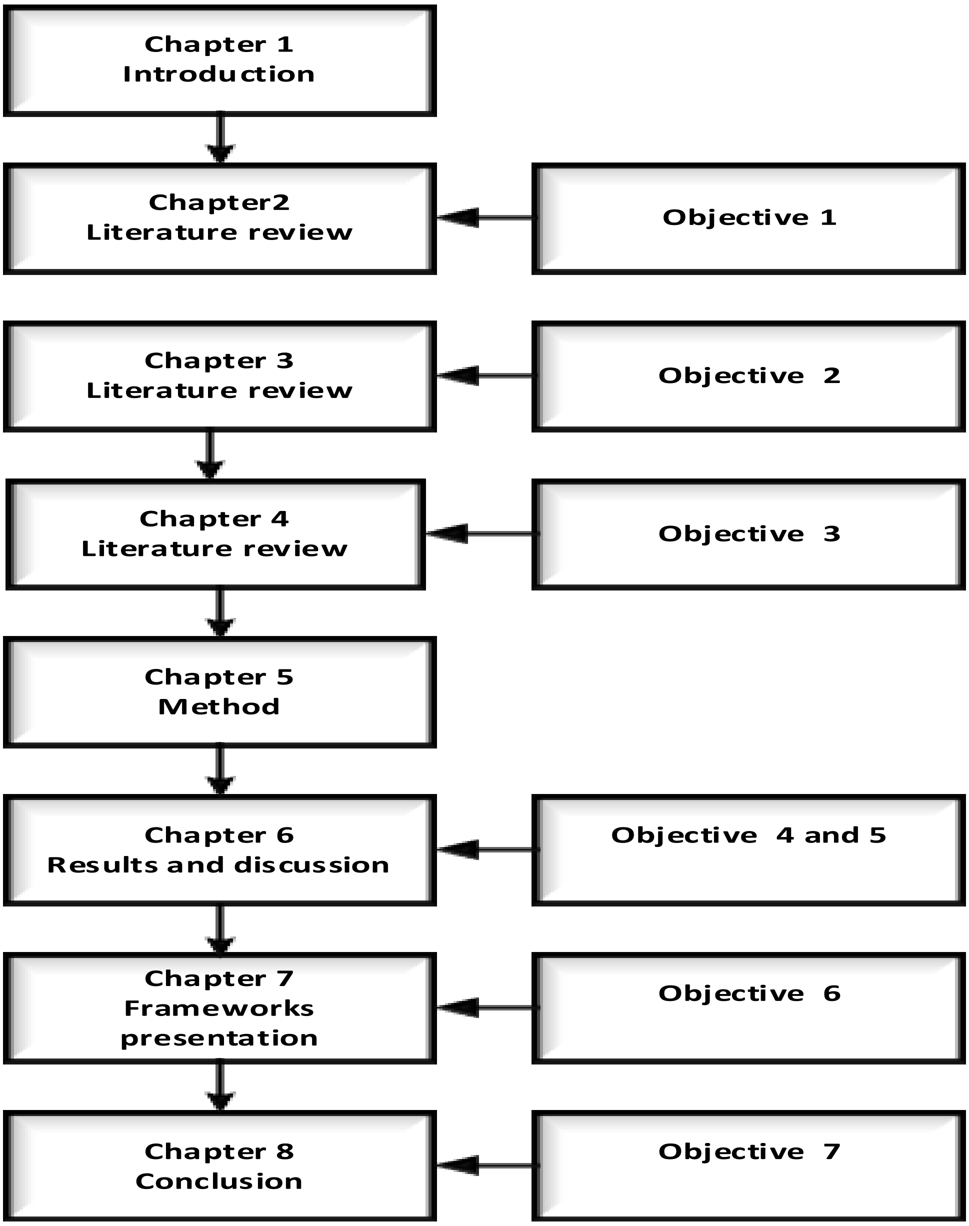

Figure 1.2: Organisation of the thesis chapters and their alignment with the study objectives.

1.10. Chapter Summary

This chapter has emphasised that solid waste, particularly construction waste generation, is a global issue with environmental, economic, and social impacts. It has highlighted problems of waste management in the Nigerian construction industry and exposed a need to minimise waste in materials procurement and construction activities through a decision–making tool. Further, it has stated the research questions, aim and objectives of the study, and provided an overview of the research design and thesis structure. The next chapter presents an overview of construction waste management as part of the study's theoretical background.

CHAPTER 2: OVERVIEW OF CONSTRUCTION WASTE MANAGEMENT

2.1. Introduction

This chapter begins with a general overview of the construction industry, definitions of waste and concept of construction waste, causes and sources of construction waste, and management strategies. In addition, the chapter presents some frameworks developed by the previous studies by summarising their key objectives. Finally, an overview of the Nigerian construction industry, its waste management challenges, and the stakeholder roles for sustainable waste management are revealed.

2.2. Overview of the Construction Industry

The construction industry is an important sector for nations' economic and social development. The global construction industry contributes up to $10 trillion to the economy, accounting for 13% of gross domestic product (GDP) and employing about 7% of the world population (Lingard, 2013; Barbosa *et al.,* 2017). This amount is predicted to rise to a total of $14 trillion by 2025 (Barbosa *et al.,* 2017). As of 2019, in the UK alone, the sector contributed £117 billion to the national economy, which equates to 6% of total economic output (Rhodes, 2019). The industry provides both building and civil infrastructure such as housing, railways, airports, and roads, amongst others; thereby, in doing so, it stimulates other economic activities fundamental to innovation. The industry's importance has led many scholars to propose several reforms to make it more environmentally sustainable and economically viable. For instance, Egan (1998) proposed '*Rethinking Construction*' to improve the efficiency and performance of the UK construction industry for client and public satisfaction. Hence, the paradigm shifts from traditional to modern construction, stimulating competition amongst construction companies.

Like other industries, the construction sector is not immune to challenges. For instance, the construction industry is often considered a loosely coupled system. This nature of the industry can affect the strength of interdependency and coordination amongst the practitioners, hindering productivity (Dubois and Gadde, 2002). In addition, there are other challenges such as the slow adoption of new technologies (Peansupap and Walker, 2006), scarce skilled labour (Kim and Castro–Lacouture, 2019), delay, time, and cost overruns (Ogunlana *et al.,*1996), health and safety (Manu *et al.,* 2018) and waste management exist. These challenges usually undermine the successful implementation of projects if not tackled early. Accordingly, researchers often look for ways to tackle them for the benefit of the industry and society.

Starting a construction project requires a detail of works to be undertaken by relevant stakeholders. A typical construction project usually begins with briefing, design, and contract agreements between involved parties. Traditional objectives for a successful project are meeting time, quality, and budget expectations (Kashiwagi and Byfield, 2002). Besides these factors, effective waste management is also critical to achieving a successful project delivery. Waste management has become a mainstream objective in the industry due to the growing environmental concerns. However, evidence suggests that practitioners do not consider effective waste management a priority in construction projects (Osmani *et al.,* 2006; Udawatta *et al.,* 2015). Accordingly, researchers tend to provide waste management solutions so practitioners can learn how to minimise waste in projects. These solutions can be incorporated into the whole lifecycle of projects (Yeheyis *et al.,* 2013), thereby allowing practitioners the optimal opportunity to manage waste effectively. Therefore, the current research contributes to the ongoing effort, especially in Nigeria and other developing economies where construction waste management research is in infancy.

2.3. Definition of Waste

The word 'waste' is usually associated with unwanted, useless, valueless, spoilt, or discarded material or substance after its usefulness. Waste may include domestic discards or MSW mostly generated in various households and municipalities. Industrial waste usually comes from the health, oil, gas, and manufacturing sectors. Generally, waste could be described as a by–product of human activities with no sustainable value and can appear in different forms. In terms of health and safety, waste can be toxic, hazardous, and non–hazardous. Regarding the state of matter, waste can be solid, liquid, or gaseous. It is worth noting that C&DW is considered an MSW in many countries (Kofoworola and Gheewala, 2009). Defra (2012) and European Union (2018) reports attempt to define wastes and their nature. The definition of waste aids in identifying the sources, health and safety concerns, management opportunities, regulations, and potential benefits. This study is focused on construction waste materials because of the environmental concerns in many countries, including Nigeria.

2.3.1. Concept of Construction Waste

Construction waste is the term used in describing unwanted materials or activities in the construction delivery process. While the terms' construction waste' or 'construction and demolition waste' are used interchangeably in the literature, there is no unified definition of the terms (Lu and Yuan, 2011). Many scholars have attempted to define waste from the industry based on a research context. Osmani (2008) sees construction waste as the waste emanating in projects due to design errors. Construction waste can be understood as a by–product of inefficient materials procurement activities (Ajayi *et al.,* 2017b). According to Kofowolola and Gheewala (2009), construction waste arises from construction, renovation, and demolition activities. Waste is the surplus and damaged materials in construction activities or waste from one–off do–it–yourself building maintenance in households (European Union, 2018).

Many studies have considered construction waste a tangible object. However, others have attempted to define it in terms of time and cost wastages, known as intangible or non–physical waste. For instance, Serpell *et al.* (1995) and Serpell and Alarcon (1998) stressed that non–value–adding work resulting in time and cost overruns is a waste in construction. According to (Ismail and Yusof, 2016), construction practitioners pay more attention to the waste of materials; however, they have limited knowledge of non–value adding works as a form of waste in projects. Therefore, waste from the construction sector implies a waste of materials, time, and costs from either design, materials procurement, construction, renovation, demolition, or non–value–adding works in all construction activities.

Further, construction materials are categorised as inert and non–inert based on recyclability and environmental risk factors. There are two types of inert materials – soft and hard. Examples of soft materials include soil, earth, silt, slurry, while hard material examples include rocks and broken concrete (Lu *et al.,* 2011). Non–inert materials include bamboo, plastics, glass, wood, and paper, amongst others (Yuan *et al.,* 2013). Also, construction waste can be classified as direct or indirect. Direct waste is complete damage or loss of materials due to transition, storage, uneconomical shapes, amongst others (Skoyles, 1976). Indirect waste is financial and time loss in projects. Indirect waste originates from the 'lean philosophy' that intends to eliminate waste of time and cost and increase productivity for clients' satisfaction in the manufacturing industry. Formoso *et al.* (1999) identified indirect waste to aid in understanding its nature. These include waiting for time, transportation and unnecessary movements. While indirect waste incurs only financial and time loss, direct waste instigates economic, environmental, and social concerns. This categorisation is also known as physical and non–physical types of construction waste.

Finally, construction waste can be categorised as avoidable and unavoidable. Unavoidable occurs when efforts for minimisation is not economically profitable (Formoso *et al.,* 2002). In contrast, avoidable waste is when the reduction cost is economically viable. Therefore, any waste management strategy devoid of financial benefits can be perceived as an economic burden by contractors. This limitation may lead contractors to adopt only those strategies with economic benefit.

Construction waste has become one of the most critical MSW streams globally, making it an important research discipline. Therefore, scholars tend to describe construction waste in a way that best defines the boundaries of their study to develop a management philosophy. According to Lu and Yuan (2011), a specific definition of construction waste gives research a meaningful and practical perspective. Therefore, the definition of construction waste in the current research represents inclusively materials waste due to ineffective materials procurement and construction delivery activities. The following sections discuss the research trend in C&DW management following (Yuan and Shen, 2011) review.

2.4. Construction Waste Generation and Source Evaluation

Understanding the causes of construction waste and its source is the first step towards developing and implementing any management strategy (Polat *et al.,* 2017). Many studies have been undertaken to assess the various causes of waste at different construction delivery stages. For instance, waste can be generated due to design errors leading to design changes (Love *et al.,* 2011). Design changes often lead to potential rework (Han *et al.,* 2013). About 33% of construction waste is estimated to be due to a design error (Innes, 2004). Inefficient materials procurement could result in waste due to a bill of quantity mistake and an inefficient supply chain partnership (Dainty and Brooke, 2004). Also, waste can be generated on a construction site due to an inadequate materials management plan (Edike, 2021).

While waste could originate at different project stages, practitioners, clients, and external factors enable the generation. A large body of research identifies these factors. For instance, Nagapan *et al.* (2012a) identified poor site management and supervision, lack of experience, inadequate planning and scheduling, and design errors as waste factors. A similar study by Al–Hajj and Hamani (2011) shows a lack of awareness, inadequate design information, rework, and variations. According to Polat *et al.* (2017), frequent design changes, detail errors, and cutting uneconomical shapes result in a waste of materials. Arijeloye and Akinradewo (2016) suggest that lack of proper work planning and scheduling, inadequate cash flow to contractors due to delayed payments, burglary, theft, and vandalism are the critical causes of waste generation in the construction stage in Ondo–State, Nigeria. There are similarities in factors causing waste; however, key factors vary in many countries due to several factors. These factors may include technological advancement (Won and Cheng, 2017), policy effectiveness (Lu and Tam, 2013), and public awareness. For instance, a country with effective design policies will likely generate less waste due to design factors than a country with inefficient design policies.

Moreover, several studies have been conducted to categorise the sources of construction waste. Nagapan *et al.* (2012b) categorised the causes of waste into the design, handling, worker, management, site condition, procurement and external factors. Construction waste origins include client, design, material handling, procurement and operation (Oladiran *et al.*, 2019). While internal factors are the leading cause of waste generation in construction, the literature also reports external factors like adverse weather conditions (McGrath, 2001), theft and vandalism (Eze *et al.,* 2017). Also, senior management low priority to waste minimisation is a root cause of waste in the construction industry (Teo and Loosemore, 2001). Low priority can result in a lack of motivation amongst employees, making waste management difficult in organisations. However, Teo and Loosemore (2001) stressed that economic incentives could motivate employees to manage materials effectively. While factors causing waste could be tackled at any stage or category in projects, there is a consensus amongst scholars that it should begin in a project's early stage (Keys *et al.,* 2000; Innes, 2004; Ekanayake and Ofori, 2004).

Meanwhile, there is a significant research effort to minimise waste only in the construction stage. Thus, several studies have argued that waste management is not a priority in the preconstruction stages as researchers have significantly neglected this area over the years (Ajayi, 2017a; Ogunmakinde, 2019). Consequently, the need to consider waste management measures in construction planning stages is growing among scholars (Ogunmakinde, 2019). It is proposed that the inclusion of waste management at the project planning stage will enhance the effectiveness of waste management in the construction industry by eliminating the potential causes of waste in projects. Therefore, this study intends to improve the industry's waste management culture by including a preconstruction stage. Table 2.1 shows some of the main causes of construction waste generation and the sources.

Table 2.1: Construction waste origin and causes (adapted from Gavilan and Bernold,1994)

Construction Waste Origin	Related Causes
Design	✓ Blueprint error ✓ Detail error ✓ Design error
Procurement	✓ Shipping error ✓ Ordering error
Material handling	✓ Poor material handling ✓ Poor storage
Operation	✓ Human error ✓ Equipment malfunctions
Residual	✓ Leftover scrap ✓ Unreclaimable
Others	✓ Project dependent or site related

The categorisation of construction waste suggests that waste origins are mostly due to human errors than a natural cause or inherent in construction activities. Tables 2.2 shows a catalogue of studies identifying the causes of construction waste across some Nigerian cities, their methods, participants, sample size and projects stage(s). Table 2.3 shows the causes of construction waste in Nigeria at the design, materials procurement and construction stages, respectively, as retrieved from the previous studies (Table 2.2). In comparison with other factors, findings revealed late design changes as the key waste factor in the design stage. Further, the purchase of substandard materials is the main waste factor in the materials procurement stage. At the same time, inadequate site supervision is the leading cause of waste generation in the construction stage. Categorising waste origin can enable practitioners to trace the sources to employ appropriate strategies for minimisation or potential prevention. However, this can only be achieved if practitioners prioritise and implement waste management measures as requisites for sustainable development (Sev, 2009).

Table 2.2*:* A catalogue of studies identifying the causes of construction waste in some Nigerian cities

No	Author	Method			Article Type			Project Stage			State/City	Participants	Research sample size
		Questionnaire	Interviews	Case study	Journal	Conference	PhD thesis	Design	Procurement	Construction			
1	Ogunmakinde, 2019	✓	✓				✓	✓	✓	✓	Lagos	**Quest.** (UP; CEO; PM; Arch; Engr; QS; QM; Builders; technician). **Inter**. (Arch; Engr; PM; QS; MC; SC; FM)	243 65
2	Oladiran *et al.,* 2019	✓			✓			✓	✓	✓	Lagos; Ogun; Oyo Osun; Ondo; Ekiti	Civil Engr; QS; Arch; Builders	167
3	Saka *et al*., 2019	✓			✓					✓	Lagos	QS	52
4	Eze *et al.,* 2018	✓			✓					✓	Abuja	Builders; QS; Arch; Engr	195
5	Ugochukwu *et a*l., 2017		✓	✓	✓					✓	Anambra	Contractors, QS, PO; SK; Artisans Tradesmen	5 Building projects The human sample is unspecified
6	Haruna *et al*., 2017	✓	✓	✓	✓					✓	Adamawa	**Quest.** (Site managers; Artisans) **Inter.** (Artisans; Craftsmen)	20 Building projects 288
7	Eze *et al*., 2017	✓			✓			✓	✓	✓	Abuja	CO; artisans; tradesmen	125
8	Aderibigbe *et al*., 2017	✓			✓					✓	Abuja; Kogi	Builder; QS; Arch; Site supervisors; Foremen; SK	30
9	Aderibigbe *et al*., 2017		✓		✓				✓	✓	Abuja	PM; QS; STO; Engr	30
10	Saidu *et al*., 2017		✓		✓			✓	✓	✓	Abuja	PM; QS; STO; Engr	30
11	Adeagbo, *et al*., 2016	✓			✓					✓	Abuja	QS; Engr; Arch; and Builders	77
12	Arijeloye & Akinradewo, 2016	✓			✓					✓	Ondo	QS; Engr; Arch; and Builders	100
13	Garba *et al.,* 2016	✓			✓			✓	✓	✓	Kaduna; Abuja	QS; Arch; and Builders	53
14	Idris *et al.,* 2015	✓			✓					✓	Gombe	QS; Engr; Arch; and Builders	80

15	Ola–Adisa *et al*., 2015	✓			✓					✓	Bauchi	Arch, Engr; QS, Builders; Contractors	Unspecified
16	Adewuyi & Odesolay, 2015	✓			✓			✓	✓	✓	Bayelsa; Cross River; Delta; Edo; Rivers	Consultants; Contractors	743
17	Saidu & Shakantu, 2015	✓	✓			✓			✓		Abuja	PM; QS; Engr; STO	30
18	Aiyetan & Smallwood, 2013	✓				✓			✓	✓	Lagos	Arch; Builders; Engr; PM; QS	72
19	Adewuyi & Otali, 2013	✓			✓					✓	Rivers	Consultants; Contractors	74
20	Oko & Itodo, 2013	✓			✓					✓	Unspecified	Contractors; Client; PD	56
21	Ayegba 2013	✓			✓				✓	✓	Niger	Contractors	40
22	Odusami *et al*., 2012	✓			✓			✓	✓	✓	Lagos	Arch; Builders; Engr; QS	20
23	Babatunde, 2012	✓			✓				✓	✓	Abuja	Unspecified	51
24	Wahab & Lawal, 2011	✓	✓		✓					✓	Lagos	Arch; Builders; Engr; QS	75
25	Oyewobi & Ogunsemi, 2010	✓			✓					✓	Niger	Unspecified	Unspecified
26	Oladiran, 2009	✓				✓		✓	✓	✓	Unspecified	Unspecified	Unspecified
27	Oladiran, 2008	✓				✓		✓	✓	✓	Lagos	Contractors; Consultants; Client; PD	46
28	Dania *et al*., 2007	✓				✓				✓	Kaduna, Lagos; Abuja	Arch; Builders; Engr; QS	62
29	Wokekoro, 2007	✓				✓				✓	Rivers	ESA; Site managers; Contractors; ESV; Arch, Civil Engineers	Unspecified
30	Akinkurolere & Franklin, 2005	✓			✓					✓	Ekiti; Lagos; Ogun; Ondo; Osun; Oyo	Arch; Builders; Engr; QS Contractors	71

Note: **PM**=Project manager; **QS**=Quantity surveyor; **STO**=Senior technical officer; **UP**=Urban planner; **CEO**=Chief executive officer; **PD**=Property developers; **CO**=Construction operatives; **ESA**=Environmental sanitation authority; **ESV**=Estate surveyors and valuers; **Arch**=Architects; **CE**=Civil Engineers; **SC**=Sub–Contractors; **FM**= Facility manager; **MC**= Main contractors; **SK**= Storekeepers; **Quest**=Questionnaire; **Inter**=Interview

Table 2.3: Factors causing waste in the Nigerian construction industry

No	Causes of Waste in the Design Stage	Reference (Refer to Table 2.2)	Frequency
1	Late design changes	[2]; [7]; [13]; [16]; [19]; [1]; [21]; [22]; [26]; [27]; [20]; [10]	12.0
2	Error in material specification	[19]; [27]; [16]; [10]; [17]; [18]	6.0
3	Misinterpretation of drawings	[18]; [26]	2.0
	Causes of Waste in the Procurement Stage	**Reference (Refer to Table 2.2)**	**Frequency**
1	Purchase of substandard materials	[1]; [13]; [25]; [26]; [27]	5.0
2	Poor storage of materials	[7]; [10]; [21]; [22]	4.0
3	Transportation	[13]; [18]; [23]; [26]	4.0
4	Delay in material delivery	[2]; [22]	2.0
5	Loading and unloading of materials	[13]; [26]	2.0
6	Ordering error	[21]; [22]	2.0
7	Lack of possibility to order small quantity	[13]	1.0
9	Packaging materials	[26]	1.0
10	Unfamiliarity with alternative materials	[26]	1.0
11	Inaccurate quantity take–off	[17]	1.0
12	Poor schedule of materials procurement	[16]	1.0
	Causes of Waste in the Construction Stage	**Reference (Refer to Table 2.2)**	**Frequency**
1	Inadequate site supervision	[1]; [8]; [15]; [20]; [21]; [22]; [26]; [27]; [28]	9.0
2	Unawareness of waste management practices	[8]; [13]; [15]; [18]; [25]; [26]; [27]; [30]	8.0
3	Poor material handling	[5]; [13]; [14]; [18]; [20]; [21]	6.0
4	Theft/Vandalism	[7]; [8]; [10]; [12]; [21]; [26]	6.0
5	Uneconomical shape	[16]; [19]; [23]; [26]	4.0
6	Rework	[18]; [20]; [21]	3.0
7	Increment weather	[2]; [18]; [21]	3.0
8	Absence of policy	[11]; [28]	2.0
9	Inadequate reuse of materials	[24]; [26]	2.0
10	Inadequate recycling of materials	[24]; [26]	2.0
12	Inadequate planning	[10]; [24]	2.0
13	Faulty equipment	[18]	1.0
14	Lack of waste segregation	[24]	1.0
15	Poorly designed formwork	[6]	1.0
16	Poor site condition	[26]	1.0
17	Setting out errors	[26]	1.0
18	Under pressure for timely delivery of projects	[2]	1.0
19	Lack of proper work planning and scheduling	[12]	1.0
20	Building failure/defects	[26]	1.0
21	Lack of material waste documentation	[3]	1.0
22	Unclear instruction to workers	[4]	1.0

2.4.1. Composition of Construction Waste

There are differences in the composition of construction materials. Variation in construction types and developmental stages leads to differences in the composition of waste streams. Observable evidence suggests that construction materials' constituents vary due to the environmental (e.g. weather condition), level of development and cultural differences amongst countries. However, construction materials mainly consist of stones, bricks, roofing materials, concrete, and materials from heating systems. Others include paper, steel, glass, timber, electrical wires, steel, plumbing materials (Lu *et al.,* 2021).

A case study on waste sources from 74 building sites in different Brazilian regions shows steel reinforcement, premixed concrete, sand, lime, premixed mortar cement, bricks, blocks ceramic, and tiles as the significant waste materials (Formoso *et al.,* 2002). Lu *et al.* (2011) identified concrete, timber, steel reinforcement, bricks/blocks, mortar, and PVC pipe as the primary waste sources from five projects in Shenzhen, South China. Ugochukwu *et al.* (2017) quantified materials waste in a case study of five projects in Anambra State, Nigeria. The results show timber has the highest average percentage of waste, with 5.5%, tiles 3.47%, sandcrete block 1.6%, reinforcement bars 1.58% and, 1.55% concrete. Adewuyi and Odesola (2015) used a questionnaire survey to identify waste compositions in six Southern states in Nigeria. They used the quantitative strategy to analyse participants' responses and presented the data in percentages. The result shows that sandcrete blocks (40%) have the highest waste composition, followed by ceiling board (20%), tiles (13%), timber and cement (10%), and steel reinforcement (7%).

Concerns for public health and safety necessitate identifying materials composition because some construction materials may contain hazardous substance(s). The UK Environmental Agency (2014) classified C&DW regarding health and safety identification coded using the English alphabet. These comprise of (a) Insulation and asbestos materials; (b) Concrete, bricks, tiles, and ceramics; (c) Wood, glass and plastic; (d) Bituminous mixtures, coal tar and tar; (f) Metallic waste, including cables; (g) Soil, contaminated soil, stones and dredging spoil; (h) Gypsum; (i) Cement; (j) Paints and varnishes; and (k) Adhesives and sealants. Materials found in these categories with an asterisk (*) attached to their codes are considered hazardous, while those without the sign are non–hazardous. According to the waste categories, construction materials containing asbestos or mixed with other hazardous materials such as coal tar and tarred products are hazardous.

Differences in materials composition affect the perception of waste management philosophies amongst countries. For instance, excavated soil material is part of C&DW composites in the UK (DEFRA, 2016). However, excavated soil may not be perceived as waste in other countries because excavated soil is inert waste (Cooper, 1996) and less worrying in safety terms than non–inert. So, when excavated soil is not mixed with hazardous materials, it constitutes minimal environmental hazard than non–inert waste such as plastic and metals. Nevertheless, all construction waste materials need to be separated to ascertain their usability and recyclability for environmental protection. Also, identifying the composition of construction materials is crucial for safety handling throughout their useful life and treatment options (e.g. landfilling or incineration) to avoid adverse environmental impacts.

2.4.2. Impacts of Construction Waste

Hore *et al.* (1997, p.4) opined that the process of building a hundred houses could potentially generate enough waste to build an extra ten houses. There is strong evidence that waste impacts the environment, economy and society (Table 2.4). These three impacts are interrelated, and they accord with the sustainability pillars in that deliberate environmental actions and resources are needed to implement sustainable waste management in any nation. For instance, a municipal budget is required to reduce the impacts of waste by investing in public awareness, machinery and logistics. Insufficient or absence of a monitory budget, policy, and human resources are drawbacks to sustainable waste management in Nigeria (Ezeudu and Ezeudu, 2019). Also, unsustainable waste management results in the emergence of dirty cities, undermining public social and environmental well–being.

Generally, unsustainable solid waste management has been linked to flooding incidence (Lamond *et al.,* 2012), the rise in global climate change, pollution, and urban violence (UNEP, 2015; World Bank, 2018). In addition, waste occupies spaces for other economic activities, such as agriculture, new homes, recreational centres. Evidence has shown that waste disposal can result in a landfill failure and potentially impacts human lives and properties. An example of a landfill failure due to construction waste occurred in China's Shenzhen city in 2015, with about 73 casualties, while 33 buildings collapsed (Yang *et al.,* 2017; Xu *et al.,* 2017). Therefore, the construction industry has contributed to environmental deterioration through waste deposits. Consequently, construction waste has continued to draw significant interest globally to minimise its impacts. Thus, the role of research has become critical to promote the idea of zero–waste globally using the basic waste management model discussed next.

Table 2.4: Sustainability impacts of construction waste (adapted from Nagapan *et al*., 2012c)

Impacts of Construction Waste	Aspect of Sustainability
Creation of illegal landfill sites	Environmental
Environmental pollution	
Land occupation	
Projects cost overruns	Economic
Projects delays	
Increases landfill charges	
A threat to the public health and safety	Social

2.5. Basic Waste Management Model (Reduce, Reuse, and Recycle)

Many studies show the waste management hierarchy as fundamental to sustainable and effective waste management. The waste hierarchy is usually presented as a pyramid that shows an order of preference for action to manage waste. Although there are numerous variations (Zhang *et al.,* 2021), the newest version recognised waste prevention as the most important to encourage a zero-waste construction industry (Figure 2.1). Meanwhile, since waste cannot completely be eliminated in the industry, the reduce, reuse and recycle (3Rs) model is widely cited in the literature to encourage waste reduction (Yuan and Shen, 2011). The model help industries prevent or reduce waste at the source. Also, wastes generated can be reused or recycled to minimise the end of pipe treatment of materials. Therefore, waste disposal remains the last resort when preventive, reduction and recovery measures have been utilised extensively. The following sections discuss the ideas of waste prevention through 'reduce, reuse and recycling for recovery.

2.5.1. Reduce

'Reduce' as the best option in the hierarchy offers the most environmental and cost benefits. It is the best way to prevent virgin materials extraction, cost of materials processing, transportation, recycling, and disposal (Ng *et al.,* 2017). As the most important aspect of the model, many studies have investigated strategies to reduce waste throughout a project lifecycle (Lu and Yuan, 2011). These studies adopt different methods, such as system dynamics modelling (Li *et al.,* 2014), interviews (Esin and Cosgun, 2007), and questionnaires (Mahpour and Mortaheb, 2018), to provide measures that can be taken before a material or product can become waste. These solutions include but are not limited to designing out waste from the source, ordering the right amount of materials, buying recycled products, and having take–back measures to avoid materials spoilage and expiring.

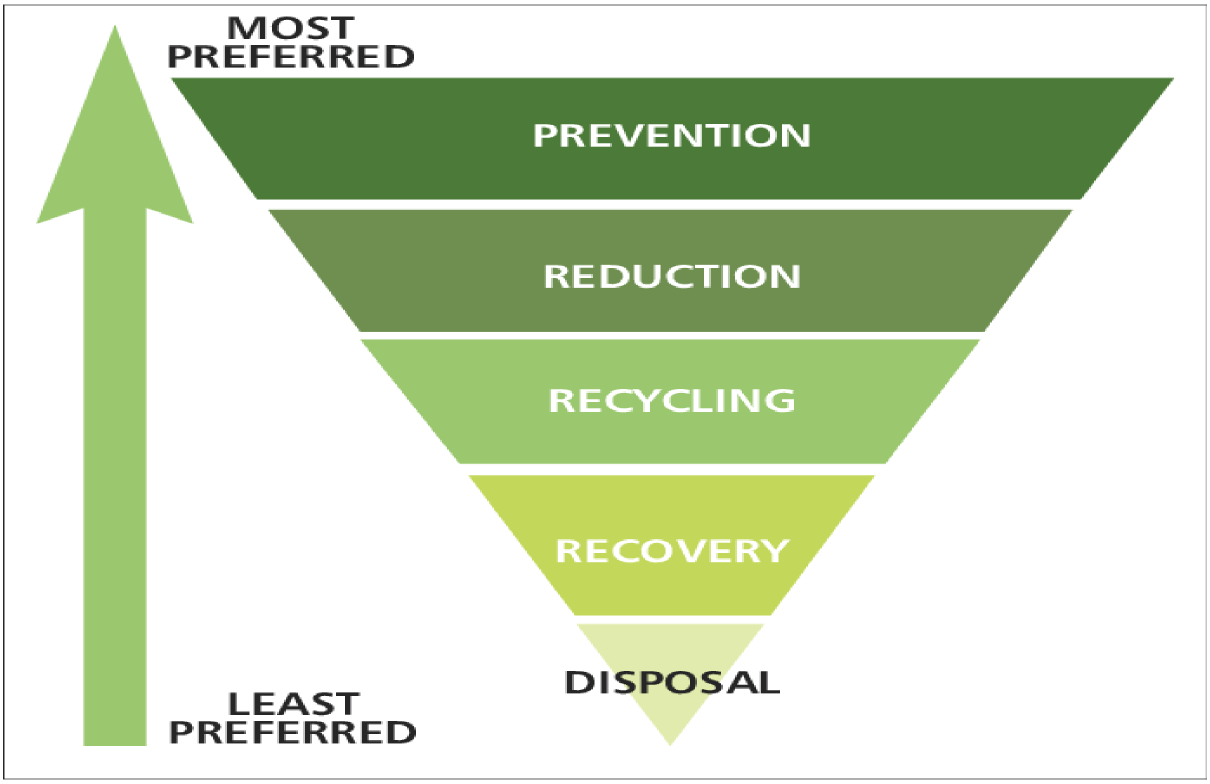

Figure 2.1: Waste management hierarchy model Adapted from (United Nations Environmental Program, 2013)

2.5.2. Reuse

'Reuse' is the second desirable in the hierarchy after 'reduce'. A reuse operation can elongate the life of a material after the initial or repeated use. Also, it helps minimise the need for virgin materials (Ng *et al.,* 2017) by ensuring that surplus materials are redirected, preserved and reused on site for economic and environmental benefits. This means that materials can be used several times, either for the same or different purposes in projects. Reusing materials has more economic and environmental benefits compared to recycling. Apart from being more environmentally friendly, reusing a material on the same site can reduce financial burdens such as transportation costs. However, logistics costs may be required when materials are to be reused on another site. Some of the materials that can be reused in construction are steel bar (Duran *et al.,* 2017), formwork (Ling and Leo, 2000), concrete aggregates (Li and Yang, 2008) and others. It is worth noting that the reusability of construction materials could easily be determined through a physical examination (e.g., timber). However, studies on 'reuse' appear scarce in the literature compared to 'reduce and recycle' (Lu and Yuan, 2011). Therefore, more research is needed to help make it easier to reuse materials and components with little or no alteration to their physical characteristics and without changing their chemical properties.

2.5.3. Recycle

When materials become unusable, recycling is the next option as it transforms waste materials into secondary products. It is, therefore, any operation in which materials or products are reprocessed into secondary products, whether for the original or other purposes. Recycling offers three main benefits: (1) reduces the demand for natural resources, (b) reduces the cost of transportation and production energy, and (c) reduction in landfill waste (Tam, 2008a). Recycling is widely promoted and implemented in developed economies due to technological advancement, stringent policies and more public awareness than low– and medium–income countries (Van Beukering *et al.,* 2006). This is because adequate logistics and finance are required for a successful recycling operation (Van Beukering and Bouman, 2001). For instance, a typical recycling facility in the USA may require a minimum of 0.8 hectares (space for operation) and durable machinery that could cost up to $300,000 and $750,000 for a 400–500 tonne/day for optimal operation (Peng *et al.*, 1997). Also, recycling requires identifying materials for recycling and a system to transport materials to recycling facilities.

While recycling is widely promoted, operating a recycling facility constitutes environmental concerns due to machinery operations. Moreover, another concern remains the acceptability of recycled materials compared to virgin materials from the economic and quality perspectives. Despite the huge investment in recycling facilities, virgin materials are usually cheaper than recycled materials (Tam and Tam, 2006a). According to Tam and Tam (2006a), recycled materials can only be desirable when considered good quality and economically viable compared to virgin materials. For instance, the quality of recycled concrete aggregate has been debated amongst scholars. While some scholars suggest that concrete aggregate quality is affected by repeated recycling (Yang and Kim, 2005; Etxeberria *et al.,* 2007), others claim that the quality remains reasonably unaffected (Thomas *et al.,* 2013). Hence, a belief that the process of recycling may alter the physical or chemical properties of materials. However, some studies argue that recycled aggregates are seldom affected; therefore, resulting in the examination of recycled concrete aggregates from different perspectives. These include the mechanical, physical (Matias *et al*., 2013), macroscopic and microstructural properties and performance (Li and Yang, 2017). Others include utilisation efficiency (Ho *et al.,* 2013) and mechanical behaviours (Gao *et al.,* 2017). While recycling is widely investigated, immature markets and limited guarantees for standard specifications are limitations in sourcing recycled products (WRAP, 2010). Moreover, inadequate regulation to promote recycling or lack of public interest can be a drawback. Consequently, developing countries mainly focus on extracting materials from the primary resources, while the developed counterparts focus more on the recovery of secondary materials.

Gertsakis and Lewis (2003) opined that the challenges facing the implementation of the '3R' model are the insignificant control exercised by government and industries regarding production decisions that influence waste generation, mostly in the non–existence of regulation. According to Wilson (1996), dealing with these challenges requires a balanced strategy. The author described the strategy as 'economic stick or carrot'. This implies a penalty for unsustainable waste management and an incentive for sustainable waste management in organisations. Governments, industries, and researchers acknowledged the waste hierarchy's relevance as a model for effective and sustainable waste management. Therefore, the model represents a fundamental waste management solution and a focal point for researchers developing management strategies (Sakai *et al.,* 2011). In addition, the CE concept is currently growing in the construction industry to promote sustainable construction by encouraging the 3Rs implementation.

2.5.4. The Circular Economy in Construction

Due to significant pressure on natural resources from human activities, countries and organisations are strongly advised to move away from a linear economy (LE) and embrace the CE. A LE means extracting and processing raw materials, using, and disposing of them after their usefulness ('take–make–use–dispose') (Marino and Pariso, 2016). This production model puts pressure on natural resources and creates waste. On the other hand, the CE is perceived as a promising business model that promotes sustainable development. The United Nations (2017) suggests that the CE philosophy can create sustainable values in businesses and countries. Therefore, the idea is perceived as a critical indicator of sustainable development.

Accordingly, some countries have developed frameworks to aid CE implementation. For instance, the British Standards Institution (BSI) developed a new standard, "BS8001:2017 framework for implementing the CE to help organisations manage their resources efficiently (BSI, 2017). In addition, the EU proposed action plans for implementing the CE, including construction and buildings (European Commission, 2020). The Chinese government also proposed the CE Law of the People's Republic of China for a similar purpose (McDowall *et al.,* 2017). Figure 2.2 demonstrates the LE against the CE concept.

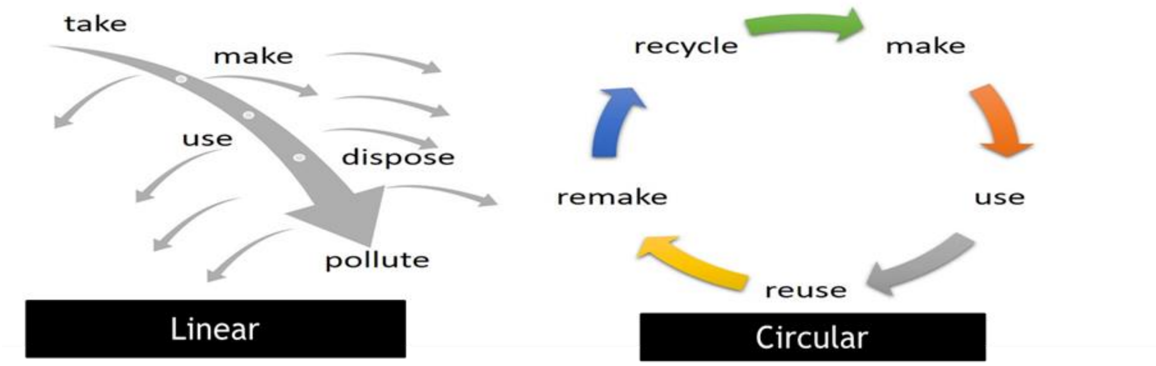

Figure 2

Figure 2.2: The linear economy versus circular economy model (Weetman, 2016)

Amongst many industries, the construction sector subscribes to the concept of CE. The aim is to maximise the life expectancy of materials and products through policies and other means to improve the environmental management of construction projects. Several authors have suggested that CE can move the industry towards sustainable waste management but cited many challenges. According to Adams *et al*. (2017), inadequate awareness from the clients, designers, and subcontractors impedes CE adoption in the construction sector. In addition, the authors suggest that the absence of incentives to design sustainable materials, modular building and reuse of materials are challenges. Some studies claim that the industry can overcome these barriers through a deliberate effort to reuse and recycle materials (Mahpour, 2018). However, there is evidence that the CE for construction waste management may be challenging due to limited information on the concept (Huang *et al.,* 2018), so the adoption may be applied inappropriately (Ghisellini *et al.,* 2016). This evidence indicates that the future of CE for construction waste management may largely depend on adequate research on its applications.

2.6. Construction Waste Management Strategies and Tools

Various studies have identified management measures using the basic model discussed above as a reference point in response to the causes and impacts of construction waste. For instance, Lu and Yuan (2010) explored critical strategies for waste management in the Chinese construction industry. These are: (1) waste management regulations, (2) waste management system (3) awareness of construction waste management, (4) low–waste building technologies, (5) fewer design changes, (6) research and development in waste management, and (7) vocational training in waste management. A similar study by Begum *et al.* (2009) shows construction–related training among employees; contractor experience in construction works; source–reduction measures, reuse of materials; positive behaviours and attitudes toward waste disposal and management are critical for waste reduction in the Malaysia construction industry. Udawatta *et al*. (2015a) identified five factors for the Australian construction industry that includes: (1) team building and supervision; (2) strategic guidelines; (3) proper design and documentation; (4) innovative waste management decisions; and (5) lifecycle management. Ling and Nguyen (2013) identified several ways waste could be minimised in Ho Chi Minh City, Vietnam. These are: (1) employment of subcontractors with waste management ability; (2) training; (3) audit and effective supervision; (4) sequence activities to reduce damage to completed work; (5) set level of wastage allowable; and enforce through punishments and rewards. Among others, these waste management strategies are a valuable reference for researchers who intend to develop frameworks or models. Further, the World Bank (2005) stated the general aspects of an integrated waste management program are, thus:

- ✓ Acknowledgement of the waste management hierarchy model
- ✓ Segregation of waste in categories after generation
- ✓ Waste management plan
- ✓ Providing authorised landfill
- ✓ Encouraging recycling
- ✓ Use of management frameworks/models (e.g. policy/regulations, public awareness, decision support)

The following section discusses some of the waste management strategies and tools used in the construction industry.

2.6.1. Waste Segregation

The first step to waste management after generation is to separate them into categories to decide treatment methods. To carry out this task, an employee can be commissioned to identify the recyclable, nonrecyclable materials, disposables and treatment methods. Also, it is essential to separate hazardous materials from contaminating non–hazardous materials. Hence, a need to be careful of hazardous waste in the handling process. As mentioned earlier, waste containing asbestos, coal tar and tarred products must be handled with great care. In some countries, like the UK, there is a regulation for handling asbestos or materials containing asbestos (Control of Asbestos Regulations) (Health and Safety Executive, 2017). Also, some materials (such as broken glasses and metal off–cuts) can present a high risk of accident or injury in a manual separation process. Thus, a mechanical separation technique could be used to minimise such risk (Huang *et al.,* 2002) because it enables minimal contact between materials and employees. The importance of waste separation includes determining amounts of reusable materials, economic viability and potentials for recycling. However, the literature shows that waste separation is not usually carried out in many Nigerian construction sites (Wahab and Lawal, 2011). It is, therefore, recommended that waste sorting be carried out on construction sites (Poon *et al.,* 2001) or sometimes offsite (Lu and Yuan, 2012) as part of a waste management plan to improve practice.

2.6.2. Waste Exchange

A waste exchange is possible when unusable construction materials are considered useful in another industry as raw materials. For instance, the Scottish government designed an online tool for waste exchange to give construction materials a longer lifespan in other industries (Zero waste Scotland, 2020). The aim is to control about 7.4 million tonnes of construction waste produced in Scotland every year. Examples of material waste that can be exchanged from construction to other industries such as manufacturing include aluminium and metals. These materials can be recycled and used to produce domestic products such as cooking utensils (e.g. metallic spoons and aluminium cooking pots).

2.6.3. Site Waste Management Plan

The Site Waste Management Plan **(**SWMP) is a template for recording waste sources, quantity, compositions, and potential disposal methods (DEFRA, 2013). McDonald and Smithers (1998) investigated the effectiveness of a SWMP policy in Australia. The case study shows a 15% reduction of waste generated before recycling, 43% less disposal to landfill and a 50% cost saving in handling charges. This evidence indicates that implementing a SWMP can save costs (e.g. transport costs and disposal fees). According to Tam (2008b), the benefits of a SWMP include identifying reusable materials and techniques to minimise waste on construction sites.

Contractors are concerned about the financial implication of implementing a SWMP. They believe that the detailed descriptions in a SWMP policy can impact construction organisations negatively. Low economic incentives and increased projects cost overhead are the two main impediments of implementing a SWMP (Tam, 2008b). In England, a SWMP is mandatory for projects exceeding £300,000 (HM Government, 2008). However, it is not a legal requirement to produce a SWMP in Northern Ireland, Scotland and Wales (WRAP, 2009c). However, the Scottish government recommends implementing a SWMP as good practice under their construction planning policy (WRAP, 2009c). Also, a SWMP is not a legal requirement for

Nigerian construction contractors. However, Oladiran (2009b) says it is an innovative waste minimisation strategy and should be adopted to improve onsite waste management practice in the country. However, voluntary implementation of a SWMP may also be challenging to contractors in Nigeria without any legal obligation.

2.6.4. Waste Prediction Tool

Various organisations have developed supporting tools to help contractors minimise construction waste. For instance, the Waste and Resources Action Programme (WRAP), a British charitable organisation in the UK, assists organisations and communities, including the construction industry, to minimise waste by utilising resources efficiently. The organisation developed NetWaste, a tool that can forecast possible waste from construction activities and identify key actions that can be taken for the reduction during the design stage. Thus, it assists designers in selecting design strategies to design out waste (WRAP, 2008). In addition, the tool can be used to estimate the cost and quantities of waste by collecting project information like building volume and materials types for evaluation. Further, WRAP identified procurement requirements for reducing waste in construction (WRAP, 2009). WRAP has published many articles to assist construction contractors to achieve sustainable and effective waste management in projects.

2.6.5. Use of Prefabricated Components

Prefabrication involves assembling building components outside a construction site in a controlled or factory environment. Studies indicate that prefabrication reduces waste on construction sites. This method has been recommended as an improved technique for waste minimisation in construction operations, especially in high rise buildings rather than cast–in–situ (Baldwin *et al.,* 2009). Tam *et al.* (2006) case study shows that prefabrication can reduce waste due to poor workmanship, including wet–trade activities such as bricklaying, drywall and about 100% of waste due to plastering. Besides waste minimisation, several studies suggest that off–site precast components in factories can speed up the construction process (Baldwin *et al.,* 2009; Jaillon *et al.,* 2009). According to Baldwin *et al.* (2009), elements such as concrete frames, precast flooring units, walls, floors, stairs, lift towers, bathroom and kitchen modules can be prefabricated to save construction time.

Kolo *et al.* (2014a) suggest that off–site construction can solve the challenges of over–dependence on traditional methods and techniques, the slow pace of construction and poor–quality housing in Nigeria. However, there is evidence that a lack of technical know–how, reluctance to innovate, paucity of codes and standards, lack of guidance and information, high capital cost (Kolo *et al.,* 2014b), and insufficient prefabrication companies impede the prefabrication of construction elements in Nigeria (Ogunde *et al.,* 2016).

Implementing the above waste management strategies will require deliberate human efforts, particularly those involved in construction activities. Therefore, construction organisations must make efforts in the required areas to manage waste effectively in the industry. Some of these areas are discussed in the following sections.

2.7. Human Factors in Construction Waste Management

Based on the evidence that human factors are the main reasons for waste generation in construction, the need to organise the workforce and build capacity for sustainable waste management cannot be overemphasised. The approaches requiring human efforts have been identified by (Teo and Loosemore 2001; Li *et al.,* 2015; Li *et al.,* 2018; Mak *et al.,* 2019). These are related to attitude change, management support mechanisms, policies, agreements, amongst others. The following sections discuss some waste management approaches requiring efforts from construction actors.

2.7.1. Effective Communication and Collaboration

Effective communication enables employees to understand the benefits of sustainable waste management. Therefore, communication is an important strategy to promote waste management strategies in construction organisations (Yuan, 2013). While ineffective waste management is one of the key factors of construction waste generation, engaging employees through effective communication can promote waste minimisation in the construction industry (Begum and Pereira, 2008). This would mean that construction companies should develop communication mechanisms such as media campaigns, conferences, workshops, and seminars to share waste management concerns to improve practices. In addition, communication can help employees discover and share new ideas and experiences from past projects, gain international awareness about sustainable waste management and best practices.

Moreover, effective communication is a tool for improving collaboration amongst construction actors. According to Constructing Excellence (2004), collaboration is an essential aspect of project management that encourages continuous partnership amongst construction actors. The literature suggests that improved collaboration is critical for achieving waste management objectives through mutual commitment amongst stakeholders (Bossink and Brouwers,1996;

Dainty and Brooke, 2004). Mutual collaboration can help minimise the fragmented project-based construction industry by promoting long–term partnerships. This means that long–term partnerships would promote transparency and bridge the gaps between interest groups as they work together to achieve waste management objectives with mutual understanding.

2.7.2. Capacity Building through Training

Lack of competency for waste management has been identified in the literature as a significant barrier to waste minimisation. Lack or inadequate training results in a low capacity to deal with waste, particularly early in projects. Training and retraining of employees will increase their waste management knowledge and technical expertise (Adewuyi and Odesola, 2016). A good quality training module will equip employees, improve their work experience and give them the required practical waste management techniques. Therefore, employees should be encouraged through training and education to see effective waste management as a prerequisite for sustainable construction.

2.7.3. Incentive reward Scheme

There is a common belief that people desire to be rewarded for excellent performance. There is evidence that incentive inspires construction operatives to improve waste management performance (Teo and Loosemore, 2001). A reward mechanism could be economic or simply acknowledging an employee's good performance. The aim is to boost employees' morale, motivate them, and encourage teamwork for performance improvement.

2.7.4. Policy and Agreement

The importance of government policy for construction waste management cannot be overemphasised. A policy is an instrument enabling the achievement and sustenance of organisations' objectives using a legal means or good faith. Therefore, an organisation must ensure that its policy is aligned with government policy, comprehensive, focus oriented, flexible and well understood by all employees to achieve its key objectives. Policies are key drivers of construction waste management (Ng *et al.,* 2015) to clarify stakeholders' waste management responsibilities. This means that organisations must be committed to implementing their waste management policies. Compliance with policies is critical in maintaining waste management standards and sustaining practices. It may be difficult to change the culture of poor waste management in the absence of policies and agreements. Legal instruments govern the construction industry and should be formulated to standardise and sustain waste management measures. Setting up waste minimisation targets and putting them into action through legal agreements drives construction stakeholders (e.g. suppliers, subcontractors) to implement their waste management responsibilities as a duty of care (WRAP, 2016).

2.7.5. Effective Leadership

Effective leadership can influence stakeholders to understand and agree on what needs to be done. A leader's job includes directing a project team by providing necessary information, expertise, and methods to achieve a goal critical in every organisation. Leadership theories have continued to receive attention encouraging best practices in construction (Pham and Kim, 2019). For instance, a wrong decision taken at any stage in a project would increase the waste output in another stage. Therefore, senior managers can influence effective waste management in construction organisations by supporting and encouraging junior employees through a top–down management approach (Shan *et al.,* 2018) by establishing proactive measures and ensuring junior employees implement them.

2.7.6. Documentation and Reviewing

Organised documentation of work plans and schedules allows people to understand project requirements. Proper and organised documentation can prevent scope creep by reducing unnecessary surprises and risks. Therefore, employees can follow a project's progress through a well–documented procedure to avoid such risks. According to Kerzner (2012), a lack of defined procedures for project implementation can result in scope creep. In addition, scope changes result in material waste in construction due to rework (Osmani *et al.,* 2008). Therefore, documentation may include capturing lessons learnt from previous projects to help review and standardise waste management practices. This may include documenting the amount of waste generated at the end of a project and using it as a benchmark considering previous projects (Masudi *et al.,* 2011) or performance (Lu *et al.,* 2015a).

2.7.7. Effective Use of Construction Equipment

Construction equipment is key to the industry, as nothing can be achieved without deploying the right equipment for projects development. Construction equipment is used to enable speedy, safe and quality construction. However, when a piece of equipment is not handled properly, there is evidence that it will cause waste of materials and undermine construction workers' health and safety. Urio and Brent (2006) suggest that inappropriate equipment and equipment malfunction contributes to waste generation in construction activities. It follows that equipment should be checked before and after being used and be kept in a safe and secured place to avoid the above scenario. Also, it is important to ensure the competency of persons using construction equipment to improve site safety.

The key stakeholders required to implement these strategies are construction actors operating in different capacities such as clients, contractors, subcontractors, suppliers, architects, site operatives and others. The waste management strategies discussed above are not exhaustive; therefore, more strategies related to the design stages are retrieved from the literature and presented in Table 2.5. In addition, strategies for materials procurement and construction stages are identified and attributed to different criteria in chapter three to develop the research conceptual framework regarding the focus of the study.

Table 2**Table 2.5:** Design waste management strategies

Strategies	References
Combination of multi–design strategies	Wang and Tam, 2015
Standardisation and dimensional coordination	Ajayi *et al.,* 2017c
Designers' positive attitude	Li *et al.,* 2015
Reduced design modification	Ding *et al.,* 2018b
Improved designers' competency	Ajayi *et al.,* 2016b
Use of BIM technology to support design decisions	Akinade *et al.,* 2018
Error–free design documents	Dainty and Brooke, 2004
Coordination and communication amongst designers	Osmani *et al.,* 2008

2.8. Construction Waste Management Frameworks in the Previous Studies

Although significant research efforts have been made to provide waste management strategies in construction, few scholars have attempted to integrate their findings in the form of a framework (Oladiran *et al.,* 2019). Construction waste management frameworks direct actions that deal with waste management problems in the industry. These frameworks are developed from different perspectives ranging from the industry, company, and project levels. The frameworks are mainly published in journals and conference proceedings, while others appear as PhD or Master's thesis. For instance, Bilal *et al.* (2016) proposed a Big Data architecture for construction waste analytics. The framework consists of three layers that include (i) Application, (ii) Analytics, and (iii) Storage, which are necessary for waste–related data storage and analysis in the design stage. The framework beneath (Figure 2.3) can help designers with instant feedback to optimise the building design.

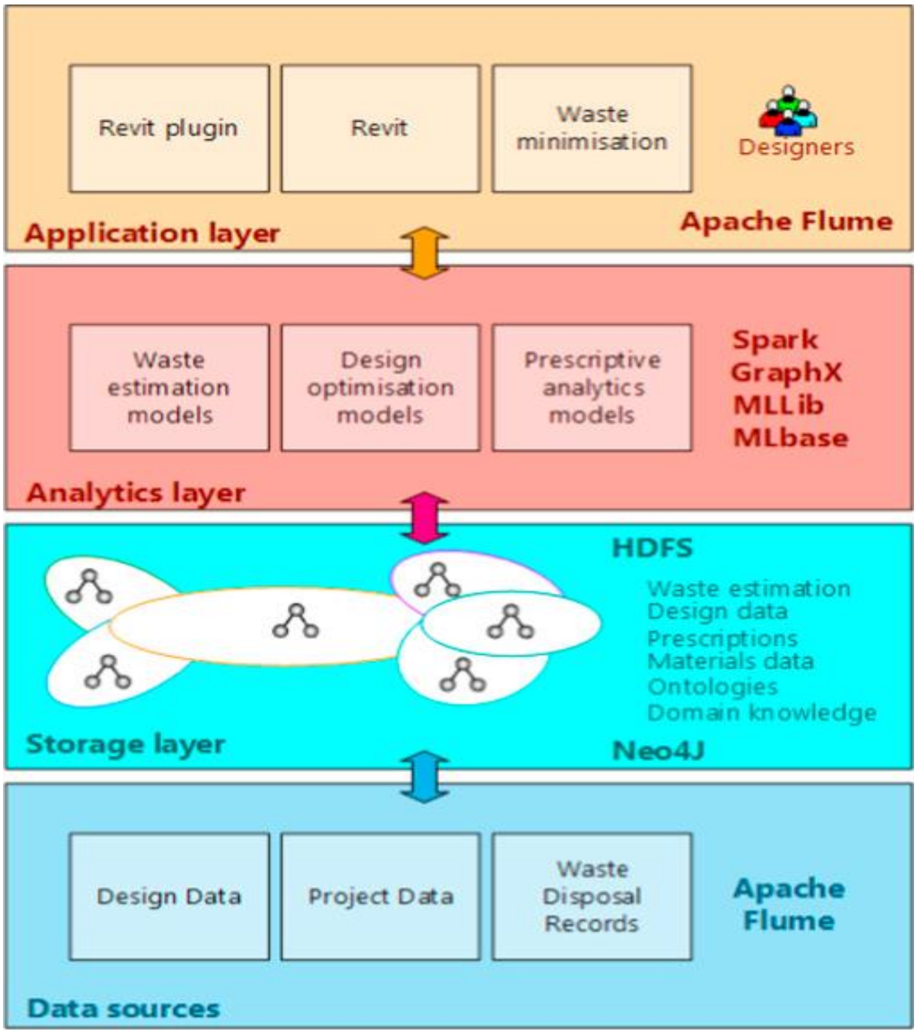

Figure 2.3: Big Data architecture for construction waste analytics (Bilal *et al.,* 2016)

Ogunmakinde (2019) developed a circular economy–based construction waste minimisation framework for Nigeria. The framework consists of four dimensions to deal with waste, arising due to design, materials procurement and construction activities. The dimensions consist of variables: attitude and perception of waste amongst practitioners, assessment tools, waste management hierarchy model, and strategies for waste minimisation in the three stages; policy and implementation factors. Bui (2018) proposed a decision–making framework to improve demolition waste management in urban redevelopment projects in Vietnam. The framework consists of five criteria for effective demolition waste management and a database to support the decision–making process of demolition waste. The criteria include technical, environmental, economic, social, and institutional factors. The framework can aid demolition waste management using a GIS tool to identify and store information on locations of projects, transportation routes, landfill site location, and site planning.

Ismam and Ismail (2014) proposed a strategic framework for planning construction waste management. The framework consists of four key criteria: regulation, policy, technology, and guideline to help the government improve waste management performance and aid stakeholders in engaging and collaborating with the government in implementing waste management strategies. Yakhlef (2020) developed a strategic framework for the Jordanian construction industry to help facilitate sustainable development. The framework consists of four criteria: government guidelines, technology, policy, and regulation to help promote sustainable waste management in a project life cycle in line with the Three R’s principle. Bao and Lu (2021) proposed a decision–support framework for planning construction waste recycling in Shenzhen, China. The framework (Figure 2.4) consists of external and internal criteria that a decision–maker should consider if construction materials should be recycled onsite, offsite or the combination.

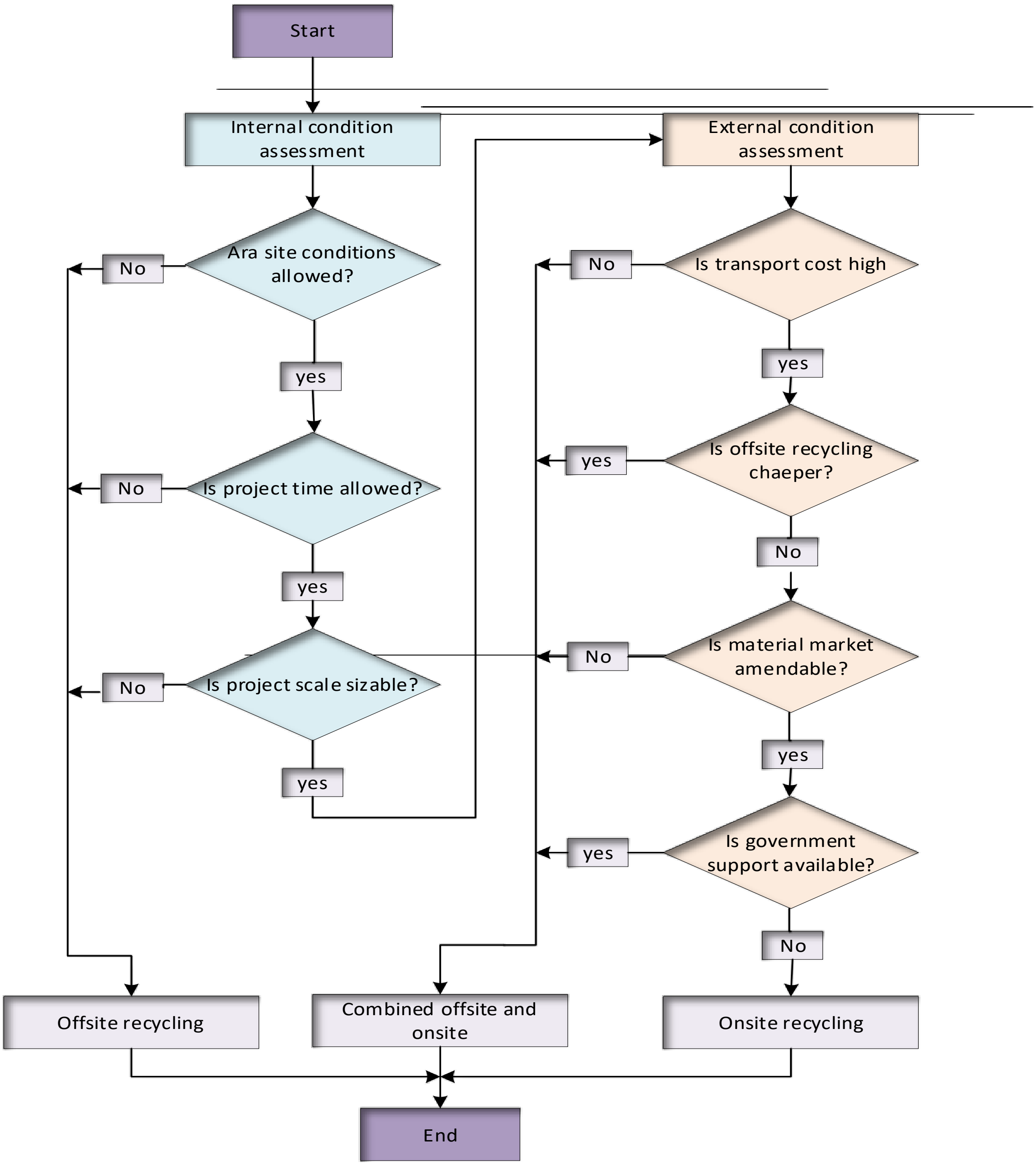

Figure 2.4: A decision–support framework for planning construction waste recycling (Bao and Lu, 2021)

Lu *et al.* (2021) developed a construction waste analytical framework for zero waste construction sites. The framework consists of three main components: system boundary, assessment period, and operation strategies. The framework shown in Figure 2.5 can be used to examine existing construction waste management practices to promote zero–waste agenda in the construction industry.

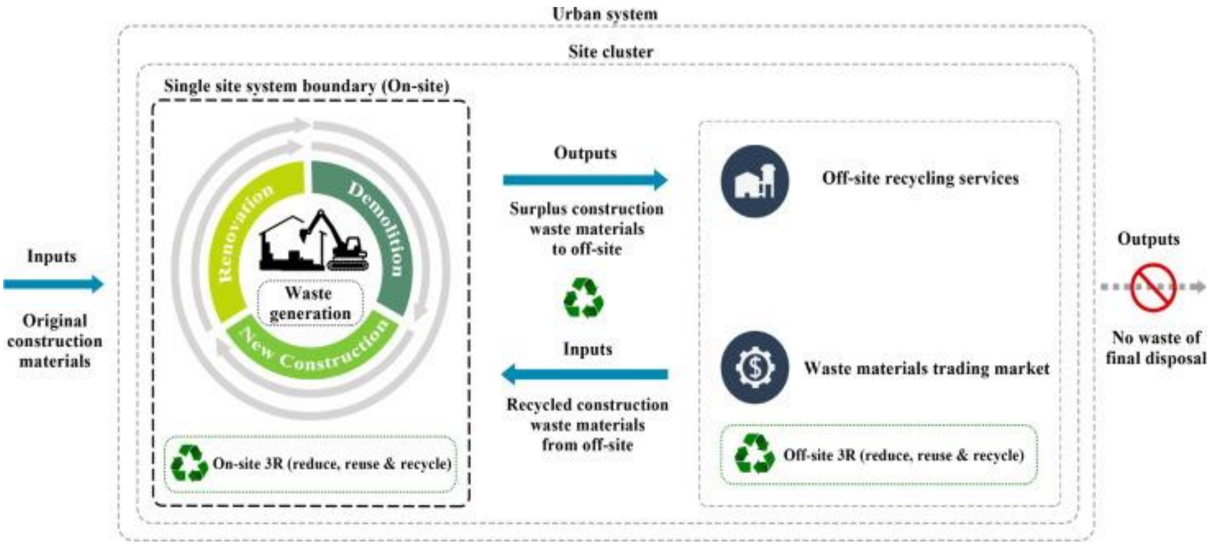

Figure 2.5: An analytical framework of "Zero Waste Construction Site (Lu *et al*., 2021)

Yeheyis *et al.* (2013) proposed a conceptual framework to maximise the 3Rs implementation in the Canadian construction industry from a lifecycle perspective. The framework contains five major areas enabling 3Rs implementation in the preconstruction, construction, renovation, and demolition stages. These are policies, design, material management, construction practice and selective demolition. In addition, the framework can guide decision–makers in selecting material, sorting, recycling, reuse, and treatment or disposal options for C&DW. Noor *et al.* (2019) proposed a supply chain framework for construction waste management consisting of five main stages: waste generation, waste collection, waste segregation, waste reusing and recycling; and waste disposal to manage materials waste such as wood, metal, steel, bricks, cement and packaging. The framework provides action for tackling waste in the five stages to manage the construction industry's supply chain for waste reduction.

2.9. Waste Management Drivers in the Construction Industry

The need to improve competitiveness in organisations has been increasing in recent years. As a result, many studies have investigated critical factors that can drive sustainable development at the regional, national or industry levels (Hofstad and Torfing, 2015; Lozano and von Haartman, 2018). For instance, sustainable construction can be enhanced by effective waste management and should be driven by several factors for effectiveness (Sev, 2009). From the literature, these drivers include the environment (Ortiz and Castells, 2010; Crawford *et al.,* 2017), economy (Begum *et al.,* 2007a), regulation (Villoria Saez *et al., 2011*; European Union, 2018), the industry and society (Udawatta *et al.,* 2015; Ding *et al.,* 2018b).

2.9.1. Environmental driven

The natural environment is threatened by resource extraction and waste generation. Construction waste mixed with hazardous substances (e.g. asbestos) poses an even more significant threat to society. Moreover, the industry is one of the major consumers of natural resources. Large quantities of these resources often become waste from extraction to end of life. Disposal of waste constitutes an environmental burden via pollution of various kinds. Pollutions, notably air pollution due to incineration, are causing global warming and climate change. Also, moving waste to recycling centres creates transportation demand, resulting in gas emissions, noise pollutions, and traffic congestion. In addition, recycling operations account for air and noise pollution. To minimise these impacts, scholars use the life cycle environmental impact assessment of construction projects and materials/products to drive waste management for environmental protection. Life cycle assessment is a systematic decision–making approach for promoting the design and construction of green buildings (Ding *et al.,* 2016). In that case, environmental impact factors such as materials extraction, transporting, storage, use treatment, recovery, and disposal can be considered to make environmentally friendly decisions in the construction industry.

Environmental management appears underdeveloped in Nigeria due to low technological development, lack of public awareness, government support, and insufficient knowledge of environmental issues. Aware of these limitations, Omofonmwan and Osa–Edoh (2008) recommend raising awareness from the grassroots by introducing environmental management techniques in Nigeria's primary and secondary school curricula to deal with some of these issues.

2.9.2. Economic Driven

The economic value of waste management is vital in the construction industry. While waste minimisation could result in economic benefit, some strategies may be cost–ineffective. Hence, the idea of avoidable and unavoidable waste was mentioned earlier (Formoso *et al.,* 2002). Al–Hajj and Hamani (2011) revealed that contractors are motivated by the financial benefits of waste minimisation more than concern for the environment. In that regard, contractors are happy to adopt waste management solutions with cost benefits rather than strategies that result in a financial loss. This attitude may likely impede the environmental management of construction waste as some important waste management strategies can be ignored due to the implementation costs.

Some studies have investigated the economic benefits of various waste management strategies. Most of these were carried out to determine the economic benefits of recycling (Duran *et al.,* 2006; Zhao *et al.,* 2010). According to Duran *et al.* (2006), waste is likely to be minimised in projects when the cost of disposal exceeds the cost of recycling and when using primary concrete aggregates exceeds the cost of recycled aggregates. Moreover, higher transportation cost is likely to make waste minimisation attractive from an economic perspective. This evidence suggests that contractors are likely to invest in the necessary training when disposal and transportation costs are more than training employees on waste management strategies.

2.9.3. Regulation Driven

While regulation is a key driver of construction waste management, evidence suggests inadequate resources limit compliance or full implementation. Shen and Tam (2002) noted that contractors in Hong Kong lament the over–active imposition of environmental regulations by the authorities. The authors identified that the key barrier to waste management implementation in Hong Kong is the cost of implications and the time–consuming process for improving environmental performance. On the other hand, stakeholders are more interested in project cost and time performance than regulations. Testa *et al*. (2011) claimed that company size is also a factor as small and medium firms may face challenges in achieving a high level of environmental compliance due to financial constraints. In addition, some firms may have limited resources to strictly adhere to all environmental regulations, thereby creating more waste management challenges. Therefore, well–developed legislation and tax measures that include incentives may be required to make environmental compliance more desirable in organisations. In that regard, legislation can be perceived more as a motivation than punishment to mitigate the barriers to improving environmental performance in construction, thus, to drive good waste management practices (Shen and Tam, 2002).

2.9.4. Industry and Public Driven

Many research studies have been published to assist practitioners in achieving effective waste management in the construction industry. Consequently, construction stakeholders are becoming aware of the issues of waste due to the significant efforts made from the academic perspective to improve the culture of sustainable and effective waste management in the construction sector (Wu *et al.,* 2019). It is expected that the internal stakeholders should be aware of the importance of effective waste management, particularly from the clients or contractors that bear the costs of waste generation (Kulatunga *et al.,* 2006). Therefore, increasing clients' awareness is a recommendable driving force (Osmani *et al.,* 2006). Accordingly, contractors may have to show acceptable waste management practices during tendering. This can enable potential clients to consider them for projects and future partnering. Furthermore, the growing need for social sustainability drives waste management objectives within the industry as organisations want to improve their public image to remain competitive in the market. Finally, the increasing environmental awareness and demand from host communities to exist in a sustainable environment have become a strong driving force.

2.10. The Nigerian Construction Industry

According to the Nigeria National Bureau of Statistics (2015), organised construction started in Nigeria in the early 1940s with a few foreign companies with high demand for their services, followed by the oil boom about ten years after independence in 1960. Due to infrastructure development needs, the country allowed expatriates and a few indigenous companies and investors to operate. Nigerian National Bureau Statistics (2019) noted that the industry was a major economic contributor post–independence, employing thousands of people and increasing the country's GDP until the discovery of crude oil that has taken centre stage as a major economic revenue to date.

The Nigerian construction industry consists of various clients that include public and private sectors. The industry consists of international establishments, small–medium enterprises (SME), and large corporations with different practitioners operating in different capacities. These include but are not limited to architects, estate surveyors, project managers, quantity surveyors, and artisans. As a developing country, the federal government is the most important client, undertaking complex and multimillion projects, with about 64.9% influence by value on the industry (Adamu *et al.,* 2015). In comparison, state governments account for only 22.7% of construction works (Adamu *et al.,* 2015).

The industry is divided into two major groups: the organised, "formal," and the unorganised, ''informal''. The unorganised is usually operated by artisans and labourers that can be hired on the streets and roadsides. The government has almost insignificant influence on their operations and receives little or no revenue taxes; hence, it can be challenging to obtain reliable statistical data about this group. On the other hand, the organised, for which all the data available is derived, constitutes all the major companies legally registered in the country with skilled employees and labourers. The construction companies are expected to operate under set rules and regulations, including adherence to environmental laws, procurement, and tendering (Dantata, 2008). Unlike the informal group, the government collects revenue taxes from the formal sector.

The Nigerian construction industry faces significant waste management challenges owing to its limited waste management infrastructures (Ogunmakinde et al., 2019). Therefore, the following section discusses factors militating effective solid waste management in Nigeria, impacting the construction industry on several fronts. Also, efforts required from different stakeholders to mitigate these challenges towards sustainable waste management in construction are discussed.

2.10.1. Inadequate Financial Investment on Waste Management

Lack of financial investment can impede the implementation of sustainable waste management in a nation. Multiple research studies across Nigeria have identified inadequate funding as one of the key issues affecting waste management (Ogwueleka, 2009; Ike *et al.,* 2018). In addition, they point out the government's inability to provide facilities required to effectively carry out waste management in many localities and their failure to sustain the already existing systems. According to Ogwueleka (2009), lack of institutional arrangement, insufficient financial resources, absence of bylaws and standards, inflexible work schedules, insufficient information on quantity and composition of waste, and inappropriate technology are the areas that require attention. Also, inadequate financial investment hampers effective waste management in the construction industry. Therefore, investing in measures such as staff training and incentives (Park and Tucker, 2017), waste skips and waste management research are some of the measures that contribute to effective and sustainable waste management in the construction industry.

2.10.2. Legislation and Policy Implementation

Many studies have identified Nigeria's waste management legislation and policies as inadequate (Abila and Kantola, 2013). Conversely, others suggest that Nigeria does not lack environmental laws, but that enforcement and compliance are the problems. For instance, Onu *et al.* (2012) argued that the environmental policies are not inadequate but monitoring and enforcing the existing regulations are the limitations. According to the study, many existing policies are fragmented, citing the National Environmental Standards and Regulations Enforcement Agency (Establishment) Act, 2007 (NESREA Act, 2007). The fragmentation makes effective implementation difficult and encourages incoherent implementation processes that promote corruption, consume time and resources (Eneh and Agbazue, 2011).

These studies suggest that solid waste management lacks adequate public participation, effective enforcement by authorities, and compliance by many organisations. Therefore, one can argue that the factors that drive waste management in Nigeria are more or less internal voluntary efforts (i.e. companies' environmental moral ethics and standards) rather than policy enforcement by the authorities. Although a voluntary effort is commendable, it may be challenging without active monitoring, encouragement and enforcement for compliance.

2.10.3. Limited Infrastructures and Skilled workforce

Effective waste management requires adequate infrastructure and skilled workforce availability. Okeke *et al.* (2019) suggest that limited infrastructures and human resources contribute to poor waste management in Nigeria. They claimed that waste management agencies lack adequate skill and human resources and, to a large extent, are not exposed to workshops and training that meet international standards on technology use, information, and knowledge management. According to Agumwaba (2008), most Nigerian's Environmental Protection Agency employees are not adequately trained in waste management solutions. This problem also reflects Nigerian construction employees' lack of or inadequate training on waste management measures (Eze *et al.,* 2017).

2.10.4. Low Level of Awareness

Public awareness is critical for sustainable waste management in any nation. Unfortunately, studies suggest that public awareness of waste management is low amongst Nigerian citizens. For instance, the Nigerian populace hardly separates waste from the source, making recycling difficult (Adekola *et al.,* 2021). According to Wahab and Lawal (2011), Nigerian contractors seldom separate wastes generated in their projects. Therefore, it has been suggested that integrating the informal sector, such as waste scavengers, in the national waste management framework will help to promote waste separation for recycling (Agunwamba, 2003; Eric *et al.,* 2019). Scavengers usually pick and separate waste materials from open landfills and sell them to potential recyclers. Although this system contributes to the recycling of materials, the lack of formalisation of the sectors makes it unsustainable and unreliable.

2.10.5. Unplanned Developments and Population Increase

Population growth and unplanned development contribute to waste management difficulties in most Nigerian cities. Unplanned urban areas are a direct consequence of weak policies, poor urban design engineering (Ogbazi, 2013), inequality and poverty. Therefore, proper urban planning and re–engineering are recommended to mitigate these problems (Amasuomo and Baird, 2016).

2.10.6. Poor Recycling Culture

Recycling of materials is a critical waste management strategy widely promoted globally. However, according to Amasuomo *et al.* (2015), Nigeria has a poor waste collection and recycling culture due to limited recycling programs. As a result, many used materials are disposed of irresponsibly. This method of treatment often poses a significant threat to the environment and to the stability of ecosystems. Unfortunately, it appears that these methods have been normalised as many Nigerian citizens are ignorant of the threats and dangers created. Hence, pragmatic solutions are required to solve this problem beginning with government commitment and citizens awareness.

2.11. Roles of Stakeholders towards Improving Waste Management in Nigeria

2.11.1. Role of Government in Waste and Environmental Management

In Nigeria, the local government authorities are statutorily charged with MSW management. However, the present state of the environment has shown that this tier of government often lacks the capacity and capability to fulfil this obligation without the states and the central government's assistance. To fill this gap, the states and federal environmental agencies have, over the years, embarked on intervention programs to assist local governments in MSW management (Muhammed, 2012). However, the states and federal government interventions also require improvement due to the obvious environmental management negligence. Therefore, it is expected that the government at all levels must step up their role to provide urgent intervention programs, policies and monitoring of industries activities, particularly for a more sustainable built environment. According to Ajibade (2007), any waste management intervention effort must be culturally feasible and relevant. Therefore, it is evident that the federal and states ministries of the environment should encourage construction companies to subscribe to an environmental management system (EMS), such as ISO 14001.

An EMS is an essential tool that helps organisations improve practices to minimise the environmental impacts due to their activities. The word ‘waste’ cannot be mentioned without relating it to the impacts on the natural environment. Therefore, efforts have been made to develop measures to protect the environment using different EMS. For instance, an EMS, particularly the ISO 14001 standard, is important for waste management. It contains many activities and processes useful for effective and sustainable waste management. Based on Plan–Do–Check–Act (PDCA) principles, Thyberg and Tonjes (2015) identified the following basic attributes of ISO 14001 standard: EMS scope; policy; environmental aspects and impacts; legal and other requirements; environmental objectives, targets, and programs; resources and responsibility. Others include competence and training; communication; documentation; control of documents; operational control; emergency preparedness/response; monitoring and measurement; evaluation of compliance; corrective and preventative actions; control of records; internal auditing; and management review. According to Rodríguez *et al.* (2007), ISO 14001 contributes to sustainable waste management in the construction industry. These contributions are related to life cycle thinking (Rosado *et al.,* 2019) and recycling (Ortiz *et al.,* 2010). Meanwhile, for an EMS to be effective, the system should comply with applicable legislation and continual improvement process (Christini *et al.,* 2004). The following benefits are attributed to ISO 14001 implementation (ISO, 2015).

- Protects the environment by preventing or mitigating adverse environmental impacts
- Mitigates the potential adverse effect of environmental conditions of an organisation
- Assists organisations to fulfil environmental compliance obligations
- Enhance environmental performance
- Influence the way organisations' products and services are designed, manufactured, distributed, consumed and disposed
- Achieve financial and operational benefits due to implementing environmentally sound alternatives, which strengthen organisations' market position
- Communicate environmental information to relevant interested parties

The updated ISO 14001 (ISO 14001:2015) standard is further divided into more requirements than the former ISO (14001:2004) but maintains the same intended outcome as stated above. ISO 14001 is voluntary; meanwhile, its adoption in many developing countries, such as Nigeria, appears low compared to the developed counterparts (Institute of Environmental Management and Assessment, 2017). Studies on EMS adoption and implementation in construction are well documented, including the limitation of adoption in developing countries. For instance, Owolana and Booth (2016) found some key opportunities and barriers to implementing EMS in the Nigerian construction industry. The authors revealed significant opportunities: improved efficiency in waste management, environmental protection, and increased employee motivation due to better training and development opportunities. On the other hand, the authors found barriers, such as lack of organisational, technological support and high EMS implementation costs. Therefore, there is a need for the federal and states' ministries of the environment to investigate these barriers for potential mitigation. This may likely increase ISO 14001 EMS adoption and implementation in the Nigerian construction companies.

2.11.2. Role of Professional Bodies

It is the role of professional bodies to promote and monitor the practices and quality of services industries provide. The Nigerian engineering professional bodies have a significant role in ensuring a sustainable built environment. For instance, the Council for the Regulation of Engineering in Nigeria (COREN) promotes a sustainable environment by verifying and registering engineering and building professionals. In addition, the council regulates and monitors the engineering and technical professions to discourage quackery. However, quackery, especially in construction, exists. This problem is a significant reason for incessant building collapse across Nigerian cities (Tanko *et al.,* 2013; Wordu and Kanu, 2021). To solve this problem, professional bodies such as the COREN and others can provide further training for graduate engineers and builders, train aspiring engineers in basic science and technical knowledge, improve the verification and registration process (Tanko *et al.,* 2013). Such a program should include vocational training in waste management practices.

2.11.3. Role of Construction Organisations

The construction industry has a significant role in ensuring environmentally sustainable practices. While the industry faces national and local barriers in solid waste management, the construction industry can embark on an agenda by identifying criteria to promote waste minimisation within organisations. Hence, it is a key objective of this study. In addition, it is expected that practitioners comply with the external existing environmental regulations as a duty of care with minimal or no monitoring.

2.11.4. Role of Researchers

The Nigerian Building and Road Research Institute (NBRRI) is responsible for researching and developing building and road materials. The institute under the Federal Ministry of Science and Technology is the research arm of the ministry with the mandate to research the following (NBRRI, 2021).

- Local building and construction materials to determine the most effective and economical methods of their utilisation.
- Architectural design of buildings to suit Nigerian climatic conditions concerning lighting, ventilation, thermal comfort and humidity.

- The design and performance of functional units in buildings, including electrical installations, plumbing, painting, drainage, ventilation and air–conditioning system.
- Local construction, foundation and earthworks for buildings and bridges, especially on problem soils.

Also, several studies have been published on solid waste management for Nigeria from different perspectives and industries (Wahab and Lawal, 2011; NBRRI, 2021). This set of studies provides information about waste management in Nigeria. They can serve as guidelines for practitioners and reference handbooks for researchers. These studies recommend research gaps that need to be filled for sustainable waste management practice. Researchers can play a significant role in ensuring that obvious gaps are adequately filled so practitioners can access construction waste management literature.

2.12. Chapter Summary

This chapter has provided an overview of the construction waste management challenges. It has revealed the concept of waste and compositions. Also, the causes of construction waste and sources were identified, particularly in the Nigerian construction industry. The chapter further discussed the basic waste management model, showing the importance of the (3Rs) philosophy in developing any waste management strategy, framework or model. Also, it shows that ineffective solid waste management in Nigeria impacts the construction sector. Thus, it presented solid waste management challenges in Nigeria and different stakeholders' roles for sustainable waste management.

Findings from the literature review reveal that late design changes, purchase of substandard materials, and inadequate site supervision are the leading causes of waste generation in Nigeria. In order to minimise construction waste effectively, several measures were discussed, but practitioners must make efforts to prioritise and implement them. The most effective measures are planning and prioritising waste management strategies early in projects for smooth operations. Also, after waste is generated, it is highly recommended to segregate them into categories toward reuse and recycling. However, contractors must be ready to invest resources to minimise waste in the construction industry. Meanwhile, contractors are reluctant to implement waste management strategies that represent an economic burden. Therefore, the literature suggests that the cost of implementing waste management strategies must be less than the disposal cost to be attractive.

It is worth noting that waste management measures can be integrated into a framework for strategic or operational improvements. Therefore, the next chapter reviews the frameworks for effective waste management strategies towards the research conceptual framework.

CHAPTER 3: FRAMEWORK FOR EFFECTIVE CONSTRUCTION WASTE MANAGEMENT STRATEGIES

3.1. Introduction

The current chapter reviews concepts through which construction waste management strategies can be implemented. First, from the literature review, a framework is presented of which the position of the current research in the wider literature can be identified. Second, the materials procurement and construction waste management criteria and attributes were identified and presented, which aided the development of the research conceptual framework to guide the research towards fulfilling its goal.

3.2. Whole–Stage Consideration

Waste management is currently considered in all project stages due to the dynamic nature of waste generation from the design to end–of–life (Yeheyis *et al.,* 2013; Bakshan *et al.,* 2015). Therefore, different stages of construction projects are being considered to identify and implement strategies necessary for managing waste in a specific construction phase. The following section reviews strategies for waste minimisation applicable in project delivery stages.

3.2.1. Design Stage Consideration

The design stage significantly impacts the amount of waste generation in construction projects. This statement echoes several studies investigating the impact of design on waste generation in construction and minimisation strategies (Faniran and Caban, 1998; Ekanayake and Ofori, 2004; Osmani *et al.,* 2008). The emphasis on the design as a preliminary origin of construction waste suggest designers need to tackle waste decisively at this stage before it starts occurring in site operations. Therefore, the literature indicates that waste can be minimised significantly by identifying and implementing the best design strategies (Ekanayake and Ofori, 2004). The earliest decision in capturing the best design strategies offers the most significant opportunities for waste minimisation. Design strategies are mainly targeted at the design team to implement efficient design devoid of waste. WRAP (2009a) captured five key attributes for effective design management and framework. These include a design for material optimisation (DfMO), design for off–site construction (DfOC), design for waste–efficient procurement (DfWEP), design for reuse and recovery (DfRR), and design for deconstruction and flexibility (DfDF). Ogunmakinde (2019) identified and used these attributes to develop a circular–economy–based framework for waste minimisation for the Nigerian construction industry.

The competency of designers to design out waste has been the subject of an investigation to find possible means of eliminating waste as earliest as possible. For instance, Ajayi *et al.* (2016b) grouped design competency into five categories: three are task–related, while two are contextual competencies related. According to the authors, the task–related are low waste design skills and construction–related knowledge. The contextual competencies include behavioural competence and inter–professional collaborative abilities. Therefore, the literature suggests a need to improve designers' competencies through tailored training is mostly required (Osmani *et al.,* 2008; Ajayi *et al.,* 2016b). The above studies indicate that lack of competency in tackling waste in the design stage increase the cost of making any change when the design has been built. This evidence is based on the philosophy that the first approach to waste minimisation is effective and collaborative design management.

3.2.2. Contract Procurement Consideration

Masterman (2002) described a procurement system as a strategy or method for procuring a project. The study suggests a procurement route should be of a client's interest and satisfy the overall project need. Procurement decisions determine an organisation's structure and arrangements, such as the line of authority and stakeholders' key responsibility, and a payment method. Also, it determines the cost, time, quality, and waste management responsibilities. Procurement decisions involve considering cost and time certainties, speed, and flexibility. Therefore, procurement systems have been compared in terms of time, budget, buildability, payment methods, waste efficiency, collaboration efficiency and projects performance (Luu *et al.,* 2003; Onosakponome *et al.,* 2011). Procurement routes are entrenched in the traditional, design and build, construction management, management contracting, partnering, and other methods. Each procurement system has its unique characteristics (Tookey *et al.,* 2001); hence, a client must be guided accordingly to meet both the client and project needs (Ambrose and Tucker, 1999). Therefore, procurement decision–making requires weighing a client's attitude to risk and other factors before selecting the right route.

The choice of a procurement route can influence waste management in projects. Gamage *et al*. (2007) claimed that some procurement systems could aid waste minimisation more than others by revealing their strengths and shortcomings. Accordingly, several models have been developed to guide construction clients in selecting appropriate procurement systems considering their characteristics (Luu *et al.,* 2003a; New Zealand government procurement, 2019). For instance, Forgues and Koskela (2009) suggest that traditional procurement reinforces socio-cognitive barriers that hinder team efficiency. Thus, construction procurement methods have evolved towards partnership–based approaches. Consequently, there is a belief that collaborative contracting encourages alliance amongst construction actors compared to the traditional. Some modern procurement methods encourage collaboration in a project delivery process; however, the application of the traditional method is common due to clients' familiarity with the system (Oyegoke *et al.,* 2009; Ren *et al.,* 2012; Oladirin *et al.,* 2013).

Since all procurement systems have unique strengths and shortcomings, the selection may continue to depend on clients demands, project peculiarity and consensus among project participants. However, it is beneficial to integrate collaboration in procurement decisions irrespective of the choice of a procurement system. Moreover, collaboration is a step towards improved waste management performance (Dainty and Brooke, 2004). Currently, literature on contract procurement for waste minimisation is scarce.

3.2.3. Effective Materials Procurement and Logistics

Besides the design stage, ineffective material logistics management is another factor of waste generation in the construction industry. Materials procurement is selecting, ordering and delivering materials required for a project. This process could be a difficult task; in the absence of effective logistics management. Some strategies to ensure a smooth materials procurement include careful materials handling during loading, transition and off–loading, correct estimation and quantity delivery (Akintoye 1995; Bertelsen and Nielsen 1997). Additionally, timely delivery of materials onsite can enable the timely completion of projects. Therefore, mistakes due to time pressure to complete a project can be reduced significantly.

Several studies suggest a strong alliance with material suppliers as one of the key procurement strategies. A long–term relationship with a supplier can potentially ensure transparency on material quality, quantity, timely delivery, and the prevention of opportunistic behaviours inherent in the construction industry (Vrijhoef and Koskela, 2000; Jiang *et al.,* 2012). According to Segerstedt *et al.* (2010), central coordination among partners, employing decentralised task management, appropriate IT solutions; and mutual trust among stakeholders are critical for an efficient alliance with suppliers. In addition, literature suggests that top management support and effective contractual arrangement with suppliers are essential for purchasing and delivery decisions (Dainty and Brooke, 2004). In that case, materials can be delivered just–in–time, in good condition and desired quantity.

3.2.4. Construction Stage Consideration

Significant research efforts have been devoted to managing waste in the construction stage due to the tangibility of waste at this phase of the construction delivery process. When waste is generated on a construction site, the first approach is to separate the waste into categories to reuse and recycle different materials (Poon *et al.*, 2001). It is, therefore, expected that contractors should maximise the reuse and recycling of construction materials before disposal to reduce waste outputs in projects.

Training employees to improve their waste behaviours is critical for onsite waste management (Li *et al.,* 2018). Other strategies include using a SWMP and low waste construction techniques (Poon *et al.,* 2003). However, the effectiveness of these strategies depends on the cooperation of the industry's stakeholders, the seriousness of the relevant authorities to develop/enforce policies and the collection of feedbacks from past projects to improve performance. Also, Teo and Loosemore (2001) identified some measures to improve waste management in the construction stage. These are management support and commitment to waste minimisation, employees' participation, incentives and training to help change the waste behaviour of employees. Other measures are related to effective contractual arrangements with sub–contractors to share waste management responsibilities. Thus, the idea of extended producer responsibility is encouraged (Lu *et al.,* 2015; Ouda *et al.,* 2018). This evidence suggests that waste management is the responsibility of everyone involved in construction activities, particularly subcontractors in collaboration with contractors.

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3.3. Technology Frameworks

Modern technologies have revolutionised the construction industry for efficient delivery of projects. These technologies have been found useful for waste management in construction. Building Information Modelling (BIM), Big Data, Geographic Information (GIS) and Bar code systems have been identified as the emerging technologies for waste management in the industry. These technologies are discussed in the following sections.

3.3.1. Building Information Modelling

Although BIM is not primarily developed as a waste management tool, the advent of BIM is a breakthrough in interdisciplinary collaboration, a measure for waste reduction in the design process. BIM offers a significant opportunity to design out waste by enabling clash detection to reduce design errors (Love *et al.,* 2011). Meanwhile, BIM has insufficient design decision–making tools for comprehensive waste management in the design stage (Liu *et al.,* 2015). Consequently, studies have proposed the extension of BIM functionalities to accommodate more waste management objectives. Therefore, there is a quest to integrate more waste management plug–ins into the BIM software based on construction stakeholders' expectations. According to Akinade *et al.* (2018), construction practitioners' expectations on BIM include: (1) BIM–based collaboration for waste management; (2) waste–driven design process and solutions; (3) waste analysis throughout building lifecycle; (4) innovative technologies for waste intelligence and analytics; and (5) improved documentation for waste management.

Other studies have demonstrated that BIM can accommodate waste management objectives by proposing different methods. For instance, Guerra *et al.* (2019) proposed a BIM waste estimation method and used concrete and drywall waste streams to demonstrate its practicality. Akinade (2017) proposed a BIM–based software for construction waste analytics using artificial intelligence hybrid models. Cheng and Ma (2013) proposed a BIM–based system for demolition and renovation waste estimation and planning. Currently, BIM enables waste minimisation through efficient design planning, team coordination and collaboration, and materials quantity take–off. Meanwhile, it is expected that more plug–ins into BIM software for waste management will improve the efficiency of design management.

3.3.2. Big Data Analytics

Big Data software can store, process and analyse large volumes of datasets. It is basically known as 'data with multiple Vs', which signifies volume, velocity, and variety (De Mauro *et al.,* 2015) because of the ability to accommodate a large amount and heterogeneous data sets and efficient processing. Studies on Big Data analytics are in their infancy in the construction waste management domain. Few have demonstrated the importance of Big Data in large–scale projects, such as storage and analysing large volumes of datasets related to waste issues. Lu *et al.* (2016) compared the effectiveness of waste management performance of public and private projects in Hong Kong using Big Data. They found better performance in waste management in public projects than in private projects amongst contractors. Bilal *et al.* (2016a) proposed a Big Data waste analytical tool for a project's life cycle, which they categorised into three layers: (1) application, (2) analytics, and (3) storage. They stressed the importance of Big Data in collecting large volumes of waste–related data, such as project code, operation code and site reference numbers, amongst others. Lu *et al.* (2015a) determined the waste generation rate (WGR) of different construction projects in Hong Kong using Big Data analytics using similar information.

Bilal *et al.* (2016a) claimed that existing waste intelligence practices are unable to tackle waste in the construction industry. The author proposed that waste analytics is the next–generation approach for construction waste management. With Big Data evolving in the construction waste management subject, scholars have proposed Big Data and BIM integration to assist waste management in the design stage (Bilal *et al.,* 2015). Big Data and BIM integration is promising for more efficient waste management in the design stage. Large and complex projects usually have large volumes and complex data, which may require urgent analysis in BIM. Such integration is expected to provide speedy computation, storage and analysis of waste management data in the design stage.

3.3.3. Geographic Information System

GIS is commonly used in environmental sciences to identify local or regional locations via real–time visualisation. The system is designed to capture, store and analyse geographical data. GIS is also an emerging technology in the construction waste management domain. Some of the importance are revealed by many studies. For instance, Zainun *et al.* (2016) used GIS to discover construction waste dumping sites in sixty–four unauthorised landfills in Kluang, Malaysia. Seror and Portnov (2018) investigated the factors causing the illegal dumping of construction waste in Haifa, Israel. The study shows that the distance to the nearest main road, the depth of a ravine at the site, and forest proximity were the main factors associated with the city's illegal dumping of construction waste.

Illegal landfill sites constitute a major environmental problem in urban cities. Therefore, revealing such sites through a remote sensing tool discourages construction companies from depositing waste in an unauthorised site. Also, it can prevent legal actions from the government or individuals who may be affected. Such deterrence could make organisations minimise waste due to the cost of depositing them in a legitimate landfill site (pay–as–you–throw). Apart from revealing illegal dumping sites, GIS can be used to find suitable locations for developing a recycling facility (Madi and Srour, 2019), enhancing construction site layout (Cheng and O'Connor, 1996), identifying and selecting a suitable landfill site (Oyinloye and Fasakin, 2013). Also, many studies have proposed integrating GIS and BIM (De Laat and Van

Berlo, 2011; Al–Saggaf and Jrade, 2015). Integrating both systems appear as another promising tool for effective construction waste management.

3.3.4. Bar Code Label

The primary purpose of coding materials is to identify a team of employees who manage materials effectively. A project manager can detect the materials and quantities used by construction workers at the end of site activities for potential incentive rewards to encourage efficient resource management amongst employees. According to Chen and Wong (2002); Li *et al.* (2003), the bar code system is based on an incentive reward program (IRP) to motivate workers to efficiently use materials in construction by rewarding them based on the amounts or values of materials saved. The study proposed a group–based incentive reward program using a bar code system for tracking quantities of materials utilised in projects. Examples of bar code label for material management is shown in Figure 3.1

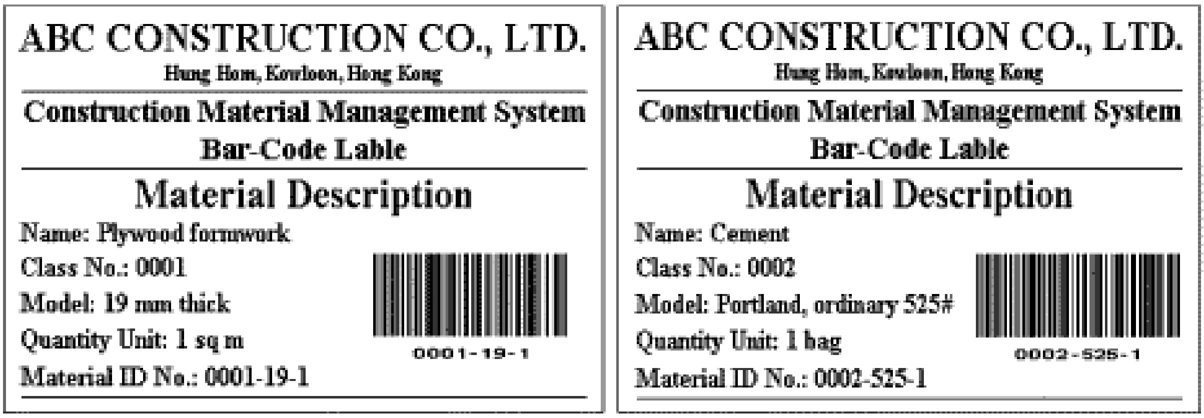


Figure 3.1: Sample bar–code for construction materials (Chen and Wong, 2002)

The Chen and Wong (2002) case study shows that HK$550,000 savings were achieved by applying material bar–coding technology in a Hong Kong residential project. However, it is possible such a system may cause under usage of material by employees to be rewarded. Therefore, despite the industry's quest to minimise waste, it is necessary to ensure that employees use the quantity of materials specified for works to avoid rework or complete structural failure due to under–used materials. This objective could be achieved through training and active supervision.

3.4. Policy Framework

For many countries, the rising level of waste due to the rapid growth of towns and cities and illegal dumping sites have become a critical issue. A policy framework is usually based on penalties and incentives for regulating waste disposal and rewarding sustainable waste management in organisations. Such measures include pay–as–you–throw or incentives, effective in many countries (Blackmer and Criner, 2014; Manni and Runhaar, 2014; Morlok *et al.,* 2017). It follows that a landfill tax policy could compel contractors to increase the reuse and recycling of materials and, in which case, waste disposal could be minimised, and those contractors who demonstrate good waste management could be rewarded.

In the EU, the Waste Framework Directive (2008) (EU Commission, 2008) represents the basic waste management policy for all the member states. The Framework includes whole–life–cycle assessment, inspection, record–keeping and methods for managing waste categories. The Framework intends to encourage each member state to draw up a waste management plan to reduce waste across the regions through green purchasing, polluters responsibility, and other means. The Framework had targeted 70% by weight recycling of non–hazardous C&DW by 2020. In addition, it extends waste management to producers by encouraging them to abide by the (reduce, reuse and recycle) principle.

In the UK, for instance, waste management is an all–inclusive responsibility. Hence, production, circulation, consumption, disposal, and recycling are everyone's responsibility (Hathaway, 2009, in Sakai *et al.,* 2011). The UK introduced a landfill tax charged by weight that includes two rates (standard and lower rates). Inert or inactive waste is subject to the lower rate, while non–inert waste is subjected to the standard rate. As of 1st April 2020, the rates were £94.15/tonne for standard and £3.00/tonne for lowers rates (HM Revenue and Customs, 2018). These rates have increased to £96.70/tonne for the standard rate and £3.10/tonne for a lower rate since 1st April 2021. The new increase is intended to discourage waste production and encourage recycling. The importance of a policy for waste management in the construction industry cannot be overemphasised (Li and Zhang, 2012; Calvo *et al.,* 2014). Therefore, local or regional authorities must develop, enforce, and monitor policies that reflect the concept of the (prevent/reduce, reuse, and recycle) waste management model.

3.5. Decision–Making Frameworks

Decision making is as old as humanity. A simple definition of decision making is the act of choosing a perceived best course of action between two or more options presented to an individual or a group of people based on preferences (Edwards,1954). Decision making is vital in many human activities, such as the home or in professional or political activities. While some decisions can be relatively simple, others may be complex or have significant or insignificant effects. Decision–making involves choices that must be considered and sometimes require a systematic approach to select the best course of action, considering the pros and cons before selecting actions with the strongest pros and weakest cons, particularly for a complex system.

Decision–making models have been applied in the area of waste management from different perspectives. These models can be categorised as those based on cost–benefit analysis (CBA), life cycle assessment (LCA), and multi–criteria decision–making (MCDM), also known as multi–criteria decision analysis (MCDA) (Morrissey and Browne, 2004; Karmperis *et al.,* 2013). The complexity of the construction industry necessitates integrating different waste management criteria to facilitate decision making. Therefore, studies have adopted participatory and systematic tools in the waste management decision making to deal with environmental, social, economic or technical issues. While Figure 3.2 shows the framework for effective construction waste management (CWM) strategies reviewed in the above sections, the following section identifies materials procurement and construction waste management criteria and their attributes.

Figure *4*

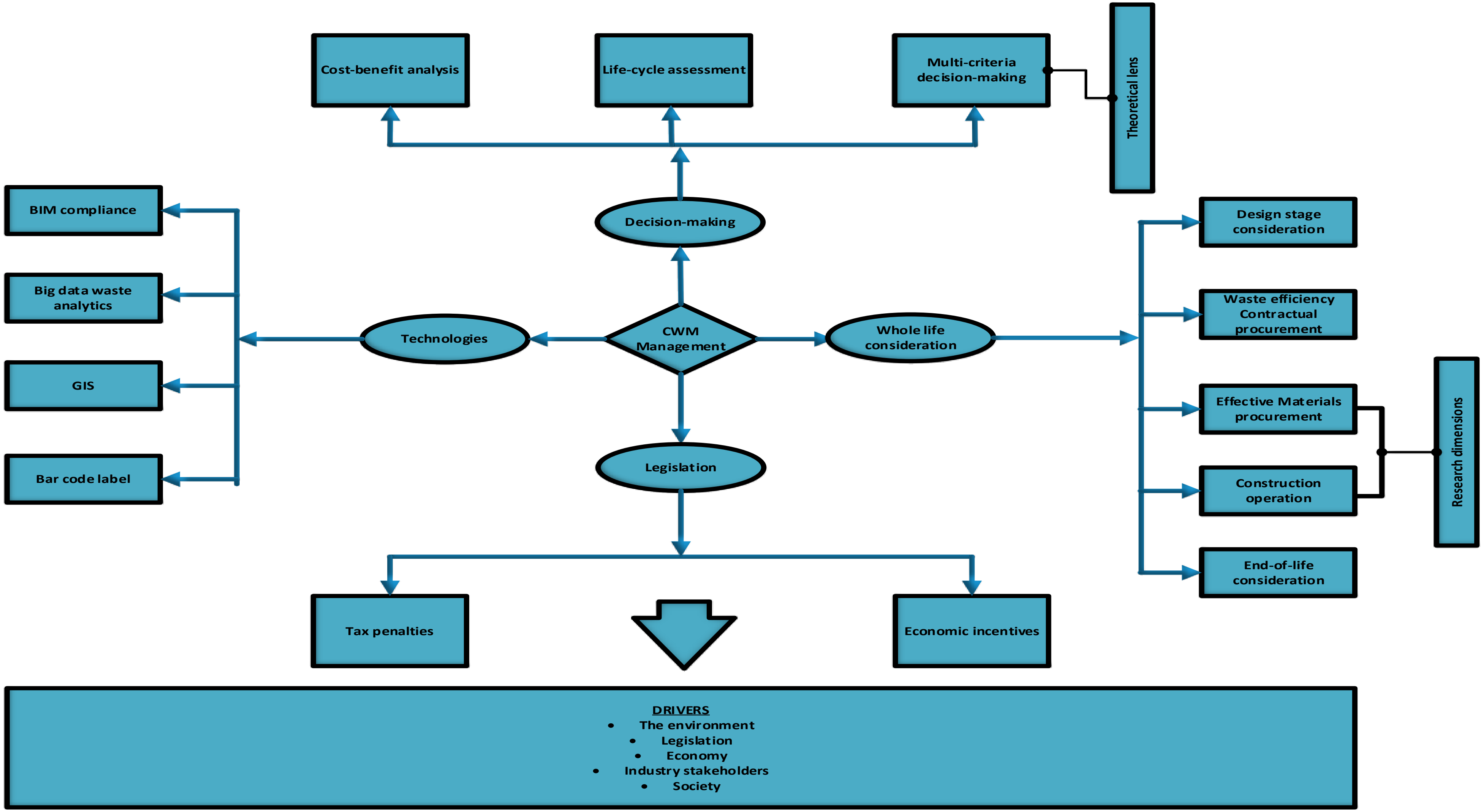


Figure 3.2: A framework for effective construction waste management strategies

3.6. Criteria Influencing Materials Procurement and Construction Waste Management

Decision–making plays a vital role in the environmental management discipline. Selecting suitable strategies to support decisions that could fulfil an environmental management goal has become a significant demand, owing to the growing awareness of environmental issues with a strong emphasis on sustainable development. Therefore, decision–making methods are widely applied in modelling solid waste management problems to find suitable solutions (Morrissey and Browne, 2004; Karmperis *et al.,* 2013). Basically, decision–making begins with problem identification towards providing processes and activities for a solution, usually accompanied by action–oriented recommendations (de Souza Melaré *et al.,* 2017). This means identifying criteria and potential attributes that satisfy the criteria to achieve a goal is vital in decision–making. Therefore, the criteria for managing waste in materials procurement and construction activities are identified regards the focus of this study. These influencing factors have been revealed in different studies.

Studies have viewed waste management from different perspectives considering the three pillars of sustainability (environmental, social and economy) factors that should be examined in the decision–making process. For instance, according to Negash *et al.* (2021), sustainable construction waste management means balancing the environmental, economic and social objectives. Recently, the technical and institutional aspects of construction waste management have been investigated (Poon *et al.,* 2001; Bui, 2018). Scholars have identified top management support systems as a criterion for engaging stakeholders to improve competency and the quality of a company's relationships with its employees and other stakeholders (Teo and Loosemore, 2001; Dainty and Brook, 2004; Tam and Tam, 2008; Ling and Lim, 2002; Ling and Nguyen, 2013; Bakshan *et al.,* 2017; Mak *et al.,* 2019). Top management support is a support system geared towards a culture change that can positively influence effective waste in construction companies. The lack of commitment and support from the top management or senior managers can result in ineffective waste management in the construction industry (Teo and Loosemore, 2001).

Some scholars pointed out that construction waste management should be based on an agreement between stakeholders to enable a contractor or client to evaluate suppliers or subcontractors waste management ability and responsibility based on minimum standards and legal requirements (Lu *et al*., 2016b; Wrap, 20016). The absence of a contractual obligation may not encourage subcontractors and suppliers to implement good waste management practices. Therefore, including waste management clauses in a contract agreement document will influence partnerships and, in doing so, promote waste minimisation at the industry and project levels (Poon *et al.,* 2004a; Cha *et al.,* 2009; Nagapan *et al.,* 2012a, Ling and Nguyen, 2013; Barritt, 2016; Lu *et al*., 2016b; Wrap, 20016; Ajayi *et al.,* 2017a; Wu *et al.,* 2019). Contractual obligations would allow subcontractors and suppliers to collaborate with contractors to implement good waste management as a duty of care. From the above studies, top management support and contract clauses are considered in this study as critical criteria for effective waste management in materials procurement and construction activities.

From the materials procurement perspective, literature shows low waste purchasing (Poon *et al.,* 2004b; Tam, 2008; Wang *et al.,* 2008; Saez *et al.,* 2013; Ajayi, 2017a; Bakchan *et al.,* 2019; Yu *et al.,* 2021b) and efficient delivery management will influence waste minimisation on projects (Bossink and Brouwers, 1996; Poon *et al.,* 2004a; Kofoworola and Gheewala, 2009; Afolabi *et al.,* 2018; Ajayi and Oyedele, 2018). Moreover, low waste purchase and delivery of materials are fundamental components of supply chain management, including just–in–time delivery of materials and inventory management to avoid damage, spoilage, theft and vandalism, and others (Mohopadkar and Patil, 2017).

From the construction stage standpoint, literature emphasises a need for contractors to develop and implement a SWMP and use low waste techniques to minimise waste. A SWMP is used to envisage and document waste types and quantities generated on construction sites and their management options (Mcdonald and Smithers, 1998; Tam, 2008b; Oladiran, 2009b; Price, 2010; Shiers *et al.,* 2014; Gangolells *et al.,* 2014). Further, a SWMP is used to benchmark a project against others for better waste management in the future. In addition, the low waste construction techniques mean using practical tools and methods that support waste minimisation in projects (Poon *et al.,* 2003; Yahya and Boussabaine, 2006; Jaillon *et al.,* 2009; Wang and Tam 2014; Umar *et al.,* 2017).

In this study, the waste management decision factors that can influence effective materials procurement are encompassed under four categories: (1) top management support (procurement), (2) procurement clause, (3) low waste purchase and (4) efficient delivery management. Similarly, the decision–making factors for construction are grouped under four categories: (1) top management support (construction), (2) construction clause, (3) SWMP and (4) low waste construction technique. Thus, these socio–technical aspects of waste management can be integrated to enable construction practitioners to manage waste effectively from different perspectives and using different methods and tools.

Tables 3.1 and 3.2 show the details of references to literature from which potential attributes for each criterion have been derived. The literature search was conducted using keywords (‘construction waste’ and ‘material procurement’; ‘construction waste management strategies’) to find potential attributes for each criterion. Twenty potential attributes were obtained and categorised amongst the criteria for materials procurement. Similarly, twenty–two were grouped amongst the construction criteria. The criteria and attributes were sent to a group of construction industry’s academic experts to verify/validate and confirm their classifications (Section 5.7). This is further discussed in the methodology chapter, the results presented in the data analyses chapter. After verification/validation, the final attributes and clustering formed the basis for this study's conceptual frameworks and the questionnaire design.

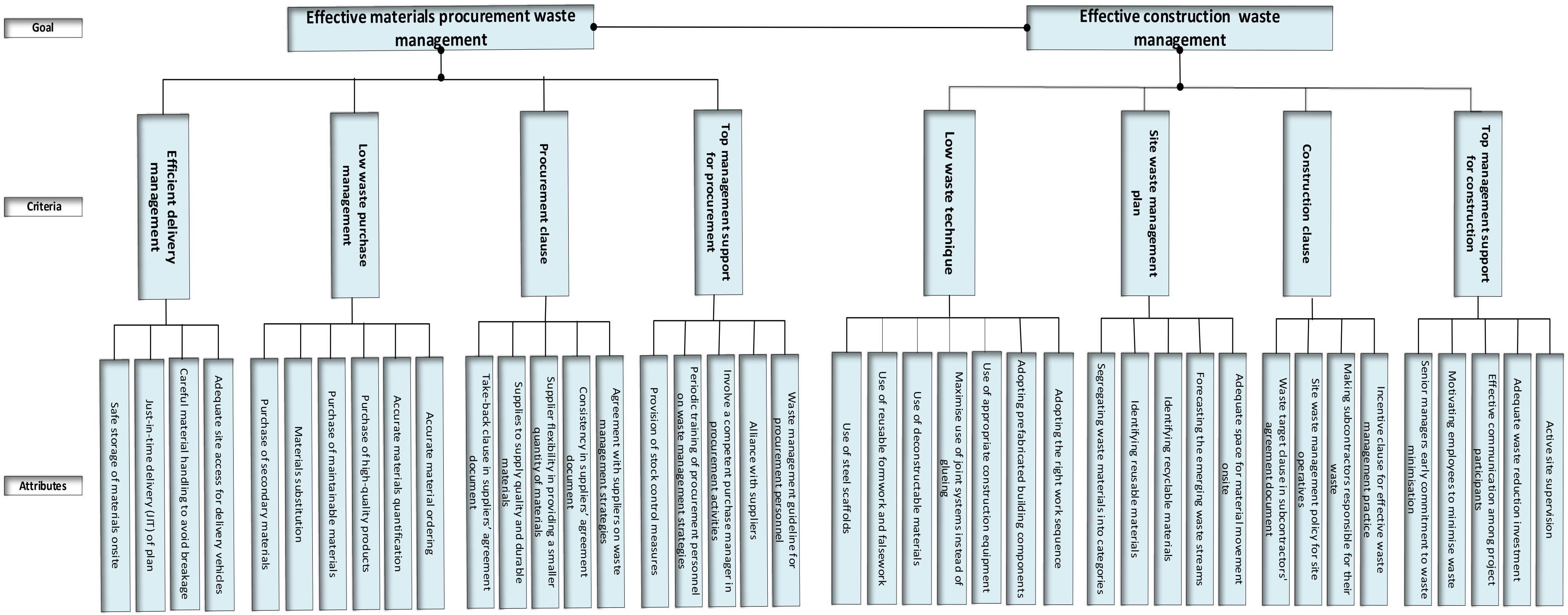
Table 3.1: Criteria and attributes factors influencing materials procurement waste management

Criteria	Attributes	References
Top management support for procurement	(1) Waste management guideline for procurement personnel	Abd Hamid *et al.,* 2016
	(2) Alliance with suppliers	Dainty and Brooke 2004; Cheng and Mydin, 2014
	(3) Involve a competent purchase manager in procurement activities	Tunji–Olayeni *et al.,* 2017b; Ahad *et al.,* 2017
	(4) Periodic training of procurement personnel on waste management strategies	Al–Hajj and Hamani, 2011; Tunji–Olayeni *et al.,* 2017; Ahad *et al.,* 2017
	(5) Provision of stock control measures	Dainty and Brooke, 2004; Williams and Turner, 2011
Procurement clause	(1) Agreement with suppliers on waste management strategies	Dainty and Brooke 2004
	(2) Consistency in suppliers' agreement document	Domingo *et al.,* 2009
	(3) Supplier flexibility in providing a smaller quantity of materials	Dainty and Brooke, 2004; Cheng and Mydin, 2014; Ajayi and Oyedele, 2018
	(4) Supplies to supply quality and durable materials	Esin and Cosgun, 2007; Nagapan *et al.,* 2011; Al–Rifai and Amoudi, 2016
	(5) Take–back clause in suppliers' agreement document	Ajayi *et al.,* 2017b
Low waste purchase management	(1) Accurate material ordering	Memon et al., 2014 ; Ajayi *et al.,* 2017b
	(2) Accurate materials quantification	Lee *et al.,* 2016
	(3) Purchase of high–quality products	Nagapan *et al.,* 2011; Al–Rifai and Amoudi, 2016
	(4) Purchase of maintainable materials	Begum *et al.,* 2007b; Wan Abdullah and Hussien *et al.,* 2016
	(5) Materials substitution	Zaman and Lehmann, 2013; Luciano et al., 2020
	(6) Purchase of secondary materials	Wang et al., 2015; Liu *et al.,* 2020
Efficient delivery management	(1) Adequate site access for delivery vehicles	Shakantu *et al.,*2008; Liu and Wang, 2020
	(2) Careful material handling to avoid breakage	Navon and Berkovich, 2006; Shakantu et al., 2008
	(3) Just–in–time delivery (JIT) of plan	Akintoye, 1995; Dainty and Brooke, 2004
	(4) Safe storage of materials onsite	Begum *et al.,* 2010; Eze *et al.*, 2017

Table 3. 2: Criteria and attributes factors influencing construction waste management

Criteria	Attributes	References
Top management support for construction	(1) Active site supervision	Cha *et al.,* 2009; Udawatta *et al.,* 2015; Bakchan *et al.,* 2019
	(2) Adequate waste reduction investment	Chen and Wong, 2002; Tam *et al.,* 2007
	(3) Effective communication among project participants	Kulatunga *et al.,* 2006; Yuan, 2013; Li and Du, 2015
	(4) Motivating employees to minimise waste	Teo and Loosemore, 2001; Chen and Wong, 2002; Chen *et al.,* 2002; Osmani *et al.,* 2006; Li and Du, 2015
	(5) Periodic training of site employees on waste management strategies	Kulatunga *et al.,* 2006; Zhang *et al.,* 2012; Park and Tucker, 2017
	(6) Senior managers early commitment to waste minimisation	Teo and Loosemore, 2001; Lingard *et al.,* 2000; Tan *et al.,* 2011
Construction clause	(1) Incentive clause for effective waste management practice	Poon *et al.,* 2013; Ling and Nguyen, 2013; Lu *et al.,* 2016a
	(2) Making subcontractors responsible for their waste	Saunders and Wynn, 2004; Tam and Tam, 2008
	(3) Site waste management policy for site operatives	Begum *et al.,* 2007b; Dania *et al.,* 2007
	(4) Waste target clause in subcontractors' agreement document	WRAP, 2016; BREEAM 2020
Site waste management plan	(1) Adequate space for material movement onsite	Yuan *et al.,* 2011a; Mortaheb and Mahpour, 2016; Abarca–Guerrero *et al.,* 2017; Yuan *et al.,* 2018
	(2) Forecasting the emerging waste streams	WRAP, 2009b; Lu *et al.,* 2016; Akinade *et al.,* 2016
	(3) Identifying recyclable materials	Tam and Tam, 2006; Tam *et al.,* 2011; Katz and Baum, 2011; Yu *et al.,* 2021a
	(4) Identifying reusable materials	Tam, 2011; Acchar *et al.,* 2013; Park and Tucker, 2017
	(5) Segregating waste materials into categories	Poon et al., 2004a; Montero et al., 2010; Lu and Yuan, 2012
Low waste technique	(1) Adopting the right work sequence	Dania et al., 2007; Ling. and Nguyen, 2013
	(2) Adopting prefabricated building components	Poon *et al.,* 2003; Tam *et al.,* 2005; Chiang *et al.,* 2006; Tam and Tam, 2006; Tam *et al.,* 2006; Shen *et al.*, 2009
	(3) Use of appropriate construction equipment	Muleya and Kamalondo, 2017; Esa *et al.,* 2017
	(4) Maximise use of joint systems instead of gluing	Akinade et al., 2017; Ajayi et al., 2017c
	(5) Use of de-constructable materials	Wang, 2018; Bertino *et al.,* 2021
	(6) Use of reusable formwork and falsework	Lau *et al.,* 2008; Lu and Yuan, 2010; Lu *et al.,* 2011
	(7) Use of steel scaffolds	Wang *et al.,* 2008; Wang *et al.,* 2014

From Tables 3.1 and 3.2, an integrated conceptual framework for effective materials procurement and construction waste management is developed based on the background literature covering C&DW management. The framework is presented in Figure 3.3, considering the VAHP decision hierarchy derived from the AHP concept comprising (the research goal, criteria and attributes).



5 **Figure 3.3.4:** The conceptual framework of the research

3.7. Chapter Summary

This chapter reviewed several concepts through which effective construction waste management strategies are implemented. From the literature analysis, an integrated framework is developed, showing the position of the current study in the wider literature. Also, due to a lack of decision–making factors to assist Nigerian contractors in implementing effective waste management in materials procurement and construction activities, several factors relevant for decision–making were identified from the literature review to fill this gap. These are top management support (procurement), procurement clause, low waste purchase, and efficient delivery management for materials procurement activities. Further, top management support (construction), construction clause, SWMP, and low waste technique were identified as criteria for effective construction activities. The literature results aided the development of conceptual frameworks for effective waste management in materials procurement and construction activities based on the AHP–MCDM decision hierarchy concept. The next chapter reviews waste management decision–making models fundamental for the research data analysis and the proposed framework development.

CHAPTER 4: WASTE MANAGEMENT DECISION–MAKING MODELS

4.1. Introduction

This chapter explores waste management decision–making models to demonstrate their basic implementation steps, strengths, and shortcomings. These models are cost–benefit analysis (CBA), life cycle assessment (LCA) and multi–criteria decision making (MCDM). In doing so, MCDM is identified as a model underpinning the development of the proposed frameworks. Thus, some of its techniques are reviewed towards choosing the VAHP as suitable for the research data analysis.

4.2. Waste Management Decision Support Methods

Over the years, decision–making methods have evolved and often consider environmental, social, economic, and technical issues in management fields, particularly the subdiscipline of operations research. For instance, Gottinger (1988) developed an integer programming model using a case study to demonstrate the effectiveness of substituting various waste treatment options in the Munich Metropolitan area. MacDonald (1996) developed a spatial decision support system (SDSS) for a decision–making development plan and evaluation of impacts of a geographical solid waste management plan. Others include the dynamic mixed integer programming model of a multi–period (Baetz and Neebe, 1994), the multi–regional model (Everett and Modak, 1996) and the static non–linear programming model (Sundberg *et al.,* 1994). According to Morrissey and Browne (2004), these studies demonstrate the evolution of solid waste management decision modelling.

Decision–making techniques rely on theories that deal with the entire process of problem–solving by making a choice. According to Edwards (1954), decision–making theory originates from psychology, economics, and mathematics disciplines. The author stated that *decision theory covers the theory of riskless choices, applying riskless choices to welfare economics, the theory of risky choices, transitivity of choices, games theory and statistical decision functions.* Others include multi–attribute value theory (MAVT) and multi–attribute utility theory (MAUT), applied in many studies (Keeney *et al.,* 1974). The basic application of decision–making systems relies on defining a goal, setting up the key variables and their logical relationship to facilitate effective, comprehensive and meaningful analysis of the system's pertinent aspect (Chankong and Haimes, 2008). Berger *et al.* (1999) pointed out some of the limitations of the early decision–making models, such as having only one time period, recyclables seldom being considered, having only one processing option of each type, or having a single generating source. According to Sudhir *et al.* (1996), these limitations can make them unsuitable for long–term planning for solid waste management.

Construction waste has become a pressing issue in many countries resulting in a need to provide suitable waste management options through decision–making. Furthermore, the advancement of decision–making methods has contributed to C&DW management improvement. Accordingly, academic publications have applied decision–support systems for resolving construction waste management problems. As mentioned earlier, these studies have been conducted using: (1) cost and benefits analysis, (2) life cycle assessment, or (3) multi–criteria decision–making. Application of these models allows construction organisations to: (1) forecast the cost and benefits of adopting and implementing different waste management strategies, (2) evaluate the likely environmental impacts of a proposed development or project by considering inter–related socio–economic, cultural and human–health impacts in terms of benefits and impacts, and (3) making a collective decision for the prioritisation or selection of waste management strategies, respectively. Therefore, the next section discusses the basic implementation steps, strengths, and shortcomings of these models.

4.3. Cost–Benefit Decision–Making Model

Cost–benefit analysis (CBA) is a systematic consideration of the potential cost and benefits of developmental activity expressed in monetary terms. The method provides a means for evaluating the benefits and liability of different alternatives to make a financial decision (Pickin, 2008). The process is carried out by estimating alternatives to determine the costs and benefits of implementing them over a period. The application of CBA is demonstrated in the planning of the waste management system in Ireland (MCCK, 1998). WRAP (2021) developed a web–based tool for CBA of food waste to weigh up the costs and benefits of implementing local management measures.

Waste management in construction can also be expressed in monetary terms to determine the costs and benefits of using a strategy to promote environmental and social sustainability in the construction industry. Decision–makers can use this method to identify the impact and benefit of adopting different construction waste management strategies in monetary terms. For instance, Begum *et al.* (2006) applied cost–benefit analysis to determine the economic feasibility of construction waste minimisation in Malaysia. The result shows that waste minimisation is economically viable and crucial for environmental management improvement.

Yuan *et al.* (2011b) developed a cost–benefit model for C&DW management throughout the waste chain by considering the impacts of raising landfill charges in Shenzhen City of China. The study suggests that a higher landfill charge will promote effective waste management with a higher net benefit and suggest regulation to maximise the net benefit.

Further, CBA provides a means to investigate and analyse whether a management approach will provide the required benefit or become a liability in a project delivery process. The aim is to analyse the cost and benefit of waste management options to ensure maximum environmental protection with minimal cost. It is expected that the selected options are for the overall net benefits to society and the organisation. However, there could be a conflict of interest, for instance, when disposal costs are less than recycling costs. In that case, some studies suggest an increase in landfill tax, especially on unsorted waste and incentives for recycling to increase materials' recovery (Calvo *et al.,* 2014). A catalogue of studies addressing construction waste issues using the CBA model are presented in Table 4.1.

Table 4.1: A catalogue of CBA applications in construction waste management research

Authors	Research Title	Summary of Findings	Methods
Yuan *et al.* (2011b)	A model for cost–benefit analysis of C&DW management throughout the waste chain	A higher landfill charging scheme would lead to a higher waste management net benefit	System dynamic modelling, CBA
Begum *et al.* (2006)	A benefit–cost analysis of the economic feasibility of construction waste minimisation: The case of Malaysia	Waste minimisation is economically feasible. It plays a vital role in the improvement of environmental management	Case study, CBA
Jain (2012)	Economic aspects of construction waste materials in terms of cost savings – A case of Indian construction Industry	Proper site waste management is economically viable and minimises waste to landfill	Case study, CBA
Ding *et al.* (2018b)	A system dynamic–based environmental benefit assessment model of construction waste reduction management at the design and construction stages	Implementing waste reduction management at the design and construction stages can effectively reduce construction waste and bring significant environmental benefits. (Reduction of 12,623.30 kg greenhouse–gas emissions, saving landfill of 3901.05 m^3 and reducing the use of illegal dumping of 688.42 m^3)	System dynamic modelling, CBA
Hao *et al.* (2019)	A model for assessing the economic performance of construction waste reduction	Combining different waste reduction strategies can result in better construction waste minimisation outcomes than a single measure. Enhancing sorting, reducing illegal dumping behaviours, promoting the government's financial subsidy on waste recycling, and raising landfill charges are four key strategies to effectively promote the economic performance of construction waste reduction.	System dynamic modelling, CBA

Zoghi and Kim (2020)	Dynamic modelling for Life cycle cost analysis of BIM–based construction waste management	Comparing the cost–benefit of the conventional approach and the BIM–based method in the design process shows that BIM can reduce construction waste management costs by up to 57%. Increasing the modularity of design and earlier realisation of the net benefit of BIM–based construction waste management will motivate managers to employ BIM in the design process; rather than higher landfill charges	System dynamic modelling and case study, CBA

4.3.1. Cost–Benefit Analysis Decision–Making Process

The decision process is created considering the cost and benefits of an investment and the interrelationship between factors affecting its economic performance. Scenarios' positive and negative effects are evaluated from the economic perspective (Morrissey and Browne, 2004). The environmental impacts of the scenarios, for instance, the cost of avoiding adverse effects of management systems such as landfilling and incineration, can be evaluated in monetary terms. Therefore, one can determine how much an organisation or individual pays for environmental protection before implementing any management system. According to Morrissey and Browne (2004), social impacts can also be evaluated similarly. The analysis usually suggests the best scenario with the most significant benefit and least cost; hence, a favourable decision can be made based on this information. The European Commission (2008) and Karmperis *et al*. (2013) identified the basic steps for conducting CBA, thus:

1. A clear definition of a project objective, discussion and presentation of the socio–economic context within the objective, considering the project's national or regional economic context.

2. Clear identification of the project boundary (e.g. project life cycle – design, construction and operation). Considering the level of analysis on their direct and network effects, the cost and benefits at a specific level or levels based on the project objective.

3. A feasibility study of the project and evaluation of alternative options for the implementation. These may include technology, personnel skills, and demand (Karmperis *et al.,* 2013). In addition, different scenarios with or without investments can be evaluated and examined by an investment analyst.

4. Financial analysis is considered at this level through a discount cash flow rate using a discount rate. In addition, financial analysis is usually carried out using a spreadsheet (e.g. Microsoft Excel). The spreadsheet enables the evaluation of investment, operational costs and total revenues. As a result, financing sources and financial

indicators of the project can be computed to determine a project's financial sustainability and the impact on an investor.

5. At this level, the economic analysis will account for the project market price by monetising all project externalities and non–market impacts. Finally, the social discount rate puts a present value on costs and benefits that may occur in the future. Thus, comparing the net future benefits against the present benefits by evaluating the economic performance indicators: the economic net present value (NPV), the economic rate of return, and the benefit–cost (B/C) ratio.

CBA may include a risk assessment to evaluate the expected performance of selected solutions. The critical variables impacting the financial/economic performance indicators can be identified, and different realistic scenarios analysed to determine the risk factors (Pickin, 2008). The analysis can help decision–makers propose actions to prevent or minimise the potential risks. The CBA mathematical model is presented below:

$$B/C = \frac{PVinflow}{PVoutflow} \qquad Equation\ 4.1$$

B/C = benefit–cost ratio; PV_{inflow} = summary of the total revenues and positive externalities; $PV_{outflow}$ = summary of the total costs and negative externalities. A project is feasible if B/C > 1. It suggests that PV (inflow) benefits are greater than the relative costs. However, B/C < 1 suggests that a project is not economically variable.

4.3.2. Strengths and Shortcomings of CBA

The basic rationale for cost–benefit analysis is a need to minimise financial risks in investment. While cost presents the amount of resources to be spent, benefits are gains to be received after expenditure in a period. CBA demonstrates how much an investor is willing to pay for benefits or accept as a financial risk (Boardman *et al.,* 2017). To identify all the risks inherent in any investment, a risk assessment can be performed to capture potential uncertainties in project development by considering how the project will perform in a period (Pollak, 1998). In CBA, alternative options can be examined and evaluated to identify the best option for viable business. Incineration with or without energy recovery is a typical example of waste management cost–benefit decision options (Karmperis *et al.,* 2013). While several benefits are attributed to frameworks developed using the CBA model, shortcomings exist. Table 4.2. present these benefits as well as the shortcomings.

Table 4.2: Strengths and shortcomings of CBA (adapted: Morrissey and Browne, 2004; Karmperis *et al.,* 2013)

Strengths	**Shortcomings**
Both direct and indirect impacts of an investment over time can be considered, summarised in monetary terms and presented in a straightforward manner	Monetising non–market goods can be complicated (e.g. landscape and wildlife)
A comprehensive risk assessment can be conducted to deal with any uncertainty in a project's development over time	It can take a considerable time to develop a comprehensive CBA model for solid waste management with a risk assessment
A CBA enables decision–makers to identify and evaluate different scenarios to decide the best scenario in social and environmental decision–making	There could be ethical issues in computing the value of some environmental and social impacts in monetary terms due to the complex nature of such systems
Through the financial and economic analyses, project performance can be examined for the benefit of an investor or society	The values of the variables used in the financial/economic analyses may change during the waste programme's lifetime. This could affect the estimated benefits (changes in landfill charges may impact the rate of recycling)

4.4. Life–Cycle Assessment Decision–Making Model

The life–cycle assessment method is used to analyse the environmental performance, energy and carbon consequences of buildings, products, or materials over their life span (Abd Rashid and Yusoff, 2015). The model enables decision–makers to define the environmental performance of construction materials and products, making it possible to select more environmentally friendly materials in construction. It is also applied in evaluating the environmental burdens associated with materials from extraction to the final disposal. In that case, the environmental performance of waste management systems can be improved by identifying the best strategies with the least environmental effects. Thus, a systematic analysis of all potential alternatives' environmental behaviour can help decision–makers in the selection process (Bovea and Powell, 2016).

Several studies have used the LCA model to assess construction and demolition waste management systems (Ortiz *et al.,* 2010; Mercante *et al.,* 2012). In carrying out an LCA of a product, the goal and scope, the reason for the study and intended application are defined. Also, the results, the system boundary and the functional unit are clearly defined. Life cycle assessment can be extended to evaluate a product's environmental or social performance (Onat *et al.,* 2014; Kulczycka and Smol, 2016). According to Morrissey and Browne (2004), data obtained from LCA can be used to evaluate economic costs by applying an economic valuation to each environmental impact category.

Butera *et al.* (2015) applied a life cycle assessment to determine the potential impacts of recovery, utilisation, and disposal of construction waste materials. In addition, several studies have integrated LCA with other tools for a more extensive assessment of construction projects environmental performance by following the basic structure of LCA in the ISO 14040 series (Klöpffer, 2012). The ISO 14040 environmental management LCA model consists of four stages: goal and scope definition, inventory analysis, impact assessment and interpretation. In construction, determining the life–cycle of a facility usually begins from design, materials selection and through to end–of–life sustainability. Materials selection is usually determined by their constructability, budgets, performance, and a facility's life expectancy (Lin *et al.,* 2012). Table 4.3 shows a catalogue of LCA applications in construction waste management.

Table 4.3: A catalogue of LCA applications in construction waste management research

Author	Goal	Functional Unit	Impact Categories	Country	Sustainability Aspects		
					Environmental	Economic	Social
Kucukvar *et al.*, 2014	Propose a comprehensive economic input–output–based hybrid life–cycle model for assessing the net carbon, energy, and water footprints of C&DW recycling, landfilling, and incineration	16×103 kWh of electricity, 0.13 TJ energy and 292 m^3 water	Recycling, Incineration, and Landfilling	USA	✓	✓	✓
Butera *et al.*, 2015	Evaluation of the environmental impacts related to the end–of–life phase of the mineral fraction of C&DW utilisation in road vs C&DW landfilling	1 Mg of C&DW	Non–toxic and toxic impact	Denmark	✓		✓
Hu *et al.*, 2013	Proposed a life cycle sustainability analysis (LCSA) to be applied in concrete recycling	1t C&DW	Concrete generation, Processing and Use	Netherlands	✓	✓	
Carpenter *et al.*, 2013	Explored various end–of–life management scenarios for C&DW debris across a broad range of different emissions	702,000 tonnes[1] of C&DW debris	Energy, greenhouse gas emissions, lead air emissions, and lead, arsenic, zinc, cadmium, chromium, copper, mercury, and selenium to water	USA	✓	✓	✓
Hiete *et al.*, 2011	Proposed LCA for optimising the minimum cost of C&DW recycling considering technical and environmental aspects	Area of 1880km^2	Disposal taxes, Transport distances	Germany	✓	✓	✓
Ortiz *et al.*, 2010	Evaluation of the environmental impacts of construction wastes in terms of build project with a code (LIFE98 ENV/E/351)	1m^2 building	Landfilling, Recycling and Incineration	Spain	✓		
Marzouk and Azab, 2014	The environmental and economic impact of recycled and disposed C&DW using system dynamic modelling	20 years	Recycling and disposal of C&DW	Egypt	✓	✓	

4.4.1. LCA Decision–Making Process

Analysing and reporting potential environmental impacts of products and services required a systematic approach. The basic steps used in developing LCA models (ISO 14040; Tukker, 2000; Bovea and Powell, 2016) are:

1. Definition of goal, scope and the intended application, the system boundary and functional unit. Comparing alternative systems is considered through a unit functional basis. The level of analysis should be clearly defined.
2. Life cycle inventory is carried out within the system boundary. All extractions and emissions are identified and placed in an inventory list to quantify inputs and outputs for each process.
3. Evaluate and analyse the potential environmental impacts identified in the inventory analysis stage. The inventory data allows decision–makers to categorise the impact factors such as the environmental, economic and social. Each category can be evaluated using the basic mathematical equation presented in Equation 4.2.
4. The LCA result and interpretation are presented at this stage. Following the inventory analysis and impact assessment, the result and interpretation should be in concordance with the identified goal and scope to draw a conclusion and make recommendations. Therefore, possible solutions and opportunities can help minimise a product's environmental impacts for cost and social benefits. The basic LCA of systems can be calculated using the mathematical model below.

$$Si = \sum_{1-j}(Ej)(eij) \qquad Equation\ 4.2$$

From the above equation: Si = the score on impact category; *Ej* = the magnitude of environmental intervention j; *eij* = the equivalency factor indicating the contribution of a single unit of intervention *j* to each impact category *i.*

4.4.2. Strengths and Shortcomings of LCA

LCA provides decision–makers with a method for evaluating the impacts of products and systems on the environment. Such a system may include recycling, incineration, and landfilling in waste management. While LCA provides a significant benefit, the literature has also identified its limitations. Table 4.4 shows the strengths and shortcomings of LCA.

Table 4.4: Strengths and shortcomings of LCA (Adapted: Morrissey and Browne, 2004; Karmperis *et al.,* 2013; Curran, 2014).

Strengths	Shortcomings
It encourages long–term benefits in environmental protection by promoting the CE concept	The process of developing a comprehensive LCA model can be time–consuming
It enables the environmental improvements that can result in economic and social benefits	Even though models developed under LCA evaluate identified scenarios, there is always space for additional scenarios that can be considered
It enables quantification of all types of pollution such as water, air and land impacts categories	Products LCA assumptions such as the boundary conditions, data sources, impact assessment criteria and weights could be subjective
It can assist in the evaluation of the materials consumption effects on the ecosystem	Reliability of an LCA model's result may not be achieved when there is limited data
Examination of waste management scenario to identify the most suitable alternative that can have the least impact on the ecosystems	LCA does not explicitly quantify impacts on ecosystems and species diversity

4.5. Multicriteria Decision–Making Model

Several studies have employed the MCDM techniques for decision–making in the waste management domain (Goulart Coelho *et al.,* 2017). This method can help decision–makers learn about a problem under consideration to find the best course for action. Therefore, MCDM allows a group of people to decide on the best solution to a problem(s) after carefully considering available and multiple solutions. This is usually carried out as a trade–off exercise where desirable solutions are selected (Saaty, 1980; Brans and Vincke, 1985; Roy and Vanderpooten, 1996).

According to Morrissey and Browne (2004), adopting MCDM requires considering several decision alternatives, often conflicting alternatives for more comprehensive decision–making than a single–dimensional objective function such as CBA. The basic approach is to identify several waste management criteria and their related sub–criteria or attributes for evaluation. In the process, concerned stakeholders are usually invited to identify and decide on criteria and attributes. The criteria and attributes should depend on the issue under consideration (Morrissey and Browne, 2004). While several MCDM models have been developed for modelling waste management objectives, the earliest models are the weighted sum model (WSM) and the weighted product model (WPM), a modified WSM (Triantaphyllou and Mann, 1989).

Other MCDM models (such as AHP, ANP, the ELECTRE family, TOPSIS, PROMETHEE family, ORESTE) have emerged and are widely applied in the environmental and operational management disciplines (Stojčić *et al.,* 2019). These models are unique, thus, from choosing the best options to sorting the options or categorising alternatives as acceptable or unacceptable. Methods of analysis may include elementary methods (Belton and Pictet, 1997), pairwise comparison (Saaty, 1980), and outranking (Roy, 1990), amongst others. While MCDM techniques have been widely used in the environmental and solid waste management domain, they have also benefited other fields (Zavadskas and Turskis, 2011). Thus, decision–makers preferences can be used to make recommendations to improve or develop a new management system. The current study aims to help contractors identify and select suitable materials procurement and construction waste management criteria that can be incorporated into their waste management practices. Table 4.5 shows previous studies that have adopted different MCDM models with similar ideas. Evidence shows that two or more MCDM techniques can be integrated to fulfil a study's objectives (Paramasivam *et al.,* 2011).

Table 4.5: A Catalogue of MCDM applications in construction waste management research

Author	Objective	Country	Model Type
Kourmpanis *et al.,* 2008	To determine the best demolition waste management alternative systems	Cyprus	PROMETHEE II
Roussat *et al.,* 2009	To choose a sustainable demolition waste management strategy	France	ELECTRE III
Gomes *et al.,* 2008	To determine disposal alternatives for plastic waste and performance evaluation of C&DW recycling facilities	Brazil	Algorithm (THOR)
Geneletti, 2010	To determine the suitability of alternative landfill sites for inert construction waste	Italy	Spatial multi–criteria evaluation (SMCE)
Banias *et al.,* 2010	To determine the best location for the development of a new C&DW treatment facility	Greece	ELECTRE III
Ding *et al.,* 2018	To select an appropriate landfill site for C&DW	China	Fuzzy AHP and GIS
Mahpour, 2018	To prioritise barriers militating the adoption of the CE in C&DW management	n/a	Fuzzy TOPSIS
Khodaverdi *et al.,* 2008	To prioritise recycling options for concrete waste	n/a	Fuzzy Analytical Network Process (FANP)
Nguyen *et al.,* 2019.	Optimisation of main factors affecting construction waste by the supply chain management	Vietnam	fuzzy logic
Mdallal and Hammad, 2019	Evaluate and select the optimum alternative to reduce concrete waste in construction sites	UAE	Fuzzy Analytic Hierarchy Process
Elshaboury and Marzouk, 2020	A model for identifying the optimum fleet required for C&DW transportation	Egypt	Genetic algorithms
Negash *et al.,* 2021	Identifying barriers to sustainable C&DW management	Somaliland	Fuzzy DEMATEL

4.5.1. Multicriteria Decision–Making Process

The basic steps for conducting MCDM (Morrissey and Browne, 2004; Karmperis *et al.,* 2013) are as follows:

1. A clear goal definition
2. A clear definition of realistic and measurable criteria related to the goal

3. Identify possible sub-criteria that satisfied the criteria
4. Defined the evaluation criteria based on their performance in meeting the goal and assign the weight values in each criterion based on stakeholders' preferences
5. Compute the numerical value of each alternative score to determine the ranking of each alternative. The best solution is selected based on the highest score; or should be given a higher priority compared to other options

The following (Table 4.6) lists the strengths and potential limitations of frameworks developed under the MCDM model.

Table 4. 6: Strengths and shortcomings of MCDM (Adapted: Morrissey and Browne, 2004; Huang *et al.,* 2011; Karmperis *et al.,* 2013).

Strengths	Shortcomings
Preferences of each decision–maker can be integrated to make a final decision to solve a problem	MCDM models mostly do not consider risks the criteria may impose on a project
MCDM allows both quantitative and qualitative criteria for the evaluation of alternatives	In the waste management field, MCDM models evaluate only alternative solutions and do not provide information for waste minimisation and waste prevention. This limitation will be overcome in this study as the study will provide actions for waste minimisation, a part of its objectives
MCDM models are flexible in application, particularly in the environmental management	Assigning weight/priority to each criterion could be highly subjective as their values can be changed in the evaluation process
Many criteria (sometimes conflicting) can be added into the management planning of a system	
Although a prioritisation of alternatives may vary in the application of different MCDM, the most prioritise alternatives may appear the same irrespective of which model is used	
Introducing fuzzy logic in many MCDM techniques have helped in dealing with crip data (ambiguous values or statements)	In a real–world situation, crisp data sometimes introduced in MCDM may not be adequate to deal with some decision problem
The selected solutions to a problem always reflect the consensus of decision–makers	The feasibility of implementing the different solutions to a problem is not always considered in frameworks developed under MCDM

4.6. Choosing the MCDM model for the Frameworks' development

The MCDM model application relies on multiple experts' knowledge to determine the best waste management solutions from multiple dimensions (Figuera *et al.,* 2005). Comparatively, LCA is mainly applied considering the environment; CBA deals with the cost and benefit of waste management systems. CBA or LCA are not suitable for quantifying the impact of the diffuse actions on waste management because of limited experts' contributions. Therefore, there is a need to rely on expert knowledge, the most effective strategy to achieve the research goal. Also, the MCDM considers multiple criteria depending on what is necessary; hence, more flexible. Further, the method can enable the people (construction practitioners) whose actions or inactions create waste in the industry to be involved in waste management solutions rather than a sole decision–making process in CBA and LCA methods. Therefore, as a model that instigates collaboration amongst different interest groups to solve a particular problem, MCDM is adopted in this research to develop the frameworks. The following sections discuss some of the MCDM techniques towards adopting a suitable technique for the study.

4.7. Multicriteria Decision–Making Techniques

4.7.1. ELECTRE

ELECTRE is an outranking–based decision aiding method dating to the mid–1960s at the European consultancy company SEMA. ELECTRE stands for (Elimination and Choice Translating reality method) was introduced by (Roy *et al.,* 1968). This method makes a direct comparison between alternatives, attributed separately to establish a relationship between alternatives.

Bernard Roy and colleagues proposed the first ELECTRE method at SEMA Consultancy Company (Figueira *et al.,* 2005). Although, not many details were available until it was renamed ELECTRE I, which later gave rise to several other ELECTRE methods that were developed over the last two decades: ELECTRE II (Roy and Bertier, 1971), ELECTRE III (Roy, 1978), ELECTRE IV (Roy and Hugonnard, 1982), ELECTRE TRI (Yu, 1992). ELECTRE versions differ in model properties; however, their similarities entail evaluating two indices: the concordance index and the discordance index, defined for each pair of alternatives for the smooth running of a function (Mary and Suganya, 2016). Besides waste management, ELECTRE's application has been proven in other areas: energy, economics, environmental, transportation and water management. For instance, it was applied to determine the best investment alternative (Yucel and Gorener, 2016) and ascertained the optimal location choice of a heterogeneous wireless network environment (Bari and Leung, 2007). More detail on ELECTRE methods can be found in (Figueira *et al.,* 2005; Govindan and Jepsen, 2016). The basic steps for the ELECTRE method are summarised (Yoon and Hwang, 1995). Besides construction waste, Table 4.7 shows studies that applied ELETRE methods for other waste streams.

Table 4. 7: Publications on ELECTRE methods for waste management

Authors	Purpose	Country	Method	Waste Stream
Perkoulidis *et al.*, 2010	Waste management strategy	Central Greece	ELECTRE III	Municipal solid waste (MSW)
Karagiannidis *et al.*, 2004	Location of MSW facility	Peloponnese, Greece	ELECTRE III	
Cheng *et al.*, 2003	Location of a landfill site	Regina, Canada	ELETCRE TOPSIS	
Cheng *et al.*, 2002	Location of a landfill site	Saskatchewan, Canada	ELETCRE TOPSIS	
Hokkanen *et al.*, 1995	Waste management strategy	Uusimaa, Finland	ELECTRE II	
Achillas *et al.*, 2010	Location of electrical and electronics waste treatment facility	Greece	ELECTRE III	Electrical and electronics waste
Andarani and Budiawan, 2015	location of e–waste dismantling and sorting facility	Banten, Indonesia	ELECTRE III	
Bellehumeur *et al.*, 1997	Wastewater management strategy	Quebec, Canada	ELECTRE III	Wastewater
Tecle *et al.*, 1988	Site selection for artificial recharge with treated wastewater	Nogales, USA and Sonora, Mexico	ELECTRE I	

4.7.1.1. Strengths of ELECTRE

Figueira *et al.* (2010), Valasquez and Hester (2013) and Gavade (2014) highlight the strengths of ELECTRE, which include:

1. It takes uncertainty and vagueness into consideration
2. The method accepts both qualitative and quantitative approaches
3. It fosters the use of fuzzy analysis as this encourages the thresholds of indifference and preference
4. The absence of systematic compensation between “gains’’ and “losses.’’

4.7.1.2. Limitations of ELECTRE

According to Figueira *et al.* (2010), Valasquez and Hester (2013) and Gavade (2014), the limitations of ELECTRE include:

1. The principles associated with determining the concordance and discordance matrices could be difficult to understand.
2. The process and outcome could be difficult to explain to a layperson.
3. Outranking the strengths and weaknesses of alternatives are not entirely specified.

4.7.2. PROMETHEE

The acronym PROMETHEE refers to (Preference Ranking Organisation Method for Enrichment Evaluation), a multicriteria decision–making method developed by (Brans *et al.,* 1986). PROMETHEE I and II are used for the partial and complete ranking of alternatives, respectively. According to Tuzkaya *et al.* (2010), PROMETHEE is well suited where a finite set of alternatives to be outranked is subjected to multiple conflicting decision–making criteria. The significant difference between PROMETHEE and other MCDM methods is that it takes the inner relationship associated with each evaluation factor into account during decision–making (Murat *et al.,* 2015). Further, other families of PROMETHEE includes PROMETHEE III, IV and V, extended by Brans and Mareschal (1992). This is to accommodate interval, complete or partial ranking of the alternatives when the set of viable solutions is continuous and for problems with segmentation constraints. Also, Brans presented the PROMETHEE VI for the human brain representation in 1995 (Brans and Mareschal, 1995). Besides construction waste, the emergence of the PROMETHEE method has been instrumental in other areas of waste management (Table 4.8).

Table 4.8: Publications on the PROMETHEE method for other waste streams

Authors	Purpose	Country	Method	Waste Stream
AlHumid *et al.,* 2019	Selection of performance indicators for seven key components of MSWM systems	Qassim, Saudi Arabia	AHP and PROMETHEE II	MSW
Panagiotidou *et al.,* 2015	Planning an optimal MSW management scheme	Balkan Region countries, Southeast Europe	PROMETHEE II	MSW
Makan and Fadili., 2020	Sustainability assessment of large–scale composting technologies	n/a	PROMETHEE I and II	MSW
Makan and Fadili, 2021	Identifying the most sustainable healthcare waste treatment system	n/a	PROMETHEE I	Healthcare waste
Mishra *et al.,* 2018	Prioritised barriers to sustainable management of healthcare waste according to adverse impact on the environment	Odisha, Indian	PROMETHEE I	Healthcare waste
Coban *et al.,* 2018	Evaluated waste treatment methods and different scenarios	İstanbul, Turkey	TOPSIS, PROMETHEE I and PROMETHEE II	MSW

The introduction of PROMETHEE as an MCDM method is essential in handling quantitative information. Also, it can be applied with qualitative information to manage associative problems that are traditionally transformed to a numerical one using an ordinary scale (Al–Rash–dan *et al.,* 1999). However, criteria rating and ranking cannot be carried out without any problem in a real–world decision situation. Therefore, the PROMETHEE was upgraded to accommodate fuzzy input data to avoid expressing a decision in crisp values – vagueness and uncertainty inherent in information such as equally'', ''moderately'', ''strongly'', ''very strongly'', ''extremely'' and a ''significant degree. Furthermore, several authors modified the PROMETHEE method in different areas in a stochastic context. For instance, the introduction of fuzzy numbers to capture the degree to which something is true or false (Gourmas and Lygerou, 2000) and associative interval concepts (Al–Rash–dan *et al.,* 1999) through mathematical programming (Fernandez–Castro and Jimenez, 2005). Figure 4.2 shows the procedural steps involved in the PROMETHEE II method. Behzadian *et al.* (2010) presented the stepwise procedure for PROMETHEE II.

4.7.2.1. Strengths of PROMETHEE

Valasquez and Hester (2013) and Gavade (2014) highlight the strengths of PROMETHEE, which include:

1. PROMETHEE harnesses both functions of quantitative and qualitative criteria, which can also be expressed in their units
2. It is readily easy to use and does not require an assumption that the requirements are proportionate
3. It requires fewer inputs for its operations than most MCDM methods
4. The information for PROMETHEE is evident for both decision–makers and analyst

4.7.2.2. Limitations of PROMETHEE

The limitations of PROMETHEE were highlighted by Valasquez and Hester (2013) and Gavade (2014). These include:

1. PROMETHEE faces difficulties in rank reversal when a new alternative is introduced
2. Lack of any specific guidelines in determining the weight criteria.
3. The PROMETHEE method does not offer a system to structure a decision problem

4.7.3. Fuzzy Logic in MCDM

The concept of Fuzzy Logic was introduced in 1965 by Professor Lotfi A. Zadeh of the University of California at Berkeley to address the necessity for real–world modelling phenomena, which are inherently vague and ambiguous. It is a systematic approach towards solving problems associated with human knowledge about complex problems with imprecise terms and natural language. Fuzzy logic is an extension of Boolean logic based on the mathematic theory of fuzzy sets to deal with partial truth in decision–making problems (Kraft and Buell, 1983). Therefore, fuzzy logic provides a lucrative and valuable condition necessary for a flexible atmosphere, making it easy to accommodate inaccuracies and uncertainties. According to Czabamski *et al.* (2017), the typical structure of a fuzzy system consists of four functional blocks: the fuzzifier (crisp inputs), the fuzzy inference engine, the knowledge base, and the defuzzifier (crisp outputs). In this method, terms such as fuzzy model, fuzzy system, fuzzy system rules, and fuzzy controller are used exhibited depending on the application type. A typical structure of a fuzzy system is shown in the Figure 4.1.

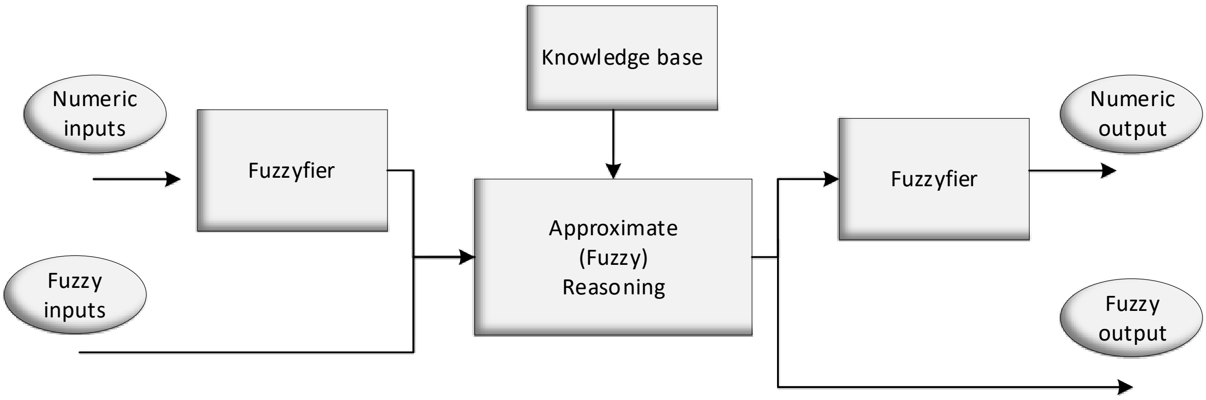


Figure 4.1*:* Structure of a fuzzy system (Czabamski *et al.,* 2017)

4.7.3.1. Application of FUZZY System

The fuzzy system is efficient in various logic systems that are instrumental to the modelling tool, based on the fuzzy theory, which is evident in areas that include: automatic controls, expert systems, pattern recognition, time series prediction, data classification, which are the backbone of the fuzzy interference system (Dernoncourt, 2013). Furthermore, since introducing fuzzy systems for MCDM techniques, it has excelled in practical applications in decision–making (Zeng and Trauth, 2005). For instance, the fuzzy concept has been applied in various waste management decision making. Chang and Wang (1997) apply a fuzzy goal programming approach to optimise solid waste management systems. The study demonstrates how decision–makers preferences can be quantified by using specific membership functions in different solid waste management systems. Bui *et al.* (2020) identified barriers limiting sustainable solid waste management performance using the fuzzy Delphi method. Besides waste management, it has been adopted in other areas of construction project management, For instance, in supplier's selection (García *et al.,* 2013), risk management (Tah and Carr, 2000), quality improvement of apartment projects (Van Luu *et al.,* 2009) and simulation for construction operations (Zhang *et al.,* 2003). The fuzzy logic mathematical equations can be found in (Czabamski *et al.,* 2017).

4.7.3.2. Strengths of the FUZZY system

Some of the strengths of a fuzzy system are highlighted (Masoumi *et al.,* 2020).

1. A fuzzy system is relatively straightforward and understandable in its methods of application.
2. Fuzzy logic allows for the modelling and inclusion of contradictions and inaccurate inputs.
3. It fosters decision making with estimated values under incomplete or uncertain information.
4. It is suitable for uncertain or approximate reasoning, especially for a system with a difficult mathematical model.
5. Fuzzy logic helps solve complex problems with more useful and accessible solutions and predict future events.

4.7.3.3. Limitations of the FUZZY system

Amongst other studies, Masoumi *et al.* (2020) also mentioned some of the limitations of the fuzzy system as follows:

1. Fuzzy logic may become an obstacle to verifying system reliability and tuning membership functions, leading to a complex problem.
2. There is an argument that some of the statements introduced by Lotfi Zadeh in 1965 fuzzy logic are not logical as classical bivalent logic.
3. The evidence of accuracy, consistency and proof–theoretic completeness of the truth interval is classed as complicated (Entemann, 2002)
4. The claims associated with fuzzy logic continue to illustrate the inaccuracies that continually lead to misunderstanding, confusion in practical (Belohlavek *et al.,* 2009),

4.7.4. TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution)

TOPSIS is a widely used MCDM technique due to its programmable and straightforward nature. TOPSIS is a concept that an ideal solution must be defined regarding a Euclidean distance from the positive and negative ideal solutions. Thus, for multiple criteria decision–making, the chosen solution should have the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution (Lai *et al.,* 1994). Hwang and Yoon developed the technique in 1981 to evaluate the performances displayed through the similarities in an ideal solution. This method favours the positive–ideal solution against the negative ideal solution. Hence, it is easy to define the positive ideal and negative ideal solutions as the preference order if alternatives are relative to the comparisons of their relative distances (Triantaphyllou, 2000). This method is widely used to complete decision–making. TOPSIS method is simple, easy to understand, efficient for the computation and measurement of the relative performance of alternative decision criteria (Triantaphyllou, 2000). The TOPSIS procedure and mathematical logic is shown (Madi *et al.,* 2016)

4.7.4.1. Application steps of TOPSIS

TOPSIS method is widely used for the management of waste. For instance, it has been applied in selecting appropriate MSW disposal methods (Roy *et al.,* 2019) and the management of hazardous waste and the impacts on the environment (Ali *et al.,* 2015). Further, the application of TOPSIS is seen in supply chain management and logistics, engineering, manufacturing systems, business and marketing, human resources, and water resources management (Panda and Jagadev, 2018).

4.7.4.2. Strengths of the TOPSIS

According to Bhutia and Phipon (2012), the strengths of TOPSIS are:

1. It is understandable, and computation processes are straightforward
2. It considers all types of criteria (subjective and objective)
3. Fairly intuitive physical meaning based on consideration of distance from ideal solutions (Gavade, 2014)
4. A clear differentiation of all alternatives (Panda and Jagadev, 2018)

4.7.4.3. Limitations of the TOPSIS

Panda and Jagadev (2018) listed some of the limitations of TOPSIS thus:

1. The method is not decisive in the rank reversal issue while adding a new alternative
2. Risk determination of decision–makers while giving different input rating
3. The normalised decision matrix operation representation creates confusion when calculating the dominance amongst alternatives

4.7.5. The Analytic Hierarchy Process the AHP

The analytic hierarchy process (AHP) is a multi–criteria decision–making method that provides a model for decision–makers to solve complex problems in a hierarchical structure which consists of the goal, objectives, sub–objectives and alternatives (Saaty, 1980). The major characteristic and distinctive function of AHP is that it uses pair–wise comparison, which is used both to compare the alternatives with respect to other criteria and then estimate the function of the alternatives. Thus, the AHP method provides an overarching view of a complex problem with a careful evaluation that helps decision–makers with criteria in the magnitude of an order that compares homogeneous alternatives.

According to Professor Saaty, who developed the technique, AHP consists of three principles: decomposition, comparative judgement, and priority synthesis. Therefore, these three contents structure the decision–making components then places them into preferences identified through the comparison matrix based on composite weights; hence, the relative priority for each alternative can be obtained and compared to make a final decision.

4.7.5.1. Application steps of the AHP

The AHP is widely applied in many studies. For instance, Yang *et al.* (2000) applied the AHP method on a semiconductor wafer fabrication to determine its competence in planning and its efficiency was further tested in evaluating a web–based multi–attributed model for engineering projects. Also, its variety of usage and application was adopted to select machine tool alternatives to improve the manufacturing process's efficiency (Yurdakul, 2004).

The AHP, sometimes combined with other MCDM techniques, are widely used in waste management systems (Pires *et al.,* 2011; Kumar and Hassan, 2013; Delmonico *et al.,* 2018). Valasquez and Hester (2013) identified that AHP application is evident in performance–type problems, resource management, cooperate policy and strategy, public policy, political strategy and planning. The AHP model includes a hierarchy with multiple levels that can effectively accommodate any decision–making situation. Moreover, this method’s characteristics make it a useful methodology considering the following functional areas: the ability to handle decisions involving subjective judgements, multiple decision–makers, and the ability to provide necessary measures of the constituency and preferred preferences. Therefore, it remains one of the most adopted decision–making models (Gavade, 2014). Ho (2008) identified the processes involved in applying the AHP procedures.

4.7.5.2. Strengths of the AHP

The strengths of AHP include:

1. It can be adjusted to accommodate decision–making problems due to its hierarchical structure (Velasquez and Hester, 2013).
2. Subjective qualitative information can be transformed into quantitative data, which can be used for management decisions (Hartwich, 1999).
3. AHP provides flexibility, accommodates inconsistencies, and intuitively appeals to decision–makers (Gavade, 2014).

4.7.5.3. Limitations of the AHP

The limitations of AHP include:

1. The sensitivity of the coefficients provides problems due to the interdependences between criteria and alternatives (Ishizaka and Labib, 2009).
2. Inconsistencies between judgment and criteria ranking (Valasquez and Hester, 2013).
3. It possesses the artificial limitation of the use of the 9–point scale (Gavade, 2014).
4. The AHP pair–wise comparison procedure is time–consuming (Hartwich, 1999).

4.7.6. Analytic Network Process (ANP)

Professor T. L. Saaty proposed the Analytic Network Process (ANP) at the University of Pittsburgh in 1966 as a decision–making method applicable to an independent feedback system. It provides internal dependence and internal feedback of specific complex systems. The ANP is a generalisation of the AHP, which considers the relationship between the various hierarchy elements. The interaction and dependence of higher–level elements in a hierarchy on lower–level elements make it difficult for many decision problems to be structured hierarchically (Saaty and Vargas, 2006). Therefore, ANP can be described as the general form of AHP, which is concerned with the network structure of decision–making criteria. Extensions on AHP allow the ANP to describe the relationships between things in the real world more accurately, making the ANP closer to reality than the AHP by effectively representing decision–making problems based on their networks. Moreover, it can solve feedback and interdependence relationships amongst criteria, which is impossible in the Analytic Hierarchy Process (Sekitani and Takahashi, 2001). In that case, the decision problems of ANP are modelled as networks, not as hierarchies. According to He *et al.* (2012), the ANP structure consists of two parts, namely:

1. The control layer deals with associative problems and decision–making rule
2. The network layer describes where the elements interact with each other and which interior is the network structure

4.7.6.1. Application of ANP

According to Garcia–Melon *et al.* (2007), ANP considers each issue as a network of criteria, sub–criteria, alternatives that communicate with each other in any way as a network element. Chung *et al.* (2005) and Kheybari *et al.* (2020) show that ANP can be summarised in four steps, which include:

1. Building a model and converting a problem into a network structure
2. Formulating a precise comparison matrix and determining priority vectors
3. Generating a super matrix and converting it to a weighted matrix
4. Selecting the best option using a network approach

Many publications on ANP have been witnessed in the waste management domain. For instance, Tseng (2009) applied ANP and Decision–Making Trial and Evaluation Laboratory (DEMATEL) methods to find the best waste management solution for Metro Manila Region in the Philippines. According to the study, the best waste management solutions are thermal process technology and resource recovery facilities. Furthermore, with combined AHP and ANP methods, Aung *et al.* (2019) assessed the medical waste management system in Myanmar. The study found that segregation is the most important criterion for medical waste management. However, areas of deficiency include treatment, collection, storage, transportation, and training. In other areas, ANP has been applied in solving problems, such contractor selection (Cheng and Li, 2004), acquiring new equipment for an establishment (Dağdeviren, 2008), financial crisis forecasting (Niemira and Saaty, 2004), product mix planning (Chung *et al.,* 2005), and the evaluation of alternative fuels for residential heating (Erdogmus *et al.,* 2006). Notably, since the emergency of ANP as a decision–making tool, the applications have been witnessed in health, safety and environmental, hydrology and water; business and financial, human resources, tourism, logistics and supply chain, design, engineering and manufacturing systems, energy management (Kheybari *et al.,* 2020).

4.7.6.2. Strengths of ANP

Tavana *et al.* (2017) mentioned the strengths of ANP as being:

1. Considers the interrelations among the elements
2. The elements of the same cluster are compared among themselves regardless of the hierarchy

4.7.6.3. Limitations of ANP

The limitation of ANP include:

1. It is still not recognised as a common decision–making method (Jharkharia and Shankar, 2007)
2. Difficulties are evident when measuring and comparing the complexity levels of factors of a system (He *et al.,* 2015)
3. Compared to AHP, ANP kinds of comparisons for an internal element can be confusing except in limited cases (Asadabadi, 2016)

4.7.7. Adopting the Voting Analytic Hierarchy Process (VAHP) for the Study

Several scholars have adopted the VAHP ranked voting system (Cook and Kress, 1990; Andersen and Petersen, 1993; Stein *et al.,* 1994; Green *et al.,* 1996; Hashimoto, 1997; Bouyssou, 1999; Noguchi *et al.,* 2002). Ranked voting is when voters select and rank more than one candidate in order of preference. Saaty proposed AHP in the 1970s to address decision problems; however, Lui and Hai (2005) introduced the VAHP, simplifying the AHP model to improve decision–making. The key intention was to provide the purchasing manager with the capacity to generate non–inferior purchasing options by systematically analysing the relevant criteria for supplier selection without pairwise comparison.

As the name implies, the VAHP is a voting–based multi–attribute evaluation method developed based on AHP and Noguchi strong ordering models (Azadeh *et al.,* 2009). Furthermore, the relatively low degree of mathematical complexity makes VAHP an attractive method for all non–experts involved in a decision process. Also, as required in standard fuzzy logic, the definition of fuzzy membership functions is not required, simplifying the process and making it more reliable. Therefore, in this study, VAHP is considered the most suitable multi–criteria group decision–making method due to its simplicity than the AHP, while maintaining its systematic nature (Liu and Hai, 2005). The method provides a straightforward approach to achieve the same purpose in deriving the weights/priority of criteria required for efficient prioritisation or selection of criteria than the traditional AHP that employs pairwise comparison, which appears relatively complex (Liu and Hai, 2005; Vaidya and Kumar, 2006). This advantage over AHP helps to minimise decision–makers workload in submitting their preferences inherent in trade–offs among different criteria.

4.7.7.1. Application steps of the VAHP

As anticipated by Liu and Hai (2005), the VAHP model has been effectively used in several disciplines, including information technology (Azadeh *et al.,* 2009) and construction (Lam *et al.,* 2017). The method combines the AHP hierarchy approach in structuring criteria and data envelopment model (DEA) to obtain individual decision–makers preferences regarding different solution options (Pishchulov *et al.,* 2019). The tree–like hierarchy model allows decision–makers to indicate their preferences as ordinal rankings, while the DEA helps to minimise subjective bias inherent in MCDM evaluation of criteria for a credible assessment (Cook and Kress, 1990; Noguchi *et al.,* 2002). According to Juang *et al.* (2009), the VAHP involves the following steps:

1. Each decision–maker is required to rank–order all the criteria and attributes to avoid inconsistency in pair–wise comparison
2. Linear programming models (DEA) are used to obtain the weight of each criterion and attribute
3. The total score of each item can be computed, and the items placed by priority

Although the VAHP has been applied across different topics in the construction industry (Manu *et al.,* 2019; Gbadamosi *et al.,* 2019), the application is relatively scarce in the area of construction waste management. Therefore, the VAHP application is appreciated in this study. According to Lui and Hai (2005), this method was specifically designed to suit experts' decision–making and efficiently exercise its importance in supplier selection.

4.7.7.2. Strengths of VAHP

According to Liu and Hai (2005), the benefits of VAHP include:

1. This method is straightforward, easy to understand, and used to get the priority or weights of decision–making criteria.
2. It provides ''vote ranking'' rather than ''paired comparison,'' which is time–efficient, thus reducing the workload in a pairwise comparison.
3. It uses vote ranking to determine the weights on the selected rank.
4. The inclusion of the AHP hierarchy model facilitates easy communication of criteria and attributes.

4.7.7.1. Limitations of VAHP

Hadi–Vencheh *et al.* (2011) pointed out some of the limitations of the VAHP (Liu and Hai, 2005) model. The VAHP mathematics equations are presented in the methodology Chapter (Section 5.10.4).

1. It uses the formula 2/n*S(S+1) to bound x_{r_s} and make it greater than zero. If the number of voters is unknown, it would be difficult to apply the model
2. It obtains the weight of each criterion and sub–criteria selection of suppliers in step four. R+P model would be run many times, which is time–consuming; R is the number of criteria, and P is the number of sub–criteria.
3. The purchasing managers must compare each supplier with respect to each factor and award a score from 0 to 10 to each supplier on each factor in step 5. The one–by–one assessment is also time–consuming.

In response to these limitations, Hadi–Vencheh *et al.* (2011) propose an improved VAHP to remove the limitations and maximise the strengths. The improved model excluded the variable n and replaced formula (5) with formula (6). Also, the VAHP is chosen to analyse the research data because the known limitations have been improved (Hadi–Vencheh *et al.,* 2011); hence, the advantage over other MCDM techniques. Furthermore, the simplicity in an application makes its desirables as practitioners could find it easy to submit their waste minimisation preferences with time efficiency to arrive at a final decision. Also, the model operations do not depend on the number of participants or criteria. Thus, it can accommodate any number of voters and criteria and is flexible regarding rank positions (Azadeh *et al.,* 2009; Pishchulov *et al.,* 2019). The VAHP steps and analysis method are further discussed in the methodology chapter (Section 5.10.4).

4.8. Chapter Summary

This chapter reviewed waste management decision–making models, including CBA, LCA and MCDM. In addition, their operational steps, strengths and shortcomings were discussed. Following the review, the MCDM method was selected to underpin the development of the frameworks based on its strengths in analysing multiple stakeholders' opinions in decision–making, which is the key objective of the current study. Further, several MCDM techniques were reviewed, and the VAHP technique was selected as suitable for the research data analysis. This is based on its many advantages over other techniques, such as ease of use and the removal of its known limitations to maximise the operational strengths. The research design and methodology is presented in the next chapter.

CHAPTER 5: RESEARCH DESIGN AND METHODOLOGY

5.1. Introduction

Research methodology is an important procedure that allows researchers to collect and analyse data for a successful outcome. Also, it allows interested parties to understand and appreciate the roadmap a researcher has followed to achieve their objectives to evaluate the overall validity and reliability. Therefore, this chapter presents a detailed methodology of this research toward adopting suitable data collection and analytical techniques and justifying them to fulfil its goal. Firstly, a quantitative research strategy was adopted through a questionnaire survey for data collection to develop the proposed frameworks. Next, interviews were used to collect data to validate the research outcomes. The chapter begins by identifying and discussing research paradigms underpinning the research. Then, the framework development and validation methods are presented, and finally, the chapter ends with a summary.

5.2. Research Paradigms

Developing new knowledge requires a systematic procedure for gathering and analysing data for validity and acceptability. Therefore, philosophical assumptions, also known as research paradigms or approaches, accompanies knowledge development, the foundation of research. In the book 'The Structure of Scientific Revolutions' the word paradigm was first used by an American philosopher, Kuhn (1962), to suggest a philosophical way of reasoning, school of thought, or set of shared beliefs that informs the interpretation of research data. Research paradigms provide a structured roadmap and intellectual assumptions needed to create new knowledge in a field of study (Kuhn, 1962). Over the years, the research paradigms have shaped social science development forming the rationale that suggests the originality of a research outcome. Philosophical assumptions drive knowledge development; therefore, their importance cannot be overemphasised. They are the conceptual lenses through which researchers look at the world.

Research paradigms explain epistemology, ontology, methodology and axiology (Lincoln and Guba, 1985; Kivunja and Kuyini, 2017). Epistemology and ontology ideologies influence the choice of a researcher's worldview, defined as the basic set of beliefs that guide action or an investigation (Guba, 1990; Scotland, 2012). Also, choice of worldview(s) suggests methodology a researcher intends to adopt for data collection and method(s) of analysis (Lincoln and Guba, 1985). Finally, axiology, defined as the role of value and ethics, supports ethical and safe–conducts of research throughout the process (Biddle and Schafft, 2015). Figure 5.1 shows the research paradigms that can guide social science research development.

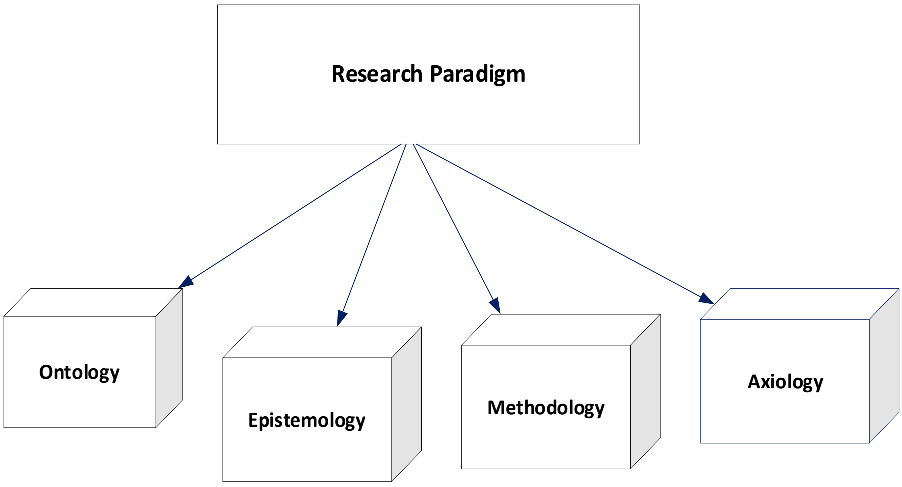
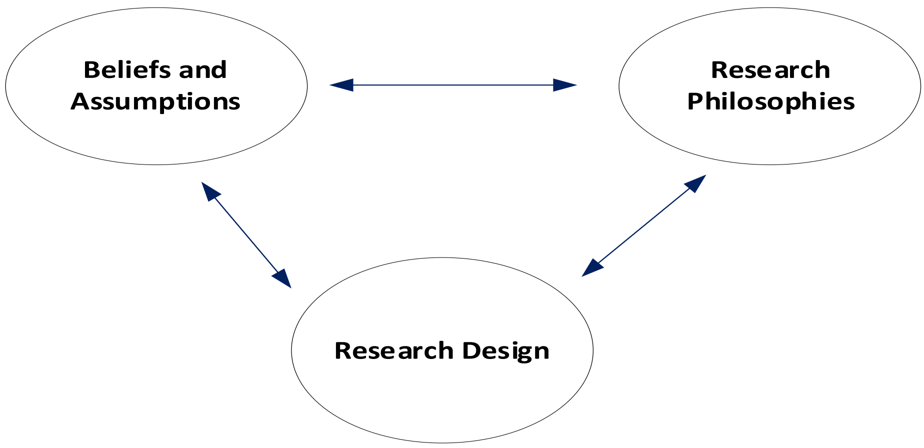


Figure 5.1: Research Paradigm Framework (Adapted from Guba and Lincoln, 2005)

According to Lincoln *et al.* (2011), a researcher must reflect carefully on the elements of the research paradigm to make the right choice for a research design. Saunders *et al*. (2015) developed a reflective model (Figure 5.2) to guide researchers to choose a research design, suggesting a need for concordance between the elements of research philosophies to achieve the objective. Therefore, research assumptions influence what should be studied, how it should be studied, and how the results should be interpreted/presented in a particular discipline. Understanding the differences and relationships between philosophical assumptions allows for the justification of a research design (Guba, 1990).



*8***Figure 5.2:** A reflective process of developing research philosophy (Saunders *et al.*, 2015)

Accordingly, researchers should evaluate various aspects of research paradigms to view the study with the right lenses to avoid confusion (Saunders *et al*., 2015). Thus, Saunders *et al.* (2009) 'Research Onion' (Figure 5.3) reveals different layers of methodological models to allow rational decision–making in selecting a suitable research design and analytical technique(s). Further, a researcher's philosophical assumption suggests whether the research will be quantitative, qualitative or a mixed–method (Antwi and Hamza, 2015). The following section discusses the elements of the social science research paradigm and worldviews.

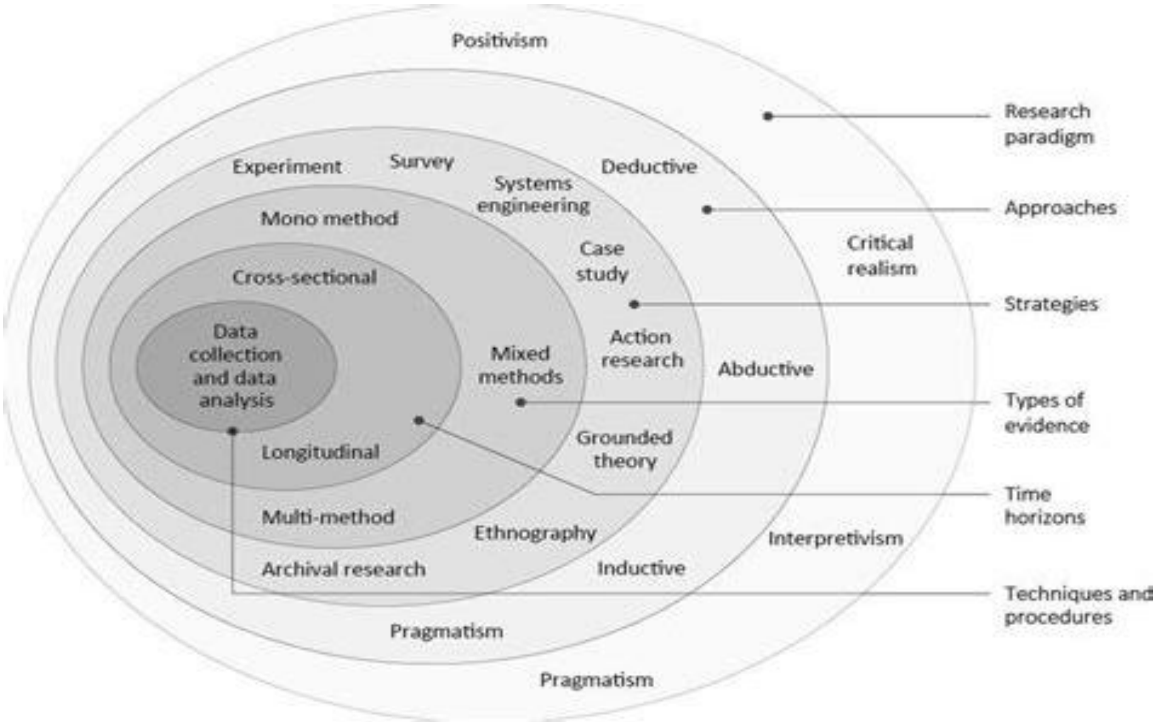


Figure 5.3: Research onion (Saunders *et al.,* 2009)

5.2.1. Ontology Position of the Research

Ontology is the study of reality and its nature (Smith, 2012). Smith and Searle (2003) further explain ontology as the study of people's belief in what constitutes social reality. Therefore, it is the nature of a phenomenon (solutions or problems) being studied. Ontological assumptions help researchers reflect on the research problem and the method to answer a research question(s) for a solution(s). There are two traditions of ontological assumption: realism and relativism (Proctor, 1998). Realism is an assumption that social phenomenon exists independent of the actor(s), while relativism is that reality is inseparable from social actor(s) (Nola, 1988). These two assumptions represent a different school of thought and what constitutes a fact in knowledge creation. Ontological assumptions show the relationship between the researcher, their research question(s), and a researcher's perception of what exists in the real world. This is because social issues could be resolved using different approaches; thus, ontology allows a researcher to choose either realism or relativism suitable for answering a question(s) or combine them when necessary (Saunders *et al.,* 2015). Crotty (1998) suggests that researchers need to take an ontological position that reflects their perception of reality.

Across the world, the construction industry generates waste, which is a concern to both the industry and society. Therefore, the study seeks to identify proven waste management strategies to help Nigerian contractors manage waste effectively in the materials procurement and construction stages. Hence, this study assumes the realism tradition because the expected knowledge (construction waste management strategies) can be found in existing literature. This would mean that unravelling this reality and providing implementation techniques is central for waste minimisation in the construction industry. Therefore, waste management criteria and related attributes were identified from the literature and introduced as integral ideas that constitute the research conceptual framework. The realism idea is contrary to relativism tradition that invalidates absolute reality. Relativism is most useful when knowledge of what constitutes reality is relatively scarce; therefore, exploring entirely new knowledge is possible. Therefore, relativism was not adopted because what constitutes reality in the current research is not scarce but could be found in the relevant literature. It is worth noting that an ontological assumption influences a researcher's epistemic choice (Lucas, 2014).

5.2.2. Epistemology Position of the Research

Epistemology is a philosophy required for research to yield acceptable and valid knowledge. As a knowledge theory, epistemology explains what we know about reality and how we know them. Epistemology means the study of the nature of knowledge and justification (Pritchard, 2013). Subjectivism and objectivism are the two epistemic traditions. Subjectivism is the acquisition of knowledge by interaction (Nonaka and Peltokorpi, 2006). It implies that the meaning of reality can only be understood inter–subjectively through interaction between a researcher and the participants. In that case, there could be no need for a pre–determined instrument for data collection as the meaning of reality is usually derived after the interaction. Also, the subjective tradition is a belief that there is no objective truth; hence, a need to clarify knowledge by reflection (Moon and Blackman, 2014). Subjectivism means interpreting reality from the participants' viewpoint rather than relying solely on the existing theory.

On the order hand, objectivism trusts in the impartiality of proven theories that exist in the real world. Thus, this tradition enables the use of existing laws/theories to explain a phenomenon in scientific observation (Gotthelf and Lennox, 2013). From the objective viewpoint, researchers begin by identifying theories and patterns in a field of interest which is the case of this study considering the ontological position. According to Guba and Lincoln (2005), objectivism makes a researcher independent of the phenomenon under observation. Therefore, objective researchers usually review the existing literature in the study area to identify trends. It, therefore, allows a researcher to propose a hypothesis to prove or reject it through testing (Farrugia *et al.,* 2010). Hence, a proposed hypothesis can be tested and then be accepted or rejected. In addition, a pre–defined instrument, such as a questionnaire, could be used for data collection (Phellas *et al.,* 2011).

An objective epistemology is the most suitable for this research. Further, objectivism can enable the generalisability of research results (Feast and Melles, 2010). A significant representation of the research sample population can enrich its value (Creswell, 2014), coupled with the cost–effectiveness of a pre–defined research instrument (Bush and White,1985). Table 5.1 shows the uniqueness of ontology and epistemology assumptions.

Table 5.1: Ontology and epistemology assumptions (Adapted from Saunders *et al.,* 2007)

Paradigm	Considerations	Objectivism	Subjectivism
Ontology	• Nature of reality	• Reality is universal • Structured in process	• Socially constructed • Multiple realities • Unstructured in process
Epistemology	• Knowledge acquisition • Acceptable knowledge • Good quality data • Contribution to knowledge	• Scientific approach • Facts/numbers • Theory observation • Law–like generalisations	• Arts and humanities • Opinions written, spoken and visual accounts • Participants' opinions • Individuals and contexts specifics

5.3. Philosophical Worldviews

Philosophical worldviews influence the choice of research methods required to provide evidence about a phenomenon under study. Therefore, it is a set of beliefs that guide researchers' choice of methodology and method. Various worldview paradigms underpin social and natural science research. Several scholars have identified worldview philosophies and have explained their strengths and weaknesses. For instance, Creswell (2014) explained positivism, constructivism, transformatism and pragmatism. Ryan (2018) described positivism, interpretivism and critical theory. All worldview traditions represent a unique belief system that supports knowledge development. A researcher can choose a worldview that best suits the research aim and objectives to answer a research question(s). Choosing a suitable worldview for research is essential to show the relationship between the researcher's belief and how the subject of interest was investigated (Crotty, 1998). While this study acknowledges the importance and uniqueness of many worldviews not presented here, the following sections discuss only the three worldview doctrines that can underpin social science research.

5.3.1. Interpretivism Worldview

Interpretivism is an ideology that reality can only be interpreted based on an individual or group's perceptions (Petersen and Gancel, 2013). It suggests that truth is not absolute but based on personal experience and reality. Hence, it is a belief that there are differences in what constitutes reality amongst people, even in the same circumstance. Since individuals can exhibit different experiences, even in the same condition; therefore, there are multiple realities rather than ones that exist in theories. In that case, researchers intend to understand and interpret reality through participants' spoken words and not entirely from the existing theories.

Interpretivism is deeply rooted in relativism ontology and subjectivism epistemology (Moon and Blackman, 2014). It is not concerned with the repeatability of an explanation, as value–free research is not usually considered in this concept. Therefore, it is rooted in qualitative research (Kaplan and Maxwell, 2005), allowing researchers to be entirely involved in the research process, making it a value–laden approach to an investigation (Myers, 1995). Also, interpretivism suggests inductive reasoning in exploring a phenomenon over a period, and researchers tend to be inseparable from the phenomenon under observation (Goldkuhl, 2012). This worldview was considered a reaction to positivism in the era of paradigm war—debate on the advantages and disadvantages of different worldviews (Gage, 1989; Bryman, 2008). However, current evidence suggests that their elements can be integrated to enhance a research outcome. This reconciliation is found in the philosophy of pragmatism (Denscombe, 2008). Nevertheless, interpretivism was unsuitable for this research because the study depends mainly on construction waste management theories to discover the existing reality to seek an objective interpretation of the results.

5.3.2. Pragmatism Worldview

Pragmatism can be adopted to answer a research question(s) by integrating different worldviews (Petersen and Gencel, 2013). In other words, pragmatism worldview does not rely only on a single worldview because it allows researchers to adopt elements of worldview traditions within the quantitative and qualitative methods. Furthermore, this worldview applies to the mixed–method of inquiry drawn substantially from multiple assumptions (Creswell, 2014). Positivism and interpretivism are two examples of worldview standpoints within the pragmatism tradition (Morgan, 2013). In that case, data triangulation is possible (Wilson, 2014). According to Creswell (2014), pragmatic philosophy allows individual researchers the highest degree of freedom and more flexibility in research. However, this approach can be cost and time consuming compared to adopting only one worldview tradition. This is because it involves two approaches of data collection and analytical techniques. However, combining a pluralistic worldview was not considered impossible in this research but unnecessary since a single worldview can answer the research questions regarding the nature of its objectives. Therefore, a single worldview was considered suitable and adequate to answer the questions.

5.3.3. Positivism Worldview

Positivism supports using a scientific approach to verify evidence by uncovering the truth about reality through evaluation and hypothesis testing. Traditionally, positivists believe the causes and solutions to problems exist in the natural world and can be measured and deduced objectively (Wynn *et al.,* 2012). Therefore, knowledge creation begins by investigating, evaluating and testing the existing theory to develop meaning (Creswell, 2003). As a result, this worldview tradition falls within the realism ontological tradition rather than relativism that does not agree with absolute truth. In that case, reality can be contextualised and generalised based on the sample of a defined population.

Positivism assumes the existence of reality is independent of the social actor(s). They employ deductive reasoning to verify empirical knowledge that can be reproduced through a scientific method (e.g. experiment). Adopting this philosophy allows for the independence of the observer from the observed (Creswell, 2014). Positivists observe reality from an objective standpoint rather than subjective (Sukamolson, 2007). Accordingly, researchers can observe and measure a phenomenon, while detached from personal emotions due to its dependency on strict scientific rules and procedures.

The positivism worldview is not free from criticism, as several authors have identified its shortcomings (Clark, 1998). Criticism associated with positivism resulted in the post–positivism movement. Post–positivism tends to deal with the biases that could be found in research adopting positivism tradition. According to Miller (2000), positivists believe that theory is unbiassed, while post–positivists claim errors could be found in scientific methods. Therefore, post–positivists suggest a need to scrutinise scientific theories to safeguard objectivity and improve scientific knowledge. Hence, efforts must be made to ensure that research procedures are unbiased while adopting the positivism worldview tradition (Creswell, 2014). Patton (2003) stressed that researchers must seek to produce honest, meaningful, reliable and valid knowledge by eliminating bias in the research process.

5.3.4. Positivism as the Adopted Philosophical Worldview

Worldview traditions influence research development based on a research question(s) and objectives and how a researcher intends to address them. Therefore, it is critical to commit to a suitable worldview(s) capable of illuminating contemporary issues under investigation (Babbage and Ronan, 2000). The current research will address three questions: (1) Considering material procurement and construction activities, what are the key criteria that can influence effective waste management in the construction industry? (2) What is the relative weight/priority of the attributes? Question number one has been answered by reviewing the extant literature in chapter three, presented as the research conceptual frameworks. Also, question two is quantifiable; thus, each attribute can be evaluated to establish its relative weight/priority using a scientific method. (3) How can contractors implement the attributes in each criterion to minimise waste in materials procurement and construction activities? The third question can also be derived from the extant literature. Therefore, findings from these questions would enable the development of the proposed frameworks. Also, the positivism worldview is suitable for answering measurable questions, such as ‘what’, ‘how much, and ‘how many’ (Sukamolson, 2007), which is the case of this study. Additionally, objectivism and realism underpinning this study are consistent with the positivist worldview (Saunders *et al.,* 2009). Therefore, the positivist worldview is adopted due to the nature of the research questions, combined with ontological and epistemic positions.

5.4. Methodology and Methods

Following a choice of worldview tradition, a researcher must decide the methodology and method of data collection and analysis, also known as research strategies, design, or inquiry approaches that enable researchers to systematically answer a research question(s) (Saunders *et al.,* 2009). Research methodologies are entrenched in the qualitative, quantitative, and mixed–method (Creswell, 2014). The third (mixed–method) integrates quantitative and qualitative elements, accepted as an inquiry method after a lengthy debate on harmony between their different philosophies calling for data triangulation (Denzin, 2010). Each of these strategies possesses a unique worldview that must align with the choice of data collection method(s) and analytical technique(s). According to Creswell (2017), a research strategy and method must align with a researcher’s philosophical assumptions. Accordingly, researchers must understand the concept of research strategies and their corresponding methods for reliable data collection and analysis (Gelo and Carlo, 2012). The following sections discuss research strategies and the related methods of inquiry.

5.4.1. Qualitative Strategy and Methods

The qualitative strategy seeks answers and meanings through peoples' understanding of their social reality. According to Hesse–Biber (2010), the qualitative strategy is used to obtain people's perceptions of the world around them. Therefore, it allows researchers to explore and describe an individual or a group of peoples' experiences in a study. Researchers adopting this strategy assumes that social reality is subjective and varies amongst individuals. This suggests that individuals perceive, interpret or relate to the same social phenomenon differently. Hence, a researcher can relate to different individuals based on their perception of what constitutes reality. Qualitative research tends towards interpretivism, which is inductive in data presentation (Mills and Birks, 2014), thus, allows researchers to be wholly involved in the process (Patton, 1990). Qualitative researchers monitor participants behaviours, body language or listen to their words to extract meanings (Creswell, 2014). Therefore, researchers can create meanings by interpreting participants' opinions and presenting them as research results.

Further, qualitative research involves collecting/collating data to extract important findings to generate meaning. The strategy allows researchers to collect open–ended emerging data and interpret them thematically. Traditionally, it involves gathering data from the participants in a broad, thematic scope and arranging them in themes to create a pattern (Creswell, 2003). This approach can help a researcher discover entirely new knowledge in a field of study. It allows researchers to explore new meanings in a phenomenon, which may not be available in the existing literature. Additionally, the qualitative approach allows researchers to reflect on the research phenomenon and listen to participants' experiences to understand and interpret them (Hesse–Biber, 2010). Some of the shortcomings of qualitative research strategy are identified by (Bryman, 2006).

- The subjective nature of qualitative research may involve a high level of bias
- Research findings are usually based on the personal view of the participants on what is significant
- It lacks standardised procedures; thus, it may be difficult to replicate as data is usually unstructured
- It may be difficult to generalise qualitative research due to a restricted scope

Bryman (2006); Fellows and Liu (2008) suggests some measures that could minimise bias in qualitative research to ensure reliability: (1) cross–checking data from transcripts to eliminate errors and; (2) use of coding in data analysis. According to Creswell (2009), bias could be minimised when similar data or perspectives are collected from individual participants. Creswell (2003) outlined five data collection methods associated with the qualitative research approach. These are Ethnographies; Grounded theory; Case studies; Phenomenological inquiry, and Narrative inquiry. These methods are discussed in the following sections.

5.4.1.1. Grounded theory

The grounded theory involves collecting and analysing data for theory development (Strauss and Corbin, 1997). Researchers adopting this method tend to discover what problems exist in a social environment by reformulating propositions until a theory is developed systematically. It allows researchers to develop a theoretical context in a study while grounding the account in empirical observation or data (Martin and Turner, 1986). It involves multiple data collection stages and the refinement of information categories (Creswell, 2014). This study did not apply ground theory as the main objectives could be best achieved using an existing theory.

5.4.1.2. Ethnography

Ethnographies allow researchers to study people in their natural environment over a period (Stewart, 1998). This method could provide holistic insights into people's beliefs, culture, or worldview through a collection of detailed interviews, observations, or artefacts supporting evidence (Fellows and Liu, 2008). Flexibility is the key advantage of ethnography in investigating the reality in peoples' way of life (Davies, 2008). However, it may require a significant amount of time to comprehend peoples' way of life or culture. Therefore, ethnography is not suitable for this research as it focuses on understanding practitioners' views on construction waste management strategies rather than their culture or ways of life.

5.4.1.3. Case study

Case study research involves a systematic and in–depth inquiry to explain a phenomenon or real–life phenomena over a pre–determined period (Merriam, 1988). A researcher can adopt a single or multiple case study (Gustafsson, 2017), relying on multiple sources of evidence to answer a research question(s). Creswell (2003) stressed that researchers are bound by time in program or activity in case study research. Thus, it is essential for investigating a small number rather than many cases (Fellows and Liu, 2008). Researchers can collect detailed information using various data collection procedures to draw meaning over a defined period. For instance, a case study could involve collecting data by interviewing participants, observation, objects, and documentary materials (Baxter and Jack, 2008). However, a case study is not suitable for this study as data collection is not aimed at pre–defined project or projects samples but different construction practitioners.

5.4.1.4. Phenomenological research

Phenomenological research allows researchers to examine participants' experiences and describe their worldview. A researcher can appear as the research instrument in phenomenological research (Moustakas, 1994). Phenomenological design is primarily used in qualitative research to study and interpret an individual’s or peoples’ life experiences and concerns around a specific phenomenon (Moustakas, 1994). Researchers who adopt this method usually set aside their own experiences to understand participants’ experiences in a study. Again, this method is not suitable for the current study as data regarding participants’ social life experience is not required to minimise construction waste.

5.4.1.5. Narrative Research

Narrative research is the study of a person’s life history and experience. It involves collecting an individual life history to be retold chronologically. According to Clandinin (2006), narrative research considers the relationship between an individual’s life experience and culture. For instance, an individual’s autobiographies can be studied considering the life experience, culture and belief to narrate how he/she had lived. However, this method is unsuitable for this study as participants’ life history is unnecessary for construction waste management.

5.4.2. Quantitative Strategies and Methods

The quantitative strategy enables researchers to quantify and test theories to find the relationship among known variables. Therefore, it applies to issues expressed in quantities (Payne and Williams, 2011). The strategy supports the positivist idea, a philosophy that there are true answers to problems in the natural world (Creswell, 2003). As earlier mentioned, quantitative research attempts to answer natural questions such as “how,” “What,” “where,” “how”, “much,” “how many.” Quantitative researchers usually start with the extant literature review to form a research background towards answering such questions to fill a gap(s) in the literature (Black, 1999). Therefore, a research problem(s) and the existing gap(s) in the literature can be identified for evaluation and solution. This approach seeks to uncover objective truth through evaluation, as data processing and analysis are deductive (Creswell, 2009).

The quantitative strategy allows researchers to propose and test a hypothesis, which becomes information (Martin and Bridgmon, 2012). According to Martin and Bridgmon (2012), evidence found in previous studies can validate the research findings, and the process should be replicable. The quantitative research method has four significant advantages: (1) precise, explicit results – the hypothesis can either be rejected or supported; (2) the results of other studies can be compared and contrasted; (3) the results of the study can be reliable due to the use of precise analytical tools, and (4) high external validity and generalisability (Savela, 2018). However, the author suggests that the objective nature of quantitative inquiry makes the process inflexible. Compared to the qualitative strategy, quantitative studies' reliability and validity could depend on a significant number of participants (Charter, 1999). In addition, the literature review and a significant number of representative samples could be required for its generalisability. The two primary data collection tools for a quantitative study include experiment and survey (Creswell, 2014).

5.4.2.1. Experiments

Research in natural science and physics mostly applies experiments to understand variables inter–dependence and causal relationships. Creswell (2009) posits that an experiment is ideal for any data that requires verification in any research focusing on proving facts and perceiving the outcomes from different adjustments. An experimental researcher identifies a sample and generalises to a population. In the physical sciences, experiments are usually carried out in a controlled laboratory to test a hypothesis and determine whether a treatment influence outcome (Creswell, 2009). On the other hand, social science research experiments are usually field–based (Svejcar and Havstad, 2009).

5.4.2.2. Survey

Researchers use the survey to collect quantifiable data for analysis. It aids the quantification of participants' opinions or trends of a population by studying the sample of that population using questionnaires or structured interviews (Babbie, 1990). In addition, a survey allows researchers to gather quantitative data to compare different variables' importance (Fowler, 2013). There are two types of survey – cross–sectional and longitudinal (Rindfleisch *et al.,* 2008). In a cross–sectional survey, data is collected to make inferences about a population in a short period by having a snapshot of the population under study. A longitudinal survey involves repeated observation of a population or variables over a more extended period than a cross–sectional survey. Data can be collected via telephonic or face–to–face structured interviews or postal, face–to–face or online questionnaires in survey research.

5.4.3. Mixed Strategy and Methods

The mixed inquiry strategy was introduced in 1959 when Campbell and Fiske used multiple methods to investigate psychological traits validity (Creswell, 2009). The mixed method integrates quantitative and qualitative elements as a later inquiry strategy. Current understanding suggests that integrating quantitative and qualitative components could lead to greater research credibility (Creswell, 2003). Researchers believe that the inherent advantages in one strategy can complement the inherent disadvantages in the other (Onwuegbuzie *et al.,* 2013; Ramlo, 2016). The mixed–method approach is used to understand a phenomenon by answering questions that a single approach may not provide. By applying the mixed–method, a researcher is not restricted to one strategy but combines quantitative and qualitative to enhance the research outcome (Onwuegbuzie *et al.,* 2013). Therefore, the strategy allows researchers to collect quantitative and qualitative data and analyse them for a better and more in–depth understanding of a phenomenon.

The mixed–method involve close–ended (quantitative) and open–ended (qualitative) data collections through quantitative surveys and narrative formats. Hence, data analyses usually include statistics, textual interpretation and images (Morse, 2010). The main barrier of mixed research is usually associated with integrating both quantitative and qualitative approaches. Bryman (2007) pointed out some of the challenges of mixed–method application in research thus:

- The different elements of qualitative and quantitative strategies could make their integration difficult
- An author preference for one method over another may lead to more emphasis on the preferred method; hence bias
- A mixed–method may require adequate time and resources to be successful
- It requires the competency of the author in both quantitative and qualitative approaches

Careful consideration of the assumptions, rules and expectations regarding research conduct is critical if one must use a mixed–method (Bazeley, 2002). The mixed research approach could be carried out either by exploratory, explanatory sequential mixed methods or concurrently. These approaches are discussed in the following sections.

5.4.3.1. Sequential Mixed Method

A sequential mixed strategy may either involve exploratory (qualitative before quantitative) or explanatory (quantitative before qualitative) sequence. Data collection and analyses are carried out in different phases to verify or comprehend the other. Ivankova *et al.* (2006) explain sequential mixed method scenarios: An exploratory sequential mixed method is when a researcher collects qualitative data and conducts analysis followed by a quantitative study. For instance, a researcher could employ interviews and subsequently distribute a questionnaire to a larger population. It is usually carried out when a researcher intends to generalise the qualitative study's findings to a larger population sample. On the other hand, an explanatory sequential mixed method begins with a quantitative method (e.g. a questionnaire survey) and subsequently, the qualitative method (e.g. interview) (Tashakkori *et al.,* 1998). The follow up qualitative results could help interpret and explain the previous (quantitative) findings in more detail or examine/explain any unexpected findings from a quantitative study (Creswell, 2009).

5.4.3.2. Concurrent Mixed–Method

Contrary to the sequential mixed method, both qualitative and quantitative data are collected simultaneously. Concurrent mixed–method research converges or merges qualitative and quantitative data in a study (Creswell, 2009). This method is time–efficient compared to the sequential mixed–method because qualitative and quantitative data can be collected concurrently. Creswell (2009) stressed that using concurrent strategy requires competency of the researcher because studying a phenomenon could require considerable effort and resources to adequately analyse and compare results of data of different forms concurrently. Nevertheless, a successful concurrent mixed–method research could be regarded as well–validated because a change of event due to time is minimised compared to the sequential mixed–method research.

5.4.3.3. Transformative Mixed Method

The transformative mixed method adopts a philosophical framework that prioritises social justice to improve human rights (Mertens, 2010). The approach allows a researcher to use sequential or concurrent approaches to investigate a social phenomenon. Sweetman *et al.* (2010) suggest a need for more advocacy research, such as applying the transformative mixed methodology. However, due to the scarcity of literature on its application, the adoption could be somewhat challenging (Sweetman *et al.,* 2010).

5.5. Adopted Research Methodology and Method

One of the important questions posed by this research is to determine the relative priority weight of material procurement and construction waste management attributes using practitioners' objective opinions. Therefore, the quantitative approach is suitable as the participants' waste management criteria and attributes preferences can be measured in weights, thus, quantifiable (Fellows and Liu, 2008). Further, the quantitative approach through questionnaire survey is widely used to evaluate the relative importance of waste management strategies in the construction industry (Wang *et al.,* 2010; Yuan and Shen, 2011; Yuan, 2013). Many strategies have been proposed for construction waste management, but the question is always 'what' is their relative importance in a regional or local context (Poon *et al.,* 2001; Jaillon *et al.,* 2009). Therefore, this study adopts a questionnaire survey to obtain data from Nigerian construction practitioners regarding their waste management preferences to develop the proposed frameworks.

5.6. The Literature Review

A literature review is a form of secondary data collection. It helps form the social science research background, particularly for a quantitative study. Therefore, it summarises trends in a subject, such as questions and gaps identification (Lu and Yuan, 2011). The literature reviewed in this study was conducted using peer–reviewed journals, conference proceedings and books irrespective of year of publication. The review of past academic works in the discipline aided the identification of materials procurement and construction criteria and attributes presented in Chapter 3. Also, it helped to identify various waste management decision–making models towards the choice of VAHP–MCDM for the study. In searching for academic works, terms such as (''construction waste management'', ''construction waste minimisation'', *"C&DW", "Construction waste*"); (''waste management models'' MCDA; MCDM) were used to identify the scholarly publications in online databases. These databases include Web of Knowledge, Scopus, Emerald Insight, Ethos, PubMed, SciELO and Google Scholar.

5.7. Materials Procurement and Construction Criteria and Attributes' Validation

While the literature review revealed the procurement and construction criteria, these criteria have not been clearly outlined for Nigerian construction practitioners. Project management criteria can be validated to align with the overall goal. Following Lam *et al.* (2017), a group of construction industry's academic experts of Nigerian origin were invited and recruited to verify/validate the criteria through purposive sampling. A structured questionnaire was designed for the verification purpose. Purposive sampling can be used to obtain information from a particular population of experts interested in a subject (Etikan *et al.,* 2016). Through publicly available email addresses and professional contacts, fourteen experts agreed to participate and were recruited. A unique code was given to each participant to ensure personal data protection and privacy. Also, their right to participate or withdraw was guaranteed through a consent form. All the participants were required to sign the consent form before participating in the survey. Participants minimum eligibility requirements include:

- Five years of teaching and research experience (construction industry)
- Master's degree
- Member of a professional body
- Must be of Nigerian origin interested in the industry challenges

The purpose of the verification/validation is to check: (1) whether the criteria and attributes are clear to experts; (2) whether the criteria and attributes are comprehensive for waste management, and (3) whether the criteria and attributes were relevant for the Nigerian construction industry; (4) and that the grouping of a set of attributes aligned with the respective criterion. Participants were required to tick *'agree or disagree'* and comment on any criterion or attribute that are not clear enough to them or relevant to the industry. In addition, participants should tick *'agree or disagree'* on the grouping of attributes, suggesting if an attribute should be moved from one criterion to another or be removed. Also, each participant is required to look at the comprehensiveness of the criteria and attributes and tick *'agree or disagree'*. Finally, suppose a participant disagrees on the comprehensiveness of the criteria or attributes. In that case, the participant can comment and provide any additional criterion or attribute they think could be relevant to ensure comprehensiveness.

Feedback from the participants would lead to the adjustments, removal or rewording of some of the criteria/attributes to make them meaningful and unambiguous. In addition, the feedback would help validate the survey constructs by grouping questions related to an underlying theme for internal reliability. The verification results are discussed in Section 6.2. Following the expert verification, a structured rank survey was designed to determine the criteria and attributes' priority weights based on their relative importance and ability to minimise waste in the Nigerian construction industry. The VAHP was used to establish their respective priority weights based on the outcome of the survey.

5.8. Questionnaire Development

A questionnaire was prepared to be administered to the intended participant. The intention was to develop a concise questionnaire with a reasonable time frame for completion. The first part of the questionnaire provided essential information to participants about the survey using a cover letter. The letter introduced the researcher and the study's aim, including a possible time to complete the survey. It was expected that participants should not spend more than 25 minutes to complete the questionnaire adequately. It also includes a consent form to allow participants the freedom to participate or withdraw at any time and assures participants of their privacy and safety. Therefore, participants answers would be anonymous and confidential.

The second part provided the main research questions, divided into five sections, as shown in Table 5.2. The questionnaire was pre–coded to ensure completion time efficiency and easy recording of information and analysis (Olsen, 2012). In addition, instructions on answering the questions were provided to ensure that participants understood them to minimise potential errors and avoid unanswered questions. The research questions were derived from the conceptual frameworks presented in Figure 3.3. Therefore, the questionnaire was designed based on the researchers' judgement and experts' verification/results of the criteria and attributes. The multiple groups of building construction practitioners from different firms rank–ordered the criteria and attributes. The groups exist within organisations' divisions or departments, so the study can be applied at the organisational and project levels because the criteria cut across several waste management solutions applicable in construction firms. The study, therefore, obtained data from these groups to analyse their materials procurement and construction waste management attributes' priorities. Table 5.2 shows details of the survey design.

Table 5. 2: Survey Design Details

Section	Assessment criteria	Task
1. **Participants Demography**	✓ Profession ✓ Highest qualification ✓ Professional body affiliation ✓ Year of experience	The participants were asked to provide their demographic information to ensure their eligibility to participate in the survey
2. **Ranking of material procurement criteria**	✓ Top management support (procurement) ✓ Procurement clause ✓ Low waste purchase management ✓ Efficient delivery management	Each section from 2 to 5: participants were asked to rank–order waste management items (criteria/attributes) based on importance following the VAHP ranking scale discussed in section 5.8.1
3. **Ranking of construction criteria**	✓ Top management support (construction) ✓ Construction clause ✓ Site Waste Management Plan ✓ Low waste Technique	
4. **Ranking of material procurement attributes**	✓ Ranking of 20 attributes categorised amongst the criteria in section 2	
5. **Ranking of construction attributes**	✓ Ranking of 22 attributes categorised amongst the criteria in section 3	

5.8.1. Survey Tool and Measurement Scale

The survey was designed using the Qualtrics software platform because of its efficiency in data management (Molnar, 2019). In developing the survey, the rank–order type was chosen to compare lists of waste management items based on participants' priorities/preferences. Rank order was found appropriate for this study for its straightforward statistical analysis. In addition, it has been applied in construction project management studies (Lam *et al.,* 2017).

In terms of measurement scale, the VAHP rank–order can vary depending on the number of criteria or attributes in a criterion. For instance, each participant can vote from 1 to S (S≤R), where R is the number of attributes in a criterion, and S is the rank order (Liu and Hai, 2005). In this study, rank–order (S) varies in the measurement scale based on the number of criteria or attributes in a question (S=R). For instance, in scoring the attributes' priority, where a criterion contains four attributes, only four rank–order are provided, and where there are five, only five rank–orders are provided and so on. Therefore, respondents are required to rank their most preferred waste management strategy in ascending order from 1, 2, 3...n. Hence, the most important attributes should be scored number 1, compared to other attributes and the second most important number 2 and so on. Therefore, based on the variable Likert measurement scale, it is required that participants type/assign the numbers on boxes provided at the right–hand side of each question.

Soltani *et al.* (2015) suggest that a significant number (81%) of studies on the MCDM method allow participants to assign weights to criteria, while (35%) of studies require participants to evaluate criteria on their own. According to the authors, the weighing process could be carried out via surveys, interviews, group meetings, or expert knowledge. A Likert scale is a form of ordinal scale measurement commonly employed in questionnaires with four, five, or more point ratings (Subedi, 2016). It is somewhat easy to understand Likert scale data in a quantitative study (Sullivan *et al.,* 2013). After the development, the survey was pilot tested to identify and correct potential difficulties a participant may encounter during the data collection exercise. The administered survey questionnaire used for the study data collection purpose is attached in Appendix 1.

5.8.2. Pilot Survey

The purpose of pilot testing the survey was to determine further the clarity of the questionnaire's language, layout, and length of time for a participant to complete it. The questionnaire, attached with a feedback sheet, was distributed to five postgraduate students reading construction project management degrees at the University of the West of England, Bristol (UWE) and twelve construction practitioners to identify any potential errors or difficulties in completing the survey. Scholars recommend varying sample sizes for the pilot exercise depending on the field or method (Johanson and Brooks, 2010). According to Hill (1998), a minimum of a sample size of ten is reasonable for a pilot exercise in survey research. Thus, amongst the seventeen questionnaires piloted, eleven were completed and returned by the participants.

Therefore, feedback from the participants was analysed. The results show that no participants had difficulty completing the questionnaire or suggested any change, perhaps due to the expert verification exercise and earlier modifications. All the participants agreed that the questions were unambiguous, straightforward and easy to understand. In terms of time for the completion, only five participants claimed that it took them a significant time to complete it adequately due to the adopted rank–order system. They suggest it took them, on average, 10–20 minutes to answer all the questions adequately. This time frame appears reasonable and considered not too long for a PhD questionnaire. Hence, no further modifications were made to reduce the time of completion. Accordingly, their claim helped advise main participants who will respond to the survey on the possible time frame for the completion. After pilot testing the questionnaire, it was distributed to the main participants for data collection and analysis.

5.9. The Population of the Study

A research population is a subset of individuals with specific characteristics required for a study to yield a reliable result. This study targeted all the registered building professionals in Nigeria affiliated with a professional body to obtain a reliable and representative sample size. The professional bodies targeted include (1) Council for the Regulation of Engineering in Nigeria (COREN); (2) Nigerian Institute of Quantity Surveyors (NIQS); (3) The Council of Registered Builders of Nigeria (CORBON); (4) Nigerian Institute of Building (NIOB). These professional bodies are responsible for regulating the building and civil engineering industry in Nigeria. This means that practitioners must belong to a professional body to participate. As a common practice in construction project management PhD theses, a minimum of one year of experience was adopted to ensure that those who intend to participate have good practical experience in the construction industry (Ajayi, 2017; Lam, 2017). This was included in the questionnaire as one of the minimum eligibility criteria for participation.

Participants were required to hold an Ordinary National Diploma (OND), as a minimum qualification, and to be employed construction professionals. Therefore, seven groups of practitioners were considered to represent waste minimisation decision–makers: (1) Project managers (PM); (2) Procurement managers; (3) Quantity surveyors (QS); (4) Civil engineer; (5) Structural engineers; (6) Mechanical engineers and (7) Site supervisors to ensure a representation of construction actors. These groups were considered for this study due to their direct involvement in materials procurement or construction project delivery. While participation was solicited across the Nigerian states/cities, participants practising in three major Nigerian cities, including Abuja, Lagos and Port Harcourt, were particularly targeted for geographical representation and significant construction activities in those states.

5.9.1. The Sample Size

A research sample is a target segment representing a whole population in a survey (Salant and Dillman, 2004). It is necessary to take a sample out of a representative population, especially when a study population is too large, or the number is unknown. Researchers use many procedures to determine sample size, depending on the type of data or study design. According to Kirby *et al.* (2002), a sample size generally depends on an acceptable level of significance, power of the study; expected effect size; underlying event rate, and standard deviation in a population. Kadam and Bhalerao (2010) stressed that sample determination could be a matter of convenience and compromise, such as precision and applicability in research. There are no publicly available data on the total number of the study population; hence, the sample size was estimated. Therefore, Cochran's (1977) sample size formula was adopted to determine the estimated sample size using Creative Research Systems (2016).

$$\mathbf{n_o} = \frac{Z^2 p(1-p)}{e^2}$$

Where:

- n_o = sample size
- z = standardised variable (confidence intervals)
- *p* = the worst-case percentage picking choice, expressed as a decimal
- e = confidence interval expressed as a decimal Sample size decisions

Based on most studies, a 95% confidence level (Creative Research Systems, 2016; *Sweis et al.*, 2021) was assumed where z = 1.96 at (α=0.05). Furthermore, to balance the level of precision, a confidence interval (*e*) of 10% was also assumed for this study. Finally, a 50% or 0.5 picking choice (*p*) in a worst–case was assumed to determine the appropriate sample size. Therefore, the sample size of this study was calculated thus:

$$\mathbf{n_o} = \frac{1.962 \times 0.5(1 - 0.5)}{0.1^2} = \mathbf{96}$$

The required sample size for the survey is 96 construction practitioners. However, it has been reported that a response rate between 20−30% is common and acceptable in several construction project management research adopting the questionnaire survey for data collection (Akintoye, 2000; Dulami *et al.,* 2003). Therefore, to achieve at least a 25% response rate, the sample size was adjusted to deal with nonresponse in the study. Thus, this study assumed a conservative response rate of 25% to arrive at the sample size of the surveyed as follows:

$$\textbf{\textit{Final sample size}} = \frac{\text{Initial } n_o}{\text{Common response rate}}$$

$$\mathbf{n_o} = \frac{96}{0.25}$$

Research sample = **384** practitioners

This sample size was doubled (**768)** following Manu (2012); to improve the number of responses and further reduce the effect of the nonresponse rate common in an online survey (Nair and Adams, 2009). Therefore, the sample size for this study is large enough compared to similar studies (Adewuyi *et al.,* 2014; Garba *et al.,* 2015; Adeagbo *et al.,* 2016).

5.9.2. Sampling and Data Collection Techniques

Inviting and recruiting participants is an integral part of a research. Therefore, after determining the research population and sample size, it is critical to consider the sampling technique for recruiting the participants for the study. A search was conducted to find eligible construction industry’s practitioners through members of professional bodies online directory of Nigerian industry professionals from the link (https://educeleb.com/professional–bodies–in–nigeria–websites/). A similar approach has been adopted in previous studies (Manu, 2012; Ogunmakinde, 2019). As a result, many engineering and construction professionals who listed their email addresses or phone numbers on the website were contacted for participation. Therefore, purposive sampling was adopted to recruit the initial participants. This is a non-probabilistic strategy that allows a researcher to rely on their judgment when choosing population members to participate in a study. Further, the purposive sampling technique has been adopted by similar studies (Shakantu *et al.,* 2008; Mbote *et al.,* 2016).

First, the questionnaire link was sent to 235 participants initially contacted through their email addresses or recruited via their phone numbers. Further, snowballing sampling technique was also used in a quest to involve more participants in the survey for a reasonable response rate. Therefore, some of the initially recruited participants assisted in recruiting other eligible participants. This approach was possible due to professional body members belonging to either WhatsApp groups or other social media platforms. According to Penrod *et al.* (2003), the chain referral technique can be used to involve hard–to–reach eligible participants in a survey. As a result, an additional 533 participants were contacted for participation, resulting in the 768 surveys distributed to facilitate data collection. Chain referral is widely used in construction waste management research (Aiyetan and Smallwood, 2013).

Data collection was carried out from the second week of September 2020 to the fourth week of November 2020. Two follow–up emails were sent to participants as reminders to maximise responses. This was to remind them of the importance of their participation in the research. Two reminders email is reasonable to improve the chance of a good response rate (Creswell, 2009). Participants were asked to ignore the follow–up emails if they had responded to the survey. Attached to the reminder emails include the questionnaire link and a reminder letter in a PDF format. Many participants responded after the last email was sent, while others did not respond. The response rate for this study is presented in Chapter 6.

5.10. Data Presentation and Analysis Methods

There are two methods used to analyse the data of this study. First, the descriptive and inferential statistical methods were used to analyse and describe data collected from the survey, respectively. Second, the VAHP was used to analyse the data. Details of adopting the VAHP data analysis method were presented in Chapter 4. These methods are discussed in the following sections.

5.10.1. Descriptive and inferential Statistics

The data collected were first analysed using descriptive and inferential statistics. Descriptive statistical analysis involved measuring frequency, mean, meridian, standard deviation, and percentiles of variables in a data set. It summarises quantitative data and presents the results using histograms, pie charts, bar charts, or tabular format. This study carried out descriptive statistics to generate the median, mean, and standard deviation for each waste management criterion and attribute under the materials procurement and construction categories. In particular, the median is suitable for measuring central tendencies of the data set because the data is in ordinal scare (Sullivan and Artino, 2013). Also, the median can effectively deal with outliers and a skewed (asymmetric) data set compared to the mean, sensitive to outliers (McGreevy *et al.,* 2009). It shows the true central tendency of the data set compared to the mean. Therefore, the median value can be taken as a true representative of the opinion of a group in a skewed distributed data set.

According to Allua and Thompson (2009), inferential statistics are based on probability theory and hypothesis testing. Inferential statistics were used to compare the treatment groups' differences of opinion and the degree of agreement on waste management strategies. The inferential statistics used in this study are non–parametric. The statistical tests do not assume data is drawn from a normal distribution (Gibbons and Chakraborti, 2020). Kendall's Coefficient of Concordance (*W*) and Kruskal–Wallis H Test are the two inferential statistics adopted in this study. These are discussed in the following sections.

5.10.2. Kendall's Coefficient of Concordance (W)

Kendall's coefficient of concordance (W) is a non–parametric statistic used to check agreements between several decision–makers who have rank–ordered several items. It is, therefore, a test for intragroup homogeneity in decision–making (Lewis and Johnson, 1971). The value of *W* ranges from 0 to 1; *W*=1 indicates perfect agreement; *W*=0 is no agreement. A value of *W* equal to 1 would mean that all the respondents ranked waste management strategies identically. In contrast, a value of *W* equal to 0 would indicate that all the respondents ranked the strategies differently (Li and Yang, 2014). Therefore, the more *W* moves closer to 1, the significance of the consensus amongst raters. Kendall's Coefficient of Concordance of the sample data was computed, which was useful to determine respondents' agreement on their rankings of waste management criteria and attributes in materials procurement and construction categories. The test was performed at 95% confidence and 0.05 significance levels. A value below the threshold of 0.05 shows a significant agreement between participants in ranking the waste management strategies. This test has been successfully applied in construction waste management studies (Yuan, 2013; Li and Yang, 2014). Details of Kendall's coefficient results are presented in Chapter 6.

5.10.3. Kruskal–Wallis H Test

Kruskal–Wallis H test is a non–parametric test used to determine whether there is a significant difference between two or more independent samples (Kruskal and Wallis, 1952). The test was conducted to observe whether participants' job/professional roles influenced their waste management priorities in the voting process. The analysis was performed for material procurement and construction criteria and attributes. The Kruskal–Wallis test was adopted because it is appropriate for ordinal data and could be used to compare two or more groups of equal or varied sample sizes (Kruskal and Wallis, 1952). The general rule of thumb is that if the Kruskal–Wallis coefficient is less than 0.05, the result is statistically significant. If the coefficient is equal to 0.05 or above, then the result is not statistically significant. The test was performed at 95% confidence and 0.05 significance levels. The results of the Kruskal–Wallis H test identify differences among the groups but does not identify which groups are different from other groups. In that case, post–hoc testing can be conducted to determine which groups are different from others. The Kruskal–Wallis test has been successfully applied in construction waste management research (Li and Yang, 2014). Details of the Kruskal–Wallis H test results are presented in Chapter 6.

5.10.4. Voting Analytical Hierarchy Process (VAHP)

Proposed by Liu and Hai (2005) and improved by Hadi–Vencheh et al. (2011), the six–step procedure for implementing the VAHP discussed in the earlier chapter could also be found in (Pishchulov *et al.,* 2019; Asah–Kissiedu, 2019). These are presented next:

Step 1—*Identify the criteria within the problem context*: The literature review was used to identify a catalogue of materials procurement and construction waste management criteria. The criteria selection process could be objective (Lam *et al.,* 2017), subjective or combined (Liu and Hai 2005; Pishchulov *et al.,* 2019). Therefore, the criteria selection process in this study is objective as they were derived from the literature review in Chapter 3.

Step 2—*Structure the criteria in a hierarchy:* The tree–like AHP model can be adopted to structure the criteria in a hierarchy (Liu and Hai, 2005). Therefore, criteria are clustered below the goal, while the attributes are clustered below the criteria according to the relation. This simplifies the decision–making process by breaking down the criteria and attributes into their constituent parts to help the stakeholders deliver credible judgements by dealing with constituents of the same order of magnitude in each hierarchy level (Pishchulov *et al.,* 2019). This study also identified the attributes through the literature review in Chapter 3.

Step 3—*Vote according to priorities of the criteria and attributes:* The concerned stakeholders are required to vote and rank–order the importance of both the criteria and attributes, respectively. Thus, this process has two stages: (1) prioritise the criteria and (2) prioritise the attributes. It requires that stakeholders submit their criteria preferences that they believe are most effective for materials procurement and construction waste management and then the attributes. (1) Seven stakeholders' groups voted on the importance of waste management criteria in material procurement and construction stages. Then, (2) after voting on the criteria, the procedure was repeated for the attributes sets in each criterion. To minimise bias, it was instructed in the questionnaire that each participant should complete the questionnaire/vote ones.

Step 4—*Evaluate the weights of criteria:* Hadi–Vendch and Niazi–Mortlagh (2011) equation, an improved Noguchi *et al. (*2002) strong ordering model utilised in Liu and Hai (2005), was used to calculate the coefficient weights (w_s) to determine the total weight of each criterion. Thus, Hadi–Vendch and Niazi–Mortlagh (2011) model can be expressed as follows.

$$\partial_{rr} = max \sum_{s=1}^{s} x_{r_s}\, w_s\ ;$$

$$\sum_{s=1}^{s} x_{r_s}\ w_s\ \leq 1\ r = 1, 2, 3 \ldots s;$$

$$w_1 \geq 2w_2 \geq \cdots \geq S w_s \geq 0 \qquad Equation.\ 5.1$$

and

$$\sum_{s=1}^{s} w_s = 1 \qquad Equation. 5.2$$

From the above equation, x_{rs} is the total votes of the *rth* criteria for the sth place by n voters. In the survey, (r=s) as mentioned earlier, i.e. the number of items within an issue under consideration equals the number of voting places. The w_s is the coefficient weight standing for the difference in weight between sth and *(s+1)th* positions. For instance, four attributes under a criterion being ranked by the respondents are thus:

w1 is the coefficient weight for the first position.
w2 is the coefficient weight for the second position
w3 is the coefficient weight for the third position.
w4 is the coefficient weight for the fourth position.

This coefficient weight was calculated using a Microsoft spreadsheet. An example of values of w_s for four rank positions is shown in Table 5.3. The results of the VAHP analysis is presented in Chapter 6. The VAHP has been successfully applied in construction project management studies (Gbadamosi *et al.,* 2019).

Table 5. 3: An example of w_s calculated for four ranking positions

Coefficient Weights Detemination

Rank/Position			1
1st	1	1	1.000
2nd		0.5	0.500
3rd		0.333333	0.333
4th		0.25	0.250
		Total	2.083

$$u_{r1} \geq 2u_{r2} \geq \ldots \geq Su_{rs}$$

$$u_{rs} \geq \varepsilon = \frac{1}{(1+2+\ldots+S)\times n} = \frac{2}{n \times S(S+1)}$$

Weight for each Rank/Position

$$w_1 \geq 2w_2 \geq \cdots \geq Sw_s \geq 0$$

	Weight (W)
W1	0.48
W2	0.24
W3	0.16
W4	0.12

$$\sum_{s=1}^{S} w_s = 1;$$

Step 5—After determining the w_s for the weights of the criteria, the procedure was repeated for determining the w_s to calculate the total weight of each attribute based on the number of votes in the rank positions.

Step 6—*Identify the global priority of attributes:* Each attribute's overall weight can be calculated at this stage. This can be achieved by multiplying the normalised weight of a criterion by its corresponding attributes' normalised weights. Therefore, each waste minimisation criterion normalised weight was multiplied by the normalised weight of the corresponding attributes within that criterion.

5.11. Data Analyses Software

Data analysis software employed in this study includes SPSS® (Statistical Package for Social Science) version 26 and Microsoft Excel Spreadsheet 2019. Firstly, SPSS was used in data screening and preliminary analysis. Again, it was subsequently used to determine the data set measure of central tendency and the non–parametric tests. SPSS is one of the most adopted computer software packages for statistical data analysis (George and Mallery, 2019). SPSS makes data analysis easy, straightforward, comprehensive, replicable and transparent. However, a researcher should be conversant with SPSS to leverage these advantages. Therefore, the author followed the SPSS guideline in data entering, coding to analyse the dataset successfully. Further, the Microsoft Excel spreadsheet was used to calculate the coefficient weights for each rank position of the criteria and attributes. Microsoft Excel® software is widely used for data analyses because it is relatively simple and reliable for computational analyses.

5.12. Role of the Researcher

Researchers must play an active role to minimise bias for meaningful and credible research findings (Patton, 2003). Bias impacts research validity and reliability when the process is prejudiced, and meaning being deviated from true findings. Several measures were taken to deal with bias in the current study: (1) The criteria and the related attributes were identified in published peer–reviewed construction waste management literature. (2) Academic experts scrutinised the literature review findings to verify their empirical authenticity. (3) The research instrument was pre–tested to make it self–explanatory; unambiguous. Personal interaction with the participant was avoided as it was conducted via the internet platform. (4) The data was collected, analysed objectively using statistics and a VAHP mathematical model. Therefore, these measures prevented potential bias that can occur in research and mar the outcome.

5.13. Ethics Consideration

Research ethics relates to the philosophy of *axiology* that promotes research value (McNamee, 1998). Problems can arise when a flawed procedure is suspected in research. Therefore, axiology philosophy enables a researcher to avoid such a problem by adhering to the right procedures. Such procedure may include protecting participants' confidentiality and their right to participate, refusing to participate, or withdrawing their data before, during or after participating in research (Heggen and Guillemin, 2012). In addition, it gives participants assurance that their personal information will not be revealed to the public; thus, protecting their dignity and individual rights throughout the research process. Furthermore, research ethics considers the researcher's safety when the researcher intends to interact physically with participants (Dickson–Swift *et al.,* 2008). Also, it considers participants' safety, especially when a researcher intends to gather data from vulnerable individuals such as children and physically challenged individuals (Wilson and Neville, 2009). Therefore, research ethics is the principles governing a research data collection process and the overall conduct.

Following an ethics application by the author, the Faculty of Environment and Technology (FET) Ethics Committee, UWE Bristol, reviewed and approved the research ethics. The research ethics was completed to ensure that the research meets the statutory and obligations of the University. Therefore, this research data collection process satisfied the, Bristol, and the University's Code of Good Research Conduct (2015) that protects human participants' rights. For further information on this research ethics, please contact the UWE FET ethics committees (https://www.uwe.ac.uk/research/policies–and–standards/research–ethics/contacts).

5.14. Overview of Method for the Frameworks' Development

The study adopts the basic MCDM as the frameworks' development concept (Section 4.5.1). Thus, the frameworks' flow chart consists of six stages from start to finish: (1) goals, (2) criteria and attributes (3) local priorities of attributes, (4) global priorities of attributes, (6) categorisation of attributes into low, medium or high priorities (6) ways of implementing the attributes for effective waste management in materials procurement and construction activities. Subsequently, the contents of the frameworks are presented in Chapter 7.

5.15.1. Frameworks' Validation Method

The purpose of validating the frameworks is to ensure they achieve the purpose they were developed. Telephone interviews were adopted to validate the frameworks due to the cost and time of travelling to Nigeria. Also, to prevent physical contact with the respondents due to the current Covid19 pandemic. Experienced construction practitioners in Nigeria were targeted for the validation exercise to ensure that the frameworks will benefit those who intend to apply them. These include building contractors, project managers, procurement managers and site managers. Purposive sampling was adopted for the validation exercise to get information–rich participants. The main selection criteria were based on job positions and a minimum of one year of experience in the construction industry. Participants were recruited through the researcher's network of contact. Afterwards, a snowball approach was used to reach out to more participants to increase responses.

A consent form was sent to each participant before the validation dates, reiterating the nature and purpose of the study and validation. In the consent form, participants were reminded in writing that their participation is voluntary; they are free to withdraw at any time, up to two weeks after involvement, without reasons and no consequences for withdrawing. All the participants signed the consent form and emailed it back to the researcher, suggesting their readiness to share their views about the frameworks. Later, the frameworks were emailed to them, and subsequent contacts were made to fix dates for the interview sections. Thus, participants were given adequate time to familiarise themselves with and understand the contents of the frameworks. Finally, the interview transcript was written based on the validation objectives stated in Chapter 7.

5.15. Chapter Summary

This chapter provided a detailed discussion and justifications of the research paradigms. These include epistemology, ontology, worldview, methodology and method. First, the quantitative strategy and survey were adopted based on the realism, objectivism, and positivism ideologies. Next, the chapter presented the research sampling technique and sample size; questionnaire design followed by its distribution method. Further, descriptive/inferential statistics and the VAHP were presented as analytical techniques. Also, the chapter discussed research ethics, the methods for the framework development and validation. The next chapter presents the results from the data analysis and discusses the key findings.

CHAPTER 6: RESULTS, ANALYSIS AND DISCUSSION

6.1. Introduction

This chapter presents the outcomes from the analyses of the survey collected from the Nigerian construction practitioners. First, it presents the participants' demographic information who validated the research conceptual frameworks and the results. Second, the chapter presents the research response rate and the descriptive and inferential statistics results. Thus, quantitative analysis was performed to determine the central tendency of the data set, such as the median rankings of the waste management criteria and attributes. Then, the results of the non–parametric tests – Kendal coefficient of concordance and Kruskal Wallis (H) are presented. Further, the VAHP results about the priority weights of materials procurement and construction criteria and attributes' local and global priority weights are presented. Third, the chapter discussed the key findings of the research, including the criteria and their top–ranked attributes.

6.2. Demographic Information of the Criteria and Attributes' Verification Experts

The demographic information of the experts that verified the criteria and attributes are shown in Table 6.1. The results show that only twelve responded out of the fourteen experts contacted for the verification exercise. The results showed that all the experts are qualified to verify the criteria and attributes according to the minimum requirements in Section 5.7**.** All the experts have a PhD as a minimum academic qualification. In addition, they all have above five years of experience in the academic (construction) field and are affiliated with one or more professional bodies.

Additionally, all the experts are of Nigeria origin and demonstrated interests in the construction industry's challenges. As mentioned in the previous chapter, the participants were given a code of identification for anonymity, thus: criteria verification' (CV) and a unique number from 01 to 14 (i.e. CV01, CV02...CV14). Also, all the criteria and attributes were coded to differentiate them for quick and easy identification. For instance, (procurement clause) can be identified as (PC) and (PC1, PC2…PCn) for the corresponding attributes. Finally, the experts' comments resulted in a rephrasing of some of the attributes for clarity.

Table 6. 1: Demographic Information of Experts in the Criteria/Attributes Verification

Experts' Identification Code	Highest Qualification	Years of Experience	Professional Body Affiliation
CV01	PhD	39	MCIOB, FRSA
CVO2	PhD	12	APM; PMI; RICS
CV03	PhD	6	MGS; ICE
CV04	PhD	29	NSE; COREN; ABEN; NIEE; ASEE; EWH; NNAWH
CV05	–	–	–
CV06	PhD	8	MCIOB; FHEA
CV07	PhD	10	IET
CV08	PhD	20	NSE; COREN; ICE; CIOB
CV09	PhD	25	FCIOB; FRICS; FAPM; FRSA; FHEA
CV10	PhD	20	APM
CV11	–	–	–
CV12	PhD	26	MCIOB; MAPM; FNIQ
CV013	PhD	19	COREN; NSE; NICE
CV014	PhD	18	NIA; ARCON

Note: IET=Institution of Engineering and Technology; **NIA=**Nigerian Institute of Architects**; ARCON=** Architects Registration Council of Nigeria; **NSE**=The Nigerian Society of Engineers; **COREN**=Council for the Regulation of Engineering in Nigeria; **ICE**=Institute of Civil Engineers; **CIOB**=Chartered Institute of Building; **FRSA**= Fellowship of the Royal Society for the Encouragement of Arts, Manufactures and Commerce; **ABEN**=America Biomedical Engineering Society; **NIEE**=Nigerian Institute of Environmental Engineers; **ASEE**= American Society for Engineering Education; **EWH**=Engineering World Health; **NNAWH**=Nigeria Network for Awareness and Environmental Health; **APM**=Association for Project Management; **NICE**=The National Institute for Health and Care Excellence; **PMI**=Project Management Institute; **RIC**=Royal Institution of Chartered Surveyors; **FCIOB**=Fellow Chartered Institute of Building; **FRICS**=Fellow Royal Institution of Chartered Surveyors; **FAPM**=Fellow Association for Project Management; **FHEA**= Associate Fellow of the Higher Education Academy; **MAPM**=Member of the Association of Project Managers; **MCIOB=**Member Chartered Institute of Building

6.2.1. Verification Results of the Criteria and Attributes

The purpose of the verification exercise was to ensure that each criterion and attribute was meaningful, comprehensive, clear, and important for effective waste management considering the research goal. In the exercise, percentages were used to measure the experts' agreement on the above objectives. From the results, (100%) of the respondents indicated that the materials procurement and construction criteria are meaningful, unambiguous, comprehensive and relevant for waste management. In terms of the attributes, most participants (91%) indicated that all the materials procurement attributes are meaningful and very clear, and approximately (97%) in construction. Therefore, (9%) indicated that two attributes (LWPM2 and LWPM7) are not very clear in the materials procurement category, and (3%) indicated one (SWMP7) in construction, respectively (see attributes code in Tables 6.2 and 6.5, respectively). Hence, they suggested the possibility of making them clearly or removing them entirely from the lists to ensure meaningfulness. In consideration, (LWMP2 and LWPM7) in procurement and (SWMP7) in construction were rephrased for clarity. In addition, two respondents (CV01 and CV06) indicated that attributes (PC4 and PC5) in the procurement overlap; thus, PC4 was removed from the list. Similarly, a respondent (CV10) indicated that (SWMP2 and SWMP3) overlap and (SWMP3) was removed from the list. Thus, PC5 for procurement and SWMP2 for construction remains on the lists.

In terms of comprehensiveness of the attributes, participants indicated that procurement (83%) and construction (75%) are significantly comprehensive. Among those who disagreed on the comprehensiveness of the attributes, only (CV01) suggested adding material substitution in the low waste purchase management list, which was added (LWPM6). Additionally, all the experts (100%) agreed to all the attributes' relevance and grouping. The following sections discuss the survey response rate, data preparation, and the data analysis results.

6.3. Data Preparation and the Survey Response Rate

After two follow up email reminders, 228 responses were received from the 768 surveys distributed, accounting for an initial response rate of approximately 30%. The 228 participants completed the questionnaire because it was conditioned (Qualtrics 'forced response setting), informing participants that all questions must be answered before submission. The setting does not allow a questionnaire to be submitted without completion to prevent missing data scenarios. Although all the questionnaires were completed without missing data, the data set was subjected to screening to determine the number of questionnaires eligible for analysis.

The purpose of screening a data set is to identify unengaged, incomplete, incorrect, or irrelevant responses in other to remove them. Thus, data screening helps eliminate inaccurate analysis to ensure valid results (Hassan Gorondutse and Abdullah, 2014; Ilyas and Chu, 2019). The dataset for this study was manually screened via visual inspection, and a total of seventeen responses were found completed incorrectly by some participants. For instance, where there are four ranking positions for four criteria, participants were instructed to complete it by scoring either 1, 2, 3 or 4 in the spaces/boxes provided beside each criterion or attribute. However, eleven participants included higher numbers in one or two boxes rather than limiting the ranking order to 4. Also, six participants indicated less than a year in the 'other' option provided in the questionnaire, which violated the minimum year(s) of experience highlighted in the previous chapter (Section 5.9). Consequently, their responses were considered incorrectly completed and were deleted from the dataset. This account for 2% out of the total questionnaire distributed, resulting in the 211 questionnaires being adequately completed. Thus, the final response rate of approximately 28% was used for the research data analysis. Therefore, this study exceeds the 25% projected response rate (Section 5.9.1), and it is reasonable compared to similar studies (Aderibigbe *et al*., 2017; Saka *et al*., 2019).

After a visual inspection, the data set was prepared for analysis. These include downloading the data from Quadrics to SPSS software version 26 and coding them according to its guideline. A preliminary analysis was conducted to check for minimum and maximum values using frequency data. Table 6.2 shows the final response rate used for the research data analysis.

Table 6.2: Participant response rate

Questionnaires	Number (n)	Percentage (%)
Distributed	768	100
Unreturned	540	70.3
Returned	228	29.7
Incorrect (removed)	17	2.2
Used	211	27.5 ~ 28

6.4. Descriptive Results of the Survey

The descriptive statistics were carried out to generate the respondents' demography and measures of central tendency, particularly the median rankings. The materials procurement criteria and attributes median values are presented in the second column of Table 6.4, while construction criteria and attributes are in the second column of Table 6.5. In support of the validity of the research results, the following sections discuss the participants' demographic information. Table 6.3 summarised the data distributions patterns of respondents concerning their profession/job roles, highest education qualifications, number of years of experience and professional body affiliation using percentages (%) and frequency (n).

6.4.1. Profession/Job Role of Participants

Knowing participants job roles is important to ensure their eligibility to participate in this study. Therefore, respondents were asked to provide information on their current profession/job roles in the construction industry. The findings of this question are presented in the second column of Table 6.3. The results show that all the participants indicated their different professional/job roles in the construction industry, as listed in the questionnaire, which confirmed their eligibility. Out of the 211 respondents, approximately 23% were project managers; 20% reported their profession as civil engineers; 15% were quantity surveyors, and 14% were mechanical engineers.

Additionally, 9% said they work as procurement managers and structural engineers, respectively. Further, the results show that 10% of the respondents are site supervisors. Frequency distributions show that respondents who identified themselves as project managers account for the highest (48), close to a quarter of participants. At the same time, structural engineers and procurement managers were the least (20) respondents each.

6.4.2. Highest Qualification of Participants

The participants were asked to indicate their highest level of qualifications. The findings of this question are presented in the third column of Table 6.3. The results show that all the participants met the minimum qualification, which means they are educated enough to understand the waste management challenges in the Nigerian construction industry. The lowest qualification requirement was an Ordinary National Diploma (OND), while the highest is a PhD. From the findings, 43% of the respondents have acquired Bachelor's degree or BEng; 22% have Higher National Diploma; 18% have a master's degree; 10% have OND; while PhD holders account for 7%. Bachelor's degree holders are 91 in frequency distributions, almost half of the respondents, while PhD has the least (14) respondents.

6.4.3. Participants' Years of Experience

The participants were asked to provide their years of experience in the industry. The findings of this question are detailed in the fourth column of Table 6.3. The results show that all the respondents are eligible according to the minimum year of experience, which is one. From the findings, 17% of the respondents indicated 1–5 years and 47% indicated 6–10 years of experience. Additionally, 26% reported 11–15; 7% indicated 16–20 years, while only 3% has above 20 years of experience in the construction industry. Therefore, most participants who answered the research question have between 6–10 years of experience, accounting for almost half (100) of the respondents according to the frequency distributions. In comparison, only 5 respondents have above 20 years of experience, thus the least in the level of experience frequency column.

6.4.4. Professional Body Affiliation of Participants

The participants were asked to indicate their professional body affiliation from the lists provided. The findings of this question are detailed in the fifth column of Table 6.3. All the participants indicated they belong to different professional body categories showing they have a certain level of expertise in their professions/job roles, thus aware of the industry's challenges. According to the findings, 32% are affiliated with the Council for the Regulation of Engineering in Nigeria (COREN); 25% are current members of the Council of Registered Builders of Nigeria; while 21% belong to the Nigerian Institute of Quantity Surveyors (NIQS). Also, 20% of the respondents are affiliated with the Nigerian Institute of Building (NIOB), while only 2% indicated the *'other'* option. A closer look shows that they are current members of the Nigerian Society of Engineers (NSE). Based on frequency distribution, those affiliated with

COREN are nearly a third of participants (67), which account for the highest, while only (4) are those in NSE, which is the least.

Table 6.3: Summary of Respondents' Demography

Demography	Groups/Labels	Frequency	Percentage (%)
Profession/job role	Project managers	48	23
	Civil engineers	40	20
	Quantity surveyors	32	15
	Mechanical engineers	30	14
	Procurement managers	20	9
	Structural engineers	20	9
	Site Supervisors	21	10
	Other	–	–
Highest qualification	Bachelor's degree/BEng	91	43
	Higher National Diploma	46	22
	Master's Degree	38	18
	Ordinary National Diploma	22	10
	PhD	14	7
	Other	–	–
Level of experience (years)	1–5	36	17
	6 –10	100	47
	11 –15	55	26
	16 –20	15	7
	Above 20	5	3
Professional body affiliation	The Council for the Regulation of Engineering in Nigeria (COREN)	67	32
	The Council of Registered Builders of Nigeria	53	25
	Nigerian Institute of Quantity Surveyors (NIQS)	44	21
	Nigerian Institute of Building (NIOB)	43	20
	Other	4	2

6.5. Non–parametric Test Results

Two non–parametric tests were performed: (1) Kendall's coefficient of concordance to observe if the respondents agreed with each other in ranking the criteria and attributes of materials procurement and construction categories. (2) Kruskal–Wallis H test to investigate if there are significant differences in the perception of respondents' ranking of the criteria and attributes based on their professions/job roles. As mentioned in the previous chapter (Section 5.11.2 and 5.11.3), all the tests were performed at 95% confidence and 0.05 significance levels. The test results are presented in the following sections.

6.5.1. Results of Kendall's Coefficient of Concordance

Kendall's coefficient of concordance (*W*) ranges from 0 to 1. While 0 means no agreement, 1 means perfect agreement. The more the coefficient of concordance moves closer to 1 and ($P < .05$), the significance of the agreement amongst participants who ranked ordered a set of items. Thus, p<.05 indicates that there is a statistically significant agreement between respondents.

The null hypothesis is that Kendall's *W* is zero in the population, indicating no agreement.

H_0: *W* = 0

The alternative hypothesis is that Kendall's *W* is not equal to zero in the population – **H_A: *W* ≠ 0,** indicating agreement.

6.5.1.1. Agreements on Materials Procurement Criteria and Attributes – Kendall's W

Kendall's *W* test was performed to observe whether the 211 participants ranked the four materials procurement criteria and the twenty attributes' categories similarly. The results of the tests indicate a statistically significant agreement between the 211 respondents in the ranking of the four criteria and twenty attributes in the materials procurement category (6th column in Table 6.4) with p–values less than 0.05 (Asymp. Sig = 0.000) (7th column in Table 6.4). These values indicate that the null hypothesis should be rejected and alternative accepted for the criteria and attributes categories.

6.5.1.2. Agreements on the Construction Criteria and Attributes – Kendall's W

Kendall's W tests were performed to observe whether the 211 participants ranked the four construction criteria and the twenty–two attributes' categories similarly. From the results displayed in the 6th column of Table 6.5, the study concludes a statistically significant agreement between the 211 respondents in the ranking of the four criteria and twenty–two attributes in the construction category with p– values less than 0.05 (Asymp. Sig = 0.000), (7th column of Table 6.4). These values indicate that the null hypothesis must be rejected and alternative accepted. In conclusion, there is a significant agreement between construction professionals in ranking construction criteria and the attributes categories, respectively

From the test results in Tables 6.4 and 6.5, respectively, Kendall's *W* values are considerably less than 1, suggesting that respondents did not completely agree in the ranking of materials procurement and construction criteria and attribute categories. Therefore, previous construction waste management studies were examined to determine how good construction actors agree on waste management strategies based on the minimum and maximum concordance coefficient found in the current study. Yuan (2013) observed a Kendall's *W* of 0.222 using 79 raters of nine professionals that ranked the 20 critical construction waste management factors. The author suggests that the respondents share a different opinion in evaluating the relative importance of waste management factors. Yuan *et al.* (2011) observed a 0.120 coefficient with 79 raters of different construction groups that ranked 16 obstacles to improving construction waste management performance in China. The authors claimed that the respondents shared similar views about the relative importance of the obstacles. Also, a coefficient concordance of 0.063 was reported when 216 participants ranked 24 decision–making factors for demolition waste management (Bui, 2018). The author suggested indifferent opinions amongst the raters.

The above evidence shows that construction actors seldom achieve a complete agreement in ranking waste management strategies. Therefore, the agreement between the 211 construction respondents in ranking the materials procurement and construction criteria and attributes categories are relatively good except for the efficient delivery management grouping, which has the lowest coefficient of concordance at 0.039, indicating that respondents agreed less compared to the previous studies mentioned above. Conservatively, considering the possible variability that would come with a perfect agreement, the agreement between the 211 respondents may be considered low by some individuals or in other disciplines. For instance, since Kendall's coefficient of concordance *W* range from 0 to 1, values below 0.3 could be considered low (Schmidt,1997).

Different stakeholders have different roles to play to support their waste management priorities. For instance, respondents with hands–on experience in administrative positions may identify waste minimisation strategies based on a top–down approach such as 'top managers early commitment to waste minimisation as most important. At the same time, respondents experienced in site operations may prioritise waste management factors from the bottom–up such as 'waste segregation as the most important. Therefore, involving, coordinating and combining different practitioners' opinions is important for achieving effective waste management in construction. To explore the differences between the respondents, the Kruskal–Wallis H Tests were conducted to check whether the lack of complete agreement is due to respondents' job roles and which professions differ. The results of the Kruskal–Wallis H Tests are presented in the next section.

6.5.2. Results of the Kruskal–Wallis H Tests

As mentioned earlier, the Kruskal–Wallis H test was employed to assess whether participants' profession/job role categories affect their perception of waste management criteria and attributes for materials procurement and construction. The null and alternative hypothesis is thus:

Null Hypothesis H_0: There is no significant difference in the participants' ranking of the criteria and attributes

Alternative Hypothesis H_1: There is a significant difference in the participants' ranking of the criteria and attributes.

6.5.2.1. Test for Significant Difference in Material Procurement Criteria and the Attributes

The Kruskal–Wallis H test was performed to investigate whether there was a significant difference in the respondents' perception of materials procurement criteria and their attributes based on their professional/job roles. Respondents' job roles were used as grouping variables in carrying out the tests, while the materials procurement criteria and attributes were used as testing variables, respectively. The results (showed in the 5th column of Table 6.4) suggest that the Kruskal–Wallis coefficient for the four materials procurement criteria were not perceived differently by the participants (P>0.05). Therefore, the null hypothesis is true and should be accepted, and alternative rejected. However, a careful look into the different groups' mean shows that the respondents perceived one attribute— *Adequate site access for delivery vehicles* (EDM1) in the Efficient delivery management criterion differently. The P–Value account for 0.003, while the remaining nineteen attributes across the criteria in materials procurement have their P–Value greater than 0.05. In that case, the null hypothesis is rejected for EDM1 but not for other attributes.

A post-hoc test using Dunn's (1964) procedure with a Bonferroni adjustment for multiple comparisons were conducted to discover which groups combination are different from other groups in the ranking of EDM1. Bonferroni adjustment minimises the risk of Type I error. A Type I error is when a statistically significant result is declared when it should not be declared. Type I error increases with every pairwise comparison for the factors under consideration. Therefore, SPSS adjusts the significance levels using a Bonferroni correction and reports the result as "Adj.Sig."

Pairwise comparisons were performed for EDM1 to present the adjusted p–values. The post-hoc analysis revealed a statistically significant difference in EDM1 mean scores between procurement managers and civil engineers with a P–Value of 0.005 but not between other group combinations. Therefore, the Kruskal Wallis test exposed that the low Kendall's coefficient of concordance in EDM was due to procurement managers and civil engineers' differences in the ranking of EDM1. However, it is insufficient to warrant a sectoral analysis of the data. Therefore, the analysis presented combines all respondents' opinions regardless of job roles.

6.5.2.2. Test for Significant Difference on Construction Criteria and the Attributes

Similarly, the Kruskal–Wallis test was performed to investigate whether there was a significant difference in the participants' perception of construction criteria and attributes based on their professional/job roles. Participants' job roles were used as grouping variables in carrying out the tests, while the construction criteria and attributes were used as testing variables, respectively. The results in the 5th column of Table 6.5 suggests that the participants did not perceive the four construction criteria differently because their P–Values are greater than 0.05. Hence, the null hypothesis is accepted, and the alternative rejected. However, the Kruskal–Wallis test results on the corresponding attributes show a significant difference in the groups' mean for *Senior managers early commitment to waste minimisation* (TMSC1) in the top management support criterion with a P–Values of 0.001. Thus, the null hypothesis is rejected for (TMSC1) but not for the remaining twenty–one attributes grouped within the criteria because their P–Values are greater than 0.05.

To further probe into the difference in participants' perception of TMSC1, a post-hoc test using Dunn's (1964) procedure was conducted, adopting a Bonferroni correction for multiple comparisons. The results revealed a statistically significant difference in TMSC1 mean score, showing that only projects managers and civil engineers differed from other groups with a P–Value of 0.025 but not between any other group combinations. Thus, the difference in participants' perceptions is in a minority of attributes and insufficient to warrant a sectoral data analysis. Therefore, the analysis presented combines all respondents regardless of job roles.

Table 6.4: Descriptive and non–parametric results of materials procurement criteria and attributes

Code	Material Procurement Criteria/attributes	Median	Mean	S.D	Kruskal Wallis Coeff.	Kendall's W	Asymp. Sig.
Code	***Criteria***						
TMSP	*Top management support (procurement)*	3.00	2.54	1.088	.240	.121	< 0.000
PC	*Procurement clause*	2.00	2.20	0.861	.062		
LWPM	*Low waste purchase management*	2.00	2.14	1.128	.053		
EDM	*Efficient delivery management*	4.00	3.11	1.089	.669		
TMSP	**Top management support (procurement) attributes**						
TMSP1	Involving purchase manager in procurement activities	2.00	2.84	1.341	.859	.063	< 0.000
TMSP2	Provision of stock control measures	4.00	3.39	1.568	.498		
TMSP3	Periodic training of procurement personnel on waste management strategies	3.00	2.96	1.052	.360		
TMSP4	Waste management guidelines for procurement personnel	4.00	3.24	1.303	.824		
TMSP5	Alliance with suppliers	2.00	2.39	1.493	.756		
PC	**Procurement clause attributes**						
PC1	Take–back clause in suppliers' agreement document	1.00	1.82	1.127	.305	.212	<0.000
PC2	Consistency in suppliers' agreement document	4.00	3.42	1.116	.058		
PC3	Supplies to supply quality and durable materials	3.00	2.95	1.301	.134		
PC4	Agreement with suppliers on waste management strategies	3.00	2.85	1.220	.113		
PC5	Supplier flexibility in providing a smaller quantity of materials	4.00	3.69	1.437	.051		
LWPM	**Low waste purchase management attributes**						
LWPM1	Purchase of secondary materials	4.00	4.01	1.507	.788	.174	< 0.000
LWPM2	Purchase of maintainable materials	6.00	4.74	1.736	.542		
LWPM3	Accurate materials quantification	2.00	2.76	1.452	.678		
LWPM4	Purchase of high–quality products	3.00	3.64	1.208	.645		
LWPM5	Accurate materials ordering	5.00	3.70	1.826	.222		
LWPM6	Material substitution	5.00	4.53	1.439	.664		
EDM	**Efficient delivery management attributes**						
EDM1	*Adequate site access for delivery vehicles*	*1.00*	*3.01*	*1.151*	*.003***	.039	< 0.000
EDM2	Careful material handling to avoid breakage	5.00	4.05	1.230	.649		
EDM3	Just–in–time delivery (JIT) of materials	3.00	2.78	1.100	.610		
EDM4	Safe storage of materials onsite	3.00	3.10	1.232	.196		

Table 6.5: Descriptive and non‒parametric results of construction criteria and attributes

Construction Stage Criteria/attributes		Median	Mean	S. D	Kruskal Wallis Coeff.	Kendall's W	Asym. Sig.
Code	***Criteria***						
TMSC	*Top management support (construction)*	2.00	2.03	1.000	.689	.104	< 0.000
CC	*Construction clause*	3.00	3.05	1.052	.230		
SWMP	*Site waste management plan (SWMP)*	3.00	2.33	1.034	.159		
LWT	*Low waste technique*	3.00	2.51	1.123	.218		
TMSC	**Top management support (construction) attributes**						
TMSC1	*Senior managers early commitment to waste minimisation*	*2.00*	*2.91*	*1.682*	*.001***	.104	< 0.000
TMSC2	Periodic training of site employees on waste management strategies	3.00	2.99	1.035	.364		
TMSC3	Adequate waste reduction investment	4.00	4.30	1.656	.316		
TMSC4	Active site supervision	5.00	4.19	1.482	.167		
TMSC5	Motivating employees to minimise waste	4.00	3.39	1.586	.155		
TMSC6	Effective communication among project participants	2.00	3.09	2.131	.072		
CC	**Construction clause**						
CC1	Waste target clause in subcontractors' agreement document	2.00	2.18	0.861	.563	.210	< 0.000
CC2	Waste management policy for operatives	4.00	3.27	1.089	.118		
CC3	Incentive clause for effective waste management practice	3.00	2.44	0.980	.684		
CC4	Making subcontractors responsible for their waste	2.00	2.02	1.049	.448		
SWMP	**Site waste management plan attributes**						
SWMP1	Adequate space for material movement onsite	4.00	3.36	1.467	.209	.139	< 0.000
SWMP2	Identifying recyclable materials	1.00	2.27	1.564	.121		
SWMP3	Forecast the emerging waste streams	3.00	2.96	1.294	.286		
SWMP4	Segregating waste materials into categories	3.00	2.71	0.985	.144		
SWMP5	Identifying reusable materials	2.00	2.59	1.031	.216		
LWT	**Low waste technique attributes**						
LWT1	Maximise use of joint systems instead of gluing	3.00	3.39	1.915	*.197*	.070	< 0.000
LWT *2*	Use of de-constructable materials	4.00	4.02	2.220	.261		
LWT3	Adopting the right work sequence	6.00	4.49	1.972	.674		
LWT4	Use of steel scaffolds	5.00	4.27	1.569	.264		
LWT5	Adopting prefabricated building components	2.00	3.00	2.309	.397		
LWT6	Use of reusable formwork and falsework	3.00	3.15	1.924	.064		
LWT7	Use of appropriate construction equipment	3.00	3.55	1.996	.225		

6.6. The Voting Analytical Hierarchy Process Results

The VAHP was used to determine the weight/priority of materials procurement and construction waste management criteria and attributes. The weight/priority of each criterion and attribute was determined by evaluating the total number of votes obtained in the data collection exercise based on their relative importance. The VAHP results are presented in the following section, which accord with the Hadi–Vencheh *et al.* (2011) six steps discussed in the methodology chapter (Section 5.11.4). From the example presented in Table 5.3, the criteria and attributes' coefficient weights were computed based on the respective number of rank positions in Table 6.6.

Table 6.6: The Coefficient *ws* According to Different Ranking Positions within Criteria and Attributes

Formulae	Number of ranking positions	Criteria	Attributes	Coefficient w_s
$w1 \geq 2w2 \geq \cdots \geq Sws \geq 0$ $\sum_{s=1}^{s} w_s = 1$	7		• Low waste technique	w1 0.3857 w2 0.1928 w3 0.1286 w4 0.0964 w5 0.0771 w6 0.0643 w7 0.0551
	6		• Top management support (construction) • Low waste purchase management	w1 0.4082 w2 0.2041 w3 0.1361 w4 0.1021 w5 0.0816 w6 0.0680
	5		• Site waste management plan • Top management support (procurement) • Procurement clause	w1 0.4380 w2 0.2190 w3 0.1460 w4 0.1095 w5 0.0876
	4	• Material Procurement • Construction	• Construction clause • Efficient delivery management	w1 0.4795 w2 0.2398 w3 0.1598 w4 0.1199

Also, coefficient weights *Ws* for four criteria or attributes in the table above can easily be calculated as follows:

$$w1 + \frac{w1}{2} + \frac{W1}{3} + \frac{W1}{4} = 1$$

$$\frac{70w_1+35w_1+23w_1+18w_1}{70} = 1$$

$$\frac{146w1}{70} = 1; w1 = \frac{70}{146}; w1 = 0.4795$$

$$Therefore, w2 = \frac{w1}{2}; w3 = \frac{w1}{3}; w4 = \frac{w1}{4}$$

$$w2 = \frac{0.4795}{2} = 0.2398\ ; w3 = \frac{0.4795}{3} = 0.1598;\ w4 = \frac{0.4795}{4} = 0.1199$$

Therefore, the local weight for each criterion or attribute can be determined thus: criterion or attribute = number of votes in the first position * w1 + numbers of votes in the second position* w2 and so on. Hence, the weight and ranking results of the criteria and attributes for materials procurement are presented in the following sections and the summaries are presented (Tables 6.8 to 6.16). The tables show the total votes at each rank position, the weight, normalised weight, the percentages, and the rank of each criterion or attribute.

6.6.1. Weights of Criteria for Materials Procurement

The outcome of the voting and analysis of the four thematic criteria for effective materials procurement waste management is presented in Table 6.7. The results show that *Low waste purchase management* has the highest weight, followed by *Procurement clause.* Both were ranked the first and second most important respectively, and together, account for more than half (56%) of the four criteria weights in the category. The '*Top management support (P)'* was ranked the third, while '*Efficient delivery management* was considered least important with both having 44% combined. Thus, the results show that majority of the respondents voted for low waste purchase management as the most important criteria for effective waste management in materials procurement. At the same time, a majority considered efficient delivery management the least important.

Table 6.7: Priority votes of four material procurement criteria from 211 respondents in the survey

Material procurement Criteria	1st	2nd	3rd	4th	Total	Weight	Normal	(%)	Rank
Top management support (P)	50	45	68	48	211	51.39	0.245	25	**3**
Procurement clause	39	113	37	22	211	54.35	0.258	26	**2**
Low waste purchase management	91	30	60	30	211	64.01	0.304	30	**1**
Efficient delivery management	30	24	49	108	211	40.92	0.194	19	**4**

6.6.1.1. Top Management Support (procurement) Attributes' Weights

Table 6.8 voting results show that *Alliance with suppliers* has the highest weight, followed by *Involving a purchase manager in procurement activities*. Collectively, these two accounts for almost half (46%) of the five attributes' priority weights in the top management support (P) criterion. Among the five attributes, *providing stock control measures* has approximately 19% weight scoring the third position in weight. Further, '*Waste management guideline for procurement personnel* has the least weight, after *Periodic training of procurement personnel on waste management strategies*. Both combined accounts for 35% of the total priority weights in the criterion. Therefore, most respondents considered an alliance with suppliers the most important attribute compared to other attributes. However, most indicated that providing a waste management guideline for procurement personnel was the least important within the top management support category.

Table 6.8: Priority votes of five attributes in top management support (procurement) criterion from 211 respondents in the survey

Top management support for procurement	1st	2nd	3rd	4th	5th	Total	Weight	Normal	(%)	Rank
Involve a purchase manager in procurement activities	19	103	29	12	48	211	40.63	0.191	19	2
Provide stock control measures	44	19	40	26	82	211	39.30	0.185	19	3
Periodic training of procurement personnel on waste management strategies	30	18	107	43	13	211	38.55	0.181	18	4
Alliance with suppliers	91	37	19	37	27	211	57.15	0.269	27	1
Waste management guidelines for procurement personnel	26	47	22	82	34	211	36.85	0.173	17	5

6.6.1.2. Procurement Clause Attributes' Weights

The analysis of participants votes on the attributes in the procurement clause shows that *Take–back clause in the suppliers' agreement document*; has the highest weight, followed by *Suppliers to supply quality and durable materials*. Together, these two attributes account for half (50%) votes of the criterion's five attributes' priority weights. Also, *Agreement with suppliers on waste management strategies* has 19% weight scoring third on the list. In addition, *Supplier flexibility in providing a smaller quantity of materials* scored approximately 19% weight, the fourth in the ranking slightly below the third, while '*Consistency in suppliers' agreement document'* is the least in weight among the five attributes in the procurement clause category. These two attributes account for 31% of the total weight out of the five attributes in the criterion. The summary of the votes and results are presented in Table 6.9. It shows that most respondents considered take–back clause in the suppliers' agreement document to be of the highest priority while most least prioritise waste management guidelines for procurement personnel.

Table 6.3: Priority votes of five attributes of procurement clause criterion from 211 respondents in the survey

Procurement clause	1st	2nd	3rd	4th	5th	Total	Weight	Normal	(%)	Rank
Take–back clause in suppliers' agreement document	110	64	10	18	9	211	66.42	0.311	31	1
Consistency in suppliers' agreement document	18	29	32	110	22	211	32.88	0.154	15	5
Suppliers to supply quality and durable materials	36	40	68	32	35	211	40.70	0.191	19	2
Agreement with suppliers on waste management strategies	23	71	65	18	34	211	40.06	0.188	19	3
Suppliers to provide materials in a flexible amount	25	22	44	23	97	211	33.21	0.156	16	4

6.6.1.3. Low Waste Purchase Management Attributes' Weights

The voting results of the attributes in the low waste purchase management category shows that *Accurate materials quantification* has the highest priority weight, followed by '*Accurate material ordering.* Both account for more than a third (42%) of the criterion's six attributes' priority weights. *Purchase of high–quality products* and *Purchase of secondary materials* are third and fourth in the ranking, 15% weights, respectively. Also, the results indicate that *Purchase of maintainable materials* has the least weight after *Material substitution.* Combining these attributes account for 28% weight of the six attributes in the low waste purchase management category. Therefore, the results summarised in Table 6.10 indicate that most respondents voted for accurate materials quantification as the most important attribute under the low waste purchase management category. In contrast, most respondents perceived the purchase of maintainable materials as the least important for waste minimisation.

Table 6.4: Priority votes of six attributes of low waste purchase management criterion from 211 respondents in the survey

Low waste purchase management	1st	2nd	3rd	4th	5th	6th	Total	Weight	Normal	(%)	Rank
Purchase of secondary materials	10	34	22	75	17	53	211	26.66	0.149	15	4
Purchase of maintainable materials	17	19	16	19	19	121	211	24.71	0.138	14	6
Accurate materials quantification	21	116	21	19	14	20	211	39.55	0.220	22	1
Purchase of high–quality products	6	12	113	21	39	20	211	26.96	0.150	15	3
Accurate material ordering	48	23	12	11	95	22	211	36.29	0.202	20	2
Material substitution	11	16	20	25	82	57	211	25.27	0.141	14	5

6.6.1.4. Efficient Delivery Management Attributes' Weights

The analysis of the respondents' votes on the four attributes for efficient delivery management indicates that '*Just–in–time delivery' (JIT)* has the highest weight, followed by '*Adequate site access for delivery vehicles*. These attributes collectively account for more than half (53%) of the four attributes' weights in the efficient delivery management category. On the other hand, *Careful materials handling to avoid breakage* has the least weight compared to *Safe storage of materials onsite.* Together, these attributes account for 47% of the weights. Thus, ranking the third and fourth in the group, respectively. The voting results are demonstrated in Table 6.11, showing that the majority of the respondents identified timely delivery of construction materials onsite as the most important attribute in the question. Also, the evidence shows that *careful materials handling to avoid breakage* was considered the least priority amongst most respondents.

Table 6.5: Priority votes of five attributes of efficient delivery management from 211 Respondents in the survey

Efficient delivery management	1st	2nd	3rd	4th	Total	Weight	Normal	%	Rank
Adequate site access for delivery vehicles	15	70	81	45	211	42.32	0.250	25	2
Careful materials handling to avoid breakage	15	38	70	88	211	38.04	0.224	22	4
Just–in–time delivery (JIT) plan	32	51	99	31	211	46.80	0.276	28	1
Safe storage of materials onsite	17	79	31	84	211	42.12	0.248	25	3

6.6.1.5. Global Priority Ranking of Materials Procurement Attributes

The results of the global weight of the 20 attributes of materials procurement are shown in Table 6.12. The results highlight the five most important attributes in this order: *Take–back clause in suppliers' agreement document* is the most important materials procurement strategy, followed by *Just–in–time delivery (JIT)* of materials*, Alliance with suppliers*, *Adequate site access for delivery vehicles and Safe storage of materials onsite. Also,* the results indicate that *Purchase of maintainable materials was ranked the least important,* followed by *Material substitution*, *Purchase of secondary materials*, *Purchase of high–quality products* and *Consistency in suppliers' agreement document.*

Table 6.12: VAHP results of global priority/ranking of 20 materials procurement attributes

Materials procurement attributes for waste minimisation	Global Priority	Global Rank
Take–back clause in suppliers' agreement document	0.080	1
Accurate materials quantification	0.067	2
Alliance with suppliers	0.066	3
Accurate material ordering	0.061	4
Just–in–time delivery (JIT) plan	0.054	5
Suppliers to supply quality and durable materials	0.049	6
Agreement with suppliers on waste management strategies	0.049	7
Adequate site access for delivery vehicles	0.049	8
Safe storage of materials onsite	0.048	9
Involve a purchase manager in procurement activities	0.047	10
Purchase of high–quality products	0.046	11
Provide stock control measures	0.045	12
Purchase of secondary materials	0.045	13
Periodic training of procurement personnel on waste management strategies	0.044	14
Careful materials handling to avoid breakage	0.043	15
Material substitution	0.043	16
Waste management guidelines for procurement personnel	0.042	17
Purchase of maintainable materials	0.042	18
Suppliers to provide materials in a flexible amount	0.040	19
Consistency in suppliers' agreement document	0.040	20

6.6.2. Weights of Construction Criteria

The results of the voting and analysis of the four thematic criteria in the construction category are presented in Table 6.13. *Top management support in construction* emerged with the highest weight, followed by *Site waste management plan.* Combining these attributes' weights account for more than half (57%) of the four criteria weights in the construction category. On the other hand, the analysis shows that *Construction clause* has the least weight, followed by *Low waste technique*. Together, these two criteria account for less than half (43%) of the weights in the category. This evidence shows that most respondents identified top management support as the most important criterion for effective waste management in the construction category compared to other criteria. However, construction clause was voted the least by most of the respondents.

Table 6.6: Priority votes of four construction criteria from 211 respondents in the survey

Criteria	1st	2nd	3rd	4th	Total	Weight	Normal	%	Rank
Top management support (C)	74	82	27	28	211	62.82	0.297	30	1
Construction clause	20	51	38	102	211	40.12	0.189	19	4
Site waste management plan	67	29	91	24	211	56.50	0.267	27	2
Low waste technique	52	53	49	57	211	52.31	0.244	24	3

6.6.2.1. Top Management Support (construction) Attributes' Weights

The results obtained from the voting analysis of construction attributes shows that *Senior managers' early commitment to waste minimisation* has the highest weight, followed by *Effective communication among project stakeholders,* ranked second. Together, these two attributes represent more than a third (43%) weights of the six attributes contained in the category. *Motivating employees to minimise waste, Periodic training of site employees on waste management strategies* ranked third and fourth, respectively. Further, the results indicate that *Adequate waste reduction investment* weighed the least, followed by *Active site supervision.* Both account for a quarter (25%) of the weights of the six attributes in the category. The evidence demonstrated in Table 6.14 shows that most respondents perceived senior managers' early commitment to waste minimisation as the most important attribute. In contrast, adequate waste reduction investment was seen as least important.

Table 6.14: Priority votes of six attributes of top management support (construction) criterion from 211 respondents in the Survey

Top management support for construction	1st	2nd	3rd	4th	5th	6th	Total	Weight	Normal	%	Rank
Senior managers early commitment to waste minimisation	82	31	16	9	14	59	211	48.05	0.221	22	1
Periodic training of site employees on waste management strategies	14	40	116	25	8	8	211	33.42	0.154	15	4
Adequate waste reduction investment	19	17	22	56	18	79	211	26.78	0.123	12	6
Active site supervision	20	22	13	13	128	15	211	27.22	0.125	13	5
Motivating employees to minimise waste	39	30	20	78	20	24	211	35.99	0.166	17	3
Effective communication among project participants	48	65	29	24	18	27	211	45.84	0.211	21	2

6.6.2.2. Construction Clause Attributes' Weights

The results generated from the VAHP analysis show that *Making subcontractors responsible for their waste* has the highest weight, followed *by Waste target clause in the subcontractors' agreement document*. Together, these attributes constitute more than half (57%) of the weights of the four attributes in the criterion. Also, the results show that a *Site waste management policy for site employees emerged as the least weighed attribute followed by* an incentive clause for effective waste management practice. Together, these attributes account for (43%) weight. The results in Table 6.15 indicate that most respondents preferred making subcontractors responsible for their waste than other attributes in the category. However, a site waste management policy for site employees was considered the least important, hence, ranked fourth.

Table 6.15: Priority votes of four construction clause attributes from 211 respondents in the survey

Construction clause	1st	2nd	3rd	4th	Total	Weight	Normal	%	Rank
Waste target clause in the subcontractors' agreement document	40	114	35	22	211	54.75	0.260	26	2
A site waste management policy for site employees	25	29	22	135	211	38.64	0.183	18	4
An incentive clause for effective waste management practice	56	26	110	19	211	52.94	0.251	25	3
Making subcontractors responsible for their waste	80	79	19	33	211	64.30	0.305	31	1

6.6.2.3. Site Waste Management Plan Attributes' Weights

The results of the SWMP attributes' weights are presented in Table 6.16. The analysis of respondents' voting indicates that '*Identifying recyclable materials* weighed the highest, emerging as the highest–ranked attribute, followed by *Identifying reusable materials.* Collectively, these two attributes represent close to half (48%) of the weights of the five attributes in the criterion. Again, *Forecast the emerging waste stream* was ranked the third in the group. Finally, *Adequate space for material movement onsite* has the least normalised weight in the category, followed by *segregating waste materials into categories*. These attributes, together, account for a third (33%) of the total weights in the SWMP category. Therefore, the results indicate that the majority of the respondents considered identifying recyclable materials as the most important waste management attribute in the SWMP category compared to other attributes. Conversely, most of them perceived adequate space for materials movement onsite as least important.

Table 6.7: Priority votes of five site waste management plan attributes from 211 respondents in the survey

Site waste management plan	1st	2nd	3rd	4th	5th	Total	Weight	Normal	%	Rank
Adequate space for material movement onsite	24	30	23	29	105	211	32.81	0.150	15	5
Identifying recyclable materials	112	21	20	25	33	211	62.20	0.285	29	1
Forecast the emerging waste stream	31	55	51	40	34	211	40.43	0.185	19	3
Segregating waste materials into categories	19	71	88	19	14	211	40.03	0.184	18	4
Identifying reusable materials	23	93	54	30	11	211	42.57	0.195	19	2

6.6.2.4. Low Waste Technique Attributes' Weights

The results of the attributes of low waste technique in Table 6.17 show that *'Adopting prefabricated building components* emerged with the highest weight followed by *'Use of reusable formwork and falsework*. Combining their weights shows that they account for more than a third (36%) priority weights of the seven attributes in the criterion. Also, the *use of appropriate construction equipment* scored the third position, while *Maximise use of joint system instead of gluing and de-constructable materials were* ranked the fourth and fifth, respectively. Further, *Adopting the right work sequence* was ranked sixth while *Using steel scaffolds* has the least weight, ranked the seventh in the category. Together, the two attributes account for less than a fourth (22%) of the total weights in the low waste technique category. Therefore, the results show that many respondents saw adopting prefabricated building components as the most important attribute compared to other attributes. However, the use of steel scaffolds was seen as least important by many.

Table 6.17: Priority votes of seven low waste technique attributes from 211 respondents in the survey

Low waste technique	1st	2nd	3rd	4th	5th	6th	7th	Total	Weight	Normal	%	Rank
Maximise use of joint system instead of gluing	30	58	36	40	11	5	31	211	34.12	0.144	14	4
Use of de-constructable materials	30	38	36	26	14	8	59	211	30.88	0.130	13	5
Adopting the right work sequence	33	9	26	18	12	104	9	211	27.15	0.114	11	6
Use of steel scaffolds	15	29	12	20	109	15	11	211	24.82	0.105	11	7
Adopting prefabricated building components	89	32	21	11	12	9	37	211	47.80	0.201	20	1
Use of reusable formwork and falsework	44	57	43	13	18	16	20	211	38.26	0.161	16	2
Use of appropriate construction equipment	39	35	41	38	15	11	32	211	34.35	0.145	15	3

6.6.2.5. Global Priority Ranking of Construction Attributes

From Table 6.18, the results of the global priority ranking of construction attributes show the five most important attributes in descending order: '*Identifying recyclable materials; Senior managers early commitment to waste minimisation; Effective communication among project participants; Making subcontractors responsible for their waste; Identifying reusable materials.* Also, the five least important attributes are presented in ascending order: *Use of steel scaffolds, Adopting the right work sequence, Use of de-constructable materials, A site waste management policy for site employees and Maximise use of joint system instead of gluing*
Therefore, the results indicate that identifying recyclable materials is the most important attribute in the global priority Table 6.19. At the same time, using steel for scaffolds emerged as the least important.

Table 6.18: The VAHP results of global priority/ranking of construction attributes

Construction attributes for waste minimisation	Global Priorities	Global Rank
Identifying recyclable materials	0.076	1
Senior managers early commitment to waste minimisation	0.066	2
Effective communication among project participants	0.062	3
Making subcontractors responsible for their waste	0.058	4
Identifying reusable materials	0.052	5
Forecasting the emerging waste stream	0.050	6
Motivating employees to minimise waste	0.049	7
Waste target clause in subcontractors' agreement document	0.049	8
Adopting prefabricated building components	0.049	9
Segregating waste materials into categories	0.049	10
An incentive clause for effective waste management practice	0.047	11
Periodic training of site employees on waste management strategies	0.046	12
Adequate space for material movement onsite	0.040	13
Use of reusable formwork and falsework	0.039	14
Active site supervision	0.037	15
Adequate waste reduction investment	0.037	16
Use of appropriate construction equipment	0.035	17
Maximise use of joint system instead of gluing	0.035	18
A site waste management policy for site employees	0.035	19
Use of de-constructable materials	0.032	20
Adopting the right work sequence	0.028	21
Use of steel scaffolds	0.027	22

6.7. Discussion of the Findings

As mentioned early, in Chapter 1, research into construction waste management for Nigeria does not usually focus on solutions but rather on the causes of construction waste in the industry. Consequently, adequate information on construction waste management solutions in the country is limited and hard to unearth. The outcome of this stage is to analyse the results of the criteria relevant for effective waste management solutions in the construction industry identified in Chapter 3—four for materials procurement and construction activities, respectively, alongside their attributes—twenty for materials procurement and twenty–two for construction. Further, their respective priority weights were determined with the aid of the VAHP. Therefore, this section aims to contextualise the above results from the data analysed in relation to the extant literature. Hence, to interpret and describe the significance of the research findings in light of what is known about the research and new insights that emerged from this study. First, the criteria for materials procurement are discussed, followed by the top–ranked attributes. In the same vein, the criteria for construction are discussed, followed by the top–ranked attributes.

6.7.1. Discussion of Materials Procurement Related Criteria

- *Low waste purchase management*

The findings of this study revealed that *low waste purchase management* has a normalised weight of 0.304. Efficient purchase management is one of the basic components of supply chain management that deals with materials purchasing information. Such waste management measures include purchasing secondary materials, purchasing maintainable materials, accurate materials quantification, purchase of high–quality products, accurate materials ordering, and materials substitution. The findings reinforced Ajayi (2017a), who confirmed waste–efficient materials purchase management as the most important criterion for waste minimisation in the UK construction industry. In addition, an earlier study by Tam (2008b) found that purchase management is the second most important criterion for implementing an effective waste management plan in the Hong Kong construction industry. Although these studies were conducted at different times and places, the findings of this study confirmed that the criterion is also of high importance to the Nigerian construction practitioners, implying that most of them recognised the importance of low waste purchasing as a way of controlling waste in their projects.

Therefore, supporting the work of Esin and Cosgun (2007) on the need to ensure that durable materials are purchased to prevent breakages in the installation or total structural failure during construction that will result to waste. This assertion was also supported by Gulghane and Khandve (2015), who maintained that buying the right quantity of materials when needed is a way to control excess materials on construction sites. As one of the key procurement strategies, it also reflects long–term waste management, such as substituting materials with more environmentally friendly ones and those that can easily be maintained to avoid future waste generation after construction. Thus, allowing the optimal performance of materials during their life span in buildings with minimum life cycle cost. This supports the idea of sustainable waste management that promotes futuristic thinking when purchasing construction materials (Wong and Yip, 2004). Such an idea also highlights the industry's need to purchase more secondary materials to minimise the already depleted natural resources due to the frequent use of virgin materials (Gálvez–Martos *et al.,* 2018). Therefore, the findings have implications for practice; they suggest both short and long–term low waste purchasing, which should be encouraged at the projects, industry and national levels. It also places a responsibility on the suppliers to meet the industry’s need for green purchasing to reduce waste in construction projects.

- *Procurement clauses*

The findings of this study show that the procurement clause criterion has a normalised weight of 0.258. The procurement clauses suggest different ways to minimise waste by collaborating with suppliers through agreements. The findings support Dainty and Brooke (2004), who found the importance of contractual clauses for improving the construction industry's supply chain for waste reduction. The findings also revealed that many practitioners perceived this criterion as a critical waste management practice, the second most important for effective materials procurement. In this study, the criterion suggests the need to include a take–back clause in suppliers' agreement document, suppliers to supply quality and durable materials and supplier flexibility in providing a smaller quantity of materials. Also, it shows a need for an agreement with suppliers on certain waste management strategies and consistency in an agreement document to avoid confusion. The findings, therefore, support the evidence that including waste minimisation enabling clauses in suppliers' agreement document could significantly reduce or prevent the causes of waste, such as disagreement between parties about how waste could be best managed and who will be responsible (WRAP, 2016).

Therefore, the findings highlight the importance of mutual and legal agreements between a contractor and suppliers to consider different measures to achieve a desired waste management outcome without any hindrance. In addition, procurement clauses are directly related to the contexts within which a contractor can assess suppliers for potential selection. This would mean that contractors must select suppliers who agree on specific terms for effective waste management before procuring materials. Such an agreement can aid waste reduction because stakeholders would agree upon waste management approaches before partnering. These efforts would require suppliers to contribute to waste minimisation in the procurement stage through contractors' established waste management clauses free from errors, deficiencies, ambiguity, and unfair risk allocation (Mendis *et al.,* 2013). Therefore, the findings imply that a mutual agreement and understanding between contractors and suppliers is necessary to implement waste management objectives smoothly. However, that may be difficult to achieve unless both parties share waste management responsibilities with mutual commitment.

- *Top management support for materials procurement*

Top management support for materials procurement has a normalised weight of 0.245. In numerous studies, top management support is widely recognised as one of the most critical factors for successful project management. This criterion aligned with Dainty and Brooke

(2004) and was acknowledged by Strandberg (2012) as management actions that support procurement activities such as policy training, goals targets and incorporating sustainability factors in the purchasing process. The findings show that various management systems are crucial for implementing green and sustainable procurement through the help of top management (Strandberg, 2012). It, therefore, brings into focus empirical studies that have highlighted genuine top management involvement as a crucial aspect of waste management in construction (Lingard *et al.,* 2000; Ling and Nguyen, 2013). However, the rank of this criterion in the third position by most practitioners indicates that top management support is not their top or immediate priority for procurement waste management. This reflects the fact that waste management is not usually supported by the top management but is left mainly in the hands of junior employees (Teo and Loosemore, 2001). Top management support grouping includes involving a purchase manager in procurement activities, providing stock control measures, periodic training of procurement personnel on waste management strategies, alliance with suppliers, and waste management guidelines for procurement personnel.

The responsibility and commitment of top management to provide the above measures are crucial requirements for successful waste management. Therefore, providing these measures would direct the projects team on the requirements of procurement activities before and after materials are delivered on construction sites. It implies that when there is no adequate support from top management, the needed requisites and acceptable standards to ensure a smooth running of procurement activities such as inventory control may lack proper organisation. Hence, it could lead to waste due to stockpiling of materials that may damage or expire before usage, resulting in waste of materials. Therefore, the findings suggest a need for contractors to support the procurement team, such as skill development for implementing procurement strategies and linking waste management to their roles.

- *Efficient delivery management*

Efficient delivery management has a normalised weight of 0.194, making it the least prioritised criterion. Nevertheless, efficient delivery management is widely recognised as an important factor for successful waste management in the construction sector (Al–Hajj and Hamani, 2011; Hassan *et al.,* 2012). The findings also support (Ajayi, 2017b), who identified efficient delivery management as an important criterion for optimising materials procurement for construction waste minimisation. Efficient delivery management grouping comprises adequate site access for delivery vehicles, careful material handling to avoid breakage, just–in–time delivery (JIT) and safe storage of materials onsite. Research studies have prominently featured delivery management as one of the important factors of supplier selection in construction (Safa *et al.,* 2014). The criterion is based on the philosophy that waste due to loading, transportation, and unloading could be prevented through protection and careful handling of materials throughout the delivery process (Garas *et al.,* 2001). It also supports the findings that materials should be delivered just–in–time on construction sites to avoid waste due to double handling of materials that usually result in breakage or damage (Al–Hajj and Hamani, 2011).

Evidence shows that one of the significant causes of waste in the Nigerian construction industry is inefficient delivery management, such as poor materials handling due to loading and unloading resulting in breakages (Oladiran, 2009; Babatunde, 2012; Aiyetan and Smallwood, 2013; Garba *et al.,* 2016). Although the above literature suggests it is a significant cause of waste, it is surprising that practitioners least prioritised this criterion despite the being a major cause of construction waste in Nigeria. Reasons as to why the criterion was ranked the least remain speculative, although they may relate to the fact that practitioners, particularly contractors, may consider materials delivery wholly a supplier responsibility. Therefore, it is evident that a lack of involvement by contractors in materials delivery planning can increase waste output on construction sites (Afolabi *et al.,* 2018). This evidence implies the need for contractors' involvement and contribution in the materials delivery process to receive their materials in good condition. The following sections discussed the top–ranked attributes in the materials procurement category.

6.7.2. Discussion of the Top–Ranked Materials Procurement Attributes

- *Accurate materials quantification*

Several attributes were identified as elements of low waste purchase management (Table 6.10). Regarding the importance of the attributes, key findings of this study revealed that most practitioners believe that accurate materials quantification will have the highest impact on waste minimisation. The findings agree with (Li *et al.*, 2016), who proposed that enhancing estimation accuracy through levels of detail and experts' knowledge could lead to better materials management in construction. The emergence of this attribute as the most important in the category shows that practitioners recognised it as a critical factor that can help them minimise waste and cost inflation of projects (Ugochukwu *et al.,* 2017; Saidu *et al.,* 2017). It explained that if buyers fail to follow specifications in the design documents or there is an error in specification, the outcome is usually over–ordering or purchasing products that do not comply with specifications. Thus, excess materials could be delivered on construction sites if materials quantity take–off is not accurately done (Muhwezi *et al.,* 2012). It further indicates that understanding the scope of a project before purchasing materials cannot be overemphasised. This is also acknowledged in the Royal Institute of British Architects (RIBA)

Plan of Work 2020 on the need to provide the required information in the pre–construction stage. Therefore, the findings from the current work underscore the need for contractors to review design documents to eliminate potential estimation errors from the designers before purchasing materials. As such, this result provides a useful reminder to contractors to double–check design documents before making purchasing decisions.

- *Take–back clause in suppliers' agreement document*

The findings of this study revealed that most of the practitioners considered the 'take–back clause in suppliers' agreement document as the most important waste minimisation measure amongst the measures attributed to the procurement clause category**.** The findings is consistent with previous studies, indicating that take–back arrangement with suppliers is an important measure of waste minimisation in material procurement. For instance, through the subjective opinion of the UK design and construction firms, Ajayi *et al.* (2017b) found that commitment to the take–back scheme is the most important procurement attribute. The finding is consistent with Mortaheb and Mahpour (2016), who identified take–back policies as the most important procurement attribute under supplier selection management in the Iranian construction industry. However, an earlier study by Al–Hajj and Hamani (2011) found that a take–back arrangement with suppliers is the ninth most important procurement attribute for waste minimisation in the UAE construction industry.

Moreover, other authors, such as Oyedele *et al.* (2013); Park and Tucker (2017), believe the take–back scheme will improve the reuse and recycling of construction materials. Therefore, the findings show that getting reusable materials back to the market can be achieved by implementing the take–back scheme in the construction industry. Further, the findings explain the growing need to shift some waste management responsibility onto suppliers by returning unwanted, excess or unused materials (Lu and Yuan, 2011). Therefore, extending waste management responsibility to suppliers would represent a relational attempt to minimise excess materials delivered on construction sites. However, this may be difficult to achieve without prior agreement with suppliers. Hence, supporting the need to add such a measure in the suppliers' contract arrangement.

- *Alliance with suppliers*

The findings of this study show that most of the practitioners perceived alliance with suppliers as the most important attribute under the top management support category. Alliance with suppliers is widely considered a critical success factor in supply chain management which is also necessary to improve waste management performance in construction. The findings support Dainty and Brooke (2004) that developing alliances with suppliers and recycling companies is the most important waste management attribute contributing to an improved supply chain management. The findings also support Bankvall *et al.* (2010), who stressed that strategic supplier alliances would reduce waste and improve the quality of the supply chain. The findings, therefore, encourages the need for commitment and a stronger relationship between clients or contractors and material suppliers. However, there is a concern about whether the construction industry is culturally prepared for mutual relationships to improve waste management performance (Dainty and Brooke, 2004). Nevertheless, there is evidence that balancing risks and gains between clients, contractors and suppliers could bridge the relationship gap and improve alliance amongst construction actors (Black *et al.,* 2000).

- *Just–in–time delivery of materials*

The key findings of this study show that just–in–time delivery of materials emerged as the most important attribute by weight in the efficient delivery management category. This finding aligns with Al–Hajj and Hamani (2011) that found that just–in–time delivery is one of the most important strategies implemented in the UAE construction industry, which helps them minimise materials waste. The study exposed that less waste is produced when the needed quantity of materials is supplied to a construction site for work rather than stockpiling them. The findings buttressed (Dainty and Brooke, 2004), who maintained that timely materials delivery would minimise the length of time of materials storage, the potentiality of double handling and over–ordering. Hence to avoid subjecting materials to frequent handling, poor weather condition and the risk of theft/vandalism. It highlights that timely delivery of construction materials will not only minimise waste due to the above factors but can contribute to faster construction. Furthermore, the findings of this study brought into focus a need to forecast materials demand accurately and use a faster delivery route to minimise time pressure for the completion of projects (Oladiran *et al.,* 2019).

These findings have implications for practice. Their commonalities indicate a need for effective materials and supply chain management to help contractors minimise waste in projects. For instance, rather than concentrating on onsite activities to manage the flow of materials, they suggest cooperation between contractors and suppliers to improve waste management offsite and onsite. This would ensure that only the right materials are supplied in the correct quantity required for a job. However, if excess or the wrong materials are delivered onsite, there is an opportunity to return them to the supplier. Although only the four top–ranked attributes are discussed above, the twenty attributes grouped across the materials procurement criteria are necessary for effective waste management in the construction industry. Therefore, contractors should focus and stress the efforts on improving waste management performance by integrating the criteria into their waste management objectives since the success of procurement activities depends on them. Also, it is important to pay close attention to the four top–ranked attributes (Accurate material quantification, Take–back clause in suppliers' agreement document, alliance with suppliers, and just–in–time delivery system). This study shows they represent the opinions of the majority of the practitioners as the most important ones. The following sections discuss the criteria in the construction category.

6.7.3. Discussion of Construction Related Criteria

This study identified four key criteria for waste management in the construction stage through the literature review. In the other of importance, findings indicate that top management support for construction emerged as the most important criterion with a normalised weight of 0.297. This is followed by the SWMP (0.267) low waste technique (0.244), while construction clause (0.189) has the least weight. These are elaborated next.

- *Top management support for construction*

Top management support for effective construction operation also underscores the willingness of top management to embrace, prioritise and promote effective waste management in their organisations. The criterion's grouping is shown in Table 6.15. The finding is consistent with (Teo and Loosemore, 2001), that proposed top management support will enhance site employee's behaviour towards effective waste management. Furthermore, the emergence of this criterion as most important reinforced (Dania *et al.,* 2007) who found that top management support for waste management has the most impact on waste minimisation in the Nigerian construction industry. This means that the industry practitioners still believe that top management should drive waste management objectives in their companies.

The findings imply that top management commitment to waste management objectives could positively contribute to site operatives' behavioural change for improved waste management performance (Kulatunga *et al.,* 2006; Li *et al.,* 2018; Mak *et al.,* 2019). Furthermore, the findings highlight that companies are unlikely to achieve their waste management targets without adequate involvement and commitment from the top management (Ling and Lim, 2002). The above studies buttressed that commitment from the top management is a key driver of waste management in construction organisations. Therefore, it is evident that the top management's visible involvement and commitment play an important role in reducing waste in the industry. It further revealed the need for a top–down approach to waste management where top management champions the cause of changing the industry's poor waste management culture.

- *Site waste management plan*

Site waste management plan grouping is shown in Table 6.16. This study revealed that a SWMP is an important instrument for waste reduction onsite. The criterion aligns with several studies promoting the development of a template to document the expected waste types, quantities, and actions for management such as reuse, recycling, disposal methods ahead and during construction operations. The findings of this study reinforced the evidence that a SWMP `can reduce waste generation through segregation, reuse and recycling (Hasmori *et al.,* 2020). In addition, a SWMP would ensure appropriate waste sorting, segregation, auditing, and diverting materials from landfills (Mcdonald and Smithers, 1998). The findings show that most practitioners recognised the importance of developing a SWMP, ranked as the second most important for effective waste management; however, it is seldom implemented in their projects (Oladiran, 2009). This claim was supported by Wahab and Lawal (2011), who suggest most Nigerian construction firms do not incorporate waste management plans in the bidding or construction planning documents. Therefore, sorting materials waste is usually neglected (Wahab and Lawal, 2011). This supports the common belief that most construction waste is not separated, mostly recorded under mixed waste due to the extra cost of segregation.

Although reasons for the limited use of a SWMP in the Nigerian construction industry remain speculative, there is evidence that contractors' lack of interest was due to financial constraints (Tam, 2008). Therefore, it implies that contractors' voluntary implementation of a SWMP may be difficult without legislative enforcement, support or incentives (Papargyropoulou *et al.,* 2011). Nevertheless, the findings of this study highlight that a SWMP is applicable with significant environmental benefits beyond the limitation, particularly for a large construction project (Tam *et al.,* 2008b; Von Meding *et al.,* 2013).

- *Low waste technique*

The low waste construction technique grouping is shown in Table 6.17. The criterion aligns with studies proposing hard measures for reducing waste in construction (Lu *et al.,* 2011; Zhang *et al.,* 2012). These studies emphasised that low waste building techniques can reduce waste from many construction activities (e.g. wet–trade) and contribute to environmentally friendly construction. However, the ranking of this criterion in the third position indicates that it is not of immediate priority to a majority of the practitioners. For instance, the findings reinforced Wahab and Lawal (2011), which confirmed that 90.9% of construction practitioners do not use prefabrication elements in their projects. This indicates that the traditional onsite production of construction materials (cast–in–situ), which maximise wet trade, resulting in waste, is mostly adopted in the industry. A recent study by Aboginije *et al.* (2021) also confirmed that the degree of adoption of the low waste techniques is not adequate in Nigeria compared to the total number of construction firms in the country.

The results of this study demonstrated that the practitioners do not adequately recognise the application of low waste techniques as critical for waste minimisation in their projects. The findings align with the general view on the slow adoption of low–waste construction techniques and innovations as the traditional methods are still commonplace, particularly in small projects (Poon *et al.,* 2003). According to (Poon *et al.,* 2003), the slow adoption of low waste building techniques in construction is due to a lack of awareness of the benefits amongst contractors. Therefore, it is evident that more awareness is needed to increase the use of low–waste construction techniques to drive the waste minimisation agenda in the industry.

- *Construction clause*

The criterion grouping is shown in Table 6.18. Construction clause criterion aligns with Ling and Nguyen (2013) that shows the importance of a contract agreement between contractors and subcontractors to improve waste management performance in construction sites. Also, the criterion agrees with Tam *et al.* (2007), who found that waste generation in construction is directly linked with a subcontracting arrangement suggesting a binding agreement between parties on how best to manage waste during tendering. However, the findings of this study show that many practitioners least prioritise construction clause criterion, indicating that they did not perceive it as a critical waste management practice. The findings support the evidence on the lack of adequate consideration for waste management objectives in construction projects contract documents (Osmani, 2013).

The findings of this study imply that contractors would have to take all the waste management responsibilities without a contract arrangement that shows how subcontractors can help improve waste management performance. Also, it indicates that a lack of key performance indicators (KPIs) for prequalifying subcontractors based on their past waste management performance and the ability to cooperate with contractors for potential selection will result in contractors taking all the waste management responsibilities. It also highlights that a skewed waste management responsibility will likely place contractors into a financial burden. Finally, the findings of this study show the need for mutual collaboration between contractors and subcontractors to improve the waste management performance of the construction industry. The following sections discuss the top–ranked attributes of the construction criteria category.

6.7.4. Discussion of the Top–Ranked Construction Attributes

- *Senior managers' early commitment to waste minimisation*

Regarding the importance of the attributes in *the top management support category, Senior managers' early commitment to waste minimisation* emerged as the most important among the six attributes with a normalised weight of 0.221. The ranking of this attribute as the most important suggests that practitioners are aware that commitment from the top managers could help them minimise waste in projects. The findings of this study align with previous studies that emphasised that senior managers awareness and commitment leads to better waste management performance (Teo and Loosemore, 2001; Papargyropoulou *et al.*, 2011). However, contrary to the findings, other studies indicate that senior managers are more interested in projects' time and cost performance than waste minimisation (Begum *et al.,* 2006). This supports the common belief that waste management is not usually a top priority to the senior managers, like cost and time. However, an early commitment from the senior managers is a proactive measure to waste minimisation in construction projects. This would mean that contractors would perceive waste minimisation objectives equally as time and cost performance of projects as factors that contribute to successful project management.

Senior managers are responsible for coordinating employees to ensure synergy in an organisation. In addition, they provide leadership that can direct project teams to success through strategic planning, policies, resource provision, and allocation. This would mean that a project with clear support from the senior managers is more likely to have good waste management performance than the one with a lack of commitment from the senior managers. While time, cost and quality are still considered the basic performance indicators for benchmarking the success of construction projects, the findings of this study imply that adding waste management to the list could help the construction industry contribute more to sustainable development (Sev, 2009). The findings, therefore, would serve as a reminder to contractors to encourage senior managers to commit to waste minimisation early if their companies must succeed in implementing effective waste management.

- *Identifying recyclable materials*

A key finding of this study shows that *identifying materials to be recycled* is the most important among the five attributes grouped in the SWMP criterion, with a normal weight of 0.285. Therefore, the findings of this study show that most practitioners believe that identifying recyclable waste will promote recycling in construction companies which minimises waste. The finding supports the idea that, since waste cannot be eliminated entirely in construction, there is an opportunity to identify the recyclables to facilitate a closed–loop material flow (Liu *et al.,* 2020a; He and Yuan, 2020). In addition, the findings support the works of numerous studies that suggest recycling as a good reaction towards waste minimisation by elongating materials' life expectancy (Mak *et al.,* 2019; He and Yuan, 2020).

The findings, however, contrast with Wahab and Lawal (2011). They found that the Nigerian contractors hardly segregate waste, which can help them identify the recyclables and their economic viability. This explains the poor attitude to recycling by the Nigerian construction contractors (Ogunmakinde *et al.,* 2019) amidst the controversy on the quality and cost of recycled materials against virgin ones and market unavailability (Wu et al., 2019). This implies that for successful recycling to be carried out, contractors must try to identify the recyclables and separate them from the nonrecyclables. Also, the findings would serve as a reminder to contractors to understand recyclable materials' economic viability and market availability as important aspects that influence recycling in the construction industry.

- *Adopting prefabricated building components*

Using prefabricated building components emerged as the most important among the seven attributes in the construction technique criterion with 0.201 normalised weight. The prefabrication concept allows the construction industry to manufacture building elements offsite to assemble them onsite. The method prevents waste factors such as poor materials handling, frequent design changes, and poor storage. The finding of this study aligns with Tam (2006), who found that the use of prefabricated building components is the most important attribute contributing to effective waste management in the Hong Kong construction industry. According to Tam *et al.* (2007), 85% of construction waste could be minimised by adopting prefabricated building components. The findings also reinforced Jaillon *et al.* (2009), who compared the traditional construction method against the prefabrication method. Their results favoured prefabrication by reducing about 52% of construction waste in Hong Kong.

The findings of this study suggest that even though many practitioners demonstrated that the attribute is of high importance to them, the application in the industry is low. This finding is reinforced by Adebayo and Dixon–Ogbechi (2017), who found that the Nigerian construction contractors have very good knowledge of prefabrication, but the adoption in housing development is low. In contrast, an earlier study suggests low awareness and unavailability of local prefabrication companies (Ogunde *et al.,* 2016). This would mean that more education is required to enhance the awareness of prefabrication technology to improve its applications in Nigerian construction projects, having been considered most important by the practitioner.

- *Making subcontractors responsible for their waste*

Making subcontractors responsible for their waste is confirmed as the most critical factor influencing waste minimisation in the construction clause category by having a normalised weight of 0.305. There is a belief amongst researchers that waste producers should be held accountable for the waste they produce (Poon *et al.,* 2013; Lu *et al.,* 2015a). This finding aligns with the concept of extended producer responsibility, which reinforced the idea that contractors and subcontractors share waste management responsibilities (Lu and Yuan, 2011). Also, the impression that contractors employ subcontractors with waste management ability (Ling and Nguyen, 2013). Since contractors are not the only waste producer, other stakeholders, such as subcontractors, should be held accountable for the waste they produce in construction (Lu and Yuan, 2011) and commit to agreed terms and conditions to ensure successful waste management devoid of dispute. The finding is evidence that the willingness of subcontractors to accept some cost of waste management will have a significant influence on waste reduction (Saunders and Wynn 2004). Therefore, the findings of this study is a reminder for contractors to penalise poor waste management performance (Dainty and Brooke, 2004). For instance, by not shortlisting subcontractors who are not committed to sharing waste management responsibilities with them.

The practical implication of these findings reflects the key aspects of good waste management in the construction stage. They show a need to integrate ''soft'' and ''hard'' measures for effective waste management in construction. The findings show that construction companies can adopt managerial instruments to address waste management issues from the social perspective using soft measures. These include training to improve employee commitment, legal or mutual agreements with subcontractors, supervision, amongst other factors. The hard measures address the waste issue from a technical perspective. These include low–waste technologies such as prefabrication instead of in situ, steel formwork and falsework instead of timber, waste segregation, reuse and recycling materials (Lu and Yuan, 2011). While this study showed that the twenty–two attributes identified across the criteria are important for waste management in the construction stage, four were the most important within the soft and hard measures. These are: (senior managers' early commitment to waste minimisation, identifying recyclable materials, adopting prefabricated building components, and making subcontractors responsible for their waste). Therefore, contractors should integrate all the attributes into their waste management objectives and pay close attention to the top–ranked attributes. They represent the opinions of the majority of the practitioners as the most effective.

6.8. Chapter Summary

This chapter presented the results of the data analysis for this research. It shows the results of the verified criteria and attributes for managing waste in materials procurement and construction activities alongside the data collected from the main survey. First, the participants' demography was analysed and presented. This is followed by showing the results of the central tendency of the data set, the results of Kendall's coefficient of concordance and Kruskal–Wallis H tests. Then, through the VAHP analysis, the procurement and construction criteria and attributes results were presented. Finally, the chapter discussed the materials procurement and construction criteria and the top–ranked attributes. The discussion revealed the areas of similarity or divergence from the previous studies. The next chapter presents the proposed frameworks and the validation results.

CHAPTER 7: DEVELOPMENT AND VALIDATION OF THE PROPOSED FRAMEWORKS

7.1. Introduction

This chapter presents the proposed frameworks for effective waste management in materials procurement and construction activities. The results of the VAHP, evidence from the literature review, and insights from the discussion section aided the development of the frameworks. The background steps to developing the frameworks are presented. Finally, the chapter presents the validation results by stating and making sense of the construction practitioners' comments on the applicability of the proposed frameworks for waste management in the industry.

7.2. Development of the Proposed Frameworks

Developing frameworks to optimise the use of materials has always been a need in the construction industry. A framework integrates relevant concepts into a predictive or descriptive solution that guides action or practice (Bose and Pekny, 2000; Gutwin and Greenberg, 2002). Theory and practice can be integrated to achieve a specific goal using different concepts to make a framework meaningful. The frameworks proposed in this study aim to help contractors identify and select the criteria they intend to incorporate into their materials procurement and construction waste management practices. The frameworks will further advise on the key actions to allow contractors to implement effective waste management in collaboration with site employees, suppliers and subcontractors based on their priorities. Thus, providing evidence–based solutions to enhance waste management in the construction industry. There are multiple evaluation criteria for waste management; therefore, the multi–criteria decision model has been selected in Chapter 4 as the method underpinning the development of the frameworks.

Karmperis *et al.* (2013) highlighted the basic procedural application of MCDM for framework development, namely: (1) identify the decision goal; criteria and attributes to achieve the goal; (2) evaluate the criteria and attributes; and (3) compute their priority scores for decision making.

Many studies have demonstrated the importance of multi–criteria decision–making models for prioritising problems or solution strategies in many industries (Prasanna Venkatesan and Kumanan, 2012; Aravind Raj *et al*., 2014) including construction (Chatterjee *et al.,* 2018).

There is a similarity in the developmental procedure but variation in the computation of criteria priority scores. Some of these studies have applied sensitivity analysis, particularly in an uncertain condition to allocate different sources of uncertainty in its inputs to deal with a lack of consensus amongst stakeholders in deciding the best option to a problem (Kazancoglu and Ozturkoglu, 2018). In many MCDM studies, researchers either select the best solution(s) from set of available alternatives or prioritise all the solutions to solve a problem.

For instance, Ding and Liang (2005) developed fuzzy MCDM, entropy weighting method and graded mean integration to select partners of strategic alliances for liner shipping in Taiwan. Georgopoulou *et al*. (2003) utilised ELECTRE Tri in defining national priorities for greenhouse gas emissions reduction in Greece's energy sector. Mahpour (2018) developed a framework for applying CE in construction waste management by prioritising the attributes using fuzzy TOPSIS. Kim and Kumar (2009) developed a framework for prioritising intellectual capital indicators in research and development, using a AHP model combined with Delphi. In this study, Mahpour’s (2018) structure is adapted to develop the frameworks by prioritising the waste management attributes and proposing various implementation actions. Also, the waste management attributes are categorised as low, medium and high priorities following the Georgopoulou *et al.* (2003) study. Therefore, frameworks for managing materials procurement and construction waste should contain the following steps.

- **Definition of the Goal**

The first step requires the identification, definition and understanding of the goal. This would mean that the stakeholders must acknowledge and understand the goal to identify clear objectives (Belton and Stewart, 2002). In this study, the goal has been identified in Chapter 1, which is to help the Nigerian contractors implement effective waste in the materials procurement and construction stages.

- **Identifying the Criteria and Attributes**

It has been suggested that to implement effective waste management; one must consider a variety of criteria so a relevant multi–criteria evaluation model can be built. According to Yahya and Kingsman (1999), stakeholders should identify and select coherent criteria and related attributes to achieve the goal. The criteria and attributes could be found in the previous research works or suggested by the stakeholders in a joint meeting (Pishchulov *et al.,* 2019). In this study, the list of criteria and the related attributes were retrieved from the literature in Chapter 3. In practice, stakeholders can be invited to identify the criteria and attributes (Pishchulov *et al.,* 2019). After identifying criteria and the attributes, practitioners should discuss and agree upon the eventual criteria and attributes. In this study, the criteria and attributes were verified by academic experts in the construction industry to ensure their reliability in fulfilling the waste management goal.

- **Structuring the Goal, Criteria and the Related Attributes in a Hierarchy**

A useful tool at this stage is a decision model, which connects the goal with the fundamental criteria and attributes (Liu and Hai, 2005). By applying this model, the problems or solutions are structured by ordering them into a hierarchical structure. As mentioned earlier, connecting the goal to the criteria/attributes in a hierarchy will ensure effective evaluation of the criteria and the attributes (Belton and Stewart, 2002). Therefore, the hierarchy should appear thus: the goal at the higher level, the criteria at the middle level and the related attributes at the lower level. In this study, the hierarchy structure is presented in Figure 3.2.

- **Determining the Weight of Different Criteria and Related Attributes in the Hierarchy**

At this stage, the aim is to allow stakeholders to vote to evaluate the weights of the criteria and related attributes based on the degree of importance (Liu and Hai, 2005). In this study, a survey was designed so practitioners can rank–order the criteria and attributes regarding their degree of importance towards contributing to waste minimisation in the construction industry. The survey should be clearly defined, meaningful and unambiguous to stakeholders. The comparisons can be achieved using different ranking scales (Liu and Hai, 2005) as per this study (Section 5.8.1). Then, the VAHP is applied for different criteria levels, and each criterion and attributes' weight at each level is calculated with the aid of Noguchi's strong ordering model. The same procedure should be repeated to determine the attributes' weight in lower levels that belong to each criterion in the higher level. The results will show the local weight of the attributes. Upon establishing the local weight, the next step is to determine the global priority of attributes in the lowest level of the hierarchy. The computation is done by multiplying the normalised weight of each criterion by its corresponding attributes' normalised weights. The results are presented in Table 6.12 for materials procurement and 6.18 for construction, respectively.

- **Grading and Categorising the Attributes into Priorities**

In order to group the attributes in priority categories, a priority point was given to the attributes based on their weights (Kim and Kumar, 2009). Therefore, from the global weight scores in Tables 6.12 and 6.18, the attributes are grouped in categories to signify how the stakeholders prioritised them to help contractors understand waste management priorities of the industry practitioners to plan for implementation actions based on available resources or circumstances. Therefore, a weighted score of $\leq$ 0.040 is considered low priority category, 0.041$\geq$0.050 medium, 0.051 and above is of high priority category. Therefore, in Tables 7.1 and 7.2, the attributes' priorities are limited to three: P1, P2 and P3, where (P1 = high priority category, P2 = medium priority category and P3 = low priority category) (Georgopoulou *et al*., 2003).

- **Proposed Actions for the Management of Materials Procurement and Construction Waste**

While the proposed frameworks will allow contractors to learn about key criteria, attributes for effective waste management, and company priorities, they further provide actions for implementation upon incorporating the criteria into their waste management practices. Figure 7.1 shows the integrated flowchart for the development of the frameworks. From the above discussion, it begins with the stakeholders defining the goal. This step is followed by deciding the criteria and attributes for achieving the goal and determining their local priorities weight, the global weight and priority categories. The process aims to help contractors think systematically about the criteria they desire to incorporate into their waste management practices and the actions required for implementation.

7.3. Structure of the Frameworks

The frameworks are demonstrated in Tables 7.1 and 7.2, respectively. The initial conceptual framework illustrated in Figure 3.2 outlined the key concepts of the study. From the findings of this research, the conceptual framework has been refined considering practitioners' rankings of the criteria and attributes. Also, the attributes are placed into different priority categories, and implementation actions are proposed to guide contractors who would incorporate the criteria in their waste management practices. The attributes are arranged in columns against their respective criterion in the frameworks. In addition, the contents of the frameworks are coded for easy identification. The description of the codes is stated at the bottom of each table. Finally, while there is a similarity in the structure entailing the five aspects of the frameworks, the contents differ. Therefore, frameworks for managing materials procurement and construction waste are presented in the following sections. While actions are proposed for all attributes, the high priority category attributes are particularly highlighted.

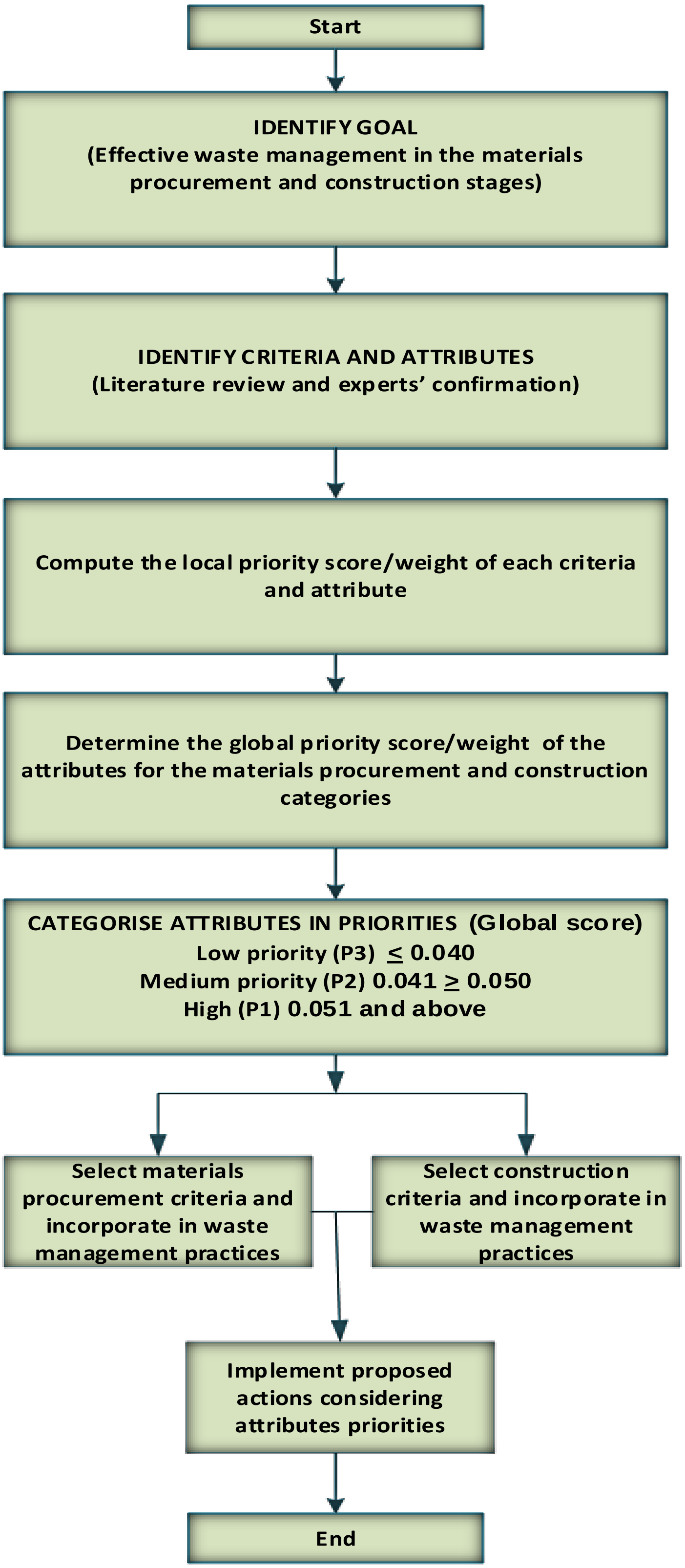


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Figure 7.1: Integrated flowchart of frameworks for effective waste management in the materials procurement and construction activities

7.3.1. Framework for the Management of Materials Procurement Waste

Table 7.1 illustrates the framework for managing materials procurement waste in the construction industry. The Tables' contents are coded, consisting of four criteria and twenty attributes, depicting the research findings alongside the proposed actions. The proposed actions support the opinion that contractors and suppliers (Dainty and Brooke, 2004; Osmani, 2012) should be committed to optimising materials procurement for effective waste management in the construction industry through partnership and mutual understanding. The following sections discuss some of the enabling actions.

Incorporating low waste purchase management *[PC1]* in waste management practices would require contractors to consider the attributes' priorities and actions for implementation. One of the high priority category attributes is accurate materials quantification *[PA1.1].* To help increase confidence that the correct quantity of materials will be purchased, the framework highlights investing in the necessary training to increase estimators' understanding of project requirements and audit the accuracy of estimated materials and labour *[PPA1.1a].* Also, it advised contractors to consider using building information modelling (BIM) for greater confidence in materials quantity take–off *[PPA1.1b].* The framework also shows that accurate material ordering *[PA1.2]* is within the high priority category while the rest of the attributes *[PA1.3; PA1.4; PA1.5, and PA1.6]* are of medium priority. It, therefore, shows that the interplay between accurate materials quantification and ordering complements each other.

The next criterion is the procurement clause *[PC2],* of which the take–back clause in suppliers' agreement document *[PA2.1]* is in the high priority category. On the other hand, two attributes *[PA2.2 and PA2.3]* are in the medium and *[PA2.4 and PA2.5]* low priority. Contractors interested in adding this criterion to their waste management practices should consider the attributes and priorities. The framework highlights that the take–back scheme will significantly impact waste minimisation. It incorporates establishing and implementing a take–back scheme as part of supplier pre–qualification/selection criteria and making it the company policy *[PPA2.1a].* Also, to achieve the first objective, the framework advised contractors to develop a pre–qualification questionnaire to assess if suppliers are ready to comply with a take–back scheme for potential selection *[PPA2.1b].* This would mean that all suppliers should confirm their willingness to comply with a contractor's take–back scheme to be selected. This can allow contractors to select suppliers who are happy to partake in waste management responsibilities. Further, it means that a purchase manager should be on the lookout for eco–friendly motivated suppliers.

For contractors who desire to incorporate top management support for procurement *[PC3]* in their waste management practices, the framework indicates that alliance with suppliers *[PA3.1]* should be highly prioritised. Others *[PA3.2; PA3.3; PA3.4 and PA3.5]* are of medium priority. For effective alliance with suppliers, the framework advised contractors to investigate suppliers' readiness for a mutual relationship, collaboration and transparency *[PPA3.1a].* Also, it highlights establishing a working relationship with suppliers and identifying measures to improve the relationship *[PPA3.1b].* Contractors' alliance with suppliers will positively influence their understanding of contractors' waste management needs for good performance. In addition, it is believed that this strategy can help reduce suppliers' opportunistic behaviours (e.g. supplying low–quality instead of high–quality products requested).

Efficient delivery management can be incorporated into the waste management practices of contractors to help minimise waste due to inefficient materials delivery. The framework highlights that a Just–in–time delivery (JIT) plan with suppliers *[PA4.1]* should be highly prioritised while *[PA4.2; PA4.3; and PA4.4]* are medium priorities. The framework highlights actions for just–in–time delivery (JIT) plan. It advised contractors to schedule materials delivery with suppliers according to work plans for each day considering external and internal factors (e.g. traffic, weather conditions, workers readiness) through efficient communication and coordination [PPA4.1a]. This will positively influence inventory management. It also helps reduce the pressure for timely completion of projects, which is one factor of waste generation in Nigeria construction projects (Oladiran *et al.,* 2019).

Table 7. 1: A framework for the management of materials procurement waste for contractors

GOAL	CRITERIA	ATTRIBUTES	PRIORITY	ACTIONS	References
[PG]	*[PC]*	*[PA]*	**P**	*[PPA]*	
Effective materials procurement waste management	***[PC1] Low waste purchase management***	***[PA1.1]*** Accurate materials quantification	P1	***[PPA1.1a]*** Invest in the necessary training to improve estimators' understanding of project requirements, audit the accuracy of estimated materials and labour ***[PPA1.1b]*** Consider the use of building information modelling (BIM) for greater confidence in materials quantity take–off	Harris *et al.* (2021) Guerra *et al*. (2019)
		[PA1.2] Accurate material ordering	P1	***[PPA1.2a]*** Audit and update purchase order as necessary considering the stock number, quantity, date needed and other remarks ***[PPA1.2b]*** Develop a quantity check system when a shipment arrives. Receiving personnel to conduct the check against the packing slip to make sure that the quantities are correct (return any excess materials immediately)	Parry (1973); Patel and Vyas (2011)
		[PA1.3] Purchase of high–quality products	P2	***[PPA1.3a]*** Increase the use of high–quality construction materials to reduce chances of damage and the need for replacement ***[PPA1.3b]*** Check that materials meet quality specifications upon delivery	Nagapan *et al.* (2011)
		[PA1.4] Purchase of secondary materials	P2	***[PPA1.4a]*** Increase the use of secondary products to encourage recycling of construction materials (Identify vendors that sell secondary products)	Gálvez–Martos *et al.* (2018); Yu *et al*. (2021)
		[PA1.5] Material substitution	P2	***[PPA1.4a]*** Establish a system for examining the environmental friendliness of various types of materials considering cost–benefit and functional performance before substituting materials	Australian Government (2003); Garth et al. (2004) Diófási and Valkó (2014)
		[PA1.6] Purchase of maintainable materials	P2	***[PPA1.6a]*** Increase the use of maintainable materials to improve the functional performance of buildings and maintenance of defects without breakage or damage	Soni (2016)
	[PC2] Procurement clause	***[PA2.1]*** Take–back clause in suppliers' agreement document	P1	***[PPA2.1a]*** Establish and implement a take–back scheme as part of supplier pre–qualification/selection criteria (make it a company policy) ***[PPA2.1b]*** Develop a pre–qualification questionnaire to assess if suppliers are ready to comply with a take–back scheme for potential selection	Gottsche and Kelly (2018); WRAP (2009)
		[PA2.2] Supplies to provide quality	P2	***[PPA2.2a]*** Include this attribute in the suppliers' agreement document as part of pre–qualification criteria for supplier selection	WRAP (2009); Duarte *et al.* (2020)

		and durable materials			
		[PA2.3] Agreement with suppliers on waste management responsibilities	P2	***[PPA2.3a]*** Set up collaborative briefing practices with selected suppliers at the beginning of a project and sign–off waste management responsibilities	WRAP (2009)
		[PA2.4] Suppliers to provide materials in a flexible amount	P3	***[PPA2.4a]*** Include this attribute as part of pre–qualification criteria for supplier selection to assess the flexibility of suppliers considering their commercial and technical ability to cater for specific project needs	Dainty and Brooke (2004); Cheng and Mydin (2014)
		[PA2.5] Consistency in suppliers' agreement document	P3	***[PPA2.5a]*** Examine waste management best practices and prepare an agreement document free of errors and understandable ***[PPA2.5b]*** Amend procurement document to include specific waste management required to deliver a targeted outcome (e.g. reduction of material packaging)	Saez *et al.* (2013) WRAP (2009)
	[PC3] Top management support for procurement	***[PA3.1]*** Alliance with suppliers	P1	***[PPA3.1a]*** Investigate suppliers' readiness for a mutual relationship, collaboration and transparency ***[PPA3.1b]*** Establish a working relationship with suppliers and identify measures to improve the relationship	Lamming *et al.* (2001); Dainty and Brooke (2004)
		[PA3.2] Involve a competent purchase manager in procurement activities	P2	***[PPA3.2a]*** Set up an interactive working plan with purchase managers to coordinate procurement activities	Faniran and Caban (1998)
		[PA3.3] Provide stock control measures	P2	***[PPA3.3a]*** Establish a well–defined stock management procedure that is practicable (Record, monitor and review stock as required) ***[PPA3.3b]*** Establish a 'first–in, first–out (FIFO) system rather than last–in, first–out (LIFO) to ensure that materials do not deteriorate/expire before use	Sindhu *et al.* (2014) Soni *et al.* (2016); Ikediashi and Udo (2021)
		[PA3.4] Periodic training of procurement personnel on waste	P2	***[PPA3.4a]*** Set up formal (regular) training for purchase management team according to goals and requirements of materials procurement	Al–Hajj and Hamani (2011); Ogunsanya *et al.* (2019)

		management strategies			
		[PA3.5] Waste management guideline for procurement personnel	P2	***[PPA3.5a]*** Provide procurement guidelines for purchase managers (e.g. decision–making framework) and a system to monitor that they demonstrate propriety and good practice	Gounden (2016); Maqsood *et al.* (2021); ISO 20400
	[PC4] Efficient delivery management	***[PA4.1]*** Just–in–time delivery (JIT) plan	P1	***[PPA4.1a]*** Schedule materials delivery with suppliers according to work plans for each day considering external and internal factors (e.g. traffic, weather conditions, workers readiness) through efficient communication and coordination	Akintoye (1995); Pheng and Tan (1998)
		[PA4.2] Adequate site access for delivery vehicles	P2	***[PPA4.2a]*** Remove any obstacle on a site's entrance to make enough room for delivery vehicles ***[PPA4.2b]*** Keep pedestrians and vehicles apart (Site should be clearly signposted)	Health and Safety Executive (2006)
		[PA4.3] Security of materials to avoid damage	P2	***[PPA4.3a]*** Provide enough and secure space to store materials, cover and elevate above sea level if necessary ***[PPA4.3b]*** Do not store materials where they obstruct access routes or where they could interfere with emergency escape ***[PPA4.3c]*** Establish a tracking system to record damaged materials as they appear on site	Said and El–Rayes (2011) Health and Safety Executive (2006)
		[PA4.4] Careful material handling to avoid breakage	P2	***[PPA4.4a]*** Establish a manual handling training program for site employees ***[PPA4.4b]*** Where necessary, materials should be handled using mechanical means (A manual handling policy can guide this action)	Rabbani and Ahmed (2020) Ling and Nguyen (2013)

Note: ***PG****=procurement goal;* ***PC****=procurement criteria;* ***PA=*** *procurement attribute;* ***PPA=****procurement proposed actions; P=priority;* ***P1****=high priority;* ***P2****=medium priority;* ***P3****=low priority*

7.3.2. Framework for the Management of Construction Waste

Addressing waste problems in the construction stage requires contractors to collaborate with subcontractors to achieve good waste management performance. Therefore, Table 7.2 mainly focuses on contractor, employees and subcontractors' relationships and responsibilities in contributing to effective waste management in the construction industry. In addition, the table presents the four criteria that contractors can incorporate into their waste management practices for improvement. The twenty–two attributes are clustered across the criteria showing their priorities and actions for implementation. The following sections highlight some of the contents of the framework.

For contractors that intend to incorporate top management support for construction *[CC1]* criterion in their waste management practices, the framework shows senior managers' early commitment to waste minimisation *[CA1.1]* and effective communication among project participants *[CA1.2]* are of high priority. Others *[CA1.3 and CA1.4]* are a medium priority, while *[CA1.5 and CA1.6]* are low priority attributes. In order to ensure that senior managers support waste management objectives, the framework recognised investing and standardising leadership training/workshops to raise senior managers awareness of sustainable waste management [CPA1.1a]. Also, it suggests that contractors monitor that all senior managers demonstrate leadership in support of waste management objectives *[CPA1.1b].* In that case, senior managers commitment and accountability will positively impact junior staff members' waste behaviour.

The research shows that incorporating SWMP *[CC2]* into contractors' waste management practices will contribute to effective site waste management. Therefore, the framework highlights that identifying recyclable materials *[CA2.1]*, identifying reusable materials [CA2.2] and forecasting the emerging waste streams [CA2.3] are high priorities*.* At the same time, *[CA2.4] is medium* and *[CA2.5] is* low priority attributes. The framework highlights that a contractor must train employees on materials composition and waste categorisation to identify recyclable and reusable materials and document the date when the materials will be recycled and the site *[CPA2.1a]*. Thus, to distinguish the recyclables from nonrecyclables and hazardous waste such as materials that contain asbestos and treatment methods. The framework also advised contractors to commission workers who can detect the construction activities that admit reusable materials to increase reclaimed materials *[CPA2.2a].* These actions can help minimise wastes that have been generated in construction sites.

The research results show that low waste techniques *[CC3]* can address waste issues in construction. Therefore, contractors who intend to incorporate the criterion should consider the attributes and the priorities. The categorisation of the attributes shows that adopting prefabricated building components *[CA3.1]* is of medium priority. Five attributes *[CA3.2; CA3.3; CA3.4; CA3.5]* are within the low priority category, while none are high. First, the framework emphasised identifying and partnering with prefabrication companies [CPA3.1a] as a rational action that can help contractors increase the use of prefabricated elements in projects. Second, educating employees to install prefabricated elements in buildings is important for waste minimisation and faster construction.

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Contractual instruments are necessary for building confidence between different parties in the construction industry. Thus, incorporating construction clauses [CC4] into contractors' waste management practices is a gateway for effective waste management in projects. From the research results, making subcontractors responsible for their waste [CA4.1] is a high priority attribute. Others such as [CA4.2 and CA4.3] are a medium priority, while [CA4.4] is considered low priority. In order to ensure that subcontractors take responsibility for their waste, the framework emphasised that contractors establish a system of extended producer responsibility and make it a part of subcontractors' pre–qualification and selection criteria *[CPA4.1a]*. Therefore, contractors need to develop a pre–qualification questionnaire to evaluate subcontractors' readiness to comply with their waste management requirements *[CPA4.1b].* These actions will help contractors select subcontractors ready to share waste management responsibility to help lessen the financial burdens associated to waste management.

Table 7. 2: Framework for the management of construction waste for contractors

GOAL	CRITERIA	ATTRIBUTES	PRIORITY	ACTIONS	References
[CG]	***[CC]***	**[CA]**	**P**	***[CPA]***	
Effective construction waste management	***[CC1] Top management support for construction***	***[CA1.1]*** Senior managers early commitment to waste minimisation	P1	***[CPA1.1a]*** Invest and standardise leadership training/workshops to raise senior managers awareness of sustainable waste management ***[CPA1.1b]*** Monitor that all senior managers demonstrate leadership in support of waste management objectives	Nasidi *et al.* (2015)
		[CA1.2] Effective communication among project participants	P1	***[CPA1.2a]*** Investigate communication mechanism for coordination between clients, suppliers and subcontractors (e.g. intranets network) ***[CPA1.2b]*** Establish internal communication lines (e.g. WhatsApp group) and continue to improve communication amongst site operatives	Karunasena *et al.* (2009) Lestari *et al*. (2020)
		[CA1.3] Motivating employees to minimise waste	P2	***[CPA1.3a]*** Set up incentive schemes to encourage site employees to minimise waste (e.g. economic reward, individual or group recognition/award)	Tam and Tam (2008); Mahpour *et al.* (2018)
		[CA1.4] Periodic training of site employees on waste management strategies	P2	***[CPA1.4a]*** Set up theoretical and practical modules and make it compulsory for staff members to undertake as required. Improve training and make it periodic as necessary ***[CPA1.4b]*** Create opportunities for staff members to acquire vocational training on sustainable waste management, monitor and review that key outcome are achieved	Zerowastescotland (2017)
		[CA1.5] Active site supervision	P3	***[CPA1.5a]*** Improve site supervision by employing a supervisor(s) to oversee site activities, document and report waste management issues to the senior management after each day work	Adewuyi and Otali (2013)
		[CA1.6] Adequate waste reduction investment	P3	***[CPA1.6c]*** Increase waste management budget by committing resources to gain access to waste management information and gears (e.g. consultations, research, equipment, waste skip, recycling)	Wong and Yip (2004)
	[CC2] Site waste management plan	***[CA2.1]*** Identifying recyclable materials	P1	***[CPA2.1a]*** A tailored train for workers on materials composition and waste categorisation to enable them to identify recyclable materials (document the date when the materials will be recycled and the site – onsite or offsite recycling)	Lau *et al.* (2008)
		[CA2.2] Identifying reusable materials	P1	***[CPA2.2a]*** Commission workers to detect the construction activities that can admit reusable materials to increase the use of reclaimed materials	Hobbs and Hurley (2001); Addis (2012)
		[CA2.3] Forecasting the emerging waste streams	P1	***[CPA2.3a]*** Forecast potential waste that could be generated in projects before the start and prescribe the best course of actions (e.g. reuse, recycle and disposal) based on waste categories	Haokun and Shuangli (2011)

		[CA2.4] Segregating waste materials into categories	P2	***[CPA2.4a]*** Commission a worker to separate waste generated at the end of each day work ***[CPA2.4b]*** Provide adequate space for waste separation to avoid the mixture of waste, locate waste (recycle) containers in strategic positions ***[CPA2.4c]*** Develop site instructions on the handling of materials waste and monitor that employee comply with the instructions ***[CPA2.4d]*** Special training on hazardous substances awareness– employees to be mindful of construction waste containing hazardous substances (e.g. asbestos), stop work and report to a supervisor for the removal (wear personal protective equipment)	Zerowastescotland (2007)
		[CA2.5] Adequate space for materials movement onsite	P3	***[CPA2.5a]*** Adopt BIM for site planning to improve material flow, traffic, health and safety on site ***[CPA2.5b]*** Establish a system for tracking and recording vehicle movements inside and around construction sites to avoid and reduce accidents that can damage materials	Kasim *et al*. (2012) Lu *et al.* (2007)
	[CC3] Low waste technique	***[CA3.1]*** Adopting prefabricated building components	P2	***[CPA3.1a]*** Identify and partner with prefabrication companies ***[CPA3.1b]*** Educate employees on the installation of prefabricated elements in buildings for faster construction and waste minimisation	Ogunde *et al.* (2016); Adindu *et al.* (2020)
		[CA3.2] Use of reusable formwork and falsework	P3	***[CPA3.2a]*** Increase use of steel rather than timber for formwork and falsework design considering environmental and technical factors (e.g. temperature, type/strength of concrete) ***[CPA3.2b]*** Adequate review of falsework design, monitoring and following removal procedures	Pallett (2003)
		[CA3.3] Use of appropriate construction equipment	P3	***[CPA3.3a]*** Protect construction equipment from damage by storing them safely ***[CPA3.3b]*** Provide a system for checking defective equipment before the use and after each day work and report any damage or defect to a supervisor for repair or replacement	Gurmu and Aibinu (2017)
		[CA3.4] Maximise use of joint system instead of gluing	P3	***[CPA3.4a]*** Increase the use of mechanical fixtures to improve structural flexibility and maintainability of buildings (Advise clients on these benefits during tendering)	Zhu *et al.* (2018)
		[CA3.5] Use of de-constructable materials	P3	***[CPA3.5a]*** Prepare feasibility studies to advise the clients of economic and environmental benefits of design for deconstruction against demolition during tendering	Khorsandnia *et al.* (2016)
		[CA3.6] Adopting the right work sequence	P3	***[CPA3.6a]*** Provide a system for early detection of faulty operation through effective supervision and monitoring	Barbarosoglu, and Arditi (2019)
		[CA3.7] Use of steel scaffolds	P3	***[CPA3.7a]*** Increase use of steel for scaffolds rather than timber to increase reuse and safety of site employees	Berry *et al.* (2002)
		[CA4.1] Making subcontractors	P1	***[CPA4.1a]*** Establish a system of extended producer responsibility and make it a part of subcontractors' pre–qualification and selection criteria	European Commission (2014)

	[CC4] Construction clause	responsible for their waste		***[CPA4.1b]*** Develop a pre–qualification questionnaire for subcontractors to assess their readiness to comply with waste management requirements	WRAP (2009)
		[CA4.2] Waste target clause in subcontractors' agreement document	P2	***[CPA4.2a]*** Establish waste targets at a project level before projects start and assess subcontractors' waste management performance based on specific credits they achieved at the end of projects. ***[CPA4.2b]*** Adapt the BREEAM Resource Management Plan (RMP)/ Site Waste Management Plan (SWMP) waste target benchmark for resource efficiency (i.e. m^3 of waste per $100m^2$ or tonnes of waste per $100m^2$) based on a project requirement	BREEAM (2020)
		[CA4.3] An incentive clause for effective waste management practice	P2	***[CPA4.3a]*** Establish a system of reward mechanism for subcontractors who achieve good waste management performance (e.g. award recognition) and consider them for future partnership	Long *et al*. (2020)
		[CA4.4] Site waste management policy for site operatives	P3	***[CPA4a]*** Sets up a robust internal waste management policy agenda for the organisation that contain realistic and achievable targets (align with local, regional and national policies) ***[CPA4.4b]*** All site employees to be aware of site waste management policy (good waste management) through induction and placing signs and signals in strategic places onsite ***[CPA4.4c]*** Site employees to sign basic waste management awareness form before site operations	Dean (2017)

Note: C*G=construction goal; CC=construction criteria; CA=construction attribute; CPA=construction proposed actions; P=priority; P1=high priority; P2=medium priority; P3=low priority*

7.4. Validation of the Frameworks

This section is focused on the validity of the frameworks to ascertain their usability and ability to influence effective waste management in the Nigerian construction industry. A validated framework shows its acceptability and applicability in an organisation or fulfils an end–user need. First, the section discussed the concept of validation and highlighted its objective for the study. Finally, it discussed participants' important responses to the validation questions.

7.4.1. Concept of Validation

The aim of validating the frameworks developed in this study is to reveal their acceptability and usability in construction companies. A validated framework proves the reliability and validity of real–life applications, suggesting that the research findings are practical. Validation is a part of a research process, mainly conducted to determine the extent to which a management tool fulfils a particular need or requirement(s). Although there is no unified definition of validity because it is primarily based on a research concept and its methodologies (Winter, 2000), several authors have attempted to define the concept of validity in different ways. According to Golafshani (2003), validity is a concept used to determine the truthfulness of research results in a study context and the degree to which a measure accurately represents what it intends to measure.

Studies usually mention internal or external validity for research, model or framework. The meaning of validity varies at different stages of a research process (Cook and Campbell, 1979). For instance, internal validity regards the consistency and theoretical validity of a study. Thus, internal validity shows the testability and adaptability of a research construct and the consistency of the findings with previous studies. On the other hand, methodological validity is that a research procedure is explicitly explained and followed throughout the process. Further, besides theoretical application, it could be expected that research has a practical application, hence, the external validity.

Questions regarding internal and methodological validity have been addressed in this study. First, the research construct was retrieved from the literature and validated using a team of academic experts in the construction industry. Also, the internal validity of the research findings is established from the continual acknowledgement of the extant literature in the discussion sections (Chapter 6). Second, in terms of methodological validity, the research procedure is adequately explained in Chapter 5 and followed throughout the research, particularly in Chapter 6. Thus, the research methodology is validated using variable scales adapted from the VAHP, pilot survey, and the VAHP mathematical formula for the data analysis. Therefore, having fulfilled the internal and methodological validity, this chapter focuses on the external validity of the research findings.

The importance of external validation is to gain confidence that the findings or outcome of the research will be beneficial to the end–users. It suggests the extent to which findings hold or generalise over variations in persons, settings, treatments, and outcomes (Fellows and Liu, 2008). According to Brinberg and McGrath (1985), validating research findings can transform the outputs into usable knowledge. The boundary search, replication, and convergence analysis are the three traditions of showing the external validity of research outputs. The essence of boundary search validation is to identify the conditions under which the outcomes of a study will not hold (Brinberg and McGrath, 1985). This research did not consider the boundary search validity due to time constraints for completing a PhD.

Many studies rarely go beyond convergence and replication to establish the validity of their research outputs, considering time to establish why research outcomes will not hold using the boundary search (Brinberg and McGrath, 1985). The research, however, acknowledged the existence of some boundaries, such as the country where the primary data were collected. Also, external validation through replication is not considered in this study because the financial and time constraints associated with repeating scientific research (PhD) could make external validation through replication difficult. Consequently, external validation through replication is rarely used by researchers (Bashir, 2013). This study, therefore, relies on convergence analysis for the external validation of the research outputs.

Researchers use different strategies in convergence analysis to establish stakeholders' opinions on their research findings. The convergence method has been adopted in many construction project management PhD theses (Manu, 2012; Mahamadu, 2016; Ali, 2018); thus, showing its wide application in the field. Furthermore, this method can be used to get the opinion of potential end–users about the usefulness of a framework or model. According to Creswell (2009), convergence analysis is the use of participants' opinions to validate research outcomes. Therefore, the validation exercise in this study is to obtain feedback on the usefulness of the proposed frameworks for effective waste management in the materials procurement and construction for Nigerian contractors by asking practitioners the following questions:

1. Are the materials procurement and construction criteria adequate and relevant?
2. Are the attributes for waste minimisation in the construction industry adequate and relevant?
3. Are the attribute priorities useful in planning an implementation strategy for waste minimisation?
4. Can the actions proposed in the frameworks facilitate effective waste management in construction companies?
5. Are there barriers that can hinder the implementation of any part of the frameworks?
6. What could enhance the frameworks' usefulness?

7.5. Validation Results

Following the distribution of the frameworks to the participants, seven out of the nine participants contacted agreed to participate. According to Dworkin (2012), 5 to 50 participants are suitable for research employing interviews for data collection. The job roles and experience of the recruited participants shown in Table 7.3 indicate that they are skilled enough to validate the frameworks according to the minimum requirements (Section 5.15.1). During the interview sections, notes were taken on important statements made by the participants because most of them declined voice recording, citing the confidentiality of their companies or names. Therefore, no recording was made to ensure the right of the participants to privacy was protected. At the interviews opening sections, each participant was given a code of identification—validation respondent (VP) and a unique number from 1 to 7; if they decide to withdraw their statements any time after two weeks, they can call or email the researcher with their codes of identification.

Table 7. 3: Background of respondents in the validation exercise

Code of identification	Job role/position	Years of experience	Company size
VR1	Subcontractor	7	Small
VR2	Purchase manager	2	Medium
VR3	Contractor	12	Medium
VR4	Site supervisor	1	Large
VR5	Project manager	3	Large
VR6	Engineer (civil)	4	Small
VR7	Contractor	2	Medium

7.5.1. Adequacy and Relevance of the Frameworks' Criteria

Objective one is to inquire about the adequacy and relevance of the frameworks' criteria. All the participants were certain that the criteria presented in the frameworks are adequate and relevant for effective waste management in the construction sector. Five out of the seven participants sounded familiar with the criteria, particularly the SWMP, low waste purchase management, and top management support. Some important points made by the participants during the sections of the interviews are stated below:

For me, the criteria for the two frameworks look very good for waste management in the industry. I am particular about the top management support. I believe if top management put more effort into waste management during projects, we can save a lot of money used in buying extra materials—[VR7].

Yes, they are relevant and reasonably adequate, but I believe some of the criteria will have more impact on waste minimisation than others—[VR5].

These criteria are important for waste management improvement. However, a criterion like a site waste management plan may be difficult to implement in Nigeria without a policy and enforcement from the state or federal government—[VR3].

These comments highlight the relevance and adequacy of the criteria for materials procurement and construction waste management, respectively. Although the results indicate that some criteria will be more effective in practice, these comments do not invalidate the ineffectiveness of others. Perhaps, it shows the areas some participants would want to incorporate to improve waste management practices in their organisations. Also, the comment from [VR3] echoed the literature findings on the limitation of SWMP, which points out the cost of implementation. However, this limitation does not mean that the SWMP is not implementable in the Nigerian construction industry but may require some external interventions.

7.5.2. Adequacy and Relevance of the Attributes

In terms of attributes' adequacy and relevance for waste minimisation, four [VR1, VR3, VR6, VR2] out of the seven participants expressed confidence that they are relevant and comprehensive. They were happy to see some measures included in the frameworks to drive collaboration between contractors, subcontractors and suppliers. Three participants agreed on their relevance but expressed that contractor may have to put more effort to implement them in real–life in the Nigerian context. Some of the comments from the participants are stated below.

Making suppliers take back excess materials is good, but contractors must ensure that the materials are not damaged. I supposed no supplier in Nigeria would be happy to take back excess material following the economic situation of this country. However, as your framework *suggests, it must be under an agreement between a buyer and a seller. Otherwise, it will be difficult in practice, especially if there is any sign of damage to materials due to rough handling—[VR2].*

I am very particular about motivating workers. I believe many project managers and site supervisors are not aware of the power of motivation. Motivation may not necessarily mean giving site workers money. However, a simple kind gesture, such as encouraging their efforts while mentioning the need to use materials according to specifications, can go a long way—[VR4].

It is good to see a study that suggests subcontractors be responsible for their waste in Nigeria. In my last project, I insisted that all the sub–trades separate their waste before I could complete their payment. I noticed that some of them were not very happy—[*VR3].*

7.5.3. The Usefulness of Attributes' Priorities for Planning an Implementation Strategy for Waste Minimisation

All the participants talked extensively about making waste management a priority in the Nigerian construction industry. They suggest that prioritising waste management strategies can enable them to plan waste management operations in terms of resource and activity allocations. Some comments from the participants are stated thus:

Not prioritising waste management interventions has contributed to uncoordinated waste management in many of our construction sites. If you do not prioritise something, how can you implement it? I noticed waste separation appears in the medium priority in your framework. However, I am afraid I have to disagree with most of your participants who refused to see waste sorting as a high–priority strategy. The least you can do is sort your waste but I am not surprised because many people do not separate waste in Nigeria—[VR6].

It is good to know what sort of strategy will have a high impact on waste minimisation in our projects and make it a critical priority. I am particular about training. The implementation can be as simple as talking to site workers before the beginning of each day work. I mean, it can be weekly, depending on workers level of awareness and a contractor's decision—[VR5]

I am happy to see the 'take–back clause in the suppliers' agreement document' in the high priority category. Suppliers don't like taking back their materials once you buy them, and as soon as we start implementing such an agreement, the better. So, I must commend your participants for considering it as one of the most important waste minimisation strategies we need in Nigeria—[VR1].

7.5.4. Can the Actions Provided in the Frameworks Facilitate Effective Waste Management in Construction Companies?

All the participants believe that the actions included in the frameworks can facilitate waste minimisation. Some (three participants) mentioned they follow a number of the actions in their companies. However, others believe that some of the actions will require huge financial implications for implementation. Therefore, they are concerned that companies that fall within small or medium construction enterprises may not afford to implement some of the actions regarding their financial status—participants made the following statements.

In my opinion, I think the actions can facilitate waste management in construction companies. I usually phone my suppliers to make sure that they deliver what I order. It usually works as they usually double–check the number of materials before leaving the market—[*VR2]*

I think many of the actions are cheap to implement, but I don't think small companies like ours can afford to use BIM. I believe BIM can help those large companies who can afford it to minimise waste, particularly in the design. I use AutoCAD. This is what I can afford for now—[VR7].

What I have learnt from your frameworks today is the need to develop a pre–qualification questionnaire for both suppliers and subcontractors to agree on waste management modalities. This is a good approach. I will try these in my next project—[VR5].

7.5.5. Barriers to Implementing any Part of the Frameworks

While some (two participants) said they could not think of any barrier, others mentioned one or two barriers to implementing the frameworks. For instance, the two contractors [VR3 and VR7] mentioned a lack of client support for waste management and the cost implications of BIM implementation. Others mentioned the lack of incentives from contractors, site operatives' attitude to waste and limited awareness of the environmental implications of waste generation amongst the Nigerian construction workers. The participants made the following statements.

Many clients do not see waste management as a priority; they are more concerned about costs and the completion of projects during tendering. They believe that adding waste management requirements to the forefront may increase project costs. Implementing the frameworks or part of the frameworks would be problematic if a contractor has the same attitude or lacks the financial ability. Also, as I mentioned earlier, some companies may not afford BIM. This is a significant limitation—[VR7].

Waste management is usually limited at the project level; this attitude from the contractors can limit the implementation of the frameworks. Moreover, training on sustainable waste management is seldom conducted at the project or industry levels. So, I am not surprised at the poor attitude of employees to materials management in Nigeria—[*VR4].*

Inadequate technology and the current economic situation in the country can limit the implementation. For example, many contractors may not be ready to give any incentive for waste minimisation because of increased project costs. Training of staff members may cost them money too.

Without a policy, implementing the site waste management plan maybe be difficult in Nigeria. So, there is a need for a policy, but whether the policy should be in the form of an incentive or strict guideline or enforcement and at what stage is a topic for another day —[VR7].

Comment from [VR7] indicates that implementing a SWMP may require strict guidelines or incentives in the absence of the industry's voluntary effort. In that case, the government has the responsibility to decide the enforcement modality. Conceivably, an attempt to combine incentives and guidelines may yield a better result, given the dynamic nature of the construction industry.

7.5.6. Recommendations that can Enhance the Frameworks' Usefulness

The majority of the participants observed that the frameworks covered the important aspects of waste management in the materials procurement and construction stages. However, two participants questioned the absence of the design stage in the framework or government role for waste management improvement in construction. However, all the participants were generally positive about the frameworks. Some of the important recommendations are stated below:

I cannot think of any recommendation as the contents of the frameworks appear comprehensive to me. I think adding the design stage in the study would be important—[VP6]

I think the frameworks need to include how government interventions can help improve waste management in construction companies. This area requires attention—[VP3].

While the participants were very positive about the contents of the frameworks, their recommendations clearly show some of the study's limitations in scope that have already been discussed in the introduction (Section 1.7). Therefore, these recommendations have been flagged as parts of the study limitations or areas for future studies.

7.6. Chapter Summary

The proposed frameworks for managing materials procurement and construction waste have been presented in this chapter. The frameworks provide robust criteria that contractors can integrate into their waste management practices to reduce construction waste and minimise the impacts on the environment from different dimensions. Also, the results of the frameworks' validation are discussed, which support the generalisability of the findings from this study. Thus, the validated frameworks established their relevance in practice. The next chapter presents the conclusion and recommendations draw from the research.

CHAPTER 8: CONCLUSION AND RECOMMENDATIONS

8.1. Introduction

This chapter presents the research conclusion in relation to the objectives. Next, the chapter presents the research contribution to the body of knowledge and implications for practice. Finally, it acknowledged the current study limitations and highlighted recommendations for future study.

8.2. Review of the Research Objectives

Chapter one of this research concluded that despite the problems of waste generation in the Nigerian construction industry, there is low awareness of the requisite criteria for waste management amongst the Nigerian contractors, on which successful waste management can be assessed. Also, there are limited frameworks for managing waste in materials procurement and construction activities. Therefore, this research developed frameworks for the management of materials procurement and construction waste for Nigerian construction contractors. A total of six objectives were proposed to achieve this aim, presented in Section 1.5.1. The six objectives were achieved through the application of different methods (Figure 1.1). The following paragraphs demonstrates how the research objectives were achieved and the questions answered. Therefore, key findings for the objectives are summarised in this concluding chapter.

Objective 1: *To review the extent literature and understand the current state of art in the waste management in the construction industry*

This objective was achieved through the literature reviewed in Chapter two. The literature review revealed that the construction industry is critical for nations' economic and social development but creates waste with significant impacts on the environment, economy, and society. Consequently, studies have continued to promote the need for effective and sustainable waste management in the industry. Hence, they have created the understanding that waste management can be incorporated into the whole life cycle of construction projects, following the evidence that waste can be generated in project's activities from the design to the end-of life. This evidence shows that besides the fundamental project objectives in the industry, such as cost, time and quality, waste management has become part of the industry sustainability agenda.

The concept of construction waste has been developed. Different concepts or definitions of waste enable researchers to consider construction waste from a different point of view. The literature review identified material loss and non–value–adding work as types of construction waste. These have been classified as direct waste and indirect waste, respectively. Direct waste is a complete loss of materials, while indirect waste refers to non–value–adding work (monetary and time loss) derived from the lean concept. The current study was proposed to aid the Nigerian construction (building) contractors minimise materials waste due to the negative environmental impacts.

Further, several research efforts have been made to identify the causes of construction waste' in many countries. Findings revealed the key waste factors in the Nigerian construction industry in the design, materials procurement and construction stages, respectively. These are late design changes, purchase of substandard materials and inadequate supervision. While the causes of construction waste could be natural or human–induced, findings from the literature confirmed that waste origins in the construction industry are mostly due to human errors than a natural cause. Also, construction waste is composed of different materials (Section 2.4.1). Awareness of materials compositions will allow practitioners to determine the treatment methods such as reuse, recycling, incineration or disposal. Findings also confirmed that construction waste might contain asbestos, coal tar, and tarred products, and these materials should be handled and disposed of with care as they are hazardous to health.

The review showed that several research efforts had been made to improve waste management practices in the construction industry. The concept of waste management hierarchy (prevent, reduce, reuse and recycle) model is widely cited by scholars as a fundamental waste management strategy in the construction industry (Section 2.5). However, the literature review suggests that the model is not appropriately applied in many developing countries; Nigeria is not an exception because disposal is still commonplace. There is evidence that practitioners' attitudes, inadequate technology, unavailability of recycled products, and lack of awareness impede the application of the model in developing countries. Therefore, many studies have recommended measures like waste segregation, training, SWMP, prefabrication, waste exchange, frameworks and models (e.g. policy/regulations, public awareness, decision support) to enable appropriate implementation of the model in the construction industry. In addition, the review showed that construction practitioners can improve waste management practices through effective communication, collaboration, use of information technologies, polluter-pay-principle, capacity building, amongst other measures (Section 2.7). Although studies have provided several waste management strategies, few scholars have attempted to integrate their findings in the form of a framework. This would mean that waste management strategies should not exist in isolation and must be integrated in a framework to be effective.

Objective 2: *To identify criteria and attributes factors that influence waste management in materials procurement and construction activities*

This objective was achieved by the review of the literature in Chapter three. The literature identified different concepts through which construction waste management can be implemented (Figure 3.2). The literature shows that construction waste can be managed from different perspectives such as legislation, technology, whole life consideration and decision–making. The literature demonstrated that construction waste can be managed for social, environmental and economic sustainability through these dimensions. This study identified four elements of social–technical criteria for managing waste in materials procurement and construction activities. The materials procurement stage includes top management support, procurement clauses, low waste purchase management and efficient delivery management. The construction stage also includes top management support, construction clauses, SWMP, and low waste techniques. Although these criteria can be found scattered in different studies, they have been integrated into the current study and should be incorporated into contractors' waste management practices. Twenty attributes were identified and clustered under the materials procurement criteria, while twenty–two were identified and clustered under construction criteria. Following experts' validation of the criteria and the attributes, a conceptual framework was developed (Table 3.3) to guide the research development. The conceptual framework reinforced the evidence that construction waste management is multifaceted, requiring different approaches and collaborative efforts from contractors, subcontractors and materials suppliers to be effective. From the literature review, the first research question was achieved.

Objective 3: *To undertake a comprehensive review of literature on waste management decision–making models and understand the concept of MCDM for the development of the proposed frameworks*

This objective was achieved through the literature reviewed in Chapter four. The literature showed that three main decision–making models had been applied extensively to solve waste management problems. These are cost–benefit analysis (CBA), life cycle analysis (LCA) and multicriteria decision making (MCDM). As a limitation, findings showed that cost–benefit analysis considers waste management primarily from the economic perspective and life cycle analysis from the environmental perspective. While MCDM has mostly been applied to explore social perspectives, it can also be used to examine any objective from multiple stakeholders' viewpoint. In addition, there is evidence that these models can be integrated to enhance waste management in construction. Following the review of waste management models, MCDM was selected based on the aim of the study to allow multiple stakeholders to contribute to waste management solutions. Since human errors mostly cause waste generation, relevant stakeholders should be involved in waste management decision–making.

Therefore, a literature review was undertaken to explore the various MCDM techniques to find a suitable method for data analysis. It was found that the MCDM systems have a different computational method but the same fundamental application in framework development. Hence, goal definition, selecting criteria and attributes and making a decision based on the best options or prioritising the attributes to provide actions for implementation. Also, MCDM models have their unique strengths and limitations. The VAHP was identified as a suitable method due to its simplicity in application, and the known limitations had been addressed. Despite the importance, the review confirmed the absence of MCDM in Nigeria's construction waste management literature; hence, the application in the current study.

Objective 4: *To gauge stakeholder opinions on materials procurement and construction waste management in Nigeria.*

This objective was achieved through a questionnaire survey of seven groups of construction practitioners in Nigeria who belongs to professional bodies to gauge their opinions on the relative importance of materials procurement and construction waste management criteria and the related attribute factors. The seven groups of practitioners include project managers, procurement managers, quantity surveyors, civil engineers, structural engineers, mechanical engineers, and site supervisors, which account for 211 responses used for the data analysis. The stakeholders' demography is summarised in Table 6. 4.

Objective 5: *To conduct a computational analysis of stakeholder survey responses to establish waste management criteria and related attribute priority weights.*

The VAHP method was used to compute stakeholders' opinions to establish the relative importance of each criterion and the related attributes. Therefore, all attributes' local and global weight were established, thus, answered the second research question. This objective was achieved in Chapter 6.

Objective 6: *To develop and validate frameworks for the management of materials procurement and construction waste for Nigerian contractors*

The proposed frameworks are presented in Chapter seven, developed from the research results in Chapter 6, information from the literature review and discussion sections. The frameworks' development process was based on the concept of the MCDM model. Therefore, the contents of the proposed frameworks include goals, criteria, attributes, and action(s) for implementation. Also, the attributes were clustered under related criteria according to local weights results in descending order. Also, the results of their global weights were used to determine the priority positions of attributes, categorised as (High, Medium or Low), showing their relative contribution to waste minimisation in the construction industry. Therefore, the proposed frameworks can allow contractors to select criteria based on their specific waste management need and act to implement attributes considering their priorities. This objective answered the third research question by providing several ways which contractors can implement the waste management attributes identified in this study.

Further, seven construction actors, including two building contractors based in Nigerian, were engaged to validate the frameworks through convergence analysis. The overall feedback from participants confirmed the usability of the frameworks. Therefore, the validated frameworks showed that the contents aligned with several standards, tools and methods for waste management in the construction industry. Further, recommendations for improvement were also suggested by the practitioners, which have been flagged as potential areas of future research.

8.3. Summary of the Study

This research reflected on the problems of waste generation in the Nigerian construction industry. Previous research has shown poor waste management practices in the industry, and many strategies have not been identified or implemented. Also, there is a lack of stakeholders' participation in waste management decision–making. Therefore, the research aims to help Nigerian contractors manage waste effectively in materials procurement and construction activities.

Therefore, the research identified eight criteria relevant for waste management in materials procurement and construction stages through the literature review. Also, twenty attributes were identified under the procurement criteria and twenty–two under the construction criteria. Then, a group of experts validated the criteria and attributes in a survey. The validation exercise established the criteria and attributes' relevance for managing waste in the two construction stages. Following the validation exercise and pilot testing, a structured questionnaire was designed to solicit participants opinions through voting to determine the relative importance of the criteria and related attributes. Two hundred and eleven construction actors participated in the voting exercise. Afterwards, the VAHP mathematical model was used to determine the weights of the criteria and related attributes. The results showed the criteria' ranks and the attributes' local ranks. Also, it shows the global ranks of the attributes in materials procurement and construction categories (Table 6.12 and 6.18), respectively.

Further, the research adopted a decision–making model to develop management frameworks that include several actionable techniques to help contractors minimise waste in materials procurement and construction activities. The accompanying conclusions from the above process are as follows:

- Results of the criteria in the materials procurement category shows that low waste purchase management will have the highest impact on effective waste management, followed by procurement clause and top management support for procurement, while efficient delivery management will have the least impact.

- In the construction stage, the results indicated that top management support in construction would significantly reduce waste in the industry. This is followed by a SWMP and low waste technique. Further, construction clause criterion will contribute less to effective waste management.

- Accurate materials quantification, take–back clause in suppliers' agreement document, alliance with suppliers and just–in–time delivery of materials are most important attributes in the materials procurement category. A contractor's and supplier's willingness to collaborate and implement these measures will ensure smooth procurement activities that will directly improve the quality of waste management in the industry. The top-ranked attributes of materials procurement for waste management suggest proactive behaviours by contractors could improve the time and cost-efficiency of projects. This is because they oversee the materials quantity appraisal and cooperation before projects begin. However, it is supposed that suppliers are unwilling to cooperate with contractors. In that case, contractors may suffer project delays which can impact the overall project duration and monetary loss due to suppliers' refusal to accept the unused or excess materials in their stores.

- Senior managers' early commitment to waste minimisation, identifying recyclable materials, adopting prefabricated building components and making subcontractors responsible for their waste are the most important attributes within the construction criteria category. This would mean that effective leadership, communication, sharing of waste management responsibility, recycling and reusing waste materials will drive effective waste management in the industry. The key findings suggest proactive, active and reactive measures to be adopted to manage waste before and after they are generated. While this measure can help reduce waste output in projects, investing in necessary training and supervision to ensure senior management are committed to waste minimisation and employing staff specifically to identify recyclable waste materials can increase labour costs. This supports the idea that contractors should invest in waste management objectives for environmental protection, even though it may result in financial costs. Also, based on extended producer responsibility, it may require a considerable time to sway subcontractors to be responsible for the waste they generate, since the idea is still growing, and due to conceivable deficiencies of collaboration in the industry.

All the attributes have varying degrees of potential to influence waste minimisation in the construction industry based on the practitioners' collective votes, categorised as high, medium or low priority attributes. Irrespective of the different priorities of the attributes, a contractor must act to implement them. This is reflected in the proposed frameworks that embody new insights into materials procurement and construction waste management practices. Several factors influence waste management in construction. Therefore, applying decision–making techniques like the VAHP would be beneficial for prioritising waste management measures that reflect the decision of a majority of construction actors. The findings of this study imply that contractors, suppliers and subcontractors are required to commit effort to implement effective waste management. Also, contractors can commit efforts and resources to implement waste management strategies by knowing and understanding their priorities. Therefore, the study's novelty lies in two parts: First, it is inspired by waste prevention/reduction initiatives and the need to achieve effective and sustainable waste management in the Nigerian construction industry through a unique method. Second, the frameworks produced for the contractors provide and potential pathways to achieve the initiatives considering the research boundaries. The proposed materials procurement and construction stage frameworks can reduce overall construction costs through effective proactive, active and reactive materials management. Adapting the frameworks may increase project duration, cost of labour due to the time to plan and execute efficient and collaborative procurement and construction, which can result in significant waste reduction in projects and contribute towards environmental sustainability. These conclusions answer the research questions that resulted in the following contributions to the body of knowledge.

8.4. Contributions to the Body of Knowledge

This study will make the following contribution to the body of knowledge:

- ***Theoretical Contributions***

- The current study provided insights into the requisite criteria for effective waste management in materials procurement and construction activities. The criteria can be adopted to enhance waste management in the Nigerian construction industry. Other studies can adopt the criteria in future studies.

- The study identified the attributes' weights necessary for planning waste management implementation. Thus, by knowing where attention should be focused to prioritise effort for time and resource savings.

- While knowing waste management priorities is one step towards waste minimisation in construction, this study also included actionable means through which contractors can implement the attributes upon integrating the different criteria into their waste management practices.

- This study has integrated the materials procurement and construction criteria in developing management frameworks rather than focusing on a single construction stage, as seen in many studies.

- ***Practical contribution***

- The key issues emerging from the study provide important aspects that can be incorporated into standard documents to help contractors reduce waste costs and environmental impacts by clearly defining their requirements to both suppliers and subcontractors at the earliest possible stage. This will help bridge the gap between contractors/subcontractors and suppliers on how best to manage waste to avoid confusion or dispute. Therefore, the frameworks can enable contractors who intend to procure projects via the traditional route to collaborate with subcontractors and suppliers to achieve a desirable waste reduction in every project. It will help improve the relationship between contractors and other stakeholders in the industry to achieve waste management goals. In addition, it will help contractors manage their employees by providing tailored training to improve waste management capacity. Thus, the study will contribute to effective construction waste management, particularly in developing countries, such as SSA, where a need for the current study is obvious.

- ***Methodological contributions***

- The methodological contribution of the research is that the study provides a successful example of applying the VAHP method to promote decision–making in the construction waste management discipline. It, therefore, provided insights into a new method to study construction waste management in Nigeria, where the use of such a method is difficult to find.

- The proposed frameworks were validated using subjective views of practitioners, thereby allowing practitioners to express their subjective opinion about the usefulness of the frameworks.

8.5. Research Limitations

There are potential limitations in every research; therefore, the limitations of this study are itemised as:

- While it is possible to generate waste in all project activities, this study is limited to materials procurement and construction activities. Therefore, the findings may be peculiar to contractors who have less or no influence in the design or demolition activities.

- The priorities of the attributes were set based on practitioners' views in response to a structured closed–ended questionnaire. Therefore, responses were restricted due to the requirement to quantify priorities.

- The priority of waste management attributes presented in the frameworks is based on Nigerian construction practitioners' opinions, which may differ in other countries. Therefore, the proposed frameworks may only be useful for Nigerian construction contractors. However, the method towards developing the frameworks can be applied more broadly.

- The proposed materials procurement meets the needs of the construction contractors that intend to procure materials locally. Therefore, contractors who intend to procure materials outside of Nigeria can defined their requirements by adapting the framework and considering the country's procurement requirements between contractors and subcontractors/suppliers to make an informed decision.

The findings of this study inform policy development within the Nigerian states to support the adoption of the waste management criteria and the implementation of the attributes provided in this study. There is a need for a broader and comprehensive discussion on the issues of effective and sustainable waste management in the industry to develop a pathway towards proactive solutions. Policy development should include extended manufacturer and producer responsibility, shared responsibility, internal stakeholders' accountability, plus incentives and penalties. Therefore, this research has provided recommendations that different stakeholders can implement to advance efforts for effective waste management in the Nigerian construction industry.

8.6. Recommendations for Stakeholders and Future Research

8.6.1. Recommendations for Contractors

- Develop and consistently improve partnerships with subcontractors and suppliers at the company level to achieve waste management goals at the project level.
- Make policies that will support the implementation of the frameworks using examples from international best practices.
- Set up a waste management vision and mission, targets at the company and project levels.
- Involve all relevant stakeholders in waste management meetings and briefings to improve their attitudes towards effective waste management.
- Identify and document any drawbacks in implementing the techniques provided in the frameworks (Review lessons learnt from each project while using the techniques).
- Waste management should be regarded as a priority environmental issue for every project.
- Evaluate, monitor and review the priorities of the attributes due to circumstantial changes that may occur in the future.
- Support the transition of waste management to the CE in the entire construction industry.

8.6.2. Recommendations for Subcontractors

- Subcontractors should comply with contractors' requirements for waste reduction. For instance, subcontractors should forecast the likely waste streams and identify options for reduction if requested by a contractor.
- Subcontractors should show evidence of good waste management practices during tendering, particularly where they are responsible for waste management.
- Subcontractors should support the development and implementation of the SWMP.

8.6.3. Recommendations for Suppliers

- Suppliers should be committed and consider themselves as part of the waste management team throughout project implementation.
- Suppliers should reduce the quantity of excess packaging.
- Suppliers should agree with contractors' take–back scheme.

8.6.4. Recommendations for Policymakers

Although this study focused mainly on the construction industry's internal functions, some recommendations are worth mentioning to indicate where external policymakers can support waste management in the construction industry.

- The government should deem it important to enact a policy, specifically to address the issue of construction waste in Nigeria.
- Establishing recycling centres for construction waste across the Nigerian states is important.
- Develop a market structure for recycled materials and subsidise recycled products.
- Develop a landfill disposal tax scheme that encourages waste segregation by considering a reduced fee for sorted waste compared to mixed waste.
- Develop an incentive scheme for contractors that demonstrate good waste management practices.
- There is a need to integrate waste management objectives into the pre–qualification and assessment of contractors.

8.6.5. Recommendations for Future Research

This study investigated the criteria for waste management in the materials procurement and construction stages. Further, the study prioritised the attributes and proposed actions to aid constructors in Nigeria to minimise the industry's waste outputs. However, the study did not cover some areas, which may require further investigation. For instance, this study focused on the materials procurement and construction stages. Future studies could particularly identify the criteria for the management of construction waste in the design stage to encourage clients and the team to design–out waste before inviting contractors for tendering. This could be achieved using a similar method applied in this study to ensure that all preconstruction stages are considered before site operations. Also, similar studies could be conducted to investigate criteria for waste management in civil engineering projects, such as roads and bridges, to cover other areas of the construction industry using a method such as the system dynamic modelling to investigate the dynamic interplay between waste management variables for better decision making. This could further enhance the effectiveness of waste management across the entire construction industry.

The criteria presented in this study were investigated through objective means. Future studies could adopt subjective methods, such as interviews, to explore other potential criteria not found in current literature. Thus, through the opinions and experiences of the industry practitioners, a more robust waste management approach can be achieved in the construction industry. In addition, this study has particularly investigated the internal criteria that require the efforts of contractors, subcontractors and suppliers to contribute to waste reduction in the construction industry. However, the study was unable to investigate external criteria requiring government or public efforts and actions to encourage effective construction waste management. Therefore, construction waste management policies and their effectiveness in Nigeria should be investigated using empirical data from relevant government ministries and agencies to enable the government and the public to realise where waste management efforts are most needed. The proposed frameworks were validated using face validity through interviews. Further research should validate the frameworks through a case study of real projects to further establish their applicability and usefulness.

8.7. Chapter Summary

This chapter presented the conclusions of the study. It discussed the steps taken to achieve the study's objectives, the theoretical, practical and methodological contributions to the body of knowledge. The chapter highlights the implications of the research results for achieving successful waste management in materials procurement and construction activities. Further, the study's limitations, recommendations and directions for future research were highlighted. In all, considering the waste management challenges currently confronting the Nigerian construction industry, management frameworks have been proposed as the overall outcome of this study. The study's outcome can direct actions to enable contractors to effectively manage waste in the Nigerian construction industry in collaboration with subcontractors and materials suppliers. Also, contractors can allocate resources considering waste management priorities within their companies.

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Appendices

Appendix A: Ethics Application form

Section 2: Project	
Section 2:1 Project details	
Full Project Title	
Development of frameworks for the management of materials procurement and construction waste for Nigerian contractors	
Project Dates These are the dates for the overall project, which may be different to the dates of the field work and/or empirical work involving human participants.	
Project Start Date	01/08/2018
Project End Date	01/01/2022
Dates for work requiring ethical approval You must allow **at least 6 weeks** for an initial decision, plus additional time for any changes to be made.	
Start date for work requiring ethical approval	10/10/2019
End date for work requiring ethical approval	01/12/2020
How is the project funded? (e.g. externally, internally, self-funded, not funded – including scholarly activity) Please provide details.	
Externally	

Section 1: Applicant Details	
First Name	CHIBUIKE CELESTUS
Last Name	CHIDIOBI
Faculty	FET
Department	ARCHITECTURE AND THE BUILT ENVIRONMENT
Co-researcher Names (internal and external) Please include names, institutions and roles. If there are no co-researchers, please state N/A.	N/A
Is this application for a staff or a student?	Student
Student Course details	Postgraduate Research
Name of Director of Studies / Supervisor	DR COLIN BOOTH
Comments from Director of Studies / Supervisor *For student applications, supervisors should ensure that all of the following are satisfied before the study begins:* • *The topic merits further research;* • *The student has the skills to carry out the research;* • *The participant information sheet is appropriate; and procedures for recruitment of research participants and obtained informed consent are appropriate.* *The supervisor must add comments here. Failure to do so will result in the application being returned*	
Click or tap here to enter text.	

Please describe the research methodology for the project. (maximum 250 words)
Phase one (Validation of the literature review) Phase one is designed to verify and validate the findings from the literature review by the industry's academic experts. The experts would be required to answer 'YES' or 'NO' on whether the lists waste management strategies identified from the literature are comprehensive, and where the answer is 'NO', there is a provision where the experts can add any additional factor. See attached lists (Lists of factors for validation - phase 1). The lists would be distributed to the experts' email addresses in Microsoft word format. **Phase two - Quantitative (Online questionnaire survey)** The survey administration is via online distribution technique with the aid of Qualtrics online survey to participants with adequate experience in the area of construction and build environment in Nigeria. The participants will be asked to rank the identified waste management strategies based on relative importance in a Likert scale in the context. Privacy notice, consent form and participant information are included at the beginning of the survey. Data would be analysed by descriptive statistics. **Phase three – Qualitative (Framework Validation)** The third phase would involve semi-structured telephone interviews with selected construction practitioners to discuss the contents of the proposed framework for real life application. Thus, to seek for recommendations that could be used to improve the overall study. The contents to be discussed includes the goal, clarity, waste management criteria, attributes and the implementation strategies included in the framework. The qualitative data would be recorded, transcribed, and analysed using textual interpretation. The aim of the study and privacy notice would be read to the participants and agreed to before the commencement of the interviews.

Section 3: Human Participants	
Does the project involve human participants or their data? *If not, please proceed to Section 5: Data Collection, Storage and Disposal, you do not need to complete sections 3-4.*	Yes
Section 3.1: Participant Selection	
Who are your participants?	
Individuals with minimum of one-year experience in the area of construction and build environment in Nigeria with a minimum of Ordinary National Diploma academic qualification. Project managers;	

Section 4: Human Tissue	
Does the project involve human tissue?	No
If you answer 'No' to the above question, please go to Section 5 Please describe the research methodology that you will use. This should include an explanation of why human tissue is required for the project and a description of the information that you and the research team will have access to about the participants/donors.	
Click or tap here to enter text.	
Please describe how you propose to obtain/collect, process, securely store and dispose of the human tissue.	
Click or tap here to enter text.	
Please explain if and how samples will be anonymised. Where samples are not anonymised, please explain how confidentiality will be maintained, including how this information will be securely and appropriately stored and disposed of.	
Click or tap here to enter text.	

Section 5: Data Collection, Storage and Disposal
Research undertaken at UWE by staff and students must be GDPR compliant. For further guidance see Research and GDPR compliance ☒Please confirm that you have included the UWE Privacy Notice with the Participant Information Sheet and Consent Form ☒ By ticking this box, I confirm that I have read the Data Protection Research Standard, understand my responsibilities as a researcher and that my project has been designed in accordance with the Standard.

Section 5.1 Data Collection and Analysis
Which of these data collection methods will you be using? Please select all that apply.
☒ Interviews ☒ Questionnaires/surveys ☐ Focus groups ☐ Observation ☐ Secondary sources ☐ Clinical measurement ☐ Digital media ☐ Sample collection ☐ Other If Other, please specify: Click or tap here to enter text. Please note that online surveys must only be administered via Qualtrics Please ensure that you include a copy of the questionnaire/survey with your application.
What type of data will you be collecting?
☒ Quantitative data ☒ Qualitative data

Section 5.2 Data Storage, Access and Security
Where will you store the data? Please select all that apply.
☒ H:\ drive on UWE network ☐ Restricted folder on S:\ drive ☐ Restricted folder on UWE OneDrive ☐ Other (including secure physical storage) If Other, please specify: Click or tap here to enter text.
Please explain who will have access to the data.
Only the researcher and the supervisors will have access to the research data.

Please describe how you will maintain the security of the data and, where applicable, how you will transfer data between co-researchers.
All data will be well secured. The soft copy would be stored in the researcher's OneDrive online cloud provided by UWE, secured with a personal password. The UWE Email will be used for communication to ensure confidentiality and formality for any data transfer. The research is externally funded; the funder has no specific requirement for the research data. The hard copy of the dissertation will be made available for the funder after completion. The funder can also assess the dissertation online after the publication.
Section 5.3 Data Disposal
Please explain when and how you will destroy personal data.
The research data would be destroyed at the end of the research. Phase 1 and 2 data would be deleted from the student's OneDrive online cloud. Phase 3 data - voice recording on recording devices would be deleted from OneDrive after transcription.

Section 6: Other Ethical Issues	
What risks, if any, do the participants (or donors, if your project involves human tissue) face in taking part in the project and how will you address these risks?	
The research will involve professional adults in their professional capacity and correspondence will be through email and telephonic interviews. Hence, there are no anticipated risks/danger to the participants or researcher while carrying out the research as there would be no physical contact. The researcher will inform the director of study if any issue arises in the research process for necessary action.	
Are there any potential risks to researchers and any other people as a consequence of undertaking this project that are greater than those encountered in normal day-to-day life? For further information, see guidance on safety of social researchers.	
Click or tap here to enter text.	
How will the results of the project be reported and disseminated? Please select all that apply.	
☒ Peer reviewed journal ☒ Conference presentation ☐ Internal report ☒ Dissertation/thesis ☐ Written feedback to participants ☐ Presentation to participants ☒ Report to funders ☐ Digital media ☐ Other If Other, please specify: Click or tap here to enter text.	
Does the project involve research that may be considered to be security sensitive?	No

Appendix B: Ethics Approval Letter

Appendix B: Ethics Approval Letter

Faculty of Environment & Technology

Frenchay Campus
Coldharbour Lane
Bristol
BS16 1QY
Tel: 0117 328 1170

UWE REC REF No: FET.19.10.012
12th February 2020
Chibuike Chidiobi
Chibuike2.Chidiobi@live.uwe.ac.uk
Dear Chibuike

Development of frameworks for the management of materials procurement and construction waste for Nigerian contractors

Thank you for resubmitting your ethics application, this was considered by the Committee and based on the information provided was given ethical approval to proceed.
Please see below the following recommendations. There is no need to resubmit or seek further approval, and these issues can be sorted out with the supervisory team.

The following standards conditions also apply to all research given ethical approval by a UWE Research Ethics Committee:
1. You must notify the relevant UWE Research Ethics Committee in advance if you wish to make significant amendments to the original application: these include any changes to the study protocol which have an ethical dimension. Please note that any changes approved by an external research ethics committee must also be communicated to the relevant UWE committee. Amendments should be requested using the form at http://www1.uwe.ac.uk/research/researchethics/applyingforapproval.aspx
2. You must notify the Research Ethics Sub-Committee if you terminate your research before completion;
3. You must notify the Research Ethics Sub-Committee if there are any serious events or developments in the research that have an ethical dimension.

The Faculty and Research Ethics Sub-Committees (FRECs and RESC) are here to advise researchers on the ethical conduct of research projects and to approve projects that meet UWE's ethical standards. Please note that we are unable to give advice in relation to legal issues, including health and safety, privacy or data protection (including GDPR) compliance Whilst we will use our best endeavours to identify and notify you of any obvious legal issues that arise in an application, the lead researcher remains responsible for ensuring that the project complies with UWE's policies, and with relevant legislation https://intranet.uwe.ac.uk/whats-

Appendix C: Literature Validation

Development of frameworks for the management of materials procurement and construction waste for Nigerian contractors

<u>RESEARCH SAMPLE INVITATION LETTER (Distributed by email)</u>

Faculty of Environment and Technology
University of the West of England
Bristol
BS16 1QY
United Kingdom
Date …/.../ 2019

This research forms part of a PhD study that aims to evaluate the factors of waste minimisation for construction projects in Nig eria. The research findings would aid the development of a best practice implementation framework that would translate the identified success factors into practice. Therefore, the research is anticipated to help to improve the competency of construction fi rms in their application of various waste management strategies in projects. It will assist the reduction of waste deposits in the Nigerian environment to agenda sustainable development, as well as a reduction in projects costs.

You are invited to participate and to indicate your expert knowledge to this survey, which forms part of the data collection for this research. If you indicate your willingness to participate, you are required to indicate 'YES' or 'NO' as to whether the lists of success factors pr ovided in the questionnaire - **page (4-5)** of this paper are complete and comprehensive. Should you indicate 'NO', there is a provision where you can add any additional factor. This process will take only a few minutes to complete. Your participation is entirely voluntary, and you can withdraw at any time.

Thank you for reading this invitation letter; your contribution to this request is greatly valued.

Yours sincerely

…C. chidiobi…………….

Chibuike C Chidiobi

Email: chibuike2.chidiobi@live.uwe.ac.uk

For further information, please contact my Director of studies

Dr Colin A. Booth (Colin.booth@uwe.ac.uk)

Participation Information Sheet

Please ensure you have read this instruction sheet and complete the consent form before taking part in this research.

Who is conducting this study?
I am Chibuike Chidiobi, a PhD student, studying construction and demolition waste management at the University of the West of England (UWE), Bristol.

Who has approved this study?
The study has been checked and meets the ethical requirement of the UWE Faculty Research Ethics Committee.

What is the aim of the study?
This research aims to develop Development of frameworks for the management of materials procurement and construction waste for Nigerian contractors.

Why have you been approached to take part in the study?
The reason you have been chosen to take part is because your professional experience; Thus, your contribution is required to validate list of waste minimisation criteria/sub-criteria, which will be used as the research questions for the successful completion of the study.

Are there any risks in taking part?
There are no foreseen risks in you answering the questions. However, please do not hesitate to raise any concerns you may have by contacting my supervisor or me in the email addresses provided in this document.

What will the validation involve?
The validation will require you to tick, answer '**Yes** or **No'** and comment thus: (1) to whether the lists of criteria/sub-criteria provided are clear to you, (2) important/relevant for the Nigerian construction industry; and (3) comprehensive. Where your answer is **'No',** you can provide any additional criteria/sub-criteria in the space provided below each table in page 3, 4 and 5 respectively.

How will the information given be kept and used?
All information that you provide during the validation will be completely anonymous. You will not be asked for any personal details that will allow you to be identified. The information you give will be secured and only available to the researcher.

Do I have to participate in the study and what if I change my mind?
Participation in the study is entirely voluntary. You are free to withdraw before, during or after the validation process. If you feel at a later date, you do not wish your views to be included in the study, please quote the unique code (given to you) to me or my supervisor and we will arrange for your views to be removed from the dataset. To manage this, the deadline for informing my supervisor will be two weeks after the date of the validation. In addition, you are free to decline from validating the research questions.

What do I do if I have any queries?
Please contact me on chibuike2.chidiobi@live.uwe.ac.uk or my supervisor Dr Colin A. Booth at the University of the West of England by email: colin.booth@uwe.ac.uk

Thank you in anticipation for your help with this study

PARTICIPANT CONSENT FORM

Study Title: Development of frameworks for the management of materials procurement and construction waste for Nigerian contractors

Researcher: Chibuike Celestus Chidiobi

Institution: University of the West of England

1. **Confidentiality:**

Your email address, profession, years of experience, highest qualification and professional body membership will not be made public. Your privacy is respected, and your personal formation will not be made public. Any personal information you provided will not be made public. Data that you submit in response to this survey would be kept private under the university data protection policy in line with the UK General Data Protection Regulation (GDPR) - Data Protection Act, 2018. Your data would not be shared by a third party..

2. **Withdrawal arrangement**

You can withdraw at any time, and here is no penalty for withdrawing. You are not required to provide any reason for withdrawing your participation. The estimated period for your response is two weeks (2nd October 2019 to 16th October 2019), and you can withdraw your response for up to two weeks from the survey end date. To help facilitate your withdrawal, you can contact the researcher at chibuike2.chidiobi@live.uwe.ac.uk Tel: +44(0)7475939568.

3. **Expected cost:** Not applicable

STATEMENT BY PERSON AGREEING TO PARTICIPATE IN THIS SURVEY

I have read and understand each part of this informed consent document. All my questions have been answered, and I freely and voluntarily choose to participate in this survey. Please chose

1. I confirm that I have read and understood the participant information sheet for the above-named study and have had the opportunity to ask questions.

2. I understand that my participation is voluntary and that I am free to withdraw at any time, up to two weeks after the validation, without giving reason and without there being any consequences.

3. I give permission for the student and their supervisor to have access to my anonymised responses. I understand that my personal information will not be identifiable in the study findings or final dissertation.

4. I agree to be a participant in the study

Jnique identification code is included in this box; please quote/write this code in case you want to withdraw ur participation. You have the option to withdraw up to two weeks after the validation.	CV06

Name/signature of participant ....

Date..............03/06/2020.....................................

Name/signature of researcher...........Chibuike Chidiobi.......................................

Date..

You can keep this document safely stored for your own record

<u>Personal Expertise</u>

Please write/tick those boxes that are appropriate.

Profession	Project manager	
	QS	
	Waste and environmental management expert	
	Academic in construction or built environment	
Highest Qualification	HND/OND	
	Bachelor’s degree	
	Master’s degree	
	Doctorate	
Professional body Membership		
Years of experience in the Nigerian construction and built environment industry	1-5	
	6-10	
	10-15	
	15-20	
	20 and above	

The following waste management criteria/attributes in table 1, 2 respectively have been synthesised through a review of global literature on construction waste management in other to apply them in Nigeria. Please read the list in the tables tick and answer the questions that follows.

Table 1: MATERIALS PROCUREMENT CRITERIA/ATTRIBUTES

Code	Criteria/sub-criteria	Please indicate by ticking any criteria/sub-criteria that is/are not clear to you
TMSP	***Top management support (procurement)***	
TMSP1	Involving purchase manager in procurement activities	
TMSP2	Provision of stock control measures	
TMSP3	Periodic training of procurement personnel on waste management strategies	
TMSP4	Waste management guidelines for procurement personnel	
TMSP5	Alliance with suppliers	
PC	**Procurement clause attributes**	
PC1	Take–back clause in suppliers' agreement document	
PC2	Consistency in suppliers' agreement document	
PC3	Supplies to supply quality and durable materials	
PC4	Agreement with suppliers on waste management strategies	
PC5	Supplier flexibility in providing a smaller quantity of materials	
LWPM	**Low waste purchase management attributes**	
LWPM1	Purchase of secondary materials	
LWPM2	Purchase of maintainable materials	
LWPM3	Accurate materials quantification	
LWPM4	Purchase of high–quality products	
LWPM5	Accurate materials ordering	
LWPM6	Material substitution	
EDM	**Efficient delivery management attributes**	
EDM1	*Adequate site access for delivery vehicles*	
EDM2	Careful material handling to avoid breakage	
EDM3	Just–in–time delivery (JIT) of materials	
EDM4	Safe storage of materials onsite	

✓ Please tick/write in the box/space provided below whether the above criteria/sub-criteria are:

1. Clear to you: Yes ☐ No ☐
2. Important/relevant for the Nigerian construction industry Yes ☐ No ☐
3. Comprehensive set of **criteria** for the coordination of waste management in the procurement stage? Yes ☐ No
4. Comprehensive set of attributes for waste minimisation in the procurement stage? Yes ☐ No ☐

If you answer NO to the number 4 question, please can you provide any additional criteria/sub-criteria that could be relevant for inclusion

I. ....

II. ....

III. ....

IV. ....

Table 2: CONSTRUCTION CRITERIA/ATTRIBUTES

Code	Criteria/sub-criteria	Please indicate by ticking any criteria/sub-criteria that is/are not clear to you
TMSC	**Top management support (construction) attributes**	
TMSC1	*Senior managers early commitment to waste minimisation*	
TMSC2	Periodic training of site employees on waste management strategies	
TMSC3	Adequate waste reduction investment	
TMSC4	Active site supervision	
TMSC5	Motivating employees to minimise waste	
TMSC6	Effective communication among project participants	
CC	**Construction clause**	
CC1	Waste target clause in subcontractors' agreement document	
CC2	Waste management policy for operatives	
CC3	Incentive clause for effective waste management practice	
CC4	Making subcontractors responsible for their waste	
SWMP	**Site waste management plan attributes**	
SWMP1	Adequate space for material movement onsite	
SWMP2	Identifying recyclable materials	
SWMP3	Forecast the emerging waste streams	
SWMP4	Segregating waste materials into categories	
SWMP5	Identifying reusable materials	
LWT	**Low waste technique attributes**	
LWT1	Maximise use of joint systems instead of glueing	
LWT *2*	Use of deconstructable materials	
LWT3	Adopting the right work sequence	
LWT4	Use of steel scaffolds	
LWT5	Adopting prefabricated building components	
LWT6	Use of reusable formwork and falsework	
LWT7	Use of appropriate construction equipment	

✓ Please tick/write in the box/space provided below whether the above criteria/sub-criteria are:

1. Clear to you: Yes ☐ No ☐
2. Important/relevant for the Nigerian construction industry Yes ☐ No ☐
3. Comprehensive set of **criteria** for the coordination of waste management in the construction stage? Yes ☐ No
4. Comprehensive set of **sub-criteria** for waste minimisation in the construction stage? Yes ☐ No ☐

If you answer NO to the number 4 question, please can you provide any additional criteria/sub-criteria that could be relevant for inclusion

I. …………………………………………………………………………..

II. …………………………………………………………………………..

III. …………………………………………………………………………..

IV. …………………………………………………………………………..

This is the end of the survey.

Thank you for your participation,

Chibuike Chidiobi (The researcher)

Appendix D: Main Questionnaire Survey Documents

INVITATION LETTER
Faculty of Environmental and Technology
University of the West of England, Bristol
BS16 1QY
United Kingdom
Date…/…/ 2020
Dear Sir/Madam,

REQUEST FOR PARTICIPATION IN RESEARCH

You are sincerely invited to participate in this doctoral research being conducted at the University of the West of England, titled: A framework for prioritising waste minimisation strategies for the Nigerian construction industry. This aims at developing frameworks for the management of materials procurement and construction waste for Nigerian contractors. Comprehensive information on this study is contained in the Participant information sheet (PIS) above. Please, it is of most importance that you complete all the questions to the best of your ability. Brief instruction is given at each section of the questionnaire on how to complete it. The questionnaire should take you approximately 10–20 minutes to complete. If you have any queries regarding this survey, please contact the research team using the contacts (chibuike2.chidiobi@live.uwe.ac.uk or Colin.Booth@uwe.ac.uk). The research has been ethically approved by the UWE ethics committee. If you have any queries that you want to be addressed by an independent person, you may contact the ethics committee at UWE by email (researchethics@uwe.ac.uk)

Chibuike Chidiobi

PhD student, University of the West of England, Bristol, UK

Participation Information Sheet for a Quantitative Investigation

Please ensure you have read this instruction sheet and consent in the next page before taking part in this research.

Who is conducting this study?

I am Chibuike Chidiobi, a PhD student, studying construction waste management at the University of the West of England (UWE), Bristol.

Who has approved this study?

The study has been checked and meets the ethical requirement of the UWE Faculty Research Ethics Committee.

What is the aim of the study?

This is a quantitative investigation using an online survey aims at frameworks for the management of materials procurement and construction waste for Nigerian contractors.

Why have you been approached to take part in the study?

The reason you have been chosen to take part is because your professional experience in the construction industry is required to rank lists of construction waste minimisation strategies based on their importance.

Are there any risks in taking part?

There are no foreseen risks in you answering the questions. However, please do not hesitate to raise any concerns you may have by contacting me or my supervisory team in the email addresses provided at the end of this document.

What will the questionnaire involve?

The questionnaire is an online survey. You are required to rank construction waste minimisation criteria and the related sub–criteria in materials procurement and construction stages, respectively.

Consent Form

1. I confirm that I have read and understood the participant information sheet for the above–named study and have had the opportunity to ask questions.
2. I understand that my participation is voluntary and that I am free to withdraw at any time, up to two weeks after the validation, without giving reason and without there being any consequences.
3. I give permission for the student and their supervisor to have access to my anonymised responses. I understand that my personal information will not be identifiable in the study findings or final dissertation.
4. I am only required to fill this questionnaire once
5. I have a minimum of 12 months of professional experience in the construction industry
6. I belong to a professional body related to the construction industry
7. I agree to be a participant in the study

Should you wish to withdraw up to two weeks after the validation, please quote the unique code provided in the right hand of this box, so that we can arrange for your withdrawal	

Name/signature of participant ....
Date..
Name/signature of researcher..
Date..

You can keep this document safely stored for your own record

Part 1: Demographic Information

Please indicate/tick in the boxes as appropriate

P1Q1.Profession/Job Role
☐Project manager
☐Procurement manager
☐Quantity surveyor
☐Mechanical engineer
☐Civil engineer
☐Structural engineer
☐Site supervisor
☐Other: please specify: ——————
P1Q2. Highest qualification
☐Bachelor's degree/BEng
☐Higher National Diploma
☐Master's Degree
☐Ordinary National Diploma
☐PhD
☐Other: please specify: ——————
P1Q3. Level of experience (years)
☐1–5
☐6 –10
☐11 –15
☐16 –20
☐Above 20
P1Q4. Professional body affiliation
☐The Council for the Regulation of Engineering in Nigeria (COREN)
☐The Council of Registered Builders of Nigeria
☐Nigerian Institute of Quantity Surveyors (NIQS)
☐Nigerian Institute of Building (NIOB)
☐Other: please specify: ——————

Part 2: General Information

The following questions contain materials procurement and construction criteria for effective waste management and the related attributes. The criterion and attributes categories have different numbers of ranks/rating positions, which depends on the number of items in a group of questions. For instance, where there are 4 criteria or attributes, the ranks/rating positions should be from 1 to 4, and where there are 5, the ranks/rating positions should be from 1 to 5, etc. PLEASE NOTE: the most important criterion attribute in a category should be given the rank of 1, thus you are required to type or key 1 in the box provided at the left–hand side of each question. For instance, 1 is more important than 2, and 2 is more important than 3 in that order.

- *Please rank the following 4 materials procurement and construction waste management criteria, respectively based on their level of importance in contributing to effective waste management in the construction industry. Please type the ranking in the boxes provided.*

P2A: Materials procurement criteria

☐Top management support for procurement
☐Procurement clause
☐Low waste purchase management
☐Efficient delivery management

P2B: Construction criteria
☐Top management support for construction
☐Construction clause
☐Site waste management plan
☐Low waste technique

- *Please rank the following 5 attributes grouped in the materials procurement criteria based on their level of importance in contributing to waste minimisation in the construction industry. Please type the ranking in the boxes provided.*

P2A1: top management support for materials procurement
☐Waste management guideline for procurement personnel
☐Alliance with suppliers
☐Involve a competent purchase manager in procurement activities
☐Periodic training of procurement personnel on waste management strategies
☐Provision of stock control measures

P2A2: Procurement clause
☐Agreement with suppliers on waste management strategies
☐Consistency in suppliers' agreement document
☐Supplier flexibility in providing a smaller quantity of materials
☐Supplies to supply quality and durable materials
☐Take–back clause in suppliers' agreement document

- *Please rank the following 6 attributes of low waste purchase management based on their level of importance in contributing to waste minimisation in the construction industry. Please type the ranking in the boxes provided*

P2A3: *Low waste purchase management*
☐Accurate material ordering
☐Accurate materials quantification
☐Purchase of high–quality products
☐Purchase of maintainable materials
☐Materials substitution
☐Purchase of secondary materials

- *Please rank the following 4 attributes of efficient delivery management criteria based on their level of importance in contributing to waste minimisation in the construction industry. Please type the ranking in the boxes provided*

P2A4: *Efficient delivery management*
☐Adequate site access for delivery vehicles
☐Careful material handling to avoid breakage
☐Just–in–time delivery (JIT) of plan
☐Safe storage of materials onsite

- *Please rank the following 6 attributes of top management support for construction based on their level of importance in contributing to waste minimisation in the construction industry. Please type the ranking in the boxes provided*

P2B1: top management support for construction
☐Active site supervision
☐Adequate waste reduction investment
☐Effective communication among project participants
☐Motivating employees to minimise waste
☐Periodic training of site employees on waste management strategies
☐Senior managers early commitment to waste minimisation

- *Please rank the following 4 attributes of efficient delivery management based on their level of importance in contributing to waste minimisation in the construction industry. Please type the ranking in the boxes provided*

P2B2: Construction clause
☐Incentive clause for effective waste management practice
☐Making subcontractors responsible for their waste
☐Site waste management policy for site operatives
☐Waste target clause in subcontractors' agreement document

- *Please rank the following 5 attributes of site waste management plan based on their level of importance in contributing to waste minimisation in the construction industry. Please type the ranking in the boxes provided*

P2B3: Site waste management plan
☐Adequate space for material movement onsite
☐Forecasting the emerging waste streams
☐Identifying recyclable materials
☐Identifying reusable materials
☐Segregating waste materials into categories

- Please rank the following 7 attributes of low waste techniques based on their level of importance in contributing to waste minimisation in the construction industry. Please type the ranking in the boxes provided

P2B4: low waste techniques
☐Adopting the right work sequence
☐Adopting prefabricated building components
☐Use of appropriate construction equipment
☐Maximise use of joint systems instead of glueing
☐Use of deconstructable materials
☐Use of reusable formwork and falsework
☐Use of steel scaffolds

This is the end of the survey

Please click the yellow arrowed button below to submit the survey. Where the submission fails, this could mean some questions have not been answered. Uncompleted questions would show red; you can click on the draw up or drop–down (^ $_{v}$) arrows to open and complete unfinished questions.

Thank you very much for your participation

Appendix E: Frameworks' Validation Interviews

Dear Sir/Madam,

I am a doctoral research student at the University of the West of England, Bristol, in the UK, studying for a PhD that is focussed on Nigerian Construction Waste Management, under the guidance of Dr Colin Booth. I am close to finishing my studies, which have enabled me to create frameworks that will hopefully help the Nigerian construction sector to improve their waste strategies and minimise the waste produced on construction projects. However, it is important that I am able to confirm the usefulness of the frameworks through a validation process.

As a professional in the Nigerian construction sector, I am inviting you to take part in the validation exercise by answering a series of questions, which will take approximately 5-10 minutes to answer. There are no foreseen risks in you answering the questions. However, please do not hesitate to raise any concerns you may have by contacting my supervisor (details provided beneath). Any information you provide will be used anonymously and the information treated in strictest confidence. Participation in the study is entirely voluntary. You can choose to consent to take part by simply replying to this email. However, you are free to withdraw at any time (before, during or after the interview). If you feel at a later date (up to two weeks after your involvement) you do not wish your views to be included in the study, please quote the unique code (created at the end of the session) to my supervisor and your contribution will be deleted from my dataset of participant responses.

You are requested to firstly read the attached participant information sheet, privacy notice and consent documents, which explain the project and your involvement. If you're happy to proceed, and agree with the consent statements, you are asked to then confirm your consent to participant by replying to this email. I will then send you the frameworks and the validation questions to answer.

The study has been approved by the University and complies with their ethical standards. If you have any queries or would like to verify the legitimacy of this study please contact Dr Colin Booth using the details provided beneath.

Thank you for reading this invitation and I look forward to receiving your response.

Yours sincerely,
Chibuike Chidiobi
Doctoral Research Student
Email: Chibuike2.Chidiobi@live.uwe.ac.uk

Dr Colin Booth
Associate Head for Research & Scholarship
Email: Colin.Booth@uwe.ac.uk

PRIVACY NOTICE FOR RESEARCH PARTICIPANTS

Research Project: **Development of frameworks for the management of materials procurement and construction waste for Nigerian contractors**

Purpose of the Privacy Notice

This privacy notice explains how the University of the West of England, Bristol (UWE) collects, manages and uses your personal data before, during and after you participate in this interview. 'Personal data' means any information relating to an identified or identifiable natural person (the data subject). An 'identifiable natural person' is one who can be identified, directly or indirectly, including by reference to an identifier such as a name, an identification number, location data, an online identifier, or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person.

This privacy notice adheres to the General Data Protection Regulation (GDPR) principle of transparency. This means it gives information about:

- How and why your data will be used for the research;
- What your rights are under GDPR; and
- How to contact UWE Bristol and the project lead in relation to questions, concerns or exercising your rights regarding the use of your personal data.

This Privacy Notice should be read in conjunction with the Participant Information Sheet and Consent Form provided to you before you agree to take part in the research.

Why are we processing your personal data?

UWE Bristol undertakes research under its public function to provide research for the benefit of society. As a data controller we are committed to protecting the privacy and security of your personal data in accordance with the (EU) 2016/679 the General Data Protection Regulation (GDPR), the Data Protection Act 2018 (or any successor legislation) and any other legislation directly relating to privacy laws that apply (together "the Data Protection Legislation"). General information on Data Protection law is available from the Information Commissioner's Office (https://ico.org.uk/).

How do we use your personal data?

We use your personal data for research with appropriate safeguards in place on the lawful bases of fulfilling tasks in the public interest, and for archiving purposes in the public interest, for scientific or historical research purposes. We will always tell you about the information we wish to collect from you and how we will use it.

We will not use your personal data for automated decision making about you or for profiling purposes. Our research is governed by robust policies and procedures and, where human participants are involved, is subject to ethical approval from either UWE Bristol's Faculty or University Research Ethics Committees. This research project has been approved by the UWE Research Ethics Committee. Any comments, questions or complaints about the ethical conduct of this study can be addressed to the Research Ethics Committee at the University of the West of England at: Researchethics@uwe.ac.uk

The research team adhere to the **Ethical guidelines of the British Educational Research Association (and/or the principles of the Declaration of Helsinki, 2013) and the principles of the General Data Protection Regulation (GDPR).**

For more information about UWE Bristol's research ethics approval process please see our Research Ethics webpages at: www1.uwe.ac.uk/research/researchethics

Development of frameworks for for the management of materials procurement and construction waste for Nigerian contractors

Participation Information Sheet

Please ensure you have read this sheet before taking part in this research.

Who is conducting this study?

I am, Chibuike Chidiobi, a doctoral research student studying for a PhD on "A Strategic Framework for Procurement and construction waste minimization in Nigerian Construction Projects" at the University of the West of England (UWE), Bristol.

Who has approved this study?

The study has been checked by my supervisor and meets the ethical requirements of the UWE Research Ethics Committee.

What is the aim of the study?

The aim of this study is to create frameworks that will hopefully help the Nigerian construction sector to improve their waste strategies and minimise the waste produced on construction projects.

Why have you been approached to take part in the study?

The reason you have been chosen to take part is because you have been identified as someone who is an experienced professional person working in the Nigerian construction sector and may be willing to share your views on the frameworks I have created.

Are there any risks in taking part?

There are no foreseen risks in you answering the questions. However, please do not hesitate to raise any concerns you may have by contacting myself or my supervisor.

What will it involve?

You will be invited to answer a series of questions, which will take approximately 5-10 minutes to answer. You are free to answer as broadly or as narrowly as you wish. Further, should you not wish to answer any particular question(s) you are free to do so.

How will the information given be kept and used?

All information you provide will be used anonymously. You will not be asked for any personal details that will allow you to be identified. The information you give will be kept securely and only available to myself and my supervisor. The responses you give will be added to other responses related to each specific question and together these will form the dataset that may be shared in presentations and/or publications.

Do I have to participate in the study and what if I change my mind?

Participation in the study is entirely voluntary. You are free to withdraw at any time (before, during or after). If you feel at a later date you do not wish your views to be included in the study, please quote the unique code (created at the end of the session) to myself or my supervisor and we will arrange for your answers to be removed from the dataset. To manage this, the deadline for informing us will be two weeks after the date of your involvement.

What do I do if I have any queries?

Please contact myself Chibuike Chidiobi (Email: Chibuike2.Chidiobi@live.uwe.ac.uk) and/or my supervisor Dr Colin A. Booth (Email: colin.booth@uwe.ac.uk).

Development of frameworks for the management of materials procurement and construction waste for Nigerian contractors

Consent Form

Please ensure you have read this sheet before consenting to take part in this research.

- I confirm that I have read and understood the participant information sheet and privacy notice for the above-named study and have had the opportunity to ask questions.

- I understand that my participation is voluntary and that I am free to withdraw at any time, up to two weeks after my involvement, without giving reason and without there being any consequences.

- I give permission for the researchers to have access to my anonymised responses, and for them to be kept in accordance with the data protection act[1]. I understand that my personal information will not be identifiable in the study findings and can be used in any presentations or publications.
[1]https://www.gov.uk/data-protection

- I agree to be a participant in the study.

Interviews Questions

1. Are the frameworks' criteria adequate and relevant for effective waste management in the construction industry?
2. Are the attributes' of the criteria adequate and relevant for effective waste management in the construction industry?
3. Are the attributes' priorities useful for planning an Implementation strategy for waste minimisation?
4. Can the actions provided in the frameworks facilitate effective waste management in construction companies?
5. Are there barriers to implementing any part of the frameworks?
6. What can you recommend to enhance the frameworks

Thank you for participating in this interview

Appendix F: Publication

Chidiobi, C., Booth, C. and Lamond, J. (2021) A review of the causes of construction waste generation in Nigeria and recommendations. In *Proceedings of the Institution of Civil Engineers–Waste and Resource Management* 174(2), pp. 37–46.